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UNIVERSITY OF ILLINOIS

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FACTORS INFLUENCING LARGEMOUTH BASS RECRUITMENT: IMPLICATIONS FOR THE ILLINOIS MANAGEMENT AND STOCKING PROGRAM

M.J. Diana, M.A. Nannini, C.S. Deboom, J.J. Mulhollem,
D.P. Philipp, and D.H. Wahl

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Division of Fisheries
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EXECUTIVE SUMMARY:

All activities outlined in the annual work plans were accomplished and within the specified budgets. The goal of this study was to develop management strategies that maximize growth, recruitment, and harvest of largemouth bass *Micropterus salmoides* in Illinois impoundments. Largemouth bass are frequently stocked in many Illinois impoundments to compensate for variable recruitment. Even so, the long-term contribution of stocked fish to recruitment and harvest of natural bass populations is unknown and we addressed these questions. In addition, information on the importance of rearing technique, size of stocked fish, forage base, cover, resident predators, physical-chemical conditions, and stocking stress in determining largemouth bass stocking success is needed to optimize use of hatchery produced fish. Because stocking is only one of several management options for this species, it is critical that additional information on factors limiting recruitment processes be identified.

In Job 101.1 we examined the most reliable and cost-effective method for mass-marking fingerling largemouth bass. Fin clips, fin clip-cauterization, and freeze branding were examined for long-term retention on 100-mm largemouth bass. Fin cauterization had the longest retention time, followed by fin clipping and then freeze branding. Identification of fin clips and fin cauterization were complicated by fin regrowth. Freeze branding does not have the problem of fin regrowth, but seasonal variation in appearance on the fish led to difficulty in identifying freeze brands in the fall when bass have darker external coloration. We found no differences in growth rates between fish with these three different marks. We evaluated seasonal variability (fall vs. spring) in mark retention for freeze brands and found that seasonal variation in largemouth bass color does influence readability. Freeze brands are difficult to read in the second fall after stocking, but are easily visible in the subsequent seasons, including both spring and fall. The best mark for use in various situations will vary with management objectives. Choices of mark will vary with number of fish to mark and associated cost of marking as well as the reason for marking fish. Freeze brands will be best if the number of fish and costs of marking are high and if the interest is in long-term survival (after the second fall). If early survival is the focus and recovery of marks in the first and second fall is important, fin clips with cauterization will be the best choice followed by fin clips.

In Job 101.2, we evaluated factors influencing stocking success of largemouth bass. Despite the widespread use of supplemental stocking, survival of age-0 and age-1 stocked fish is often variable and stocking success is not commonly evaluated through adult size-classes. We evaluated the long-term contribution of stocked largemouth bass *Micropterus salmoides* from three annual stockings in 15 reservoirs in Illinois. Stocked largemouth bass were marked with fin clips and sampled for 5 years. Contribution of stocked fish to the population was highest for age-0 (21%) and age-1 largemouth bass (17%) but decreased significantly in adult fish (5%). Contribution of stocked bass was not associated with either populations of wild largemouth bass or latitude. Survival of stocked fish was similar to survival of wild fish through age 1. Age-0 abundance of wild and stocked largemouth bass were positively correlated in the fall following stocking, suggesting that similar factors may influence initial survival. Survival of stocked fish from age-1 to adult age decreased significantly compared to wild fish, resulting in low contribution of stocked bass to the adult population. Adult and age-1 catch per unit effort of stocked largemouth bass were positively correlated with the mean size of stocked bass in the first fall after stocking and the following spring, indicating that lakes with higher growth rates have increased contribution of stocked fish. We found limited contribution of stocked fish to adult largemouth bass populations due to low survival from age-1 to adult age. Assessments of fish stocking success should evaluate survival of stocked fish through adult ages or they may omit a critical period for mortality.

We compared growth and survival (including losses to stocking stress and predation) of four sizes of largemouth bass Micropterus salmoides in four Illinois reservoirs. Fish were stocked as small fingerlings (55 mm total length) in July, medium fingerlings (100 mm) in August, large fingerlings (150 mm) in September, and advanced fingerlings (200 mm) the subsequent spring. Survival of small fingerlings was very low (catch per unit effort, 1 fish/h of electrofishing in the fall after stocking), and fish stocked as small fingerlings were not observed in electrofishing samples after the spring following stocking. In samples collected soon after stocking, large and advanced fingerlings were larger and more abundant than other sizes. However, in subsequent sampling, there were no differences in size or survival among fish stocked as medium, large, and advanced fingerlings. Long-term growth of stocked fish was similar to that of wild fish, but survival of stocked fish was low for all sizes. Mean initial stocking mortality for fish held in cages was variable but generally low (0.0–5.6%) and was related to lake temperature at stocking. The diets of predators (primarily adult largemouth bass) contained high numbers of small-, medium-, and large-sized fingerlings after stocking, but no predation was observed on advanced fingerlings. Cost of producing fish increased with size, and cost–benefit analysis determined that medium (100-mm) fish had the greatest return per cost. We recommend stocking medium fingerlings because the stocking of larger fingerlings did not produce a significant increase in survival.

We conducted a study comparing intensive and extensive rearing techniques for largemouth bass. Intensively reared fish were raised in raceways and fed pellets, whereas extensively reared fish were raised in ponds and fed zooplankton and minnows. Extensively reared fish experienced better survival through the spring following stocking, but by the following fall (age-1) there was no difference in abundance between the two rearing techniques. We observed a high level of variation in the number of fish produced in the rearing ponds. Cost of rearing was much higher for the extensively reared fish for both hatchery ponds and lake side rearing facilities. Higher initial survival and larger size in the fall of extensively reared fish initially appears to justify the added cost. However, long term survival was low for both rearing types and very few stocked fish were recruited to the fishery. We also began evaluating stocking techniques to improve survival of stocked largemouth bass. Three lakes were stocked with largemouth bass, with half the fish stocked at the boat ramp and half dispersed throughout the lake and into woody or vegetated habitat. Very few stocked fish have been recaptured from any stockings conducted thus far regardless of method. CPUE of stocked fish in this experiment has been lower than observed in stockings conducted in previous parts of this project and we hope to observe greater survival in future studies in order to evaluate the success of these two stocking strategies.

In Job 101.3, we evaluated the survival and reproductive success of stocked largemouth bass relative to resident populations. To determine the contribution of stocked fish, the MDH B2B2 allele was used as a genetic tag for fingerlings stocked into six study lakes. Once these fish were part of the reproducing population, it was possible to assess the reproductive success and recruitment of these stocked fish in five of the six lakes by comparing the pre-stocking with post stocking MDH B2 allele frequencies. We also examined lake size and resident bass CPUE as possible factors that may have influenced reproductive success. Stocked fish survival to adulthood was variable in the five study lakes, ranging from less than 10% to around 35%. Contribution of stocked fish to reproduction was also variable and was higher in small lakes than in larger ones. The density of resident bass as measured by CPUE had no relationship to the contribution of stocked bass reproduction in the lakes that we studied. Based on the proportion of stocked adults in the populations we could predict the change in the frequency of the MDH B2 allele to determine how reproductive success of stocked fish compared to wild fish. We found that reproductive success of stocked fish was similar to wild fish. Our results indicate that stocking is most likely to be successful in small lakes and that the genetic influence of stocked fish will persist in successive generations.

In Job 101.4, we evaluated a number of different factors to determine how they potentially influenced largemouth bass recruitment. Incorporating potentially important events during the first year of life across multiple environmental conditions is needed to generalize models of fish recruitment. Using previous conceptual models as a framework, we quantified sources of intra- and inter-system variation in recruitment of largemouth bass. We measured young-of-year (YOY) abundances, first year growth, and potentially important environmental variables across 12 populations and five to seven year-classes. Inter-population differences in average recruitment to age 1 were set by variation in number of YOY surviving to fall. Survival to fall was in turn positively related to density of juvenile bluegill. First year growth was positively related to turbidity and abundance of adult largemouth bass. For individual lakes, variables explaining a significant amount of intra-population variation in recruitment strength were factors associated with either production of YOY from the parental care stage (peak density of YOY largemouth bass) or prey fish abundance (densities of larval and juvenile bluegill). Abundance of larval bluegill was higher in systems where largemouth bass recruitment to age 1 was not related to bluegill abundance than in lakes where recruitment strength was sensitive to annual fluctuations in prey fish abundance. The relationship between output from the parental care stage and recruitment strength suggests that management should focus on actions designed to influence nest success. Where recruitment is also limited by prey fish availability, management actions can also be directed towards community attributes that influence the growth and production of important prey species.

In order to assess how the number of nests and density of eggs affected the total number of recruits, we conducted pond experiments in six ponds stocked with breeding largemouth bass. Nesting activity and reproductive output was measured during daily snorkel surveys. The number of nests and the quantity of eggs was assessed and compared to the number of young-of-year fish produced in each pond. While density of fall recruits generally increased with either total density of eggs deposited or density of successful nests, the strength of these relationships was affected by the presence of bluegill. High densities of bluegill appeared to limit the amount of recruitment possible by largemouth bass, resulting in fewer recruits being added as either nest or egg counts increased. Though recruitment increased with number of successful nests, even under conditions of high bluegill density, these models explained less than half of the variation in fall recruitment.

We conducted a multi lake experiment examining the influence of vegetation on largemouth bass recruitment. Lakes were divided into treatments by the vegetation management strategy and controls. Four lakes with experimental treatments and nine control lakes were monitored for fish populations and prey organisms and were compared through time to determine if they were related to vegetative cover and density. Two lakes (Stillwater and Airport) were treated for vegetation in an effort to reduce the vegetation present and yield more intermediate vegetation densities. The vegetation treatments were initiated in 2010 and have been successful at reducing vegetation in Stillwater Lake, but not Airport Lake. Two lakes (Paradise and Dolan) experienced management to increase vegetation. Vegetation planting was initiated in 2008 in Lake Paradise and planting efforts continued through 2012. We evaluated the success of different species of vegetation and the size of cage used. American pondweed has shown the greatest long-term survival and the large cages were most effective in producing vegetation. We also evaluated fish and invertebrate communities associated with vegetated and non-vegetated cages and observed higher densities of both fish and invertebrates in vegetated cages. Rehabilitation at Dolan Lake has continued to yield higher vegetation and reduced gizzard shad and carp numbers, however, there is some evidence of gizzard shad populations rebounding. The 13 lakes that were sampled in the vegetation management experiment were also examined for relationships of vegetation with largemouth bass populations and recruitment and prey densities. CPUE of young of year largemouth bass was marginally higher in lakes with greater vegetation densities. No other lake conditions that were measured were related to vegetation density. Lakes with vegetation enhancement and removal have not resulted in changes in abundance of young-of-year largemouth bass and no enhancements in recruitment were evident.

We also assessed the role of woody structure in influencing recruitment of largemouth bass. We conducted two experiments evaluating largemouth bass and bluegill responses to coarse woody habitat additions in pond environments. Adult largemouth bass and bluegill growth were compared for both an overwinter (October – March) period and a warm-water period (May – October). Experiments evaluated the responses of fish growth and survival across a gradient of coarse woody addition ranging from 0-55% increases in surface area relative to the pond bottom (equivalent to a gradient of 0-11 trees per tenth acre pond). In the overwinter experiment we found that increasing additions of coarse woody habitat increased adult largemouth bass growth but did not affect the growth of adult bluegills or the survival of either species. Furthermore, largemouth bass growth appeared to asymptote at a level of coarse wood addition equivalent to around a 25% increase in surface area relative to the pond bottom (5 trees per tenth acre pond). In the summer experiment we found a linear trend of increasing largemouth bass growth with increasing coarse woody habitat addition. This effect was independent of submerged aquatic vegetation density which had an independent negative effect on adult largemouth bass growth. Similar to the overwinter experiment there was no relationship between coarse woody habitat addition and adult largemouth bass survival.

We examined patterns in abundance of young-of-year largemouth bass, other fish species, and associated biotic communities among vegetated, woody, and open lakeshore habitat types in two Illinois lakes. Areas of each habitat type were enclosed with a large seine and sampled for fish, zooplankton, and macroinvertebrates. While we did not find significant differences in age-0 largemouth bass densities among the microhabitat types sampled in our enclosure surveys, we did find significant differences in the community composition and abundance of potentially important prey items (juvenile sunfishes, caddisflies, chironomids, stonefiles and cyclopoid copepods). Increases in abundance of potential invertebrate and fish prey in vegetated and wooded sites supports the idea that these habitats are important sources of littoral productivity.

Dam escapement may influence largemouth bass recruitment and other fish populations through loss of fish during high water events. In order to access dam escapement, we sampled downstream of the dam on two reservoirs, Ridge Lake and Forbes Lake via backpack electrofishing and seines. Some largemouth bass were observed in sampling below the dam at both Forbes and Ridge Lake following high water events however there were few fish in all sampling. The assessment of dam escapement is in the very early stages of implementation and evaluation and much more data is needed to draw conclusions about the effect of escapement on largemouth bass populations and recruitment. Additional data will be collected so that a baseline can be established in order to compare largemouth bass numbers after an increased discharge event to largemouth bass numbers during low flow periods.

In job 101.5, we examine the potential for angling to influence largemouth bass populations. In particular, competitive tournament fishing for black bass has grown rapidly over the past several years. Previous work has shown high levels of mortality associated with these tournaments in other parts of the United States. However, little is known about the effects of tournaments on largemouth bass recruitment. We examined the effects of largemouth bass tournaments on individual fish, nest success, and largemouth bass populations. We monitored largemouth bass spawning activities at Lincoln Trail Lake using spring snorkeling surveys. Largemouth bass nesting initiated from April 4 through May 4 and varied by year and was typically concluded by early June. We assessed the habitat of largemouth bass nests as well as the available habitat in the littoral zone. Largemouth bass appeared to prefer cobble, pebble and gravel nesting substrates, while avoiding vegetation and detritus. The number of nests was not related to the number of adults observed in spring electrofishing samples or the number of young-of-year largemouth bass in fall electrofishing samples.

The popularity of tournament angling for largemouth bass during nesting remains high, leading to concerns about the effects on populations. Catch-and-release angling and its effects on nest abandonment have been well documented, but few studies have examined the effects of competitive angling on nest abandonment. We conducted a study examining the rate of nest abandonment of largemouth bass subjected to tournament and catch-and-release angling. Nest-guarding male largemouth bass were subjected to one of three treatments: no angling controls, catch-and-release angling, and simulated tournament angling. Abandonment rates were assessed at 24 h following angling. Both angling treatments experienced higher abandonment rates than the control group (3%) with tournament-angled males abandoning their nests at a higher rate (90%) than catch-and-release males (33%). Additional research will be required to determine the population-level consequences of these angling practices. Until then, a conservative recommendation would be for organizers to consider alternative tournament formats during the reproductive season for largemouth bass.

In addition to reduced nesting success, we examined the effects of tournaments on individual largemouth bass stress and survival. Sub-lethal physiological disturbances and mortality were quantified in largemouth bass subjected to small, club-style angling tournaments (< 30 teams) held at two central Illinois lakes. Between April and October, four tournaments were assessed at Lake Bloomington for physiological disturbances, and four tournaments at Evergreen Lake for mortality. Indicators of physiological disturbances were evident in largemouth bass following club angling tournaments, with some temporal variation in responses. Plasma glucose concentrations increased in tournament-caught fish relative to reference fish in all months, except during October, when glucose concentrations did not change; plasma cortisol values among tournament fish were also lowest during October. Plasma potassium levels decreased only in April whereas chloride levels were unaffected by tournaments. Sodium concentrations varied across months, but the magnitude of tournament-induced decreases were similar across all months. Whole blood hemoglobin was lowest in May and hematocrit significantly decreased in tournament-caught fish in May but remained unchanged in other months. Lactate increases occurred during all tournaments and were of similar magnitudes even though water temperatures ranged from 15.7 ºC to 27.6 ºC. Small, yet significant, temporal differences were observed in plasma sodium and whole blood hemoglobin concentrations from reference fish collected in each month via electrofishing, indicating temporal changes in baseline values for some parameters. Mortality at tournaments was low (< 5%) and did not appear to vary across months. Our results suggest that physiological responses of largemouth bass to small, club-style tournaments can vary temporally and are similar to those sustained during professional tournaments, even if mortality rates are generally low.

Livewell conditions during competitive angling events are thought to affect fish mortality. We examined the effects of livewell additives on initial and delayed mortality of largemouth bass Micropterus salmoides. We applied three treatments (salt, ice, or salt and ice) to livewells during tournaments conducted on lakes in Illinois as well as in laboratory and pond experiments designed to examine the effects of fish size and ambient water temperature on mortality. Fish were collected after weigh-in and monitored for delayed mortality every 24 h for 5 d. Initial mortality did not differ among livewell additives during field evaluations. Although delayed mortality was high it was not significantly different among livewells that contained salt (56%), ice (48%), ice and salt (40%) and controls (30%) suggesting that additives may have a null or possibly a negative effect as compared to controls. Additives administered during laboratory evaluations, at cool water temperatures, resulted in significantly lower delayed mortalities than those observed during the field evaluations when ambient water temperatures were warmer. Initial and delayed mortality did not differ among livewell additives during the laboratory evaluations. Larger fish in field evaluations had significantly greater delayed mortality than smaller fish even though initial and delayed mortality did not differ among livewell additives. Our results suggest that that fish size and ambient water temperature have a greater influence on delayed mortality observed during competitive angling events than the specific livewell additives (i.e. salt and ice or their combination) studied here.

Despite evidence that largemouth bass will abandon nests due to tournament fishing, little is known about how abandoning the nest influences population level recruitment. We examined population level affects through pond experiments, lake tournaments at Ridge Lake, and using a multi lake experiment using lakes with varying tournament pressure. Largemouth bass tournaments were simulated in ponds during the spring throughout the spawning season in two years. Each year, four ponds were randomly designated as treatment ponds that were subjected to simulated tournament angling procedures, and the other four ponds served as undisturbed controls. Nest success was much higher in control ponds, but the average number of recruits to the fall did not differ between treatments. We did find differences in the size structure of young individuals between treatments with larger fish present in the control ponds, and this led to increased biomass of juvenile bass. Pond experiments suggest tournament-style angling may influence some aspects of largemouth bass recruitment dynamics, with effects on biomass but not numbers. Habitat characteristics such as prey availability for newly hatched individuals may be as important as tournament angling when examining factors that affect largemouth bass recruitment.

Largemouth bass tournaments were conducted in alternating years on Ridge Lake to evaluate the effect of spring tournaments on recruitment. A series of spring tournaments were conducted in 2007 and 2010 and largemouth bass populations were compared among tournament and non-tournament years. There was no difference between tournament and non-tournament years for CPUE of young-of-year largemouth bass, CPUE of largemouth bass greater than 200 mm or CPUE of bluegill from fall electrofishing samples. We also observed no significant differences in prey resources in tournament and non-tournament years (larval fish, zooplankton, and benthos densities). These preliminary results suggest that spring tournaments may not adversely affect reproduction and additional tournaments will be conducted as part of future projects.

Due to the raised concerns of largemouth bass tournament angling on largemouth bass populations and nesting success, we examined an alternative format using paper tournaments. Paper tournaments provide an alternative format to weigh-ins which add a good deal of stress to largemouth bass and can create both lethal and sublethal effects. Paper tournaments resulted in similar ranking of anglers as with traditional weigh in with the mean change in rank of only 1.1 ranks. In addition, paper tournaments allow directors to evaluate the catch of fish that are not legal to harvest and allow for some alternate measures of angling skill. We found large changes in rank when sub legal size fish and fish that were culled were included in paper tournament results. We have demonstrated the utility of paper tournaments and provide one of the first measurements of error involved with using a paper format.

We have evaluated largemouth bass tournament activity and monitored largemouth bass populations in a number of lakes to examine how populations were influenced by tournament pressure. We attended tournament weigh-ins to determine what fish were targeted by anglers and conducted interviews to determine the level of culling and number of sub legal fish caught. When tournaments occurred during the spawning period, anglers were targeting spawning fish and a large majority of fish weighed in were actively spawning. Anglers did not target a specific sex as the male to female ratio was similar in spawning season tournaments and summer and fall tournaments. Anglers caught a range of sub legal fish, but very few fish were culled due to a low number of anglers reaching their bag limit. We examined largemouth bass populations in lakes with known tournament pressure. Twelve lakes were categorized into no tournament pressure, medium tournament pressure and high tournament pressure based on data provided by tournament directors. Greater recruitment was observed on no tournament lakes but densities of adult largemouth bass were lower. Angler catch rates were related to the abundance of fish in electrofishing transects and was higher on larger lakes. We did not detect any changes in abundance or size structure of largemouth bass vulnerable to tournament angling or production of young-of-year fish related to tournament pressure. We will continue to collect tournament and weigh-in data and examine relationships between tournament angling and fish populations in future projects.

In Job 101.6, a portion of Clinton Lake that was closed to fishing was sampled to continue assessment of the effects of a refuge on largemouth bass populations. Electrofishing samples yielded a higher abundance of adult largemouth bass in the refuge than in the main lake, however no increase in the number of largemouth bass has been observed lake-wide. Based on these results, areas closed to angling may not increase largemouth bass population. However, these results are based on only one lake. Refuges were also put in place at Otter Lake in two coves and we began monitoring changes in largemouth bass populations in the refuge and throughout the lake. The refuge was closed to fishing in June 2010 and seine and electrofishing samples were conducted prior to the refuge (2007-2010) and after the refuges were closed (2011-2012). CPUE of largemouth bass from seine and electrofishing samples in 2011 and 2012 were lower than the mean pre-refuge conditions in both the control sites while the refuge sites remained the same. We would not expect large changes in the largemouth bass community in the first year and a half following implementation of a refuge and any conclusions from the data would be premature. We will continue to monitor Otter Lake and make recommendations based on these findings in future projects.

We also assessed the effects of harvest regulations on largemouth bass populations. We constructed a database of lakes using the Fisheries Analysis System (FAS) containing electrofishing data from 2000-2007 collected by DNR biologists. We grouped lakes by regulation type into 7 groups; Bag by Size (Bag limit above and below a specified size), Catch-and Release (no harvest allowed), Standard (14” length limit, 6 fish creel), Lowered Bag (14” length limit, <6 fish bag limit), Raised Length (>14” length limit, 6 fish bag limit), Raised Length/Low Bag (>14” length limit, <6 fish bag limit), No Length (No minimum size limit), and Slot (no fish harvest slot). We compared catch rates of young-of-year and adults (greater than 14 inches), memorable (greater than 510 mm), and proportion stock density (PSD). Lakes with slot limit regulations had the highest CPUE of young-of-year, total, and memorable sized largemouth bass. No other significant differences existed among groups. These data can then be used to guide future discussions about various regulations and adaptive management experiments that might be implemented to assess harvest regulations.

Job 101.1 Evaluating marking techniques for fingerling largemouth bass

OBJECTIVE: To determine the most reliable and cost-effective method for mass-marking fingerling largemouth bass.

INTRODUCTION:

The ability to reliably identify stocked fish is useful when evaluating supplemental stocking programs. The choice of a particular fish marking technique depends primarily on the scope of the management question. An ideal mark should be inexpensive, easy to apply, have long-term retention, and have minimal impact on the health of the fish. In some instances, short-term marks can provide sufficient information to address management questions. However, in most cases, it is important to identify marked fish throughout their lifetime. In Illinois, freeze branding (Mighell 1969) is a commonly used method for mass-marking largemouth bass fingerlings. Although this technique permits marking large numbers of hatchery fish both quickly and inexpensively, long-term retention of freeze brands in centrarchids is variable (Coutant 1972). Because this variability can compromise the quality of recapture data, it is important that a relatively long-term mark be identified.

Several marking techniques have the potential to produce long-term physical marks on largemouth bass. Fin clipping can permanently mark largemouth bass if all fin rays are carefully clipped at the point of attachment to the bone (Wydoski and Emery 1983). Partial or incomplete removal of fin rays, however, can result in fin regeneration and preclude our ability to identify stocked fish. Boxrucker (1982; 1984) used a combination of fin clipping followed by freeze cauterization of the wound to create a long-term mark on fingerling largemouth bass. This technique required more man-hours than fin clipping or freeze branding alone (Boxrucker 1982).

PROCEDURES:

We evaluated the long-term retention rate associated with three different marking techniques for 4" largemouth bass. Marking techniques included (1) fin clipping, (2) fin clip with cauterization, and (3) freeze branding. Fin clips were obtained by removal of the right pelvic fin. Removing the left pelvic fin and ‘freeze-branding’ the wound with liquid nitrogen made fin cauterizations. Freeze branding was accomplished by holding fish for 2 s against a branding iron chilled to -190 °C with liquid nitrogen. Freeze brands were located on the left side of individual fish, just below the dorsal fin. Groups of fingerling bass with each mark (75-100 each) were then stocked into 3 ponds (1/3 acre) at a total density of 250 fish per pond. In case fish lost their mark, fish used in these experiments were previously identified as either the1:1, 1:2, or 2:2 MDH-B genotype. At the beginning of the experiment, fish with known genotypes were assigned to a specific physical mark so that they could be genetically identified if marks disappeared or could not be positively identified in the field. Fingerling bass were stocked into ponds on December 14, 1998. Fish growth, differences in mark retention rates and percent regrowth among marking techniques were measured and assessed each spring and fall from May 1999 through March 2004. Seasonal differences in fish coloration can make it difficult to detect freeze brands, which has raised some concerns with this marking technique. Therefore, in November 2003, we initiated an evaluation of seasonal variability in visibility of freeze brand marks. We marked 100 fingerling bass (137 mm, TL) with vertical and horizontal freeze brands. Seasonal readability was assessed in spring 2004 and was completed in fall 2004.

FINDINGS:

In the long-term pond experiments (1999-2004), fin cauterization was the longest lasting mark followed by fin clip and freeze brand marks (Figure 1-1). Whole fin regeneration for fish marked with fin clips (10.4%) was greater than that for fish marked with fin cauterized clips (5.3%) during the six years. Fin clips and fin cauterized marks had considerable amounts of fin regrowth that made them less desirable than freeze brand marks. Fin cauterized marks had 20% less fin regrowth than fin clips. Less fin regrowth in fin cauterized marks made them more obvious than fin clips and required less handling time to identify marks. Freeze brand marks were the most distinguishable and required the least amount of handling time to identify. Freeze brand marks were 7% less distinguishable during fall sampling (0 = 93%) as compared to spring sampling (0 = 100%) because of darker external fish coloration. Conversely, fin clips and fin cauterized marks (0 = 100%) were distinguishable regardless of season (i.e., fish coloration).

Long-term growth appears to be unhampered by fin clips, fin cauterization, or freeze brand marks. Fish grew to similar lengths over the 6-year period regardless of the three marking techniques (Table 1-1). The removal of a fins (fin clip0 = 293 mm, TL; fin cauterized; 0 = 292 mm, TL) compared to freeze branding (0 = 289 mm, TL) does not appear to impact foraging success or energy allocation.

In the short term experiment (2003-2004), vertical and horizontal freeze brands (96%) were both very readable during the spring, but less so in the fall (78%). Of those marks that were determined to be poor, two were horizontal and two vertical. Variability in juvenile largemouth bass color does appear to significantly influence readability in the second fall after stocking, but not at other times of the year.

RECOMMENDATIONS:

Previous experiments suggest OTC-marks are preferable over fin clips, fin cauterization, freeze brand, and photonic dye. However, this recommendation is based strictly on retention rates coupled with ability to mark large numbers of fish quickly. Specific scientific and management related objectives should be considered because OTC marked fish must be sacrificed for identification, which may not be acceptable for all applications. For those scientific and management efforts that wish to reduce mortality, fin clip marks (with or without cauterization) should be employed since they had comparable retention rates as OTC.

Long-term marking results suggest that freeze brand marks are more distinguishable and take less handling time to identify than fin clips and fin cauterized marks. Although all three marks had good retention freeze brand marks resulted in the most discrete and reliable means for largemouth bass identification. The speed and low cost that freeze brands afford suggest that this is the best method for long-term marking of 4" largemouth bass in some situations.

Freeze branding can be used to mark a large number of largemouth bass quickly, and they are discernible over a long time period, except in the first and second fall periods. In our study the majority of indistinguishable freeze brand marks occurred in the first two falls, after which the majority of remaining marks were readily distinguishable. These indistinguishable marks can most likely be attributed to the branding process resulting from insufficient tissue contact time with the branding iron bar and/or inadequate bar temperature coupled with a slightly darkened integument during colder months in the fall. In order to ensure adequate scarring we suggest that the tissue contact the branding bar for at least two seconds. In addition, freeze brands on juvenile largemouth bass develop as dark marks and therefore should be applied vertically to lightly pigmented areas. Consideration should also be given to the hazards of working with liquid nitrogen that require strict safety precautions. Liquid nitrogen must be carried outside of the passenger compartment of vehicles and requires the use of specialized containers and transfer devices.

Fin cauterization and fin clip marks were good as a long term marking method that lasted for at least six years. Fin cauterized clips tended to exhibit slightly less fin regeneration. Fin regeneration adds considerable time to fish identification and additional stress by prolonging air exposure. Unfortunately, minor variations exist in fin clipping techniques among workers. If these variations result in incomplete removal of the fin at its insertion at the pelvic girdle regeneration, will most likely occur and may result in misidentification. Fin clips performed on fish that have been anesthetized (e.g. with MS-222) may lessen the amount of incomplete fin clips. Fin clips may add considerable time to complete, particularly if cauterization is employed, resulting in additional monetary costs associated with labor.

Our results suggest that freeze branding had good retention rates and more importantly were readily distinguishable when properly applied. In addition, freeze branding appears to the least labor intensive and thus the most cost effective means to mass mark large numbers of juvenile largemouth bass. Freeze brands will work for assessment of long-term survival, but will be less effective in the first two falls after stocking for assessments of short-term survival. Fin cauterization and fin clips proved to be effective for marking juvenile largemouth bass. However, additional time is required to mark and in the field to distinguish regenerated fins compared to fins that had not been clipped. We suggest using fin clips only for marking small numbers of fish when time allows careful attention to making complete clips.

Job 101.2. Evaluating various production and stocking strategies for largemouth bass.

OBJECTIVE: To compare size specific survival and growth among different sizes of stocked largemouth bass fingerlings and to compare various rearing techniques.

INTRODUCTION:

Supplemental stocking of largemouth bass *Micropterus salmoides* is a commonly used management tool to enhance populations. Supplemental stocking efforts are directed at either increasing harvest rates and reproductive potential, or restoring predator/prey balance in a fish community. However, for these positive benefits to occur, stocked fish must contribute to the natural population. Numerous studies have examined either the introductions of different genetic stocks of largemouth bass (Rieger and Summerfelt 1978; Maceina et al. 1988; Mitchell et al. 1991; Gilliland 1992; Terre et al. 1993) or the introductions of largemouth bass into ponds (Dillard and Novinger 1975; Modde 1980; Stone and Modde 1982). Surprisingly, few studies have examined the factors thought to influence supplemental stocking of largemouth bass. The few studies that have examined the contribution of stocked largemouth bass to a natural population, examined only one (Lawson and Davies 1979; Buynak and Mitchell 1999) or two lakes (Boxrucker 1986; Ryan et al. 1996). Given that lakes are highly variable, examining stocking evaluations from only one or two lakes limits our ability to make generalizations.

Factors influencing stocking success may include predation, prey availability, and abiotic variables (Wahl et al. 1995). Predation from older age classes of largemouth bass may be especially important given that they have been shown to prey heavily on other species of stocked fish (Wahl and Stein 1989; Santucci and Wahl 1993) and are highly cannibalistic (Post et al. 1998). The availability of appropriate sized prey has also been shown to be important to survival of stocked fish for other species (Fielder 1992; Stahl and Stein 1993). Finally, abiotic factors such as water temperature at time of stocking may contribute to stocking success. High water temperatures at time of stocking may increase stocking stress and subsequent mortality (Clapp et al. 1997). Determining which of these factors is most important to stocking success has important implications for deciding the appropriate locations and times to stock.

Previous stocking evaluations conducted in the Midwest have often examined species that do not naturally reproduce in the recipient water body (e.g. muskellunge *Esox masquinongy*, Szendrey and Wahl 1996; walleye *Stizostedion vitreum*, Santucci and Wahl 1993). Largemouth bass, however, reproduce naturally in most Midwestern impoundments, and therefore supplemental stocking programs are directed at enhancing existing populations. The number of natural fish produced during the year of stocking may influence stocking success through competitive interactions for food and habitat. Because native largemouth bass may out compete stocked largemouth bass, a large natural year class may decrease stocking success in an individual lake. Conversely, stocked largemouth bass may do well in years where the population exhibits high natural recruitment because they are potentially influenced by the same variables.

Differences in rearing and stocking method (e.g., intensive raceway versus extensive ponds and point versus dispersed stocking) of the largemouth bass fingerlings may also influence growth and survival. Largemouth bass raised on commercial food pellets have been shown to grow better when stocked into rearing ponds than those fed a diet of fathead minnows (Hearn 1977). A number of Illinois reservoirs and impoundments are stocked with largemouth bass raised extensively in rearing ponds. These and other lakes can also be stocked using largemouth bass raised at state hatcheries. The relative merits of these two rearing techniques have not yet been assessed. In addition, stocking fish into habitat may be preferred to the common practice of point stocking at the boat ramp. Bass have shown increased ability to avoid predation when stocked in a variety of habitats or habituated before stocking (Schlechte et al. 2005). However, these two stocking strategies have not been directly compared in a field setting.

Previous experiments dealing with trophic interactions and largemouth bass stocking suggest many possible effects on receiving aquatic communities (Drenner et al. 2000; Nowlin et al. 2006). Of primary concern to fisheries managers are the potential impacts of stocked largemouth bass on other sportfish such as bluegill and potential "biomanipulation" effects that may result from cascading effects of increases in predator demand such as changes in water clarity (Shapiro et al 1975, Drenner et al 2000, Lathrop et al. 2002). Such effects may depend on a number of characteristics of the receiving lake the most important being prey species traits and nutrient levels (see Drenner and Hambright 2002 for a current review). The specific outcome of predator stocking is often variable which limits accurate prediction of the impacts stocking may have (Schaus and Vanni 2002, Schulze 2006). In this segment we conclude our exploration of the community responses caused by stocking of largemouth bass in Illinois lakes. These analyses shed light on the potential impacts of largemouth bass stocking and will help managers to predict the likely community response of stocking this predator.

The objectives of this job were to evaluate largemouth bass stocking success and explore methods to increase growth and survival. First we assessed growth and survival of largemouth bass stocked in a number of lakes and compared them to wild fish. Next we attempted to enhance growth and survival through stocking different sizes of largemouth bass, employing different rearing techniques, and utilizing alternative stocking methods. All of these methods were assessed to determine how growth and survival of stocked largemouth bass can be enhanced and ultimately produce better quality largemouth bass fisheries.

PROCEDURES:

Long-Term Stocking Success

We evaluated the long term survival and growth of largemouth bass stocked in Illinois Lakes. Largemouth bass fingerlings (100 mm) were stocked in 15 lakes and were given pectoral fin clips for future identification. Spring and fall electrofishing samples were used to evaluate growth and survival of stocked fish compared to wild fish. Detailed procedures can be found in Appendix A (Diana and Wahl 2008).

Stocking Size

We compared the growth and survival of largemouth bass stocked at different sizes and times of year. Four lakes were stocked with 4 sizes of largemouth bass at different times of year (50, 100, 150, 200 mm). All fish were clipped with distinctive marks. Spring and fall electrofishing sampling was conducted to assess growth and survival. We also estimated stocking mortality using mortality cages on site for 48 hours following stocking. Predation of newly stocked fish was measured by examine diets of predators for a month following stocking. Detailed procedures can be found in Appendix B (Diana and Wahl 2009).

Rearing Technique: Intensive Versus Extensive

The effects of rearing techniques on growth and survival of stocked largemouth bass were evaluated in Lakes Shelbyville, Jacksonville and Walton Park. Extensively reared bass were produced at the Little Grassy Fish Hatchery where they were held in ponds and fed on minnows until stocking. Walton Park was stocked directly from Little Grassy Fish Hatchery in early August. Jacksonville and Shelbyville utilized lake side rearing ponds. Fish were delivered to the rearing pond in June along with minnows for prey and were allowed to grow until fall. The rearing ponds were drained in late August and fish were marked using fin clips and stocked into the main lake. Intensively reared bass were produced at the Jake Wolf Fish Hatchery where they were held in 265 L concrete tanks and fed commercially produced pellets until stocking. Each fish was given a distinct pelvic fin clip for future identification of rearing technique. Fish were transported from the hatchery in oxygenated hauling tanks to the recipient lakes. Hauling time ranged between 0.5 to 3 hours. Fifty largemouth bass were measured (nearest mm) and weighed (nearest g) before stocking on each date. Fish were released near shore at a single location at each lake. Attempts were made to stock largemouth bass at a rate of 60 fish per hectare, however rates varied by individual lake due to varying success of rearing ponds and hatchery production.

Stockings were conducted from 1999 through 2004 and we monitored stocked fish until they were no longer found in electrofishing samples. Growth and survival of stocked largemouth bass was determined in each fall and spring by sampling during the day with a 3-phase AC electrofishing boat. Three shoreline transects on each lake were electrofished for 0.5 h each on a sampling date and all largemouth bass were collected, measured, weighed, and examined for clips. Scales were removed from all clipped fish and aged by two independent readers. The stocking year and rearing type was determined for each fish using the age of the fish and the existing clip. Catch per unit of effort (CPUE) was calculated as the number of stocked fish collected per hour and was used as a relative measure of survival across lakes. Growth was estimated using the mean size of bass for each age class at the time of sampling. Hatchery costs of producing fish were provided by the hatchery and included the feed cost per fish as well as the estimated hatchery labor and operation cost. The costs of operating the lake side rearing facilities were determined as the price of electricity used to pump the ponds, and the cost of fertilizer and minnows. Data was available for cost per fish produced from the rearing pond on Lake Shelbyville, Lake Jacksonville, and the Little Grassy fish hatchery which served as the rearing pond for Walton Park. Cost per fish was then used to estimate the mean total cost of producing fish per acre for each lake. We calculated the cost per number of fish surviving as the total cost of stocking divided by the CPUE from electrofishing in the 1st, 2nd, and 3rd fall following stocking. Rearing pond survival was also evaluated for each lake and compared to the number of fish stocked from the hatchery.

Stocking Technique: Boat Ramp Versus Dispersed

We evaluated the influence of stocking location on survival of stocked largemouth bass. Otter Lake, Homer Lake, Mingo Laker, and Lake Charleston (n=4) were stocked with 100mm largemouth bass fingerlings from 2008 through 2012 using two stocking techniques. Half of the fish at each lake were stocked at the boat ramp, directly from the hatchery truck, while the other half were loaded into aerated hauling tanks in boats and distributed throughout the lake. Distributed stockings targeted placing fingerlings into wood and vegetated habitat dispersed throughout the lake. Fish were marked with a pelvic fin clip two weeks prior to stocking at the Jake Wolf Memorial Fish hatchery. Fish stocked at the boat ramp were given a left pelvic fin clip and fish to be dispersed were given a right pelvic fin clip. Lakes were sampled two times in the fall and two times in the spring using DC electrofishing. Three 30 minute electrofishing transects were performed on each sampling date and all largemouth bass were collected, measured for total length, examined for clips, and scales were collected from all clipped fish for age determination. CPUE was calculated for stocked and wild fish and contribution of stocked fish to the total bass population was calculated. The CPUE from this segment was combined with the data from 3 years of previous stockings in the same lakes. Catch rates and mean size were calculated for each year class and compared between the two rearing techniques. CPUE from electrofishing was calculated and differences between stockings were examined using repeated measures ANOVA and Tukey-Kramer (T-K) adjusted P value were used to determine significance in post hoc tests.

Influence of Stocked Fish on Resident Populations

Lakes for this analysis were stratified into those containing a gizzard shad prey base (N=7) and those without gizzard shad (N=6) to account for the strong community interactions of this prey species (Dettmers and Stein 1996) and to examine differences in response between these lakes. Comparisons before and after stocking were then made between lakes receiving largemouth bass stockings (with shad N=3, without shad N=3) and those without stockings (with shad N=4, without shad N=3) using a replicated before-after control-impact (MBACI) design (Underwood 1994, Kough and Mapstone 1995). These analyses are suited to the detection of abrupt changes in the mean of the parameter being investigated as well as gradual changes through time (Keough and Quinn 2000). Data collection and stocking methodology were as described in the previous section “Mechanisms Influencing Stocking Success” and are not described here.

FINDINGS:

Long-Term Stocking Success

We evaluated the long term survival and growth of largemouth bass stocked in Illinois Lakes. We observed low survival of stocked largemouth bass and significant mortality at age-2 compared to wild populations. Detailed findings can be found in Appendix A.

Stocking Size

We compared the growth and survival of largemouth bass stocked at different sizes and times of year. We observed low survival of all sizes of stocked largemouth bass. Cost benefit analysis supported the stocking of four inch fingerings due to low cost and similar survival and growth compared to other sizes. Detailed findings can be found in Appendix B.

Rearing Techniques: Intensive Versus Extensive

Mean survival of fish stocked into the rearing pond was 46% in Jacksonville and 42% in Shelbyville. We could not estimate pond survival for Walton Park because the fish were provided directly from the hatchery. The mean number of extensively reared fish stocked per year was similar to the intensively reared fish in Jacksonville (extensive n = 5511 ± 2271 SE; intensive n = 4250 ± 750 SE), Shelbyville (extensive n = 8684 ± 1821 SE; intensive n = 8813 ± 12.5 SE), and Walton Park (extensive n = 625 ± 0 SE; intensive n = 625 ± 0 SE) and no significant difference existed between the number of intensive or extensive fish stocked (paired t-test; t= -12; P = 0.91). Because there were no significant differences in the number stocked, we did not adjust CPUE when evaluating survival. Variation in number stocked was much greater for the lake side rearing ponds than for fish produced by the hatchery. Mean stocking size was larger for extensively reared fish than intensively reared fish in Jacksonville (ext. = 144 mm; int. = 99 mm) and Walton Park (extensive = 120 mm; intensive = 101 mm), but stocking size was similar for both stocking techniques in Shelbyville (extensive = 101 mm; intensive = 108 mm) fish.

Significant differences existed between CPUE of largemouth bass from each of the stocking strategies through time. There was also a significant interaction between stocking strategy and time after stocking (RMANOVA, F = 2.21, P = 0.007). Extensively reared largemouth bass were recaptured at a significantly higher rate than intensively reared fish the first fall following stocking (Figure 2-1 A., T-K, t = 4.11, P = 0.02) and the following spring (T-K, t = 4.33, P = 0.007). After the first spring, catch rates for both intensive and extensive fish declined to below 1 fish per hour of electrofishing and there was no longer a significant difference in survival between the two rearing strategies (P > 0.05). Despite better initial survival of extensively reared fish, we found low long term survival of stocked fish from either rearing strategy and no long-term differences in relative abundance.

Significant differences also existed in mean size among intensive, extensive, and wild fish. There was again a significant interaction between stocking strategy and time following stocking (RMANOVA, F = 8.97, P < 0.0001). Extensively reared fish were larger than wild fish (T-K, t = 4.18, P = 0.02) but not significantly larger than intensively reared fish (T-K, t = 3.06, P = 0.50) the first fall following stocking (Figure 2-2). Wild and intensively reared fish were also not different in size in the first fall following stocking (t = 0.58, adj. P = 1.00). Differences in size were no longer significant in the spring following stocking. Extensively reared fish were similar in size to both wild (T-K, t = 2.64, P = 0.82) and intensive fish (T-K, t = 0.38, P = 1.00) and no difference existed between intensive and wild fish (T-K, t = 1.60, P = 1.00). Wild, intensive and extensive fish remained similar in size throughout the remaining months they were collected in electrofishing samples. Although extensively reared fish were larger than intensively reared fish and wild fish when they were stocked, size differences were short lived and by the spring following stocking there are no differences in size among these fish.

The cost of producing fish varied among rearing types and individual lakes. Lake Shelbyville was less costly to stock per acre due to its large size, but fish were stocked at a lower density. For all lakes, mean total cost of stocking was higher for extensively reared fish (Table 2-1) as a result of the greater cost per fish produced. The hatchery cost of producing the two inch fish to stock into rearing ponds is very low and a large number of fish can be produced at a low cost. However the cost of maintaining the fish in the rearing pond due to minnow expenses greatly increases the cost of producing fish to stock. Because the initial survival of extensive fish was higher than intensive fish, the cost per relative survival was similar in the first fall following stocking. However, extensive fish experienced low long term survival resulting in the cost per fish surviving to increase in subsequent years. Because of this the cost was twice that of the intensive fish when considering the high cost and no differences in long term survival.

Stocking Techniques: Boat Ramp Versus Dispersed

Four lakes were stocked with four inch largemouth bass in 2008 through 2012 for comparison of boat ramp and dispersed stocking. All lakes continued to have very low survival of both boat ramp and dispersed stocked fish to the first fall following stocking (Table 2-2). Continued low survival of the stocked fish from both stocking methods has made it difficult to evaluate these methods. At this point there is no difference in mean CPUE of boat ramp or dispersed stocked fish in the first fall following stocking and catch rates the following spring are very low. We have begun to find some fish from previous stockings in our electrofishing samples, but the CPUE is very low and there is no consistent difference between stocking method. The poor survival of all stocked fish may be due to the warm water temperatures on the date of stocking. High mortality of dispersed fish could be affected by the increased handling time associated with loading the fish onto a boat and dispersing them throughout the lake. We did not however observe good survival of fish stocked at the boat ramp where this handling did not occur. Additional years of stocking are required to evaluate differences in these stocking techniques. We will continue to stock four lakes each year as part of future studies using these strategies in order to make management recommendations regarding stocking locations to maximize survival.

Influence of Stocked Fish on Resident Populations

We found significant declines in average juvenile bluegill density in lakes where gizzard shad were absent in response to supplemental stocking of largemouth bass (Table 2-3) whereas this effect was not observed in lakes containing gizzard shad (Table 2-4). Although we found evidence of an effect of supplemental stocking of largemouth bass on juvenile prey fish abundance, these changes had only weak effects on other components of the food web and did not influence adult bluegill density (Tables 2-3 and 2-4). There was no significant change after largemouth bass stocking in the zooplankton (density and/or size of cladoceran zooplankton and chaoboridae); total phosphorous concentration, or water clarity in either set of lakes relative to controls (Tables 2-3 and 2-4). Reductions in littoral juvenile bluegill densities in lakes where gizzard shad were absent did influence total macroinvertebrate densities that increased significantly after the onset of largemouth bass introduction (Table 2-3). No such effects of largemouth bass introduction were found in lakes where gizzard shad were present (Table 2-4).

RECOMMENDATIONS:

Long-Term Stocking Success

We evaluated the long term survival and growth of largemouth bass stocked in Illinois Lakes. We observed low survival of stocked largemouth bass and significant mortality at age-2 compared to wild populations. Detailed discussion can be found in Appendix A.

Stocking Size

We compared the growth and survival of largemouth bass stocked at different sizes and times of year. We observed low survival of all sizes of stocked largemouth bass. Cost benefit analysis supported the stocking of four inch fingerings due to low cost and similar survival and growth compared to other sizes. Detailed discussion can be found in Appendix B.

Rearing Techniques: Intensive Versus Extensive

Comparisons between intensive and extensive stocked fish showed differences in growth and survival initially following stocking. Extensively reared largemouth bass had higher survival than intensively reared fish and were larger than wild fish in the fall following stocking. Extensive fish remained more abundant than intensively reared fish the following spring, but were no longer larger than wild fish. Despite higher initial stocking success with extensively reared fish, there were no differences in growth or survival by the second fall following stocking and survival was low for both stocking strategies (< 1 fish per hour of electrofishing). The low long-term survival of stocked fish results in no differences in catch rates between rearing method after the first year. Many factors influenced the variation in the number of fish produced by the rearing ponds. In Lake Jacksonville, the rearing pond had green sunfish contamination which resulted in only 125 largemouth bass being produced in 2002. The Lake Shelbyville rearing pond had gizzard shad accidentally introduced during a high water year that yielded a larger size variation in the fish produced. Rearing pond production is less predictable and varies greatly in success and this must be considered in producing fish for stocking.

Raising fish in a rearing pond greatly increases the cost of production, however when fish are harvested from the pond, they are generally larger than the intensively produced fish. In addition, the greater survival of extensively reared fish until the second fall following stocking suggests there is potential for extensive rearing to produce more harvestable fish, however long term mortality was high and there was no difference in abundance after the second fall. Because the cost of producing extensive fish is much greater than that for intensive fish, there was no difference in cost per CPUE in the first fall following stocking. The cost per CPUE for extensive fish increased through time as the catch rates decreased making the cost per CPUE much higher than intensive fish. We do not know the absolute number of stocked fish surviving through time, but the cost per CPUE can be used to compare between the two rearing methods because the relative abundance can be measured from electrofishing CPUE. The ratio of intensive and extensive fish captured can be used to evaluate the relative cost of each rearing strategy. There may be other benefits to using lakeside rearing ponds for producing fish due to the rearing occurring in a more natural environment and allowing the fish to feed on natural prey rather than artificial feed before stocking. Due to the close proximity to the stocking lake, these fish should experience a similar thermal regime to their destination lake and may reduce the acclimation time required when released in the lake. Experience with feeding on fish prior to stocking has been shown to result in greater growth and survival following stocking for other species (Suboski and Templeton 1989; Szendrey and Wahl 1995; Wahl et al. 1995b) as well as for largemouth bass in laboratory experiments in this project (see previous reports). However, low survival of all stocked largemouth bass led to few fish growing large enough to contribute to the fishery. Fish did not reach 14 inches until their fourth year in the lake. CPUE for these fish was less than 0.5 per hour of electrofishing and they did not significantly contribute to the adult largemouth bass population.

Stocking Techniques: Boat Ramp Versus Dispersed

We will continue evaluating stocking location as part of project F-152 to assess the potential to increase survival of stocked largemouth bass. At this point, we have observed very low survival of largemouth bass stocked both at the boat ramp and dispersed throughout the lake. Survival of fish in this study has been lower than survival observed from previous stockings we have evaluated. Survival may have been limited due to the high temperatures on the dates of stocking or the increased handling time due to the stocking techniques. Future efforts will be made to stock the fish during the lowest possible temperatures to facilitate survival. We will continue to compare survival of point stocking versus dispersed stocking at multiple locations of optimal habitat throughout the study lakes. In future studies we will stock Lake Charleston, Homer Lake, Lake Mingo, and Otter Lake using these two methods. We will evaluate growth and survival by conducting spring and fall electrofishing. Ultimately we hope to evaluate if increased survival of stocked largemouth bass can be achieved through these techniques and provide management recommendations on best stocking method.

Our results continue to suggest the need to evaluate long-term survival of largemouth bass to fully evaluate stocking success. Although stocked fish may exhibit similar survival to wild fish in a lake initially following stocking, significant mortality can occur through adulthood. Stocking success could be evaluated incorrectly if long-term survival is not considered. We have found that recruitment of largemouth bass is not determined in the first year after stocking. Many previous evaluations of stocking success for other species have not examined stocking success beyond the first spring. These studies may omit a critical period for determining survival of stocked fish. For largemouth bass, success of stocked fish in the first year is often not reflected in future creel data providing further evidence for variable survival following the first year after stocking (Boxrucker 1986; Neal et al. 2002). Managers should consider survival to age-1 and adult fish when managing a lake or reservoir by stocking. Considering the availability of appropriate prey and habitat for larger stocked fish may reduce mortality and increase recruitment to the fishery. We will continue to evaluate different stocking methods which may increase long term survival of stocked largemouth bass. At this point, we have not been able to find benefits of stocking extensively reared fish or larger fish. Future efforts will be required to assess if stocking fish into optimal habitat can increase stocking success. In future studies we will examine other lake specific factors that may influence stocking success such as prey abundance and availability, available habitat, thermal regimes, and fishing pressure. We will examine variation among lakes in order to further explore what factors may play a role in determining growth and survival of stocked fish.

Influence of Stocked Fish on Resident Populations

Reductions in prey fish abundances such as those observed in stocked lakes without gizzard shad have the potential to cause trophic cascades that affect the entire food web and ultimately affect water clarity and primary production. Our results however show little evidence of cascading responses in stocked lakes beyond juvenile prey fish abundance and littoral macroinvertebrates. Several possible reasons exist for this lack of further responses including the ability of bluegill and gizzard shad to outgrow the gape limitation of predators. If sufficient numbers of juvenile prey fish are able to survive each year to maintain predation on lower trophic levels and to maintain recruitment into larger size classes we might expect little effects of stocked largemouth bass on lower trophic levels or population level effects on bluegills. Other possible limiting mechanisms may be the diversity of fish diets, which may weaken links in the food web, poor long-term survival of stocked largemouth bass, compensatory reproductive output by adult prey species or other complex nutrient-planktonic interactions. Aquatic food webs of Illinois lakes appear to be more resilient to perturbations of top predator biomass than the northern lakes where the trophic cascade hypothesis was initially developed and tested. The resilience of Illinois lake communities however does not mean that managers should ignore the potential impacts of supplemental largemouth bass stockings on lake communities. Reductions in littoral prey fish abundances are not trivial effects considering that the abundance of juvenile bluegill sunfish is a primary driver of recruitment in many Illinois lakes. Our results suggest that an unintended consequence of supplemental largemouth bass stocking may be increased intraspecific competition for limited prey resources. Juvenile bluegills are a limiting resource in some Illinois lakes and their abundance should be a primary consideration when making decisions regarding supplemental stocking of largemouth bass populations.

Job 101.3 Assessing the long-term contribution of stocked fish to largemouth bass populations.

OBJECTIVE: To evaluate the long-term contribution of stocked largemouth bass to the numbers of reproducing and harvestable adults.

INTRODUCTION:

Fish stocking is common throughout North America for a number of species. Fish may be stocked to introduce a species to a new system (Douwalter and Jackson 2005), sustain a population in areas where the fish do not reproduce naturally (Santucci et al. 1994), supplement wild populations that have been reduced due to anthropogenic influences (i.e. fishing, habitat degradation; Wingate 1986) or to alter the genetics of a population (Maceina et al. 1988, Buckmeier et al. 2003). The initial success of a stocking program depends on the survival of introduced fish. Much research examining the success of stocking programs has focused on initial survival (Boxrucker 1986, Buckmeier and Betsill 2002, Hoffman and Bettoli 2005), Though more recent work has focused on survival to adulthood (Diana and Wahl 2008, Buynak and Mitchell 1999, Wahl and Stein 1993).

Despite high initial survival, stocked fish often represent only a small proportion of the population as adults (Diana and Wahl 2008, Buynak and Mitchell 1999). The reasons for the poor survival between introduction and adulthood often remain unclear, but does suggest that stocked fish are less equipped for long-term survival than wild fish (Buynak and Mitchell 1999). If the longterm goal of stocking includes increasing the population of the stocked species, success depends not just on survival to adulthood, but also on long-term reproductive abilities (Currens and Busack 1995, Waples and Do 1994). However, understanding how stocked fish contribute to the reproductive output of the populations into which they are stocked has received little attention.

If poor survival of stocked fish is tied to their ability to obtain resources or exploit preferred habitats (Donovan et al. 1997, Szendrey and Wahl 1996), then those fish that do survive to adulthood may exhibit poorer reproductive output compared to their wild counterparts. Furthermore, hatchery rearing conditions (high density, disease treatments, water quality issues), may also affect the development of reproductive organs (Huntingford 2004) or modify the behavior of fish in such a way that it could affect reproductive ability of adults (Berejikian et al 1997, Jonsson and Jonsson 2006). For example, stocked Atlantic salmon females have been found to deposit fewer eggs, display fewer courtship behaviors, spend less time breeding, and have lower survival of eggs than wild fish (Jonsson 1997). Likewise, stocked male Atlantic salmon have lower success at mate acquisition than their wild counterparts (Jonsson 1997). As stocked fish become part of the adult population, it is important to understand the reproductive abilities of these fish in order to determine how stocking affects long-term population dynamics.

Largemouth bass are stocked regularly into lakes and reservoirs throughout their range and are often used to supplement naturally reproducing populations (Boxrucker 1986, Maceina et al. 1988, Buynak et al. 1999). Previous work examining success of stocked fish to adulthood have found that survival is often lower than wild fish (Diana and Wahl 2008, Buynak and Mitchell 1999). Although it is assumed that increases in the standing stock of populations are the direct result of stocking efforts, little data exist to either refute or support that idea for largemouth bass. If the stocking does indeed increase the standing stock of adult largemouth bass, it also remains unclear how those increases effect reproduction and recruitment in subsequent generations.

Largemouth bass likely home to natal areas to spawn (Ridgway et al. 1991, Waters and Noble 2004), and it is possible that introduced fish may not compete successfully with resident fish for optimal spawning sites or may simply make poor choices in selecting nesting sites. Under either of these scenarios, the level of reproductive success of stocked bass would be lower than that of resident bass. To justify continued stocking efforts for largemouth bass in Illinois, it is important to determine the actual contribution that stocked fish make to bass populations. The objective of this job is to compare the survival and reproductive success of stocked bass to resident populations. In this way, we can assess the costs and benefits of the bass stocking program in a long-term timeframe.

METHODS

Largemouth bass for stocking were produced at the Little Grassy Fish Hatchery, Illinois Department of Natural Resources, and bred specifically to be fixed for the malate dehydrogenase (MDH) B2 allele (Philipp et al., 1979). Genetically tagged fish were then stocked into five target lakes. Prior to stocking (1998), a sample of 100 naturally produced largemouth bass were collected from each study lake and analyzed to determine the inherent background frequency of the MDH-B2 locus.

Five lakes were stocked with largemouth bass in early July at a density of ~60 fish/hectare with a target size of 100 mm TL; Lake Shelbyville (Shelby County, IL) and Forbes Lake (Marion County, IL) beginning in fall 1998, and Walton Park (Montgomery County, IL), Lake Murphysboro (Jackson County, IL), and Sam Parr (Jasper County, IL) beginning in fall 1999. Stocking continued in all lakes in fall of each year through 2005. Samples of fish from the hatchery rearing ponds were sampled each year, and protein electrophoretic analysis (Philipp et al., 1979) was used to confirm that these fish had the MDH B2B2 genotype. Stocked fish were also marked with a pelvic fin clip which alternated each year between left and right fins so that age could be determined if they were recaptured. Adult largemouth bass were sampled by electroshocking during the spring and the fall of each year (2002-2007). In each season, the entire perimeter of each lake was sampled on 2-3 dates. Stocked fish that were sampled (identified by a pelvic fin clip) were measured to the nearest mm, and scales were taken to determine age. Fish were determined to be reproductive adults at age 3. These sampling efforts were used to document the survival and contribution of stocked fish to the reproductive population. In addition, shoreline seining was used to assess small fish prey abundance. Seining was conducted using a 9.2-m bag seine (3.2 mm mesh) pulled along the shoreline for 12 m at six fixed sites at least one time per month each year. All fish species were counted and up to 50 fish from each species were measured to total length (mm) and density estimated (N/m2). One hundred young-of-year largemouth bass from the each of the five lakes were sampled by boat electroshocking in each year to determine any changes in the frequency of the MDH B2 allele through protein electrophoresis.

Correlation analysis was used to determine if several measured variables were important in influencing the change in MDH B2 allele frequency across years in the study lakes. Adult largemouth bass catch per unit effort was examined to determine if stocked largemouth bass reproductive contribution was affected by competitive interactions with other adult bass either for food, habitat or nesting site resources. We examined the role of prey resources by examining the density of small fish prey resources. We also determined if lake size had an influence on the contribution of stocked fish. Lake size was inverse transformed to meet the assumptions of normality.

Finally, to determine if B2B2 adults were contributing to reproduction in proportion to their presence in the population, observed MDH B2 allele frequency was regressed against predicted frequency. To estimate the predicted MDH B2 allele frequency of naturally spawned young-of-year from adult fish, we calculated the total frequency of the MDH allele in the adult population. The proportion of natural adult largemouth bass was multiplied by the background MDH B2 allele frequency for those fish and was added to the proportion of B2B2 adults in the population. If stocked fish are contributing to reproduction equal to their proportion in the population, the slope of the regression of actual and predicted MDH B2 allele frequencies in young-of-year fish should equal 1. Deviations from 1 indicate either lower or greater contribution than expected.

FINDINGS

All hatchery fish analyzed from each stocking were 100% MDH B2B2 genotype with the exception of fingerlings stocked into Lake Shelbyville in 2001. In that lake and year, 10 % of the fingerlings had the MDH B1B2 allele. A correction factor to account for the contamination was used in subsequent analyses for Lake Shelbyville. Analysis of initial stocking success of young-of-year largemouth bass found that stocked fish in the first fall represented from 5-60% of the total population of largemouth bass in the lakes (Figure 1). As adults, stocked fish represented from 1-35% of the total adult largemouth bass population (Figure 1). The proportion of the population made up of stocked fish decreased significantly from the fall after stocking through maturation in the study lakes ($F1,3 = 24.44$, $P = 0.01$; Figure 1).

The initial background frequencies of largemouth bass from four of the five study lakes had less than 20% of the individuals with the MDH B2B2 genotype (Table 1). The frequency of the MDH B2 allele in response to stocking increased in most lakes though that change varied substantially among lakes (Figure 2). Walton Park showed a major increase (from 0.16 to 0.42) in the frequency of the MDH B2 allele due to stocking, whereas Forbes Lake (from 0.33 to 0.38), and Lake Shelbyville (from 0.14 to 0.16) showed little influence of stocked fish to the reproducing population (Table 1, Figure 2). Sam Parr Lake (from 0.18 to 0.36) and Lake Murphysboro (from 0.12 to 0.21) showed a moderate increase in the proportion of the MDH B2 allele. Lake size showed a significant negative relationship with the change in the frequency of the MDH B2 allele (Pearson $r = 0.91$, $P = 0.03$, Table 1).

We also examined the influence of the density of adults in each population and the density of forage fish on the change in frequency of the MDH B2 allele. Catch per unit effort of adults had no relationship with the change in frequency of the MDH B2 allele (P=0.9), indicating that intraspecific competition with other adults did not affect the success of stocked fish. The density of forage fish also had no relationship with the change in the frequency of the MDH B2 allele (P = 0.4), indicating prey resources did not appear to affect breeding success of stocked fish.

Stocked adult largemouth bass appear to have similar reproductive potential as natural largemouth bass if they reach maturity. The slope of the regression of predicted against actual MDH B2 allele frequency was not significantly different from 1 (slope = 0.72+0.15, F1,28=3.54, P=0.07; Figure 3), indicating that stocked largemouth bass are contributing as effectively as natural largemouth bass. Thus, the contribution of stocked fish to total reproduction in a population appears to a function of the number of stocked individuals surviving to adulthood.

RECOMMENDATIONS

Stocked fish in the study lakes did survive to adulthood. Like other studies, we found that the stocked fish did not survive as well as wild fish (Buynak and Mitchell 1999, Diana and Wahl 2008). The proportion of the adult population made up of stocked fish was lower than the proportion of stocked fish as young of year. Survival was lake-dependent, with some lakes like Walton Park and Sam Parr having high proportions of stocked fish in the adult populations, whereas others had much lower survival of stocked fish to adulthood. Local conditions may contribute to the high variation in survival among lakes. If the factors that affect natural reproduction act very early (i.e. during egg development or immediately post hatching), then high contribution of stocked fish introduced late in the season could occur. Likewise, stocked fish in lakes with good natural recruitment may be at a competitive disadvantage compared to wild fish (Gunn et al. 1987, Wintzer and Motta 2005).

Given that largemouth bass did survive in these lakes (up to 35 % of the adult population) their contribution to future generations could be assessed. We found that not only do stocked largemouth bass contribute to reproduction in these lakes, they contribute similarly to wild fish. In contrast, stocked salmonids have been found to have lower reproductive success than their wild counterparts (Berejikian et al. 1997). Cultured Atlantic salmon females underperformed wild salmon in egg production, reproductive duration, egg survival, and are courted less by wild males (Jonsson 1997). We did not find a decrease in reproductive success for stocked largemouth bass compared to wild fish. Examining the reproductive behaviors of wild and stocked largemouth bass would provide additional insight into potential differences between cultured salmonids and centrarchids.

We did measure several factors that may have contributed to reproductive success of stocked largemouth bass, including the relative abundance of adult largemouth bass, the density of prey, and the size of the lake. Neither relative abundance of adult largemouth bass nor density of prey were related to the proportion of B2 alleles in YOY fish suggesting competitive interactions with wild fish were not important. Previous studies have suggested stocked fish may not compete well with wild fish for resources and nesting sites (Ridgway et al. 1991, Waters and Noble 2004, Diana and Wahl 2009).

If this were the case then as the number of adult largemouth bass increased, the proportion of B2 alleles should have declined. We also expected lower prey abundance to affect stocked fish more strongly, ultimately affecting reproductive success. Suggestions of poor foraging abilities in stocked fish, however, have been mainly confined to juvenile life stages (Wintzer and Motta 2005, Diana and Wahl 2009) and have not been assessed for adult fish. Stocked fish that do survive to adulthood may be the individuals that were able to compete successfully with their wild counterparts for resources through the juvenile life stages and thus show no competitive disadvantage as adults.

Lake size was related to the increase in MDH B2 alleles across lakes, with smaller lakes showing a greater increase in the MDH B2 allele frequency compared to large lakes. We suspect these patterns could be driven by a relationship between survival and lake size. Despite all lakes being stocked at the same rates, survival even to the first fall after stocking was higher in small lakes compared to large lakes. Survival differences may be related to the way in which fish are often stocked at a single location. Locally high densities of stocked fish could lead to increased density dependant mortality or poorer estimates of lake-wide survival (Noble et al. 1994, Buckmeier and Betsill 2002). Larger lakes also have more diverse predator assemblages (Barbour and Brown 1974, Keller and Crisman 1990) which could lead to higher losses of stocked fish (Diana and Wahl 2009).

The successful reproduction of stocked largemouth bass raises concern about the possible genetic effects of these stocked fish on wild populations. Stocked fish can have both direct and indirect genetic effects (Waples 1991, Waples and Do 1994, Goldberg et al. 2004). Possible direct effects include lower population genetic variation and outbreeding depression, whereas indirect effects can include reduced population size and different selective forces acting on hatchery and wild fish populations (Krueger and May 1991, Waples 1991, Waples and Do 1994). Continual stocking could affect the ability of resident populations to adapt to localized conditions and decrease genetic variability between populations. Outbreeding depression could also be a concern because stocked largemouth bass reproduced as well as wild fish. Lower fitness of a population due to hybridization between genetically distinct populations can result from disruption of locally or intrinsically coadapted gene complexes (Waples 1991, Goldberg et al. 2005). Outbreeding depression has been observed for largemouth bass with lowered survival (Philipp et al. 2002) and resistance to disease (Goldberg et al. 2005).

The different selective environments in hatcheries compared to the wild could also be important (Lynch and O'Hely 2001, Huntingford 2004, Jonsson and Jonsson 2006). For example, hatcheries have lower predation, less competition and lower fry to juvenile morality than natural systems (Waples 1991, Huntingford 2004). These differences ensure survival of individuals that normally may not have survived in the wild. This in turn can select for traits and behaviors that while beneficial in a hatchery context can be detrimental in a more natural environment (Lynch and O'Hely 2001, Huntingford 2004). For example, hatchery environments favor individuals with higher growth and increased aggressiveness (Jonsson and Jonsson 2006), these same traits can make fish more vulnerable to predation when stocked (Huntingford 2004, Diana and Wahl 2009). Those individuals that survive to reproduce could increase those traits and behaviors in the population. These selective effects can be even more dramatic if hatcheries do not collect broodstock from natural populations (Krueger and May 1991, Waples 1991).

We found that stocked largemouth bass that survive to adulthood reproduce as effectively as wild fish. These results have important implications for largemouth bass stocking programs. If the goal of a stocking program is to increase the reproductive potential of a population, then that goal is directly tied to the ability of stocked fish to survive to adulthood. Higher survival and reproduction may also be dependent to some extent on lake size, with smaller lakes responding more strongly to stocking efforts. However, survival and reproduction by stocked fish also increases the potential for negative genetic interactions that could lower the overall fitness of the population that is being targeted for stocking. These pros and cons should all be taken into consideration when making management decisions regarding stocking largemouth bass.

Job 101.4. Evaluating factors that influence largemouth bass recruitment in Illinois.

OBJECTIVE: To determine important mechanisms affecting largemouth bass recruitment in Illinois impoundments and develop recruitment indices for management.

INTRODUCTION:

Largemouth bass *Micropterus salmoides*, similar to other fish species, experiences variable recruitment among populations and years (Jackson and Noble 2000). In general, reproductive capacity of the adult population (Ricker 1954; Rutherford 2002), food availability during the larval life stage, and predation on early life stages (Houde 1987) are general mechanisms of fish recruitment. With slight modifications, these three hypotheses could apply to the specific case of largemouth bass recruitment. The reproductive behavior of largemouth bass potentially complicates any relationship between spawning stock and recruitment. Besides spawning, largemouth bass reproductive behavior includes nest construction, courtship, and brood defense. Typically, spawning stock is the abundance of all fish of a specific age or size range associated with sexual maturity. However, for a species with courtship, territoriality, and parental care, a much smaller fraction of mature fish may be responsible for the majority of surviving young of the year (YOY), therefore, typical estimates of spawning stock may inadequately assess the reproductive capacity of the adult population (Raffeto et al. 1990). Furthermore, conditions (e.g., temperature) and human behaviors (e.g., angling) that affect nest success influence reproductive output and, potentially, recruitment (Philipp et al. 1997; see also Job 101.5).

An important factor in the environment of any developing YOY fish is the availability of food. Ultimately, food availability within a given system is driven by its productivity. The reliance of larval fish on zooplankton is often the critical relationship influencing recruitment strength (Hjort 1914). With fish species that are primarily piscivorous as adults, such as largemouth bass, a successful transition from invertebrate to fish prey during the first year of life could be critical for future survival and success (Mittelbach and Persson 1998). The availability of both invertebrate prey during the earliest life stages and vulnerable fish prey are likely to be important for the consistent and timely development of piscivory (Olson 1996). The growth advantage gained by a switch to piscivory should be important to recruitment due to the size-dependent nature of YOY mortality.

Size-dependent mortality of YOY may be especially important for largemouth bass recruitment due to either selective predation on smaller bass or size-specific winter mortality. Predation often exacts a heavy toll on YOY fishes, potentially influencing recruitment strength (Houde 1987). Typically, the most important form of predation on YOY largemouth bass is cannibalism by earlier hatched individuals and largemouth bass from previous year classes (Post et al. 1998; Parkos and Wahl 2002). Predation pressure may also influence mortality of YOY largemouth bass during their first winter, when they are dependent on their bodies' lipid reserves for survival (Miranda and Hubbard 1994; Ludsin and DeVries 1997). Winter mortality may the most important recruitment bottleneck for YOY largemouth bass, but no evidence for this relationship has been previously found for Illinois populations (Fuhr et al. 2002).

Aquatic vegetation is a habitat feature that influences the abiotic and biotic conditions that determine largemouth bass recruitment strength. Aquatic vegetation is often an important habitat feature for age-0 fishes and recruitment (Wright 1990; McRae and Diana 2005). Aquatic vegetation can benefit fish by decreasing turbidity, providing substrate for spawning, increasing structure for avoiding predators, and acting as habitat for important prey (Savino and Stein 1982; Carpenter and Lodge 1986; Scheffer et al. 1993). Previous examinations of the effects of aquatic vegetation on largemouth bass growth and recruitment have been mixed. Whether or not aquatic vegetation has a positive or negative effect on YOY largemouth bass is likely to be dependent on the level of vegetation coverage. Too much vegetation will negatively influence YOY largemouth bass foraging efficiency and subsequent growth (Anderson 1984; Caliteux et al. 1996; Sammons et al. 2003), while a moderate amount of coverage could positively affect YOY survival (Miranda and Pugh 1997). Any benefits provided will also vary by the type of structure offered by different vegetation species (Havens et al. 2005). In this job, we are evaluating the role of vegetation by relating densities and types with largemouth bass recruitment.

Woody debris may also provide some of the same benefits offered by aquatic vegetation. Studies have shown a potential for higher overwinter survival of young-of-year largemouth bass with increasing available woody brush habitat when predators are present (Miranda and Hubbard 1994). In reservoirs, higher centrarchid abundance was associated with coarse woody habitat (Barwick 2004) and removal of coarse woody habitat has also been shown to cause reduced growth rates in largemouth bass and a shift to eating more terrestrial prey (Sass et al. 2006). Numerous studies have demonstrated that complex wood substrate provides habitat for macroinvertebrates (O'Connor 1991; France 1996; Smokorowski et al. 2006). These available food resources concentrate prey fish and in turn provides forage for largemouth bass increasing their foraging success (Hickey and Kohler 2004). All these previous data suggest that woody habitat provides an integral component of multiple trophic levels in many aquatic ecosystems. We conducted management experiments where vegetation and woody habitat are manipulated (e.g. plantings and removals, varying density and presence versus absence) to examine changes in largemouth bass growth and survival at the lake scale.

Spatial heterogeneity in physical littoral habitat has been shown to influence many population and community characteristics of fish assemblages within lake ecosystems. Studies focused on largemouth bass have shown littoral habitat to be an important determinant of age-0 fish distribution and these studies generally have found that largemouth bass prefer structurally complex habitats in the form of woody cover, leaf pack, coarse substrates and aquatic vegetation (Annett et al. 1996; Irwin et al. 1997). Laboratory and field studies have shown that complex physical habitat provides a refuge from predation for juvenile fishes while simultaneously increasing prey resources (Savino and Stein 1982; Miranda and Pugh 1997). While previous research has identified influences of habitat variability on population dynamics of largemouth bass (Meals and Miranda 1991) the majority of studies have been conducted on spatial scales that incorporate multiple habitat patches which has made it difficult to discern how fish use qualitatively different microhabitats (Summerfelt 1993; Annett et al. 1996). In addition, specific differences in the biotic communities among microhabitats (e.g. macroinvertebrates, zooplankton) within the littoral zone have not received considerable attention. We sampled 3 common and distinct shoreline microhabitats including vegetated shorelines, shorelines with laydown coarse woody debris, and bare shorelines across two Illinois lakes to examine microhabitat associations of fish communities and invertebrates. This work is intended to identify the degree to which fish and invertebrate communities can be distinguished based on microhabitat associations and also will aid in the identification of patterns in abundance of food web components that may be important to age-0 largemouth bass.

Despite the importance of identifying the processes operating during the early life stages of largemouth bass that influence recruitment to age-1, these mechanisms remain largely unknown. The current study addresses this critical gap in knowledge by monitoring multiple largemouth bass populations and their associated aquatic communities across multiple years. By monitoring over several years, our study encompasses variable environmental conditions and recruitment levels. Identification of important mechanisms and indexes of largemouth bass recruitment will guide management of sustainable largemouth bass populations and aid in prioritization of stocking efforts for lakes less likely to produce strong year classes.

Another potential factor influencing largemouth bass recruitment is dam escapement. Escapement from reservoirs generally increases by four times in the spring and summer when water levels are high (Paller et al. 2006). The increase in escapement coincides with the time when largemouth bass are reproducing and may impact recruitment. In addition, this potential influence might be greater on smaller lakes where fish have a higher probability of being in close proximity to the discharge over the dam. Therefore, it may be possible to develop an index of watershed to lake acreage that could be used to predict potential lakes where escapement could be a concern.

PROCEDURES:

Largemouth Bass Recruitment

Lake Recruitment

Incorporating potentially important events during the first year of life across multiple environmental conditions is needed to generalize models of fish recruitment. Using previous conceptual models as a framework, we quantified sources of intra- and inter-system variation in recruitment of largemouth bass. We measured young-of-year (YOY) abundances, first year growth, and potentially important environmental variables across 12 populations and five to seven year-classes. Detailed methods can be found in Appendix C (Parkos and Wahl 2009).

Pond Experiments

Captive populations of wild-caught largemouth bass adults were established in 0.4-ha ponds at the Sam Parr Biological Station, Marion County, Illinois, USA. In 1999, six ponds were stocked with eight males and ten females each, and in 2001 and 2002, each pond was stocked with ten males and twelve females. Adult largemouth bass were captured by electrofishing from Lake Shelbyville and Forbes Lake. Adult largemouth bass were stocked in April of each year, with fish distributed so as to have a range of adult sizes [males: 247 – 488 mm total length (TL); females: 259 – 557 mm TL] and similar overall size structure in each pond. In 1999, each pond was stocked with 958 bluegill (716 fish 10-75 mm TL, 238 fish 75-150 mm TL, and 4 fish >150 mm TL). No bluegills were stocked in 2001 and three of five ponds contained 3900-4300 juvenile bluegill (60-150 mm TL) in 2002. Bluegills were included in these experiments because of their important ecological relationships with largemouth bass. Bluegills are initially important nest predators (Eipper 1975), then competitors with invertivorous young-of-year (YOY) largemouth bass (Olson et al. 1995), and finally an important prey species for piscivorous largemouth bass individuals (Olson 1996; Parkos and Wahl 2010). Additionally, bluegill have been found to affect patterns of mating success and nesting behavior, two factors that influence brood recruitment (Parkos et al. 2011).

Nesting activity and reproductive output was measured during daily snorkel surveys. A pvc tag with a unique identification number was placed near each newly-discovered nest. In 2001 and 2002, nests were assigned a score from one to five that represented number of eggs in a nest (Kubacki 1992). In 2002, this scoring technique was combined with egg counts. Area covered by a nest was measured and eggs were counted in 2-cm^2 grids placed along a transect bisecting the brood. Total eggs in a brood were estimated by multiplying nest area by the egg count per square centimeter. These egg counts were positively related to scores of brood size and a model was developed from this data to convert brood size scores in 2001 to egg counts for each nest (Parkos et al. 2011; egg score 1 = 9000 eggs, egg score 2 = 13100 eggs, egg score 3 = 14700, egg score 4 = 29100 eggs, egg score 5 = 35800 eggs). Only nest count data was available from 1999 surveys. In 1999, one nest was removed from each of three ponds in order to increase variation among ponds in total successful nests.

An information-theoretic approach was used to assess relative support for relationships between total recruitment and either total eggs or total successful nests, and whether or not bluegill density affected these relationships. In late October and early November, ponds were individually drained and recruitment was assessed as total surviving young-of-year largemouth bass in each pond. Recruitment was modeled with repeated-measures analysis of variance (ANOVA), with each pond as the repeatedly sampled subject in the analysis. Data were modeled with compound symmetry error structure and Satterthwaite-corrected degrees of freedom. For 2001 and 2002 combined, the set of compared recruitment models were total eggs deposited, total successful nests, bluegill stocking density, or bluegill stocking density combined with either total eggs or successful nests. The repeated-measures ANOVA analysis was conducted again for all three years combined, omitting models with total eggs as a variable. The relative support for each model was assessed with Akaike's information criteria corrected for small sample size (AIC_c), with most supported model in the set having the lowest AIC_c score. Models within 5 AIC_c units were considered to have equivalent empirical support, and performances of the most supported models were measured with coefficients of determination (Anderson 2007). Nest density was natural log-transformed in all analyses.

Vegetation Management Experiment

We conducted a multiple lake experiment to evaluate different vegetation management strategies. We identified 11 lakes and divided them into three treatments based on management objectives. Treatments include management to increase vegetation, management to reduce vegetation, and control treatments where vegetation was not be manipulated. Management to increase vegetation was conducted on Dolan Lake and Lake Paradise. Dolan Lake was drawn down in winter of 2006-2007 and treated with rotenone in an attempt to remove carp and gizzard shad and expose the seed bank to promote vegetation growth. Successful reduction or removal of carp coupled with establishing new vegetated areas should increase overall vegetated cover in Dolan Lake. Paradise underwent a significant vegetation planting effort in 2008 through 2012.

We evaluated a large vegetation planting effort in Lake Paradise through cooperation with Illinois District Biologist Mike Mounce and the City of Mattoon Water Department. Exclosures were constructed in 2008 using varying designs to reduce loss of vegetation from carp and turtles. Exclosures were constructed using varying lengths of PVC coated wire fencing. Fencing was shaped into a cylinder and closed using cable ties. Lengths of rebar were driven into the substrate and attached to the fencing cylinders using heavy duty wire ties to secure the exclosure in place. After attachment to the rebar, the cage was driven into the substrate an additional 50 to 100 mm (depending upon substrate) to seat the exclosure and ensure no fish passage under the fencing. Exclosures were utilized in two plantings in 2008. The first planting occurred in early June and was designed to test the success of three different exclosure types for planting of wild celery and sago pondweed tubers. One replicate included a large exclosure, four small dispersed exclosures and four small clustered exclosures. Large exclosures were constructed of 6.1 m of fencing creating an exclosure with a 2.0 m diameter (area = 3.0 m^2). Small exclosures were constructed from 3.0 m of fencing creating an exclosure with a 1.0 m diameter (area = 0.7 m^2 approximately ¼ the size of large exclosures). Wild celery were planted using small bags of cheese cloth weighted with pea gravel with 5 tubers in each bag. Large exclosures were planted with 26 bags of wild celery and small exclosures with 6.5 bags per exclosure. Sago pondweed tubers were planted in a similar manner with 7 tubers in each bag. Large exclosures were planted with 31 bags of sago pondweed and small exclosures were planted with 8 bags. Ten replicates were planted with wild celery and 9 replicates were planted with sago pondweed.

The second planting in 2008 occurred in late June and was designed to test the success of chara, coontail, and American pondweed. These species were planted three stems in a cluster at 1 foot spacing throughout an exclosure. One replicate consisted of two large exclosures and four small exclosures. Three replicates were planted for each vegetation type. For all treatments, planting location was along low sloping shoreline, with adequate sunlight, and shorelines protected from southern wind in order to promote successful establishment and growth of aquatic vegetation. I n 2010 and 2011, cages with plants still growing successful were expanded and additional cages were constructed and planted in areas of good plant survival.

Exclosures were visited in summer 2008-2011 to evaluate planting success. Each exclosure was divided into 4 quadrates. Each quadrate was visually assessed for percent cover of planted vegetation. We supplemented the initial plantings by adding American pondweed and wild celery in cages where there was no survival from previous plantings in July 2009. American Pondweed was planted in 11 large cages and 20 small dispersed cages and wild celery was planted in 12 large cages and 33 small dispersed or clustered cages. These cages were revisited and scored for vegetation in summer of 2009 and 2010. At this time, cages that were initially planted and had plant survival were revisited and scored for percent cover. In 2010, cages were scored for presence of vegetation in late July. Five cages that have had consistent survival of American pondweed were expanded to 9.14 m perimeters (2.9 m diameter). An additional 5 cages were replanted with American pondweed. All cages will be scored in summer of 2011 and the subsequent 2 years.

A subsample of exclosures were sampled for fish, macroinvertebrates and biomass of vegetation in summer of each year. Fish were collected using a backpack electrofisher (250 V DC, 6 Amps). A 1 meter circle was electrofished around each exclosure and then the interior of the exclosure was sampled. All fish were identified to species, measured for total length and released. Benthic invertebrates were collected using a modified stovepipe sampler. The benthos was sieved through a 250-μm sieve bucket and preserved in ETOH and rose bengal. Invertebrates were sorted, identified, and measured at the lab. Vegetation was collected if it was sampled in the modified stovepipe sampler. All vegetation was identified to species and weighed. We will monitor the success of the different exclosure designs and vegetation types by assessing vegetation in July and August in future segments.

We monitored two lakes as part of the vegetation removal treatment. Stillwater Lake and Airport Lake have high vegetation densities and are in need of treatment to remove vegetation. Monitoring of pre vegetation management began in 2007 and continued until the initiation of the treatment. Treatment for vegetation began in the spring of 2010. Sonar was applied to Stillwater in the spring of 2010 and 2012 with the intention of completely removing Eurasian milfoil from the lake as well as other vegetation which has become overabundant. Eurasian milfoil is the dominant vegetation type and is invasive in Illinois. Airport Lake was treated in 2010, 2011, and 2012 with Reward two times each year, once in the spring and once in July. Reward is being applied to reduce the vegetation lake wide and was targeted to remove Eurasian milfoil which had begun to establish in the lake. We monitored changes in largemouth bass populations and prey organisms throughout and following the treatment period. Control lakes were used to compare changes in largemouth bass populations to lakes where vegetation is being manipulated to determine the effects of vegetation management. Control lakes include 3 levels of vegetation (high, medium, and low) based on percent cover.

We sampled 13 lakes for fish, prey and productivity condition including seven for control conditions, two for rehabilitation conditions and two for the vegetation removal. Largemouth bass populations, vegetation, prey resources, and fish communities were monitored. Three AC electrofishing transects were sampled on two dates in the spring and two in the fall at each lake. All fish were identified to species and measured for total length. Largemouth bass were also weighed and scales were taken for age and growth estimation. Benthic invertebrates were sampled two times annually in June and August at six sites using a stovepipe sampler. Zooplankton, larval fish and seine samples were performed bimonthly on 8 lakes and monthly on the remaining 5 lakes. Larval fish were collected using a 0.5 m diameter plankton push net with a 500um mesh and a 1:5 width to length ratio. Larval pushes were sampled for 5 minutes and total water sampled was measured using a torpedo flow meter mounted in the center of the net. Zooplankton was sampled using vertical tows at 4 inshore and 4 offshore locations at each lake using 0.5 m diameter plankton net with 63 um mesh and a 1:3 width to length ratio. All samples were preserved and brought to the laboratory where they were identified and counted. Seine samples were taken at 4 shoreline locations on each lake using a 1.2 x 9.1 m seine with a 1.2 x 1.2 m bag. The width, length, and depth of each transect were recorded to determine the volume of water seined. All fish collected were identified to species and a minimum of 50 individuals were measured for total length and additional fish were counted.

Lakes were mapped for vegetation in June and August using GPS mapping techniques. A GPS unit was used to trace the vegetated edge and waypoints to identify transitions in types and densities of vegetated areas. GPS data was then converted into GIS layers and digitized in ArcGIS 9.1. Once areas of homogenous vegetation were identified, density and mass of each species was measured. Ten rings of 0.5 m diameter were distributed throughout the different vegetated areas. All vegetation in a ring was removed (excluding the root mass), separated and identified to species and weighed. The mass of each vegetation type in a ring was used as a representative sample for the vegetated area. These rings will be used to estimate densities and biomass of each vegetation type present. Vegetation rings were used to assign densities and mass of each vegetation type to polygons of homogenous vegetation. GIS tools were then used to calculate vegetated area and vegetated perimeter of the lake and used to quantify vegetation.

Woody Habitat Pond Experiments

Two studies were conducted to investigate the response of fish production and the biotic community to a gradient of coarse woody habitat addition in pond communities. These experiments were designed to answer two main questions regarding the addition of woody habitat to aquatic systems. What is the shape and functional response of fish growth and survival across a gradient of woody habitat addition? Is there a threshold of wood addition needed before fish community productivity might be affected? The first experiment was designed to examine overwinter responses and was conducted from October of 2010 to March 2011. The second experiment focused on responses over the warm-water season and was conducted from May 2011 to October 2011.

Prior to introducing fish and starting of the experiments 50 oak trees (shingle oak; *Quercus imbricaria)* were cut from the area surrounding the Sam Parr Biological Station. After felling, each tree was dried for a period of two weeks (to remove foliage) and was then measured for several morphological characteristics including total length, bole diameter, and surface area using a centimeter tape and surface area (Gregoire et al. 1995). Trees ranged in length from 2.43-5.48 meters and were from 0.15 - 0.42 meters in diameter. After measurements were taken, trees were then allocated among 8 individual ponds to create treatments of between 3 and 55 % relative increase in surface area (relative to the pond bottom of 404 square meters). Wood additions were quantified as percentage increases in surface area as the added area for invertebrate colonization is thought to be a driving mechanism by which woody habitat affects fish growth. The metric also offers an easily interpretable benchmark for management (Pardue 1973). We carefully allotted individual trees to standardize the average length and bole diameter of the trees added to each pond. Two ponds received no wood and served as controls. Each individual tree was spaced equidistantly around the littoral zone of each pond perpendicular to the pond edge with the crown facing the pond center. All woody structure was reassigned to a new pond for the summer experiment to control for any pond effects.

After filling each pond to a depth of 1.5 meters and placement of wood, ponds were allowed to stablilize for two weeks prior to introducing fish (to allow for colonization by invertebrates). Ponds were also left dry for two week between experiments. Each of the 10 1/10 acre ponds was then stocked with 150 small bluegill (TL range 30-60 mm), 40 mid-sized bluegill (TL range 70-110 mm), and 15 adult bluegill (>140 mm). In addition, each pond received 5 adult largemouth bass (range 350 – 400 mm) to serve as a predator. All fish were measured for total length and weight and were introduced between October 1st-8th 2010 in the overwinter experiment and between May 1st and May 5th 20011 in the summer experiment. In addition, all adult bluegills and largemouth bass received PIT tags to better track growth of these slower growing adult fish.

During the overwinter experiment ponds were sampled for temperature, dissolved oxygen, chlorophyll a, phosphorus, zooplankton, and macroinvertebrates on sediments and wood surfaces during the first week and final week of the experiment. Mid-winter (January 3rd 2011) temperature and dissolved oxygen measurements were taken by drilling through the ice-cover to ensure adequate oxygen was being maintained. Ponds were drained during the final week of March. Upon draining all adult fish were identified via PIT tags and measured for total length and weight. Juvenile fish were frozen for later enumeration and a subsample across the entire length range was measured for total length and weight (n = 50 fish per pond). Length-weight regressions for each pond allow for correction of any effects of preserving on length and weight measurements of remaining fish. Mean change in length and weight standardized by values of surviving largemouth bass and adult bluegills were regressed against the relative surface area of wood added to each pond.

Sampling during the summer experiment included all variables measured in the overwinter experiment with the addition of submerged aquatic vegetation which was allowed to grow naturally and was included as a random covariate in all analyses. Sampling was conducted for all parameters on a bimonthly basis from May – October 2011. An index of fish reproduction was collected by seining each during the first week of July. Procedures for draining, measurement and enumeration of fish were identical to the overwinter experiment with the exception that all young of year fish were also measured and enumerated. As in the overwinter experiment we regressed changes in length and weight of adult fish against the relative surface area of wood added to each pond.

Vegetation and Woody Habitat Enclosures

Abundance of YOY largemouth bass, other fish species, and associated biotic communities including zooplankton and macroinvertebrates were examined among three common lakeshore habitat types in two Illinois lakes. During August 2009 and again in

August 2010 three replicate vegetated, wooded and open shoreline sites were randomly selected in Lincoln Trail Lake and Lake Paradise. At each site, a block net (100 X 3.04 m) was used to enclose an area of shoreline (mean area ± SE = 48.5 ± 1.7 m^2) during sampling. Within vegetated sites three 0.5 m diameter circular quadrats were sampled for species identify, stem density and standing biomass of macrophytes. Benthic macroinvertebrates were sampled from littoral sediments using a modified stovepipe sampler as described in previous sections. Three zooplankton samples were collected in each site using a 9.5 cm diameter tube sampler (mean volume ± SE = 9.7 ± 0.07 liters). Each of the three subsamples was pooled by passage through a 64-µm-mesh filter. Storage and processing of zooplankton and invertebrate samples was as described in previous sections. In addition to zooplankton and benthic macroinvertebrate samples the macroinvertebrate communities associated with the surface of coarse woody habitat were sampled from wooded sites. Woody debris was sampled for macroinvertebrates by first enclosing individual branch segments (N = 3 per site) in a 64 µm mesh bag and clipping the segment using a hedge clipper. Samples were then lifted from the water invertebrates were removed using a soft nylon brush held over a pan. Fish communities were sampled via three passes within the enclosed area using a backpack DC electrofisher. All collected fish were identified to species and measured for total length. Community data sets including fish species densities, macroinvertebrate densities, and zooplankton densities expressed as individuals per square meter (fish and macroinvertebrates) or per liter (zooplankton) were pooled across years and analyzed using correspondence analysis to examine the degree to which habitats could be distinguished based on the density of each taxa found. This approach allowed for a test of the degree to which each habitat could be distinguished based on its biotic community and also served as a data reduction step by identifying important taxa for further analysis. Data from each lake was analyzed separately due to known differences in community composition. Individual taxa were included in discriminant functions derived from correspondence analysis by using a stepwise selection procedure and all groups with a p-value <0.10 were included in final functions. When discriminant functions indicated significant effects of individual taxa these were further examined using univariate ANOVAs blocked by year to test for differences among habitat types. When a significant univariate ANOVA was found fisher's protected lsd was used to separate means and determine specific differences among habitats.

Dam Escapement

In order to access dam escapement by largemouth bass we sampled downstream of the dam on two reservoirs, Ridge Lake and Forbes Lake via backpack electrofishing. To sample fish escapement from Forbes Lake, we set up three transects in the Lost Fork River approximately 0.5 miles downstream of the dam on Forbes lake. Each transect was electrofished moving in an upstream direction towards the dam. All fish collected in each transect were counted and measured to the nearest millimeter (TL). The dorsal caudal fin on all fish was clipped in order to identify fish recaptured in future surveys. The volume of water coming over the dam was also measured, as well as any peak volume that occurred between sampling periods. In addition, rainfall was recorded at the Sam Parr Biological station located approximately 1 mile downstream of the dam. Downstream area of the Ridge Lake dam was sampled in a similar manner in 2008. A 200 m stretch of the stream was sampled via electrofishing in an upstream direction and in one transect. Starting in the spring of 2010, all fish escaping over the spillway were collected in 12 m X 6 m catch basin with a 2.54 cm mesh gate. The catch basin was seined at regular intervals or after a major rainfall event and the fish collected were measured and checked for pit tags. Rainfall data was collected from the Eastern Illinois University rainfall gauge approximately 5 miles to the North. The total rainfall that fell between sampling dates was calculated and divided by the number of days in order to compare precipitation to escapement.

FINDINGS:

Largemouth Bass Recruitment

Lake Recruitment

Inter-population differences in average recruitment to age 1 were set by variation in number of YOY surviving to fall. Survival to fall was in turn positively related to density of juvenile bluegill. First year growth was positively related to turbidity and abundance of adult largemouth bass. For individual lakes, variables explaining a significant amount of intra-population variation in recruitment strength were factors associated with either production of YOY from the parental care stage (peak density of YOY largemouth bass) or prey fish abundance (densities of larval and juvenile bluegill). Abundance of larval bluegill was higher in systems where largemouth bass recruitment to age 1 was not related to bluegill abundance than in lakes where recruitment strength was sensitive to annual fluctuations in prey fish abundance. More detailed results and discussion can be found in Appendix C.

Pond Experiments

While density of fall recruits generally increased with either total density of eggs deposited or density of successful nests, the strength of these relationships was affected by the presence of bluegill (Table 4-1; Figure 4-1). There was more support for a relationship between recruitment and nest counts than there was with egg density, and in both analyses, models including bluegill density were most supported by the data (Table 4-1). High densities of bluegill appeared to limit the amount of recruitment possible by largemouth bass (Figure 4-2), resulting in fewer recruits being added as either nest or egg counts increased (Figure 4-1). Though recruitment increased with number of successful nests, even under conditions of high bluegill density, these models explained less than half of the variation in fall recruitment (Table 4-1).

Vegetation Management Experiment

Vegetation plantings on Lake Paradise were evaluated for 3 years following each planting. All cages planted in 2008 and 2009 were scored for density of surviving vegetation. Cages planted with American pondweed had the greatest percent cover throughout the 3 years following planting (Table 4-2: A). All other vegetation planted in 2008 had no survival through 2010 with the exception of one cage planted with wild celery. Mean plant cover of cages in 2009 was lower than those planted in 2008 after 1 and 2 years. This may be due to planting location as all cages planted in 2009 were cages with no survival in 2008 that were replanted. American pondweed planted in 2009 again had the greatest mean plant cover of vegetation types planted (Table 4-2: B). When examined together, we observed similar results for vegetation planted in Lake Paradise across years. Cages were determined successful if they had any vegetation surviving from the previous year. Cages were over 50% successful for all vegetation types in the first fall following planting with the exception of Chara (Figure 4-3). After the first winter all vegetation types decreased in success and only American pondweed had any significant survival after the first winter. Mean vegetation cover ranged from 0 to 50% in successful cages across all vegetation types (Figure 4-4). When the cages were successful, American pondweed and wild celery had similar densities of vegetation. It is difficult to evaluate chara, coontail, and sago pondweed because the number of successful cages is very low and the mean density is based on a very few number of cages.

We also examined the influence of cage size on survival of vegetation. All sizes of cages had high success through the fall following planting (Figure 4-5). The small clustered cages had no overwinter survival of vegetation and there was no vegetation present in the evaluations in the second or third year following planting. The dispersed small and the large enclosures experienced similar success in the second and third year and decreased through time. There were similar densities of plants in all three cage sizes when they were successful (Figure 4-6). Cage size does not appear to affect the density of plants in successful cages. Vegetation in the large cages did not differ from the small dispersed cages in success or density. Because the large cages cover a much bigger area, they did achieve larger vegetated plots.

In addition to evaluating the vegetation in the enclosures we examined the density of fish and benthic invertebrates associated with vegetated and non-vegetated enclosures. The density of fish collected from vegetated cages was slightly higher than non-vegetated cages (Table 4-3). The density of fish varied with plant type, but the sample sizes were low for sago pondweed, coontail and wild celery. Fish density was highest in wild celery followed by American pondweed. The highest density was observed in a single cage with sago pondweed, but this was the only cage due to low survival of sago pondweed. Species richness was much higher in vegetated cages (12 species) than in non-vegetated cages (7 species). The only largemouth bass that were observed were associated with cages that contained vegetation. Density of invertebrates was higher in the vegetated cages than non-vegetated cages (Table 4-3) due primarily to the very high density of chironomids found in cages containing vegetation. Invertebrate density varied by vegetation species with the highest being associated with sago pondweed, followed by wild celery and American pondweed. In general, prey fish and invertebrates appear to be found in greater density in the vegetated cages and the vegetation plantings may produce preferred habitat for young-of-year fish.

Planting efforts in Lake Paradise did not result in an increase in lake wide vegetation. Vegetation covered 5.3% of the lake area and 37% of the shoreline perimeter prior to the planting efforts and did not increase in area (5.8%) or perimeter (46.9%) in assessments following plantings. Although almost half of the lake perimeter is vegetated, it is primarily water willow which is growing close to shore and does not provide significant habitat for largemouth bass. We did not observe changes in recruitment due to planting efforts and the mean CPUE of YOY largemouth bass in fact decreased from 14.1 fish per hour in pre-planting years to 10 fish per hour following planting. There was an observed increase in adult largemouth bass from 16 fish per hour prior to planting to 29.8 fish per hour following planting, but it is not likely that this is a result of the planting efforts due to the lack of success in establishing vegetation over the long-term.

We evaluated the rehabilitation effort at Dolan Lake by examining the catch rates of gizzard shad and common carp, the fish targeted in rotenone treatments. Mean CPUE of gizzard shad from electrofishing dropped from 34.3 fish/hour from 1998 through 2005 to 0 fish/hour in 2007 and a mean of 2.8 fish/hour in 2008 through 2010. However in 2011, gizzard shad abundance had increased to 27.3 which was close to pre-treatment catch rates. The mean density of gizzard shad in larval fish samples was low in 2008 through 2011 (1.0 fish per L) compared to other lakes with gizzard shad (Range 0.4 to 2.8 fish per L, mean 2.0 fish per L), but reproduction is occurring in Dolan Lake. Common carp were present in low numbers in Dolan starting in 2003 through 2005 (Mean CPUE = 1.6 fish per hour). Although carp numbers were not high in electrofishing samples prior to the drawdown, we have not observed carp in any sample since the rehabilitation effort In addition, larval carp were not observed in any of the monthly sampling in Dolan Lake. The period from the drawdown until 2011 did have reduced gizzard shad and common carp populations and was evaluated for changes in largemouth bass recruitment.

Decreases in gizzard shad and carp densities should allow water quality changes and reduce feeding and uprooting of vegetation allowing the density of plants to increase. Before the drawdown and rotenone treatment, Dolan had a mean of 1.4% of the surface area and 5.7% of the perimeter vegetated from 2002 through 2005. In 2007, 76% of Lake Dolan's shoreline contained vegetation. Vegetated shoreline increased to 93% in 2008 providing evidence that vegetation may be increasing. In 2008 through 2011, the mean percent shoreline that was vegetated was increased at 86.2% and has continued to be much higher than in pretreatment assessments. In Dolan Lake the mean CPUE of largemouth bass over 200mm post treatment was the highest in all lakes sampled as part of this job (47.8 fish/hour). However the CPUE of young-of year fish in the fall was among the lowest (14.8 fish/hour). The largemouth bass population was intentionally reduced and restocked as part of the 2007-2008 drawdown. There was a substantial spawning population at Dolan Lake and as expected, recruitment increased in Dolan Lake. The mean CPUE of adult largemouth bass significantly increased from 12.9 in pre-treatment to 47.7 in post-treatment years ($t = -5.84$; $P < 0.001$). Mean CPUE of YOY largemouth bass increased, but not significantly from 8.6 in pre-treatment to 14.6 in post-treatment years ($t = -1.22$; $P = 0.25$). The increase in vegetation should allow for adequate habitat for newly spawned fish resulting in higher recruitment due to a greater abundance of adult largemouth bass, but we have not observed a significant increase in the number of YOY largemouth bass surviving to the first fall. We will continue to monitor Dolan Lake in order to evaluate long-term changes in largemouth bass populations in future projects.

In 2010 vegetation removal treatments were initiated in Airport and Stillwater. Airport Lake had 100% of its area vegetated in spring and fall assessments prior to treatment. The chemical treatments in Airport Lake occurred in the spring of 2010, 2011, and 2012 in late May or early June. Spring assessments conducted shortly after treatment measured slightly decreased vegetated lake area (mean vegetated area for 2009-2012 = 66.9%). Fall assessments however measured vegetation to have returned to cover 100% of the lake area by the end of August and no long term change in vegetation densities were observed. Stillwater Lake had a mean vegetated area of 77.8% with 100% of the lake perimeter vegetated. Stillwater Lake was treated prior to the spring vegetation assessment in May of 2010 and retreated in June of 2012. Vegetation had already begun to decrease by the June assessment in 2010. The density of vegetation in Stillwater Lake was very low when assessed in the fall and had dropped from 100% in 2007 through 2009 to only 1% of the total lake area in the fall of 2010. Vegetation in the lake rebounded slightly along the perimeter of the lake with the mean of 64.8 of the shoreline vegetated in 2010 through 2011, but the middle of the lake remained open and the area of the lake vegetated was greatly reduced with a mean of 14.8% from 2010 and 2011. There was no significant difference in CPUE of YOY largemouth bass from pre to post treatment in Airport ($t = 1.42$; $P = 0.25$) or Stillwater ($t = -0.73$; $P = 0.52$) Lakes. Similarly there was no significant difference in catch rates of adult largemouth bass between pre and post treatment in Airport ($t = -0.08$; $P = 0.94$) or Stillwater ($t = -0.94$; $P = 0.42$) Lakes. At this point there were no observed changes in largemouth bass recruitment or abundance related to changes in vegetation management. We will continue to follow vegetation changes in these two lakes and evaluate changes in largemouth bass recruitment in the spring and fall sampling in Airport and Dolan in future projects.

We monitored 13 lakes from 2007 through 2012 to examine the role of vegetation in determining largemouth bass recruitment. Vegetative cover ranged from 0-100% in the study lakes (Table 4-4). Lake vegetation has varied among lakes across years, but lakes maintained their high, medium or low vegetation designation throughout the treatment time period (2007-2012). Percent of the lake area that was vegetated was significantly correlated with the perimeter of the shore that is vegetated in our spring and fall assessments (Spring: $r = 0.72$; $P < 0.0056$; Fall: $r = 0.67$; $P < 0.012$). Both vegetated area and perimeter were also significantly correlated from the spring to the fall for both percent vegetated area ($r = 0.99$; $P < 0.0001$) and vegetated perimeter ($r = 0.98$; $P < 0.0001$).

We also monitored larval, juvenile, and adult fish communities as well as zooplankton and benthic macroinvertebrates to assess the effect of aquatic vegetation. CPUE was calculated from electrofishing samples for young-of-year largemouth bass (< 200 mm), adult largemouth bass (> 200 mm), and all bluegill (Table 4-5). Mean annual density was also calculated for total zooplankton, total benthos, and total larval fish as well as larval bluegill and gizzard shad. These variables were then examined for correlation with the vegetated area and perimeter of each lake. Mean YOY largemouth bass CPUE from electrofishing (2008-2011) was not significantly correlated with any measure of vegetation density in the 13 lakes ($p > 0.05$). In fact, measurements of vegetation did not correlate with larval fish, macroinvertebrate or zooplankton densities as well as catch rates of bluegill or adult largemouth bass. In order to evaluate differences in largemouth bass recruitment related to varying vegetation densities, we separated the 13 study lakes into categories based on the mean proportion of the lake area and perimeter that was vegetated in 2008-2012. The categories were low (n=3; 0-10%), medium (n=4; 20-80%), and high (n = 4; 90-100%). We performed an ANOVA to determine if there as a significant difference in YOY largemouth bass CPUE from fall electrofishing among groups. YOY largemouth bass densities were lowest in medium vegetation lakes, followed by low density and the highest in high density vegetation lakes (Figure 4-7). These differences were marginally significant ($F = 3.74$; $P = 0.07$) with recruitment varying among vegetation density classes.

Woody Habitat Pond Experiments

Largemouth bass growth in both length and weight was significantly affected by the percentage increase in relative surface area across the woody habitat gradient in both the overwinter and the summer experiments. In the overwinter experiment the relationship between largemouth bass growth in weight and woody habitat addition was curvilinear and was best fit by a quadratic function (r –squared = 0.69; $t = -3.61$; $P = 0.01$; Figure 4-8A). Growth in weight appeared to increase linearly with surface area up to around a 25% increase in area relative to the pond bottom and declined thereafter. Unlike growth in weight, growth in length in the overwinter experiment was best fit by a linear function. The plot however strongly suggested a curvilinear relationship which was marginally significant (r –squared = 0.61; $t = - 2.16$; $P = 0.07$; Figure 4-8B). Adult largemouth bass survival in the overwinter experiment was not related to the relative surface area added by woody debris (ANOVA; df = 1,7; $F = 0.42$; $P = 0.53$).

In the summer experiment adult largemouth bass growth showed a linear positive relationship with woody habitat addition however this relationship was initially masked by a significant negative effect of submerged aquatic vegetation density. An analysis of covariance model including submerged vegetation as a random covariate showed a significant positive effect of wood addition on growth in weight (ANCOVA; df = 1, 6; $F = 7.77$; $P = 0.03$; Figure 4-8C) and growth in length (ANCOVA; df = 1, 6; $F = 20.39$; $P < 0.01$; Figure 4-8D). There was no significant relationship between the addition of woody habitat and the number of adult largemouth bass surviving the summer experiment (ANCOVA; df = 1,6; $F = 0.96$; $P = 0.36$).

Adult bluegill growth was not significantly related to the percentage increase in relative surface area provided by woody debris when measured as either growth in weight (ANOVA; df = 1, 7; $F = 1.63$; $P = 0.24$) or growth in length (ANOVA; df = 1, 7; $F = 0.06$; $P = 0.81$). Similarly, we found no effect of added surface area in the form of woody debris on overwinter survival of adult bluegill (ANOVA; df = 1, 7; $F = 1.79$; $P = 0.21$).

Vegetation and Woody Habitat Enclosures

Correspondence analysis indicated that fish community composition was a significant predictor of habitat types in Lincoln Trail Lake (Pillai's Trace = 1.27; df = 12, 22; $P < 0.01$). Further examination of discriminant functions indicated that a combination of species densities including bluegill, warmouth sunfish, yellow bullhead, and redear sunfish and crayfish density could correctly classify 89% of sites. Univariate tests indicated that bluegill (ANOVA; $F_{2,14} = 7.9$; $P < 0.01$) and warmouth sunfish densities differed significantly among habitats (ANOVA; $F_{2,14} = 3.6$; $P = 0.05$). Post hoc tests for bluegill indicated that vegetated areas had significantly higher bluegill densities than open shorelines ($P = 0.03$) whereas wooded enclosures had intermediate densities (Figure 4-9 A). Post hoc tests for warmouth sunfish indicated that this species was significantly more abundant in wooded and vegetated sites than open shorelines (all $P < 0.05$) while vegetated and wooded shorelines had similar warmouth densities (Figure 4-9 B).

In Lake Paradise discriminant analysis indicated that fish community composition was not a strong predictor of habitat types (Pillai's Trace =0.25; df = 2,15; $P = 0.11$). Examination of ordination plots indicated that white crappie density was the only important factor suggested by discriminant analysis. Subsequent univariate tests indicated a marginally significant overall effect of habitat type on density of white crappie (ANOVA; $F_{2,14} = 3.1$; $P = 0.07$). Post hoc comparisons indicated that white crappie density was significantly higher in wooded habitats than in either open or vegetated sites (all $P < 0.05$; Figure 4-9 C).

Zooplankton Communities

In Lincoln Trail Lake correspondence analysis indicated that habitat types could be distinguished based on zooplankton communities ((Pillai's Trace = 1.11; df = 10,24; $P = 0.01$). A discriminant function that included densities of cyclopoid copepods, as well as organisms of the families bosminidae, sididae and chydoridae could correctly classify 88% of habitat types. Univariate tests across habitat types for these taxa indicated significant differences in the density of cyclopoid copepods (ANOVA; $F_{2,14} =3.55$; $P = 0.05$) and chydorids (ANOVA; $F_{2,14} =4.71$; $P = 0.02$). Post hoc tests comparing cyclopoid densities between habitat types revealed that cyclopoid copepods were significantly more abundant in vegetated habitats than in open habitats ($P <0.03$) with wooded habitats being intermediate (Figure 4-10 A). Post hoc tests on densities of chydorids between habitat types indicated that these organisms were significantly more abundant in vegetated habitats than either open or wooded sites (all $P < 0.03$; Figure 4-10 B).

In Lake Paradise correspondence analysis indicated that habitat types could be distinguished based on zooplankton communities (Pillai's Trace = 0.55; df = 4,30; $P = 0.04$). A discriminant function that included densities of sididae and harpacticoid copepods could correctly classify 61% of sites by habitat. Univariate comparisons of sididae densities between habitats indicated that densities of these organsisms differed between habitats (ANOVA; $F_{2,14} = 3.48$; $P = 0.05$). Post hoc tests revealed that sididae were more abundant in vegetated habitats than in open habitats ($P = 0.02$) with wooded habitats being intermediate (Figure 4-10 C).

Macroinvertebrate communities were significant predictors of habitat types in Lincoln Trail Lake ((Pillai's Trace = 0.64; df = 6,40; $P = 0.01$). A discriminant function incorporating densities of pelecoptera and trichoptera could correctly classify 50% of sites to habitat type. Univariate comparisons of pelecopteran densities across habitat types indicated that there was a marginally significant difference among habitat types (ANOVA; $F_{2,14} = 2.6$; $P = 0.08$). Post hoc tests revealed that pelecopterans were significantly more abundant in vegetated sites than on wood surfaces or wooded sediments (all $P <0.05$) with and open sites being intermediate (Figure 4-11 A). Univariate comparisons indicated that trichopteran densities also differed among habitat types (ANOVA; $F_{2,14} = 4.1$; $P = 0.04$). Post hoc tests revealed that trichopterans were more abundant on wood surfaces than on any of the other habitats (all $P <0.05$; Figure 4-11 B).

Similar to Lincoln Trail Lake macroinvertebrate communities were a strong predictor of habitat types in Lake Paradise ((Pillai's Trace = 1.1; df = 12,57; $P < 0.01$). A discriminant function including densities of chironomidae, dipteran pupae, ephemeropterans, and nematoda correctly classified 66% of habitat types. Univariate comparisons between habitats for these taxa indicated significant differences for chironomidae (ANOVA; $F_{3,19} = 6.57$; $P < 0.01$); dipteran pupae (ANOVA; $F_{3,19} = 5.18$; $P < 0.01$) and nematoda densities (ANOVA; $F_{3,19} = 3.15$; $P = 0.04$). Post hoc tests revealed that chironomid densities were significantly higher on wood surfaces than in all other habitats (all $P < 0.02$; Figure 4-11 C). Post hoc tests for dipteran pupae indicated that these organisms were more abundant in wooded sediments than all other habitat types (all $P < 0.05$; Figure 4-11 D). Similarly post hoc tests on the density of nematodes found that these organisms were also more abundant in wooded sediment than in other habitats (all $P < 0.05$; Figure 4-11 E).

Dam Escapement

Dam escapement has been evaluated in Forbes and Ridge Lake. However, due to the drought conditions in 2012, no water or fish passed over the spillway at either lake. Data collected thus far suggests largemouth bass escapement in Forbes Lake is affected by precipitation and ultimately the amount of water exiting the spillway. The average number of largemouth bass that are sampled below Forbes Lake appears to be related to the average precipitation for the month (Figure 4-12). As expected, adult largemouth bass collected in the stream appear to peak in spring and decline in the summer, whereas young of year largemouth bass appear later in the spring and summer (Table 4-6). However, it is important to note that largemouth bass sampling below Forbes Lake represents only relative numbers of largemouth bass between sampling dates. The data from Ridge Lakes allows for a better estimate of the total numbers of largemouth bass exiting that lake. Early indications from this expanding data set are that the number of bass escaping Ridge Lake are low (Figure 4-13). In the 10 continuous months of sampling in 2010 and 2011, only 4 adult sized largemouth bass were collected in the Ridge Lake catch basin. Small numbers of young of year largemouth bass were also present in the catch basin in May and June (Table 4-6). The timing of escapement does not appear to be associated with rainfall (Figure 4-13), nor does timing appear to be associated with time of year. This early data indicates that large numbers of adult and young of year largemouth bass are not being lost from these lake populations due to dam escapement.

RECOMMENDATIONS:

As fishes pass through developmental stages during their first year of life, they experience highly variable growth and survival. Success during each developmental step influences growth and survival during subsequent life stages (Ludsin and DeVries 1997), but the relative importance of stage-specific performance on overall recruitment strength will vary by life history strategy and community context (Bremigan and Stein 2001; Lidicker 2002). By encompassing a variety of lakes, years, and developmental stages, we were able to assess the relative influences of factors affecting survival during different stages in the first year of life on recruitment to age-1 in largemouth bass. Inter-lake differences in relative year class strength were established by fall, with recruitment positively related to number of juvenile bluegill. The relative importance of either reproductive output or prey fish in explaining intra-system variation in recruitment differed among lake environments. Some lakes always had high production of fish prey; therefore, there were few limitations on the opportunities for YOY largemouth bass to switch to piscivory. Other lakes had years where there was insufficient production of prey fish, resulting in lower recruitment even when largemouth bass reproductive success was initially high. Recruitment strength in the smallest lake in this study was influenced by winter temperatures. The strong influence of both reproductive output and prey fish abundance on largemouth bass recruitment reflects the importance of nest success for a species with elements of both a periodic (seasonal, synchronous reproduction) and equilibrium (parental care) life history (Winemiller and Rose 1992), and the importance of a successful diet shift to fish prey for a species adapted for piscivory (Mittelbach and Persson 1998; Aday et al. 2009). For largemouth bass, we did not find a relationship between recruitment strength and abundance of spawning-sized adults. We did measure a positive relationship between mean size of YOY largemouth bass at the end of the growing season and stock abundance, but the mechanism underlying this association is unclear.

The availability of prey is often a strong determinant of fish recruitment strength, and in the case of largemouth bass, availability of fish prey was important in both inter-system and within lake variation in year class strength. Bluegill, the primary fish prey of YOY largemouth bass (Olson 1996), was an important predictor of largemouth bass recruitment patterns. When protracted reproduction of bluegill produces vulnerable-sized fish prey throughout the growing season of the YOY predator, late season availability of fish prey may improve the survival of late-hatched largemouth bass, increasing year class strength. Gizzard shad were also abundant in populations where recruitment strength was influenced by density of bluegill, and yet, fluctuations in gizzard shad abundance did not influence largemouth bass recruitment. Variation in abundance of fish prey may also have positively influenced largemouth bass recruitment by providing an alternative prey resource for predators that would otherwise consume age 0 largemouth bass.

In general, winter was not an important survival bottleneck for largemouth bass cohorts in this study. Recruitment strength of largemouth bass in Ridge Lake was driven in part by winter severity, but pre-winter size structure and winter severity did not influence recruitment in any of the other 11 populations. Furthermore, inter-system differences in recruitment strength were set by fall. Several studies have demonstrated that mortality of largemouth bass during their first winter is size-specific, but evidence for the importance of this mortality to overall recruitment strength is equivocal (Parkos and Wahl 2002). Largemouth bass populations in Illinois occupy the center of the largemouth bass native range; therefore, winters may be severe enough to limit losses to predators but not enough to cause heavy losses of juveniles.

In general, we found most lakes to group into systems where recruitment to age 1 was related to either survival through the parental care stage or abundance of fish prey. Where productivity of prey needed by YOY largemouth bass to complete and sustain a diet switch to piscivory was low, recruitment to age 1 was sensitive to fluctuations in the availability of fish prey. Abundance of bluegill also defined inter-system differences in survival of YOY largemouth bass through the first growing season, itself an important factor identifying among-lake differences in average recruitment. Managing survival of YOY largemouth bass through the nesting stage of their life can include regulating the recreational fishery for largemouth bass during nesting (Suski et al. 2002), providing adequate habitat (Hunt et al. 2002), and if the system is an impoundment, managing water levels (Kohler et al. 1993). In systems where it is desirable, these same factors can be manipulated to limit largemouth bass recruitment. Managing largemouth bass recruitment through availability of bluegill as prey for YOY largemouth bass can take the form of enhancing bluegill reproduction through harvest regulations, adequate nesting habitat, and reduction of competitors such as gizzard shad. Even if bluegill abundance promoted higher largemouth bass recruitment indirectly through reduced predation on YOY largemouth bass individuals, efforts to enhance bluegill reproductive success should provide benefits for largemouth bass recruitment.

Within Illinois, there was a large enough range of environmental contexts (e.g., lake size, prey abundance, gizzard shad presence or absence) for us to test and find differing mechanisms of recruitment; therefore, expanding this type of study to other portions of the largemouth bass range, encompassing community and environmental contexts not found in our study, would deepen our understanding of recruitment even further. The general environmental setting of the largemouth bass populations in our study was eutrophic impoundments within the central portion (mid-latitudes) of the largemouth bass range. The inhabited range of largemouth bass is expansive enough to cover environments with very different growing season lengths and winter severity (e.g., Ontario, Canada versus Alabama, USA), resulting in potential differences in timing and duration of nesting and in community composition (e.g., presence or absence of gizzard shad; Aday et al. 2009). These latitudinal differences in seasonality could lead to differences in the timing of year class establishment as well as the mechanisms involved (e.g., predation versus starvation during winter; Garvey et al. 1998; Fullerton et al. 2000). Systems with very different growing seasons and productivities should exhibit spatial variation in growth rate, leading to potential differences in largemouth bass life history (e.g., age at maturity; Aday et al. 2009) that could alter pathways of recruitment. In addition, the outcome of complex food web interactions should also change along latitudinal and productivity gradients (e.g., relative influence of gizzard shad and predator-prey relationship with bluegill; Garvey et al. 2002b; DeVries et al. 2009). Timing of year class establishment will likely vary with the severity of disturbance (e.g., angling pressure, storms, water level fluctuation) during largemouth bass nesting (Parkos and Wahl 2002), with the frequency and severity of these disturbances varying among system types (e.g., natural lakes vs. impoundments) and latitude (e.g., high versus low latitudes). To continue making progress in the study of recruitment, more studies are needed that simultaneously address multiple potential mechanisms influencing recruitment and account for spatial and temporal variation in the environmental context of early life history.

A relationship between stock and recruitment is tenuous for centrarchid bass species, most likely because of disconnect between abundance of mature adults and the number of effective spawners and parental individuals (Raffetto et al. 1990; Parkos et al. 2011). Defining the effectiveness of adults by mating success somewhat improves the relationship with recruitment, but recruitment in this study was still only weakly related to total mating output (i.e., total eggs produced or total successful nests). In one of the years of this study (2002), DNA fingerprinting of broods and recruits revealed that the earliest spawning males had the highest contribution to recruitment (Parkos et al. 2011). Across a variety of conditions, a similar number of parental males produced the majority of the recruits, and relative differences in the mating success of these few individuals may be what determine differences in system-wide recruitment. Under certain environmental conditions, the earliest nests and the largest males may not be the largest contributor of recruits, but enumerating adult abundance and nest density appears to be an unreliable indicator of recruitment potential. Instead, total recruitment is related to the success of a small subset of parental adults. Given the potential uncertainty with predicting which adults will have the most reproductive success, a more risk-averse approach to managing centrarchid bass fisheries is to protect all nesting males. We cannot be too comfortable with tabulating total abundances of either mature fish or nests and using these numbers as guidelines for when it is acceptable to subject nesting fish to increased angling pressure. The relationship between output from the parental care stage and recruitment strength suggests that management should focus on actions designed to influence nest success. Where recruitment is also limited by prey fish availability, management actions can also be directed towards community attributes that influence the growth and production of important prey species.

Additional information on the role of aquatic vegetation to largemouth bass recruitment has been identified as an important goal for management in Illinois. There are a number of potential management strategies for manipulating vegetation that are of interest to managers in Illinois, including chemical treatment to reduce overabundant vegetation and/or nuisance vegetation (e.g. Eurasian milfoil) and habitat restoration to increase vegetation where it is lacking. We have continued a multi lake experiment examining lakes with a range of vegetation densities and have been measuring recruitment of largemouth bass in those systems. We have begun to treat vegetation in Stillwater and Airport Lakes and will continue to monitor changes of vegetation for several years as part of future projects. Vegetation removal in these lakes has been accomplished primarily through chemical treatments appropriate to reduce the dominant problem vegetation. We have monitored the vegetation in these lakes and evaluated the success of the removal process. We evaluated fish exclusion fences and transplanted vegetation at Lake Paradise in order to assess if increases in vegetation would result. Results suggest American pondweed as the species with the highest survival rate and future planting efforts in Lake Paradise and similar lakes should focus on this species. Large cages were shown to produce both larger continuous areas of plants and a greater survival rate of plants inside an enclosure. We recommend the use of larger cages when attempting to establish vegetation in a lake. There is a higher potential for large cages to pull away from the substrate, allowing turtles, carp and other animals to enter the cage and feed on the plants and extra effort should be spent when constructing these cages to ensure they are seated well into the substrate. We expanded successful cages in an attempt to attempt to spread the vegetation previously planted with little success. We have monitored the lake-wide implications of these vegetation enhancement efforts in a number of lakes. In Dolan Lake, the water level was drawn down in an attempt to eliminate carp and gizzard shad. Removal of these fish and the exposing of the seed bank, resulted in significant increases in vegetation throughout the lake. Measurements of carp and gizzard shad indicated the fish removal efforts have successfully reduced their numbers. However, gizzard shad numbers have increased since the initial treatment and even though they are low, larval fish have been observed in samples and are increasing in number each year. Vegetation at Dolan Lake has increased since the drawdown and fish removal. These changes resulted in an increase in adult largemouth bass population, but little increase in recruitment of largemouth bass. In future projects, we will continue to monitor control and treatment lakes and relate changes in largemouth bass recruitment, growth, and abundance to management practices. We will evaluate largemouth bass recruitment, abundance and growth in lakes with varying vegetation densities in order to identify critical levels of vegetation to target for management.

Previous research in reservoir ecosystems has documented significant effects of littoral habitat on relative abundance and distribution of juvenile and age-0 fishes however a majority of these studies have been conducted on systems with little vegetative or other complex habitat structure (Meals and Miranda 1991; Irwin et al. 1997). While we did not find significant differences in age-0 largemouth bass densities among the microhabitat types sampled in our enclosure surveys, we did find significant differences in the community composition and abundance of potentially important prey items (juvenile sunfishes, caddisflies, chironomids, stonefiles and cyclopoid copepods). Increases in abundance of potential invertebrate and fish prey in vegetated and wooded sites supports the idea that these habitats are important sources of littoral productivity. Differences in fish and invertebrate community structure may influence the foraging success and relative energetic value of different habitats to age-0 largemouth bass and other juvenile fishes. We have designed controlled experiments evaluating the potential influence of differences in community structure among habitats on the feeding performance of age-0 largemouth bass. These experiments will help to draw links between habitat heterogeneity, biotic community structure and energetics of age-0 fishes.

Our results for largemouth bass growth suggest that woody habitat may play a role in foraging and energetics of adult fish. Furthermore our results suggest an optimum or asymptote in the effects of woody debris at approximately a 25% increase in surface area for overwinter growth. Woody habitat may increase largemouth bass growth through increases in invertebrate production, or by altering behavioral activities associated with foraging (cruising vs. ambushing prey; capture success etc.). Recent studies suggest woody habitat may affect adult largemouth bass primarily through behavioral influences and consequent effects on energy balance (Ahrenstorff et al. 2009). The asymptote in growth at higher wood densities may reflect a point at which woody cover begins to interfere with bass foraging; for example by providing refuge for prey fish and invertebrates. Results for adult bluegill in the overwinter experiment suggest that they may be less sensitive to added prey resources in the form of wood associated macroinvertebrates. One explanation for this may be that they are not confined to littoral habitats by predation risk and can forage on alternative prey such as zooplankton.

The assessment of dam escapement is in the early stages of implementation and evaluation and more data is needed to draw conclusions about the effect of escapement on largemouth bass populations and recruitment. Early indications suggest that escapement is not a major factor affecting largemouth bass populations and recruitment. However, differences between the two lakes sampled and their apparent link to precipitation may indicate that other factors (i.e. drainage size, lake size, spillway type, etc.) may affect the timing and numbers of largemouth bass lost due to escapement. Additional data still needs to be collected to determine if the trends observed thus far represent real patterns. Data will continue to be collected from both sites in future projects in order to build a large enough database to be able to answer questions about escapement effects on largemouth bass populations in a more rigorous manner.

Job 101.5 Assessing the impact of angling on bass reproductive success, recruitment, and population size structure.

OBJECTIVE: To assess the level of angling for nesting bass in Illinois and to determine its impact on reproductive success and annual recruitment, as well as to determine how much long term exploitation of Illinois bass has changed the size structure of those populations.

INTRODUCTION:

The growth in the popularity of competitive angling events targeting black bass has been substantial in the United States over the last 40 years with exceptional growth occurring in the past decade. Highlighting this recent growth, about 18,000 events were estimated to occur in North America in 2000 whereas over 32,000 were estimated to occur in 2005 in the United States alone (Kerr and Kamke 2003; Schramm and Hunt 2007). Although tournament rules require the release of captured bass following the conclusion of the "weigh-in," high mortality (>50%) has been reported during tournaments within the last 10 years (Neal and Lopez-Clayton 2001; Gilliland 2002; Wilde et al. 2002a), necessitating investigations into strategies to minimize mortality during these events. Mortality can be capture-related (i.e. hooking mortality) but can also be due to the collective impact of several sub-lethal stressors incurred by bass throughout the tournament process (Kwak and Henry 1995) such as the disturbances sustained during livewell confinement or the weighing procedure. In addition, the sub-lethal physiological disturbances incurred by bass that ultimately survive the tournament process can negatively impact growth (Wendelaar Bonga 1997) and fitness (Schreck et al. 2001; Ostrand et al. 2004) and increase susceptibility to disease (Pickering and Pottinger 1989). Clearly, identifying factors that influence the sub-lethal and lethal consequences of tournaments on largemouth bass and potential avenues to mitigate these impacts is important for the sustainable use of bass fisheries.

Removal of spawning males by angling has been shown to reduce the reproductive success of an individual largemouth bass, often causing brood reduction and nest abandonment (Philipp et al. 1997). However, the population-level impact of reduced reproductive success of some individuals is unclear. In the spring, male largemouth bass (Micropterus salmoides) build solitary, highly visible (depending on water clarity) saucer-shaped nests in the substrate in order to court and spawn with females (Kramer and Smith 1962; Pflieger 1966; Coble 1975). Once spawning is completed, females leave the nesting area and the male remains to provide all parental care of the developing offspring, a period that may last four or more weeks (Ridgway 1988; Cooke et al. 2002). While male bass are providing parental care for their broods, they are extremely aggressive (Ridgway 1988; Cooke et al. 2002) and, therefore, highly vulnerable to many angling tactics (Neves 1975; Kieffer et al. 1995). Even though this vulnerability has never been assessed accurately, many fisheries management agencies have invoked closed fishing periods, catch-and-release regulations, and various length and harvest limit scenarios in an effort to enhance or promote bass reproduction and recruitment (see Schramm et al. 1995). We assessed the relationship between nesting success and recruitment in Lincoln Trail Lake. In addition, we also directly tested the effect of angling on recruitment through manipulative pond experiments. The strategy of maximizing reproductive success by protecting successful spawning bass from angling assumes that there is a positive relationship between reproductive success and recruitment, which has not been specifically determined. Also, density-dependent interactions in young-of-the-year largemouth bass may cause populations to compensate for the lost reproductive success of some individuals.

Exploring recruitment in a controlled setting allows us to isolate and test different mechanisms regulating survival. In particular, competitive tournament fishing for black bass has grown rapidly over the past several years. Previous work has shown high levels of mortality associated with these tournaments in other parts of the United States, but tournament procedures continue to improve. Less is known about smaller club style tournaments which can occur more frequently, but are not as large and often have reduced weigh-ins. We evaluated the effects of small club style tournaments for largemouth bass (VanLandeghem et. al In Press). We measured both mortality and physiological disturbances incurred by largemouth bass during club events to determine if these types of tournaments have impacts on fish compared to larger tournaments. We also monitored largemouth bass tournaments during the spawning period and post spawn to determine if nesting bass were targeted. Thus far we examined the effects of tournaments on largemouth bass at the individual level, but the influences of tournament angling on lake wide recruitment are unknown. Therefore, we also initiated a pond experiment to directly examine the population consequences of tournament angling during the spawning season. In addition we conducted spring largemouth bass tournaments at Ridge Lake in order to examine the effects on tournament angling on largemouth bass recruitment at the lake level. These pond and lake experiments will allow us to further evaluate the potential effects of spring tournament angling on largemouth bass recruitment.

Substantial mortality and sub lethal stress can be associated with large scale tournaments with extensive weigh-in procedures (Wilde 1998; Allen et. al 2004; Suski et. al 2003; Suski et. al 2004). We examine how livewell treatments can be used to reduce stressors fish experience when captured by tournament anglers and held in the livewell. Understanding the physiological changes and survival related to different treatments will allow us to make recommendations regarding their utility in maintaining the health of an individual fish. Due to the stress and mortality associated with these large tournaments, we continued to evaluate the use of paper tournaments to reduce potential negative effects. Paper tournaments allow anglers to release fish shortly after they are caught and in the same vicinity as their capture as well as remove the stress associated with livewell confinement and weigh-in procedures. Little is known about how varying tournament angling pressure can influence the life history traits of largemouth bass populations. Therefore, we are also evaluating the long term influence of tournament activities on populations of largemouth bass. Our objective is to quantify tournament pressure for a number of lakes and examine differences in largemouth bass populations in lakes with varying tournament pressure.

PROCEDURES

Nest Observations

Snorkeling surveys were used to assess bass spawning activity, nest site selection by males, aggressiveness of males guarding a nest, and the level of nest predation in Lincoln Trail Lake. Spring snorkeling was conducted in six transects from 1999 through 2012. Each located nest was given a nest tag and an egg score (1-5) based on the number of eggs in the nest (for description of egg score, see Appendix D). The water depth of the nest was recorded as well as the developmental stage of the offspring. A visual length estimate of the guarding male was noted as well as the presence or absence of a hook wound. The number of predators in the nest was recorded, as well as their size and amount of time spent in the nest. Habitat within a 4m x 4m quadrant around the nest was mapped, making note of substrate, cover and potential nest predators. Beginning in 2006, we also assessed the available habitat within each transect to determine if largemouth bass were exhibiting any substrate selectivity for specific nesting sites. Transects were snorkeled perpendicular to the shoreline and substrate was quantified at 5-meter intervals. At each interval, 5 point estimates were visually assessed for dominant substrate along each transect from 2m of depth to the shore. These data were used to estimate the proportion of each substrate type available within each snorkeling transect and compared to the substrate at each nesting site. A Chi-squared test was used to determine significant variation of used habitat from available habitat in 2006 through 2010. Data from 2011 and 2012 were omitted due to issues with water clarity and timing of the spawn. The absolute value of residuals (greater than 1.96) determined which substrate type was used significantly greater than (+) or less than (-) expected. To determine if different nest substrates pose greater risks of predation, percent composition of nests with potential nest predators were separated from nests with no potential predators. A random distribution of selected nest sites would yield equal numbers of nests with and without nest predators.

Effects of Tournaments on Nest Abandonment

Spring snorkeling transects were used to identify nesting largemouth bass in Lincoln Trail Lake. Nests were administered one of three treatments, catch-and-release angling, tournaments angling, or control. Guarding male largemouth bass were removed from the nest in angling treatments and either released 10m from the nest (catch-and-release) or held in livewells and exposed to simulated tournament conditions. Snorkeling surveys were conducted 24 hours following angling and evaluated for presence or absence of the male and the nest was evaluated for egg quality. Detailed methods can be found in Appendix D (Diana et.al 2012).

Effects of Small Club Tournaments on Largemouth Bass

Sub-lethal physiological disturbances and mortality were quantified in largemouth bass *Micropterus salmoides* subjected to small, club-style angling tournaments (< 30 teams) held at two central Illinois lakes. Between April and October, four tournaments were assessed at Lake Bloomington for physiological disturbances, and four tournaments at Evergreen Lake for mortality. Further detailed methods can be found in VanLandeghem, et al.(In Press).

Livewell Treatments

Livewell conditions during competitive angling events are thought to affect fish mortality. We examined the effects of livewell additives on initial and delayed mortality of largemouth bass Micropterus salmoides. We applied three treatments (salt, ice, or salt and ice) to livewells during tournaments conducted on lakes in Illinois as well as in laboratory and pond experiments designed to examine the effects of fish size and ambient water temperature on mortality. Fish were collected after weigh-in and monitored for delayed mortality every 24 h for 5 d. Detailed methods can be found in Appendix E (Ostrand et. al 2011).

Pond Experiments

Over two years, we stocked eight, 1-acre ponds with largemouth bass and bluegill in densities representative of regional water bodies. Each year, four ponds were randomly designated as treatment ponds that were subjected to simulated tournament angling procedures, and the other four ponds served as undisturbed controls. Simulated tournaments in the treatment ponds began prior to the onset of spawning, and lasted until the completion of spawning. We monitored nest success, size structure of young-of-year bass, and overall recruitment to the first fall in all ponds, as well as measured a host of environmental variables that could potentially influence parameters of the juvenile bass population.

Influence of Spring Tournaments on Recruitment

Tournament angling for largemouth bass has been shown to cause nest abandonment for fish angled off the nest. However the population level effects of nests abandonment have not been examined. In this study we conducted an experiment at Ridge Lake examining the effects of tournament-style angling of nesting largemouth bass in a population previously unexploited during the spawning season. Ridge Lake has a controlled creel operated by the Illinois Natural History Survey. The lake has traditionally been closed to fishing until mid-May and no tournaments have been conducted at Ridge Lake prior to the beginning of this experiment. In the early spring of 2007 and 2010, seven angling tournaments were conducted during the spawning season (April 22 - May 22, 2007; April 17 – May 17, 2010) on Ridge Lake, prior to the opening of the regular public angling season. During each tournament, anglers fished for four hours targeting largemouth bass. All fish caught were brought back to the dock, measured for total length, weighed, and scales were collected. The fish were then kept in a lakeside pen for 2 hours following the tournament when they were released back into the lake. Recruitment of largemouth bass was measured as the relative CPUE from fall electrofishing samples and mean density of young-of-year largemouth bass collected in seines in late August and early September. Additionally, a complete creel census has been conducted on Ridge Lake during the open angling season of each year. Prey resources were also monitored at Ridge Lake throughout the season (zooplankton, larval fish, seine, benthos cores, and water quality; see job 101.4 for methods). We will monitor largemouth bass populations and prey resources in Ridge Lake through both tournament and non-tournament years and examine the relationship between spring angling tournaments and lake wide recruitment. No tournaments were conducted in 2006, 2008, 2009, 2011, and 2012 and these years will be used as a comparison with the years where tournaments were conducted.

Paper Tournaments

We conducted paper tournaments on 5 lakes in Illinois to determine their potential for reducing largemouth bass mortality through the elimination of the weigh-in. Anglers were asked to record the total length of each fish caught to the nearest quarter inch. All fish were also measured for total length and weight using a typical weigh-in. Anglers were then ranked under a variety of scoring criteria, including the official tournament results (total weight of fish > legal limit), total paper length (sum of total length of all fish caught), total paper weight (sum of weight estimated from paper lengths of all fish caught), paper length from legal fish (sum of lengths from fish over the legal limit), and paper weight from legal fish (sum of weight estimated from paper lengths). Paper lengths were converted to paper weights using a length weight regression developed from largemouth bass collected in Illinois Lakes by electrofishing. Once anglers were ranked under each scenario, the difference of each ranking from the official weigh-in ranking was calculated as the absolute deviation from the weigh-in rank. We compared the differences in ranking among the tournament scenarios in order to evaluate each technique.

Long-Term Effects of Tournaments

Throughout the spawn and post-spawn period, we monitored largemouth bass tournaments at Mill Creek, Lake Mattoon, Forbes Lake, and Lake Shelbyville to determine if nesting males were more at risk from anglers than either non-nesting males or females. The total length, sex, and reproductive condition of each fish brought to weigh-in was recorded. In addition, anglers were interviewed at select tournaments to determine the amount of fish released during a tournament. Anglers can release fish either through culling or due to them being smaller than the harvest regulation. Anglers were asked to report the number of sub legal fish caught and released as well as the number of fish released due to culling. We used these data in an attempt to determine the level of culling occurring during an average tournament as well as the extent of catch and release angling of small fish. Culling can influence the sex ratio of fish being weighed in if there is a difference in the size of male and female largemouth bass as well as increase the number of fish subjected to livewell conditions.

We began to evaluate how long-term harvest and varying tournament pressure has impacted the population abundance and size structure of largemouth bass populations through selection-driven changes in life history traits. Electrofishing transects were performed in twelve lakes in the spring of 2010, 2011, and 2012 and all largemouth bass were collected, measured for total length and weighed. Lakes were categorized as high tournament pressure, low pressure, or no tournament pressure lakes. Scales were collected from each largemouth bass and were aged by two independent readers to determine mean length at age for fish in each lake. In spring electrofishing samples, sex was determined when possible as well as maturity status (mature or immature) and spawning status (ripe, running, or spent). Largemouth bass were collected from each lake for size ranges that were too small to determine sex and maturity status in the field and returned to the laboratory. Tournament pressure was determined for lakes where we could identify all tournament activity on a lake. We coordinated with DNR biologists, lake managers and tournament organizers to obtain records of all tournaments conducted on a number of lakes. We also worked with tournament organizers and lake managers to obtain tournament results and weigh-in data for all tournaments conducted. When all weigh-in results were not available, we estimated weigh-in results using similar tournaments from the same lake. We examined the intensity of tournament activity at each lake and evaluated the abundance and size structure of the associated largemouth bass population.

FINDINGS:

Nest Observations

The first date of observed largemouth bass nesting in Lincoln Trail Lake varied between years from April 2 being the earliest to May 4 being the latest (Table 5-1). The number of nests observed in a season ranged from 35 to 220 in the six snorkeling transects with a mean of 112 nests. Nesting frequency often peaked in the week of or following the initiation of spawning with a gradual decline, but was often bimodal with peaks following increases in temperature. The number of nests was not significantly correlated with CPUE of adult largemouth bass in spring electrofishing samples ($r = -0.49$; $P = 0.15$) or young-of-year largemouth bass in fall electrofishing samples ($r = 0.44$; $P = 0.23$). In addition the CPUE of adult largemouth bass in the spring was not significantly correlated with the CPUE of young-of-year in the fall ($r = 0.34$; $P = 0.25$) demonstrating no stock/recruit relationship.

Nest substrate use was significantly different than available habitat in all four years ($P<0.001$). Largemouth bass preferred to spawn on cobble, pebble, and gravel nest substrate and these substrates were used significantly more than expected based on availability (Table 5-2). In contrast, vegetated areas were not commonly used as spawning areas and were used less than expected based on availability. There was a greater likelihood of nest predation when bass spawned on gravel and cobble and a lesser likelihood when bass spawned on vegetation, wood, and detritus (Figure 5-1).

Effects of Tournaments on Nest Abandonment

Angling treatments experienced higher abandonment rates than the control group (3%) with tournament-angled males abandoning their nests at a higher rate (90%) than catch-and-release males (33%). In addition nests that were abandoned had significant decreases in the number and quality of eggs in the nest suggesting that nests that were abandoned did not successfully produce broods. Detailed findings can be found in Appendix D.

Effects of Small Club Tournaments on Largemouth Bass

Indicators of physiological disturbances were evident in largemouth bass following club angling tournaments, with some temporal variation in responses. Plasma glucose concentrations increased in tournament-caught fish relative to reference fish in all months, except during October, when glucose concentrations did not change; plasma cortisol values among tournament fish were also lowest during October. Plasma potassium levels decreased only in April whereas chloride levels were unaffected by tournaments. Sodium concentrations varied across months, but the magnitude of tournament-induced decreases were similar across all months. Whole blood hemoglobin was lowest in May and hematocrit significantly decreased in tournament-caught fish in May but remained unchanged in other months. Lactate increases occurred during all tournaments and were of similar magnitudes even though water temperatures ranged from 15.7 ºC to 27.6 ºC. Small, yet significant, temporal differences were observed in plasma sodium and whole blood hemoglobin concentrations from reference fish collected in each month via electrofishing, indicating temporal changes in baseline values for some parameters. Mortality at tournaments was low (< 5%) and did not appear to vary across months. Our results suggest that physiological responses of largemouth bass to small, club-style tournaments can vary temporally and are similar to those sustained during professional tournaments, even if mortality rates are generally low. Additional findings and discussion can be found in VanLandeghemet al. (In Press)

Livewell Treatments

Initial mortality did not differ among livewell additives during field evaluations. Although delayed mortality was high it was not significantly different among livewells that contained salt (56%), ice (48%), ice and salt (40%) and controls (30%) suggesting that additives may have a null or possibly a negative effect as compared to controls. Additives administered during laboratory evaluations, at cool water temperatures, resulted in significantly lower delayed mortalities than those observed during the field evaluations when ambient water temperatures were warmer. Initial and delayed mortality did not differ among livewell additives during the laboratory evaluations. Larger fish in field evaluations had significantly greater delayed mortality than smaller fish even though initial and delayed mortality did not differ among livewell additives. Our results suggest that that fish size and ambient water temperature have a greater influence on delayed mortality observed during competitive angling events than the specific livewell additives (i.e. salt and ice or their combination) studied here. For detailed findings and discussion see Appendix E.

Pond Experiments

Nest success was much higher in control ponds (P = 0.01), but the average number of recruits to the fall did not differ between treatments (P = 0.35, Figure 1). We did find differences in the size structure of young individuals between treatments with larger fish present in the control ponds, and this led to increased biomass of juvenile bass (P = 0.05, Figure 5-3). Zooplankton densities were important for largemouth bass recruitment in ponds, and explained a significant amount of variation in experimental systems (Figure 5-4). Other habitat variables, including turbidity and phosphorus, also explained variation in sizes of juvenile bass in the summer and fall. Pond experiments suggest tournament-style angling may influence some aspects of largemouth bass recruitment dynamics, with effects on biomass but not numbers. Habitat characteristics such as prey availability for newly hatched individuals may be as important as tournament angling when examining factors that affect largemouth bass recruitment.

Influence of Spring Tournaments on Recruitment

Tournaments were conducted in the spring of 2007 and 2010 on Ridge Lake. In 2007, 7 tournaments were conducted and anglers caught 448 largemouth bass over 168 angler hours for a mean tournament CPUE of 2.67 fish/angler-hour (range 1.00 – 4.42

fish/angler-hour). In 2010 a total of 7 tournaments were conducted and the average angler hours per tournament was 22.3 hours. The anglers caught 167 fish totaling 180.9 pounds. Recent population estimates at Ridge Lake averaged 311 largemouth bass implying a large portion of the spawning fish were captured in the tournament and that the spring tournament angling is affecting a majority of the population. Tournament data from 2007 and 2010 during the spawning season were compared to non-tournament years in 2006, 2008, 2009, 2011 and 2012 (Table 5-3). In addition, fish populations and prey resources were compared in tournament and non-tournament years. Recruitment was assessed as CPUE of young-of-year largemouth bass from fall electrofishing. There was no significant difference between tournament and non-tournament years for CPUE of young-of-year largemouth bass ($F = 0.09$; $P = 0.78$), CPUE of largemouth bass greater than 200 mm ($F = 0.08$; $P = 0.79$) or CPUE of bluegill ($F = 0.30$; $P = 0.61$) from fall electrofishing samples (Figure 5-2). We also observed no significant differences in prey resources in tournament and non-tournament years ($P > 0.05$ for larval fish, zooplankton, and benthos densities). These results are based on only a few years of tournament and non-tournament fishing data and any interpretation should be made cautiously until additional years of data are collected. These preliminary results suggest that spring tournaments may not adversely affect recruitment. We plan to conduct tournaments again in the spring of 2013 and no tournaments were conducted in the spring of 2012 to provide additional data. Future research as part of F-152-R will allow further evaluation of the influence of tournaments during the largemouth bass spawning season.

Paper Tournaments

Data from 8 largemouth bass tournaments that ranged from 14 to 39 participating anglers were used to assess paper tournaments (Table 5-4). Results from the paper tournaments were similar to the official weigh-in results when only fish greater than the legal limit are included. Mean deviation in rank for each angler was slightly greater than 1 for both total paper length and converted paper weight of legal sized fish (Figure 5-5). An average of 1.1 anglers that were ranked in the top five in the official weigh-in were no longer in the top 5 due to the use of paper tournament results for legal fish (Table 5-5). These results suggest that paper tournaments can rank anglers similarly to official weigh-in results and may be used to replace the weigh-in and still identify the tournament winners. When paper tournaments considered all fish caught in angler rankings, rank deviation for each angler increased to around 4. Similarly the number of top 5 anglers that dropped out of the top five increased. Paper tournaments would allow organizers to consider fish that were caught that are too small to keep in a traditional weigh-in. These methods of evaluating who is the best angler will dramatically change the ranking of angler and may be a better or alternative measure of fishing skill rather than only considering legal sized fish. Paper tournaments can also evaluate traditional measures of winners based on anglers with the largest fish. Paper lengths for both tournament scenarios were similar to the weight results and converting paper lengths to weights is not necessary to rank anglers.

Long-Term Effects of Tournaments

Sampling of largemouth bass fishing tournaments was conducted on four lakes during the largemouth bass spawning period and the post-spawning period (Table 5-6).

Tournament anglers in the spring do appear to target spawning bass. The percentage of bass that were reproductively active ranged from 66% to 100% of all fish captured. A majority of both male and female bass sampled in spring tournaments had signs of spawning activity (ripe, running, swollen pore, and fin erosion). Similar proportions of males to females were angled during the spawning period when compared to post spawn in all lakes except Shelbyville which had a greater proportion of females during the spawning season than post spawn. This would imply that there is no sex specific targeting depending upon if the tournament occurs during the spawning period. Male fish are caught in a higher proportion than females during all seasons except during the spawn in Shelbyville. However this difference is small in Lake Shelbyville and sex specific targeting of fish may not occur in this lake. These results are contrary to conventional wisdom that female largemouth bass are targeted because of their larger size. We also did not observe large differences in the size of female largemouth bass weighed in at tournaments compared to male fish during either season.

A total of 45 anglers were interviewed from 2003 to 2008 to examine the prevalence of culling. The number of sub-legal fish that were caught-and-released varied by lake (Table 5-7). Very few short fish were caught in Lake Mattoon (0.25 per angler) while Mill Creek (3.1 fish per angler) and Shelbyville (5.4 fish per angler) had higher numbers of short fish released. Culling was low on all lakes (0.27 fish per angler) primarily due to few anglers reaching the creel limit for largemouth bass and not needing to release fish when caught. Culling appears to be minimal, except possibly in large tournaments, and should not influence estimates of sex ratios of fish in tournaments.

Information from tournaments conducted on 9 lakes was used to evaluate varying tournament pressure. All tournament activity was recorded for each lake and tournament results are used to evaluate the tournament pressure, catch rates, and angler success (Table 5-8). In addition we identified 5 lakes where no largemouth bass tournaments occur and use these lakes as a control to compare largemouth bass populations across varying tournament pressure. Tournament pressure was calculated as angler hours per acre and varied from 0 to 21.6 hours/acre. The mean number of participants across tournament lakes was 33.5 anglers and the average tournament was 6.8 hours long. When examining only the lakes with tournaments, lake size was significantly correlated with the number of anglers per tournament ($r = 0.80$; $P = 0.009$). Larger lakes tended to have larger tournaments with a higher number of participants. Despite having larger tournaments, the size of the lake was not significantly correlated with total tournament pressure on a per area basis (angler hours per acre; $r = -0.09$; $P = 0.77$) or the number of tournaments ($r = 0.31$; $P = 0.29$). Catch rate measured as fish caught per angler was not significantly correlated with tournament pressure ($r = 0.27$; $P = 0.49$). No relationships existed between catch rate and the number of tournaments, length of tournaments, and number of anglers in a tournament ($P > 0.05$). Lakes with the highest number of tournaments had the lowest mean weight per fish caught ($r = -0.68$; $P = 0.04$). Catch per unit effort was calculated from spring electrofishing transects for all largemouth, YOY, largemouth bass over 14 inches, and memorable as well as PSD for each lake (Table 5-9). CPUE of all largemouth bass, young-of-year largemouth bass, and largemouth bass greater than 14 inches was not significantly correlated with tournament pressure ($P > 0.05$). CPUE of largemouth bass greater than 14 inches was significantly correlated to lake size ($r = 0.82$; $P = 0.001$) and the mean number of fish weighed in at a tournament (r

= 0.58; P = 0.048). As expected, the total number of fish weighed in is also significantly correlated with lake size (r =0.75; P = 0.02). Angler catch rates were related to the abundance of fish in electrofishing transects and was higher on larger lakes. We did not detect any changes in abundance or size structure of largemouth bass vulnerable to tournament angling or production of young-of-year fish related to tournament pressure. However, these data are preliminary and are based on two years of data. We will continue to collect tournament and largemouth bass population data on these lakes and add additional lakes to this analysis as part of F-152-R to further understand the influence of tournaments on largemouth bass populations.

RECOMMENDATIONS:

Largemouth bass tournament angling continues to be popular and we evaluated the effects of these tournaments on fish populations and recruitment. We have demonstrated that largemouth bass can be targeted during nest guarding and that these angled fish are likely to abandon the nest. Thus far, we have been able to assess spawning activity and assess recruitment during seven years at Lincoln Trail Lake. Monitoring has allowed us to determine the duration of spawning as well as the relative number of nests formed each week. The number of nests was not related to adult stock or the number of recruits produced. Monitoring largemouth bass nesting in Lincoln Trail has allowed us to determine where nesting is occurring and the types of habitat bass prefer for spawning. Largemouth bass preferred to spawn on cobble, pebble, and gravel nest substrate. Our evaluation of preferences in spawning habitat and available habitat for bass spawning is important in order to understand what factors may influence nesting success. Management strategies such as improving nesting habitat may be important in lakes where spawning success is low due to lack of appropriate habitat.

We demonstrated high levels of nest abandonment when largemouth bass are subjected to tournament angling. In addition, nests that are abandoned resulted in brood loss and the nest does not contribute to recruitment. While angling during the spring spawning season is permitted in many areas (Quinn 2002), our study, along with others (Phillip et al. 1997; Suski et al. 2003, Siepker et al. 2009), provide evidence that angling has negative effects on the reproductive success of individual black bass. Some fisheries management agencies have limited competitive tournaments, or invoked closed fishing periods, catch-and-release regulations, and various length and harvest limits in different combinations in an attempt to limit angling of largemouth bass during the spawning season (see Schramm et al. 1995). These measures leave some portion of the spawning population unexposed to angling practices. We provide evidence that there is substantial nest abandonment associated with angling, especially during tournaments. Catch and release angling can increase abandonment rates in largemouth bass guarding a nest, but at significantly lower levels than tournament angling. The most cautious approach is for anglers and managers to consider limiting tournaments during the reproductive periods or consider alternative tournament formats (e.g. paper tournaments) where the weigh-in is removed from the process. Further discussion of effects and potential management options for tournaments can be found in Appendix D.

We measured low mortality associated with small club largemouth bass tournaments. Physiological results exhibited temporal patterns whereas mortality did not. These results highlight the importance of minimizing the sub-lethal physiological disturbances incurred by largemouth bass during tournaments, even if such disturbances are not associated with mortality. Physiological disturbances and associated stress responses have previously been linked to negative outcomes including disease susceptibility (Wendelaar Bonga 1997), an impaired ability to escape predators (Schreck et al. 1997), altered movement and activity patterns (Pankhurst and Dedual 1993; Pankhurst and van der Kraak 1997; Thorstad et al. 2004; Gurshin and Szedlmayer 2004) and reduced fitness (Ostrand et al. 2004). Physiological parameters examined in this study suggest small, club-style tournaments can have physiological impacts on largemouth bass similar to those sustained during professional tournaments (Suski et al. 2003), despite earlier work suggesting that a reduced degree of organization may actually result in greater negative impacts relative to larger, tour-style events (Ostrand et al. 1999). Not all tournament groups follow the same procedural guidelines as the one in this study, thus incorporating tournaments with different levels of organization should be a future goal. The results of this study do suggest that small and large angling tournaments can have similar effects on largemouth bass and tournament organizers and anglers should implement previously-suggested procedures (e.g. proper aeration and minimizing air exposure) regardless of season and temperature.

Results from livewell experiments suggest that fish size and ambient water temperature may have a greater influence on delayed mortality observed during competitive angling events than specific livewell additives. Fish appear to have greater long term survival following tournaments that were conducted when ambient water temperatures were cooler. Many organizations continue to sponsor black bass tournaments during late spring and summer months when ambient water temperatures are at the highest. Although a variety of practices have been adopted to reduce initial and delayed tournament mortality, our results suggest the benefits of livewell additives on post-release survival of competitively angling largemouth bass are minimal; water temperature when tournaments are conducted and the size of fish angled appear to be more important. Our results suggest that tournament organizers should consider conducting events when ambient water temperatures are cooler. In addition, tournament organizers should consider alternative rules and formats that may result in less physiological stress on fish such as reduced creels or paper tournaments, where captured fish are immediately measured and released at their capture location (Ostrand et al. 1999).

Pond experiments demonstrated some negative effects of tournaments on spawning largemouth bass populations. In some cases population level effects on recruitment may result. In lakes where largemouth bass recruitment is low, effects of tournament angling during the spawning season should be considered. Systems that are already known to have attributes that limit recruitment (water level fluctuation, lack of prey resources, etc.) may be at further risk of recruitment problems from tournament angling. In these situations, we suggest regulations limiting tournament pressure during the spawn or the establishment of refugia so that some fish can reproduce undisturbed.

We will continue to evaluate largemouth bass tournaments and their procedures and assess how they affect fish populations. Results from the experiment at Ridge Lake have not shown any evidence of reduction in recruitment of young-of-year largemouth bass due to springtime tournaments or changes in adult populations. To assess the effects of angling practices and tournaments on largemouth bass reproduction and recruitment we will continue these experiments as part of future projects. Experimental angling tournaments were conducted on Ridge Lake in 2007 and 2010. We will conduct a third season of tournament angling in the spring of 2013 providing assessment of 3 years of largemouth bass recruitment in years with tournament angling to compare to 3 years of non-tournament angling.

Paper tournaments have the potential to remove the stress associated with livewell confinement and weigh-in procedures, and reduces the time a male is removed from nesting sites. We have demonstrated that paper tournaments can accurately rank anglers as well as allow tournaments to include smaller fish and should be considered as an alternative to traditional weigh-ins especially during high temperature times of year and the spawning season. In addition, paper tournaments allow the inclusion of fish that are caught, but shorter than the legal limit. These fish are ignored in a traditional weigh-in, but provide an alternative way to evaluate who is the best angler. We have shown the potential of paper tournaments and encourage organizers to consider their use in future tournaments.

Monitoring of tournaments for spawning condition and sex ratios was also conducted. A large proportion of largemouth bass caught in tournaments during the spawning period were mature fish that were actively engaging in spawning activities. Fish angled off the nest in tournaments have been shown to have extremely high nest abandonment rates. Tournaments during the largemouth bass spawning seasons have the potential to influence spawning success for individual fish and potentially affect the entire fish population. Fish targeted in tournaments are generally of mature size and may be more vulnerable during spawning activities. In particular male largemouth bass that are guarding a nest may be overly aggressive and located in shallow areas vulnerable to fishing gears. However we did not observe male fish being captured at higher ratios during the spawning than in the post spawning period suggesting that they are not targeted in tournaments. We did have some evidence that male fish are caught in greater numbers than females throughout the year, but the ratio is not greatly skewed. Information provided by tournament angler surveys suggests that the culling and release of smaller males for larger females is minimal and not skewing sex ratio estimates. Catch and release angling has been shown to have reduced effects on nesting largemouth bass compared to tournament caught fish and leads us to conclude that catch-and-release angling should not limit spawning success. Additional research to determine the implications of angling bass from the nest on the overall bass population and year class strength are needed. With these data, we will be able to make predictions about how different types of angling will affect recruitment of largemouth bass.

Greater recruitment was observed on lakes without tournaments but densities of adult largemouth bass were lower. Angler catch rates were related to the abundance of fish in electrofishing transects and was higher on larger lakes. We did not detect any changes in abundance or size structure of largemouth bass vulnerable to tournament angling or production of young-of-year fish related to tournament pressure. We will continue to monitor tournament activity at these lakes as well as compile weigh-in results as part of a new project F-152-R. These data will allow us to further examine the relationships between tournaments and the influence on fish populations. We will also incorporate creel data in order to assess fishing pressure on these lakes and relate them to largemouth bass size structure. We will incorporate FAS data from DNR biologist electrofishing sampling to supplement INHS electrofishing data. We will continue to determine sex and ages of largemouth bass in lakes with varying fishing exploitation. We will examine how angling activities influence sex specific characteristics such as growth, longevity, and age of maturity. Using this data, we will be able to make predictions about how angling will affect recruitment of largemouth bass and adult populations. This will allow us to identify the potential impacts of tournaments and harvest to life history characteristics in largemouth bass populations.

Job 101.6. Evaluating the impact of spawning refuges, habitat manipulations, harvest regulations and other management strategies on largemouth bass recruitment in Illinois.

OBJECTIVE: To develop a model to evaluate the effects of various angling scenarios and pressures on Illinois bass recruitment and size structure. To evaluate the effects of fish refuges on Illinois bass recruitment and size structure.

INTRODUCTION:

Refuges

Largemouth bass can be vulnerable to anglers during spawning and reproductive success may depend on the level of angling stress the fish undergoes during this period. This has sparked a recent controversy among anglers as to whether or not bed fishing (angling fish off the nest) is detrimental to bass populations. Our recent research (see Job 101.5) suggests that angling largemouth bass off nests can cause nest abandonment, which results in the failure of the nest to produce offspring. Many states have implemented closed seasons or spawning refuges, which are closed to fishing in an attempt to alleviate this problem. It is unclear if these management techniques are appropriate for Illinois reservoirs.

Clinton Lake is an approximately 2000-hectare lake that is operated as both a power plant cooling lake and a recreational lake. In the fall of 2001, a portion of the lake adjacent to the Clinton Lake Power Plant was permanently closed to boaters and anglers. This closed area serves as a refuge for largemouth bass from angling. Otter Lake is a 310-hectare lake that operates as a water supply and recreational lake. Jeffrey Pontnack (District 14/15 Fisheries Biologist) and Dennis Ross (General Manager of Otter Lake Water Commission) proposed closing two large bays to fishing and boating, providing a spawning and fishing refuge for largemouth bass and other fish species. The two bays were closed to fishing in summer of 2010. The refuges may be beneficial to largemouth bass, by increasing spawning success and decreasing fishing mortality. We are using these lakes to evaluate the success of refuges in increasing the density and size structure of the largemouth bass populations.

Harvest Regulations

There are many potential harvest regulation strategies that can be used to help manage bass populations, including size limits, closed seasons, and spawning refuges. Each of them can have a different impact on the population, either by affecting size structure or density. Some regulations have the potential to impact recruitment more than others, but right now, we cannot make accurate predictions. Increasing the quality of angler catch or harvest rates are common rationales for harvest regulations (Paukert et al. 2007). However, compilation of 91 studies using minimum-length limits and slot-length limits concluded that most studies were conducted over too short a period and did not include creel data to document if a regulation increased angler catch rates (Wilde 1997). Many regulation decisions are not influenced by information available on black bass biology (Paukert et al. 2007). There is a need for further research examining the effects of angling regulations (Novinger 1984; Wilde 1997; Paukert et al. 2007). In this job, we are also evaluating current regulations used in Illinois largemouth bass management in order to determine the effects on population size structure and density as well as angler catch rate.

PROCEDURES:

Refuges

Population abundance and size structure of largemouth bass were assessed in Otter and Clinton Lake using spring and fall electrofishing and seining. The Clinton Lake refuge was closed in 2001 and samples were taken both before and now after implementation of the refuge. Samples collected on Clinton during 1999 – 2001 represent pre-refuge and 2002 to 2012 represent post-refuge. Sampling consisted of pre and post refuge electrofishing transects and seines hauls in both the spring and fall in Clinton Lake. Two, thirty minute electrofishing transects and two seine hauls were performed inside the refuge on each sampling date. Two transects were also electrofished and seined outside of the refuge. Sites outside of the refuge were located adjacent to and at approximately 2 lake kilometers from the refuge. Seining was conducted using a 9.2-m bag seine pulled along the shoreline at fixed transects. In addition to Clinton Lake, in the summer of 2010, two refuges were closed to fishing in Otter Lake by running a buoy line with a no fishing marker attached. We began post-refuge sampling in Otter Lake in 2011 because the buoy lines were put in place after largemouth bass spawning was completed in 2010. Samples conducted in 2007 through 2010 were considered pre refuge conditions and samples collected in 2011 and 2012 were considered post refuge conditions. Sampling was conducted on two dates in the spring and two dates in the fall for each year. On each sampling date, one 30 minute electrofishing transect and one seine haul were conducted in each refuge location. In addition, three control sites were sampled (1 electrofishing transect and 1 seine haul in each) within the lake. One reference was located near each proposed refuge, and the final reference location at the midpoint between the refuge sites. Fish were identified to species and total length was recorded. All fish were counted and up to 50 fish were measured for each species. All largemouth and smallmouth bass collected inside refuge sites were given an upper caudal fin clip in order to determine if fish in the refuge move into adjacent areas of the lake. Catch per unit effort (CPUE) was then calculated as the number of fish per hour of electrofishing and number per square meter area seined.

Harvest Regulations

Largemouth bass angling regulations in Illinois Lakes are also being evaluated. We have compiled seven years of data (2000-2007) from lakes with differing regulations identified from the FAS database. Data collected through IDNR fall surveys and entered into the FAS database were used to assess largemouth bass populations. The FAS data base was reduced to the lakes that were sampled in the fall at some point from 2000-2007 using AC shoreline electrofishing and had regulations posted in the IDNR Fisheries

Bulletin. The lakes were categorized using their existing regulations into eight categories, bag by size (Bag limit above and below a specified size), catch-and release (no harvest allowed), standard (14” length limit, 6 fish creel), lowered bag (14” length limit, <6 fish bag limit), raised length (>14” length limit, 6 fish bag limit), raised length/low bag (>14” length limit, <6 fish bag limit), no length (no minimum size limit), and slot (no fish harvest slot). These lakes were then compared across regulation type for differences in CPUE of young-of-year largemouth bass, CPUE of largemouth bass greater than 14 inches, and proportional stock density (PSD) with stock size being 200 mm and quality size being 300 mm. In addition we determined the number of memorable (510 mm and larger) sized fish in electrofishing samples.

FINDINGS:

Refuges

Mean CPUE for largemouth bass in Clinton Lake prior to the refuge from 1999 through 2001 was 26 fish per hour of electrofishing. This is in the lower range of our study lakes, which have a range of CPUE from 15.2 to 106.0 fish per hour. As a result, there is the potential for an increase in abundance of largemouth bass in Clinton Lake from the establishment of the refuge. Sampling at sites inside the refuge in 2002 through 2012 yielded a much higher CPUE than sites outside the refuge (Table 6-1). In addition, CPUE was greater inside the refuge after closing than samples taken before the refuge was closed. This suggests that bass numbers are increasing in the refuge potentially due to the elimination of fishing pressure. Young-of-year largemouth bass densities have also increased inside the refuge. CPUE of young-of-year largemouth bass has fluctuated in the refuge sites but has increased since 2007 (Table 6-1A). The CPUE of young-of-year largemouth bass has decreased in the control sites since 2001. Density of largemouth bass in seines is also the highest in the refuge sites and has increased after the refuge was closed (Table 6-2A). Despite the increase in adult and young-of-year largemouth bass in the refuge sites, there is no evidence of the benefits of the refuge extending into the remainder of the lake. No clipped fish were observed in electrofishing or seine samples taken outside of the refuge. This implies that there is little or no movement of fish from the refuge to the open portion of the lake.

We began monitoring refuge and continued monitoring reference sites in Otter Lake during. The spring of 2011 was the first spawning season since the two refuges were closed to fishing and boating. In the spring and fall of 2007- 2010, we observed similar catch rates of adult and young-of-year largemouth bass in electrofishing samples in the refuge sites compared to the control sites (Table 6-1). The proposed refuge sites appear to be in areas with good largemouth bass abundance and closing these areas to fishing has the potential to increase recruitment. Spring electrofishing CPUE of largemouth bass in 2011 and 2012 were lower than the mean pre-refuge conditions in both the control sites while the refuge sites remained the same. Similar trends were observed in density of largemouth bass from seine hauls in the control and refuge sites (Table 6-2B) however catch rates for largemouth bass were low and variable. We would not expect large changes in the largemouth bass community in the first year and a half following implementation of a refuge and any conclusions from the data would be premature. We will continue to assess if limiting disturbance of these fish during nesting may increase spawning success and yield larger year classes in future projects. Effects of a refuge may be easier to detect on Otter Lake than on Clinton due to its smaller size and these refuges merit further evaluation.

<u>Harvest Regulations</u>

We summarized 7 years of FAS data to evaluate electrofishing catch rates and size structure of largemouth bass among differing management regulations. We calculated CPUE from fall electrofishing in all lakes reported in the FAS database from 2000-2007 resulting in catch rates for 429 lakes. Regulation data was then compiled from the Illinois Department of Natural Resources (IDNR) fishing regulations guide for these same lakes. The resulting database was 218 lakes that had both electrofishing data and regulation data available. Regulations were grouped into 8 categories; catch-and-release (n = 1), bag by size (n = 1), standard (n = 50), lowered bag (n = 20), raised length (n = 26), raised length and lowered bag (n = 65), no length (n = 37), and slot (n = 18). Largemouth bass populations in lakes with slot limits differed the most from populations with other regulations. Mean CPUE of largemouth bass from electrofishing was significantly different among regulation types (F = 3.38; P = 0.006) with slot limits being the highest and significantly greater than all regulation types except no length regulation lakes (Figure 6-1). There was also significant differences in the CPUE of young-of-year largemouth bass (F = 3.67; P = 0.003) with slot limits being significantly higher than raised length, standard, and raised length lowered bag lakes (Figure 6-2). CPUE of memorable fish was low in all lakes (0.19 to 0.88) but there were significant differences among regulation types (F = 5.09; P = 0.0002). Again slot limit lakes had the highest CPUE of memorable fish and were significantly greater than all regulation types except Standard (Figure 6-3). PSD was also different among lakes (F = 2.41; P = 0.04) but only between Slot Limit lakes and Standard regulation lakes ($P < 0.05$). The Slot limit lakes had the lowest PSD of all regulation types due primarily to the high number of smaller fish in these lakes rather than a lack of larger fish.

RECOMMENDATIONS:

There are many potential harvest regulation strategies that can be used to manage bass populations, including size and creel limits, closed seasons, and spawning refuges. Each of them, either singly or collectively, can have a different impact on the population, either by affecting size structure and/or abundance. Some regulations have the potential to impact recruitment more than others, but right now, we cannot make accurate predictions. Other management options include habitat, prey, and predator manipulations. Thus far we have been evaluating a spawning/fishing refuge on Clinton and Otter Lakes. Largemouth bass populations inside the refuges at Clinton Lake had large increases in the number of adult fish after they were closed to fishing. However largemouth bass populations outside of the refuge did not increase and there is no evidence of fish leaving the refuge and moving into the main lake. This refuge has resulted in enhanced recruitment and survival of largemouth bass, but may not increase catch rates lakewide for anglers. We plan to continue our evaluation in Otter Lake as part of a new study (F-152-R) by conducting seine hauls in the spring and fall at sites within the refuge and sites on the main lake to estimate the abundance of young-of-year largemouth bass. We will also conduct electrofishing transects in the spring and fall within the refuge and on the main lake to monitor adult largemouth bass populations. Data will be compared after the refuges were initiated to those from the same sites during the years preceding the implementation of the refuges. Bass captured in both seine hauls and electrofishing transects inside the refuges will also be marked with a caudal fin clip. All bass collected will be examined for existing clips in order to determine if bass in the refuge are moving into the main lake. These studies will provide information regarding the value of fishing refuges for increasing largemouth bass recruitment.

Adaptive management experiments to evaluate habitat manipulations, including vegetation and the role of woody debris were evaluated as part of Job 4. Management experiments manipulated vegetation (e.g. plantings and removals) to examine changes in largemouth bass growth and survival. The experiment includes control lakes, as well as treatment lakes to either increase or decrease the density of aquatic vegetation. These experiments were used to make management recommendations regarding vegetation and woody habitat in order to increase largemouth bass recruitment (see Job 4).

Regulations vary greatly in Illinois reservoirs. Our analysis thus far shows that lakes with slot limits have the most differences in largemouth bass size structure among lakes from other regulation types. It is unclear if this is a result of the regulation, or reason the regulation was implemented. Usually a slot limit is implemented when there is a need to protect fish in a critical size range to allow them to grow into the upper slot. However, it also allows for harvest of small size fish and can be implemented to encourage harvest of smaller size classes when their density is high enough that the population could be limited by resources. Future research should examine time series data to determine how populations change as regulations are implemented. If possible, data before and after regulation changes should be examined and the length of time a regulation has been implemented will be evaluated. We plan to continue this research as part of a new study (F-152-R). We will utilize creel data that is available as part of F-69-R to determine the level of harvest associated with each regulation and if harvest rates are high enough to induce changes in fish populations. We will continue to incorporate lakes with FAS data and INHS sampling to develop a long term database of lakes with fish community data and creel sampling. The number and frequency of lakes where angling creels were performed will limit the number of lakes that can be included in this aspect of the study. We will create an extensive database that can be used to examine differences in electrofishing catch, and a reduced database including creel data. We will contact DNR district biologists and determine when regulations were initiated and use creel and FAS data to compare catch rates of anglers, CPUE from electrofishing and size structure of largemouth bass in these lakes before and after the regulation were put in effect. In doing so, we hope to better understand the value of differing management regulations on lakes throughout Illinois. These data can then be used to guide future discussions about various management experiments that might be implemented.

Job 101.7. Analysis and reporting.

OBJECTIVE: To prepare annual and final reports summarizing information and develop management guidelines for largemouth bass in Illinois.

PROCEDURES and FINDINGS: Data collected in Jobs 101.1-101.6 were analyzed to develop guidelines for largemouth bass regarding stocking and management techniques throughout Illinois.

Segment 14

Job	Proposed Cost	Actual Cost
Job 101.1	$0	$0
Job 101.2	$64,914	$64,914
Job 101.3	$27,047	$27,047
Job 101.4	$189,332	$189,332
Job 101.5	$64,914	$64,914
Job 101.6	$140,647	$140,647
Job 101.7	$54,096	$54,096

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Table 1-1. Growth rates for 4" largemouth bass marked with fin clips (FC), freeze brands (FB), or fin cauterization (FCFB). Seventy-five fin clipped, 100 freeze brand, and 75 fin clip cauterized fish were stocked into three 0.3-acre ponds on 14 December 1998 and sampled every subsequent spring and fall. Unidentifiable fish were recognized by their respective genotype: fin clipped (1:1), freeze brand (1:2), and fin clip cauterized (2:2).

	Growth Rate (g/d)		
Date	Fin clip	Freeze brand	Fin cauterization
12/14/98 to 5/27/99	0.10	0.09	0.10
5/27/99 to 10/26/99	0.19	0.23	0.22
10/26/99 to 3/20/00	0.05	0.05	0.03
3/20/00 to 11/2/00	0.38	0.30	0.41
11/2/00 to 3/15/01	0.08	0.08	0.10
3/15/01 to 10/18/01	0.04	0.05	0.06
10/18/01 to 3/12/02	0.18	0.18	0.18
3/12/02 to 10/16/02	0.76	0.66	0.78
10/16/02 to 3/19/03	0.05	0.07	0.06
3/19/03 to 10/22/03	0.15	0.26	0.19
10/22/03 to 3/18/04	0.07	0.09	0.03

Table 2-1: Cost of producing fish for three lakes in Illinois stocked for 5 years with both intensively reared and extensively reared fish. Extensively reared fish were produced in ponds and fed zooplankton and fathead minnows, whereas intensively reared fish were produced in raceways and fed pelleted diet. Mean total stocking cost is calculated as the cost per fish multiplied by the mean number of fish stocked into the lake. Total Cost per CPUE is calculated as the total stocking cost of stocking divided by the CPUE (#/hr.) from electrofishing in the 1st, 2nd, and 3rd fall following stocking.

Lake	Lake Area (acres)	Rearing Method	Hatchery Cost / Fish	Rearing Pond Cost / Fish	Total Cost per Stocked Fish	Mean Total Stocking Cost	Total Cost per CPUE		
							1st Fall	2nd Fall	3rd Fall
Jacksonville	476	Extensive	$0.03	$0.48	$0.51	$3,095	$900	$2,579	$4,486
Shelbyville	11,100	Extensive	$0.03	$0.48	$0.51	$7,758	$2,255	$6,465	$11,244
Walton Park	30	Extensive	$0.05	$0.55	$0.60	$375	$109	$313	$543
					Mean	$3,743	$1,088	$3,119	$5,424
Jacksonville	476	Intensive	$0.15	NA	$0.15	$638	$759	$1,821	$1,875
Shelbyville	11,100	Intensive	$0.15	NA	$0.15	$1,322	$1,574	$3,777	$3,888
Walton Park	30	Intensive	$0.15	NA	$0.15	$94	$112	$268	$276
					Mean	$684	$815	$1,955	$2,013

Table 2-2: Stocking information for four lakes stocked with largemouth bass both at the boat ramp and dispersed into habitat throughout the lake. CPUE is catch per hour from electrofishing transects conducted in the fall after stocking and the subsequent spring.

Lake	Stocking Date	Boat Ramp Stocking			Dispersed Stocking		
		# Stocked	Fall CPUE	Spring CPUE	# Stocked	Fall CPUE	Spring CPUE
Charleston	8/15/2008	3500	2	0	3500	2	0.4
	8/25/2009	3500	0.8	0	3500	0	0.7
	9/2/2010	3500	1.3	0	3500	1.3	0
	8/12/2011	3500	0.7	0	3500	1.1	0
Homer	8/16/2007	1400	0	0	1400	0.3	0
	8/24/2009	1000	0	0	1000	0.3	0
	8/26/2010	1000	1.7	0	1000	0	0.7
	8/11/2011	1000	1.7	0.3	1000	2.3	1
Mingo	8/16/2007	3400	0.7	0	3400	2	0
	8/14/2008	2150	5.7	0	2150	3.7	0.7
	8/24/2009	2125	0	0	2125	0.3	0
	8/26/2010	2125	1.3	0	2125	0.3	0
	8/11/2011	2125	0.3	0	2125	0.7	0.3
Otter	8/15/2007	7650	0	0	7650	0	0
	8/13/2008	11400	0.8	0	11400	0.2	0
	8/25/2009	7650	0.4	0	7650	0	0
	8/25/2010	7650	0.9	1.7	7650	0.4	0
	8/15/2011	7650	0.6	0	7650	2	0.2
Mean Total			1.05	0.11		0.94	0.22

Table 2-3. Multiple Before-After, Control-Impact (MBACI) analysis to test for changes in water quality variables following supplemental introduction of largemouth bass in lakes where gizzard shad were absent. Mean values for each parameter for treatment (M_i) and control lakes (M_c) are shown before ($_b$) and after introduction ($_a$). F statistics and P-values are for the Trt x Period term from the repeated measures ANOVA.

Parameter	M_{ib}	M_{ia}	M_{cb}	M_{ca}	$F_{1,4}$	*P*
Prey Fish Density (N/m^2)	4.51(2.05)	1.00(0.27)	1.47(0.80)	2.17(0.50)	8.5	0.04
Prey Fish CPUE (N/hr)	290.83(61.60)	176.86(21.29)	235.11(103.02)	182.07(50.45)	0.01	0.93
Daphnid Concentration (N/L)	18.39(4.61)	27.33(5.75)	12.14(5.16)	7.25(1.23)	2.12	0.22
Cladoceran Length (mm)	0.47(0.04)	0.45(0.01)	0.48(0.05)	0.57(0.03)	3.95	0.12
Chaoborid Concentration (N/L)	0.13(0.10)	0.05(0.02)	0.48(0.20)	0.19(0.06)	0.64	0.47
Total Macroinvertebrates (N/m^2)	5039.18(1700.75)	7960.39(1947.93)	7000.60(2187.70)	3620.40(523.80)	11.07	0.03
Chironomid Density (N/m^2)	486.64(119.55)	983.87(280.46)	3424.64(1280.53)	1629.66(287.18)	5.35	0.08
Ceratopogonid Density (N/m^2)	195.99(51.79)	266.53(61.70)	783.18(279.00)	494.26(112.73)	2.89	0.16
Chlorophyll *a* (µg/L)	24.47(7.10)	30.06(4.45)	19.50(6.97)	14.50(3.36)	0.28	0.63
Secchi Depth (m)	0.55(0.12)	0.65(0.05)	1.66(0.22)	1.57(0.16)	0.84	0.41
Total Phosphorous (µg/L)	149.80(31.21)	268.38(58.26)	67.88(22.82)	95.86(15.79)	0.36	0.58

Table 2-4. Multiple Before-After, Control-Impact (MBACI) analysis to test for changes in water quality variables following supplemental introduction of largemouth bass in lakes where gizzard shad were present. Mean values for each parameter for treatment (Mi) and control lakes (Mc) are shown before (b) and after introduction (a). F statistics and P-values are for the Trt x Period term from the repeated measures ANOVA.

Parameter	M_{ib}	M_{ia}	M_{cb}	M_{ca}	$F_{1,5}$	*P*
Prey Fish Density (N/m^2)	1.10(0.67)	0.52(0.13)	1.05(0.52)	0.57(0.16)	0.11	0.75
Prey Fish CPUE (N/hr)	285.84(84.04)	305.1(48.21)	370.54(37.18)	245.31(23.72)	1.06	0.36
Daphnid Concentration (N/L)	2.68(1.09)	3.85(1.00)	1.51(0.45)	3.92(1.48)	0.16	0.71
Cladoceran Length (mm)	0.44(0.03)	0.47(0.01)	0.47(0.04)	0.46(0.02)	0.75	0.43
Chaoborid Concentration (N/L)	0.50(0.20)	0.10(0.05)	0.10(0.05)	0.19(0.12)	0.61	0.47
Total Macroinvertebrates (N/m^2)	4411.33(902.00)	3577.10(411.51)	3028.29(1498.78)	4042.84(918.25)	3.33	0.13
Chironomid Density (N/m^2)	2876.25(648.83)	2271.38(225.22)	1274.69(417.28)	2212.83(450.85)	8.08	0.04
Ceratopogonid Density (N/m^2)	155.42(47.08)	153.89(47.49)	250.51(99.10)	290.23(90.05)	0.36	0.56
Chlorophyll *a* (µg/L)	29.38(3.70)	27.73(3.50)	42.96(8.85)	34.08(5.21)	0.49	0.52
Secchi Depth (m)	0.57(0.06)	0.62(0.07)	0.59(0.08)	0.58(0.05)	0.04	0.84
Total Phosphorous (µg/L)	175.46(34.37)	129.30(12.64)	195.07(69.51)	143.55(20.54)	0.36	0.57

Table 3-1: The influence of stocked fish on the MDH B2 allele frequency for each of the five study lakes as a function of lake size. Proportional change was based on the average percent increase in allele frequencies in each of the lakes compared to initial allele frequency.

Lake	Lake Size (hectares)	MDH B2 Allele Frequency		Percentage Increase	Influence
		Initial	Ending		
Shelbyville	4494	0.14	0.16	2%	Minor
Forbes Lake	226	0.33	0.38	5%	Minor
Lake Murphysboro	58	0.12	0.21	9%	Moderate
Sam Parr Lake	58	0.18	0.36	18%	Moderate
Walton Park	12	0.16	0.42	26%	Major

Table 4-1: Comparison of fit of models of recruitment as a function of total eggs deposited, total successful nests, bluegill stocking density (BLG), and a combination of bluegill stocking density with either total eggs or nests (years 2001 and 2002). This analysis was also conducted on three years of data (1999, 2001, 2002), excluding the variable total eggs per pond (0.4-ha). Bluegill stocking density was treated as categorical in the analysis (no bluegill, medium density = 954 fish/0.4-ha pond, high density = 3906-4340 fish/0.4-ha). Models are ranked by AIC_c scores (Akaike Information Criteria corrected for small sample size), with the lowest AIC_c scores representing models in the set with the best fit. Models within 5 AIC_c units are considered to have equivalent fit to the data, and an R^2 is presented for models with the most empirical support.

Years	Model	AICc	R^2
1999, 2001, 2002	Successful nests + BLG	240	0.35
	BLG	258	
	Successful nests	277	
2001, 2002	Successful nests + BLG	159	0.35
	BLG	174	
	Successful nests	178	
	Total eggs + BLG	183	
	Total eggs	203	

Table 4-2: Mean percent cover for each species of vegetation planted in Lake Paradise in June and July of 2008 (A.) and July of 2009 (B.). Percent cover was visually assessed in each of three sizes of enclosure (large, small dispersed, and small clustered).

A. Planted in 2008

Vegetation Planted	Size	Number Planted	Percent Cover		
			2008	2009	2010
American Pondweed	Large	6	78	5	34
American Pondweed	Small	12	61	2	12
Chara	Large	6	1	0	0
Chara	Small	12	0	0	0
Chara	Clustered	4	0	0	0
Coontail	Large	7	16	1	0
Coontail	Small	16	3	0	0
Coontail	Clustered	4	0	0	0
Sago	Large	4	23	0	0
Sago	Small	34	12	6	0
Sago	Clustered	16	12	0	0
Wild Celery	Large	13	22	1	0
Wild Celery	Small	59	14	1	1
Wild Celery	Clustered	52	15	1	0

B. Planted in 2009

Veg Planted	Size	Number	Percent Cover	
			2009	2010
American Pondweed	Large	11	19	6
American Pondweed	Small	20	11	17
Wild Celery	Large	12	4	3
Wild Celery	Small	33	4	5

Table 4-3: Density of fish from backpack electrofishing and density of invertebrates from stovepipe core samples associated with vegetation enclosures planted in Lake Paradise in 2008 and 2009.

Vegetation	N	Density (#/m2)
	Fish	
American Pondweed	21	0.71
Coontail	1	0.80
Sago	1	2.55
Wild Celery	6	0.94
All vegetated cages	29	0.82
No Vegeation	26	0.70
	Benthic Invertebrates	
American Pondweed	12	22672
Sago	1	44012
Wild Celery	9	35250
All vegetated cages	22	28788
No Vegetation	9	17610

Table 4-4: Mean data from spring and fall vegetation assessments from 2008 through 2011 on 13 Illinois lakes. Vegetation on each lake was mapped using GPS to estimate the area and perimeter of the vegetated area of the lake. Percent vegetated area and perimeter are the proportion of the entire lake.

Lake	Type	Percent of Lake Vegetated			
		Spring		Fall	
		Area (%)	Perim. (%)	Area (%)	Perim. (%)
Airport	Removal	75.2	97.7	100.0	100.1
Dolan	Drawdown	17.2	85.4	20.5	87.1
Forbes	Control	12.3	92.8	13.0	87.1
Kakusha	Removal	0.5	2.0	0.0	0.0
Le-Aqua-Na	Control	17.8	54.7	12.7	28.9
Lake of the Woods	Control	0.6	4.1	0.3	4.4
Lincoln Trail	Control	19.4	88.0	20.8	93.6
Paradise	Planted	5.9	46.1	5.2	38.3
Pierce	Control	20.4	85.2	22.2	86.0
Ridge	Control	34.7	98.3	38.1	92.4
Stillwater	Removal	37.0	96.1	55.5	77.6
Walnut Point	Control	2.3	6.9	2.5	6.6
Woods	Control	0.0	0.0	0.0	0.3

Table 4-5: Mean CPUE for young-of-year and adult largemouth bass from 2008 to 2011 in 13 lakes with varying vegetation densities (see Table 4-3). In addition, mean larval fish, zooplankton, and benthic macroinvertebrate density for each lake from spring, summer and fall samples from 2008 through 2011.

Lake	Type	Mean Fall Electrofishing CPUE (#/hr)			Larval Fish Density (#/m3)			Mean Total Zooplankton Density (#/L)	Mean Total Benthos Density (#/m^2)
		YOY LMB (<200mm)	BLG	LMB >200mm	Shad	Lepomis	Total		
Airport	Removal	28.8	68.2	12.9	0.0	1.1	1.1	384.2	10344.3
Dolan	Drawdown	11.8	72.3	50.1	1.0	34.9	36.0	327.1	12783.2
Forbes	Control	10.5	80.3	26.0	2.9	4.7	7.8	556.2	12526.6
Kakusha	Removal	28.5	68.5	32.0	0.0	0.1	0.1	1240.3	10522.8
Le-Aqua-Na	Control	18.4	93.4	31.1	0.0	1.0	1.0	332.7	19930.8
Lake of the Woods	Control	14.3	71.4	22.5	1.3	5.9	7.4	351.2	14161.8
Lincoln Trail	Control	44.5	62.8	38.3	0.0	5.0	5.1	268.3	7870.4
Paradise	Planted	12.1	67.7	22.9	2.6	5.9	8.5	391.4	5471.5
Pierce	Control	27.2	43.1	23.2	0.4	0.4	0.8	297.2	10464.7
Ridge	Control	30.5	60.3	32.0	0.0	3.5	3.5	589.2	8112.5
Stillwater	Removal	30.9	36.9	14.5	0.0	3.3	3.7	333.8	7477.2
Walnut Point	Control	33.0	65.6	18.8	0.0	8.6	8.7	662.6	19789.3
Woods	Control	8.4	87.4	15.3	2.8	4.9	7.7	408.2	12000.9

Table 4-6: Numbers of young of year largemouth bass found in the streams below the dams of both Forbes Lake and Ridge Lake by month.

Lake	April	May	June	July-Oct.
		YOY		
Forbes	0	3	2	32
Ridge	0	8	26	0
		Age 1+		
Forbes	5	6	2	1
Ridge	2	0	0	2

Table 5-1: The number of nests observed on six standardized snorkeling transects during the spring of 1999 – 2012 in Lincoln Trail Lake.

Year	First Nest	April 2-13	April 14-21	April 22-29	April 30-May 5	May 6-13	May 14-21	May 22-29
1999	5/4/1999	0	0	0	24	60	35	14
2000	5/3/2000	0	0	0	49	79	20	1
2001	4/23/2001	0	0	55	90	15	10	0
2002	4/22/2002	0	0	16	4	Too Turbid to Continue		
2003	Not Sampled Due to Water Clarity							
2004	Not Sampled Due to Water Clarity							
2005	4/18/2005	0	54	2	0	31	0	0
2006	4/19/2006	0	0	27	4	12	3	0
2007	4/23/2007	0	0	32	31	1	1	0
2008	4/23/2008	0	0	11	NA	26	12	4
2009	4/23/2009	0	0	25	10	0	0	0
2010	4/14/2010	0	76	45	24	15	0	0
2011	4/13/2011	14	Too Turbid to Continue					
2012	4/2/2012	68	56	57	NA	39	0	0

Table 5-2: Chi-squared residuals for largemouth bass nesting substrate in Lincoln Trail Lake in 2006-2010. Absolute values greater than 1.96 indicate substrates that were significantly over expressed (positive values) or under expressed (negative values) relative to their availability.

Year	Vegetation	Wood	Sticks	Leaves	Detritus	Sand	Gravel	Cobble	Pebble
2006	**-1.97**	**5.06**	**4.58**	**-2.26**	**-2.70**	-0.69	-0.30	**3.11**	**3.83**
2007	**-2.49**	0.27	0.30	**-1.79**	-1.09	0.91	**2.27**	**3.38**	**3.28**
2008	**-2.75**	0.84	0.35	1.07	-0.77	-1.36	**3.51**	**2.84**	1.69
2010	0.95	**-2.46**	-1.11	**-2.14**	0.46	**-3.05**	**9.36**	**15.99**	**4.56**

Table 5-3: Lake characteristics of Ridge Lake in years with springtime tournaments and years with no tournaments.

Year	Type	Mean Fall Electrofishing CPUE (#/hour)			Larval Fish Density (#/L)	Zooplankton Density (#/L)	Benthos Density (#/m2)
		YOY LMB (<200mm)	BLG	LMB >200mm			
2011	No Tourn	12.0	69.9	42.9	1.4	612.1	936.21
2010	Tourn	18.1	66.0	15.6	3.4	135.1	10065.59
2009	No Tourn	52.5	80.6	19.2	9.2	1150.7	5127.31
2008	No Tourn	39.2	96.8	49.9	0.11	458.8	11502.06
2007	Tourn	59.2	67.2	52.3	1.15	399.4	7563.53
2006	No Tourn	29.1	50.8	41	0.5	352.2	3859.86

Table 5-4: Tournament information from the 8 paper tournaments conducted on Clinton Lake, Lake Sara, Mill Creek Lake, Ridge Lake, and Lake Shelbyville. Paper tournament participants recorded the length of each fish caught in quarter inch increments.

Lake	Date	Start Time	End Time	# of Anglers	Total number of Fish Weighed In	# of Paper Participants
Clinton	7/10/2004	5:45	13:45	20	6	14
Lake Sara	5/22/2004	5:45	13:45	24	27	16
Lake Sara	5/23/2004	5:45	13:45	25	27	16
Mill Creek	5/8/2004	6:30	14:30	26	4	14
Ridge	4/17 to 5/17/2010	10:00	14:00	39	171	39
Shelbyville	6/12/2004	5:30	13:30	22	9	13
Shelbyville	6/13/2004	5:30	13:30	23	8	16
Shelbyville	5/22/2005	6:00	15:00	65	152	33

Table 5-5: The number of anglers that were ranked in the top five in the official weigh-in that were no longer ranked in the top five under a variety of paper tournament scenarios. Paper tournaments were conducted on 5 lakes and a total of 8 tournaments where anglers recorded the length of each fish caught to the nearest quarter inch. Paper tournaments for all fish included data from all fish caught, while paper tournaments of legal fish included only fish larger than the legal length limit of the lake.

Lake	Date	Paper Weight All Fish	Paper Length All Fish	Paper Weight Legal Size	Paper Length Legal Size
Clinton	7/10/2004	0	0	0	0
Lake Sara	5/22/2004	4	4	2	2
Mill Creek	5/8/2004	1	2	0	0
Ridge	4/30/2010	1	1	3	3
Shelbyville	6/12/2004	1	1	1	1
Shelbyville	6/13/2004	1	3	0	0
Shelbyville	5/22/2005	2	2	2	2
	Mean Total	1.4	1.9	1.1	1.1

Table 5-6: Number of fish surveyed, sex ratios, average total length, and percent spawning male largemouth bass from tournament catches on Mill Creek, Lake Mattoon, Lake Shelbyville, and Steven Forbes Lake during spawn and post-spawn periods from 1999 to 2007. TL refers to the total length of the fish.

Lake	Season	# of Tournaments	Total # of Fish	% Male	TL of Females	TL of Males
Forbes	Spawn	10	61	57	453	407
	Post Spawn	5	32	63	399	439
Mattoon	Spawn	7	70	59	454	409
	Post Spawn	6	51	59	414	387
Mill Creek	Spawn	6	128	66	428	369
	Post Spawn	4	84	49	406	401
Shelbyville	Spawn	5	101	35	431	382
	Post Spawn	5	280	51	424	408

Table 5-7: Angler interview responses regarding the number of released fish during tournaments. Fish were released due to culling for large fish or because they were below the legal limit (short fish).

Lake	Date	# of Anglers Interviewed	Mean # Culled	Mean # of Short Fish
Mattoon	8/11/04	10	0.0	0.5
Mattoon	8/9/06	3	0.0	0.0
Mill Creek	8/8/04	11	0.0	0.0
Mill Creek	7/26/06	5	0.0	3.2
Mill Creek	8/9/06	7	0.1	3.4
Mill Creek	5/16/07	4	1.8	5.8
Shelbyville	5/11/03	5	0.0	5.4
Total		45	0.3	2.6

Table 5-8: Mean tournament pressure for 2009 and 2010 on nine lakes located throughout Illinois. Tournament participation and catch rates were obtained from organizers of events on each of the lakes.

Lake	Size (acres)	Mean Number of Tournaments	Mean Number of Participants	Mean Hours Fished	Mean # of Fish Weighed in	Mean Weight (lbs.)	Mean Annual Angler Hours	Angler hours per acre
Bloomington	635	14.0	33.6	5.4	32.0	2.7	2540	4.0
Clinton	5000	25.0	54	9.3	47.2	3.1	12555	2.5
Coffeen	1100	49.0	27.4	7.4	53.1	2.1	9935	9.0
Evergreen	886	15.5	28.6	5.4	28.9	3.4	2394	2.7
Forbes	525	41.0	27.6	5.8	19.1	2.2	6563	12.5
Mattoon	1050	8.5	23.8	4.9	17.2	2.4	991	0.9
Mill Creek	811	94.0	28.7	6.5	47.6	1.9	17536	21.6
Sangchris	2165	48.0	28.5	8.0	58.5	1.8	10944	5.1
Shelbyville	11100	45.0	49.2	8.1	79.2	2.1	17933	1.6

Table 5-9: Catch per unit effort on lakes with and without tournaments in Illinois from spring electrofishing transects for all largemouth bass (Total), young-of-year largemouth bass (YOY), largemouth bass over 14 inches, and memorable largemouth bass. PSD is the proportion of stock density for each lake. Lakes were separated into None, Low and High based on the level of tournament activity.

Lake	Tournament Pressure	Total	YOY	Over14	Memorable	PSD
Forbes	High	20.0	0.7	4.7	0.7	46.6
Mill Creek	High	12.7	6.0	0.0	0.0	50.0
Bloomington	Medium	11.4	4.0	2.0	0.7	27.3
Clinton	Low	13.8	1.0	5.1	0.0	56.0
Evergreen	Low	19.3	5.3	5.3	0.0	57.1
Mattoon	Low	21.3	0.0	6.0	0.7	71.9
Shelbyville	Low	43.7	4.7	16.0	0.0	69.2
Charleston	None	11.0	0.7	3.0	0.3	83.9
Lincoln	None	27.2	9.6	0.4	0.0	18.2
LOTW	None	18.7	1.4	7.5	0.0	67.6
Walnut	None	14.0	7.7	1.7	0.3	52.6
Woods	None	7.7	1.0	2.3	0.0	60.0

Table 6-1: Catch per unit effort (#/hour) of largemouth bass and young-of-year largemouth bass in spring and fall electrofishing on Clinton Lake (A) and Otter Lake (B). Refuge sites were located in areas of the lake closed to fishing and boating and control sites were located outside of the closed areas.

A. Clinton Lake

Year	Control Sites				Refuge Sites			
	Total LMB		YOY LMB		Total LMB		YOY LMB	
	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
1999	19.8	23.3	10.6	10.4	56.0	24.0	32.0	12.0
2000	32.4	5.5	16.9	4.0	18.0	0.0	8.0	0.0
2001	26.0	48.7	6.0	30.7	10.0	22.0	0.0	8.0
Pre Mean	26.1	25.8	11.2	15.0	28.0	15.3	13.3	6.7
2002	8.3	29.0	1.0	17.3	0.0	0.0	0.0	0.0
2003	21.5	23.8	5.5	6.0	0.0	87.5	0.0	12.0
2004	20.7	28.3	2.5	7.0	42.0	146.0	9.0	16.0
2005	25.1	18.3	1.9	4.3	32.0	25.0	0.0	8.0
2006	13.9	16.5	1.4	3.4	48.0	98.0	8.0	32.0
2007	12.7	32.7	4.0	6.0	90.0	88.0	14.0	12.0
2008	36.5	36.0	6.3	4.3	76.0	220.0	0.0	18.0
2009	15.0	29.2	0.0	9.8	75.0	98.0	5.0	18.0
2010	13.0	5.0	2.0	2.0	14.6	78.0	0.0	22.0
2011	16.0	28.0	2.0	6.0	86.0	57.0	6.0	21.0
2012	26.0	NA	4.0	NA	14.0	NA	6.0	NA
Post Mean	19.0	24.7	2.8	6.6	53.1	99.7	5.3	17.7

B. Otter Lake

Year	Control Sites				Refuge Sites			
	Total LMB		YOY LMB		Total LMB		YOY LMB	
	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
2007	NA	43.6	NA	11.8	NA	69.0	NA	33.0
2008	25.8	45.5	1.0	16.8	14.9	23.0	0.0	0.0
2009	28.8	55.0	4.5	16.8	23.0	51.9	5.0	8.3
2010	35.5	31.5	7.3	7.6	26.0	34.0	12.0	6.0
Pre Mean	30.0	43.9	4.3	13.2	21.3	44.5	5.7	11.8
2011	19.9	38	1.7	7.3	9.2	44.5	1.5	8
2012	27	NA	4.3	NA	31	NA	8	NA
Post Mean	23.5	38	3	7.3	20.1	44.5	4.8	8

Table 6-2: Density of fish from seine hauls performed in refuge (n=2) and control sites (n=2) on Clinton Lake (A) and Otter Lake (B). Density is reported for all fish (Total), largemouth bass (LMB), bluegill (BLG), and gizzard shad (GZS).

A. Clinton Lake

Year	Control Seine Density (#/m2)				Refuge Seine Density (#/m2)			
	Total	LMB	BLG	GZS	Total	LMB	BLG	GZS
				Pre Refuge				
1999	0.37	0.02	0.12	0.25	0.35	0.03	0.04	0.11
2000	0.34	0.01	0.05	0.05	0.25	0.01	0.04	0.28
2001	0.36	0.01	0.09	0.06	0.38	0.03	0.07	0.1
Pre Mean	0.35	0.01	0.09	0.12	0.33	0.02	0.05	0.16
				Post Refuge				
2002	0.43	0.02	0.08	0.09	0.44	0.05	0.25	0.11
2003	0.75	0.12	0.12	0.26	1.11	0.02	0.26	0.11
2004	0.64	0.04	0.13	0.34	0.34	0.03	0.04	0.02
2005	0.41	0.12	0.11	0.05	0.65	0.19	0.14	0.05
2006	0.21	0.03	0.06	0.02	0.54	0.09	0.3	0.08
2007	0.48	0.01	0.1	0.06	0.48	0.03	0.07	0.03
2009	0.41	0	0.01	0.21	0.22	0	0.05	0.13
2010	0.2	0	0.04	0	0.2	0.03	0.03	0
2011	0.14	0	0	0	1.33	0.29	0	0
2012	0	0	0	0	0	0	0	0
Post Mean	0.37	0.03	0.07	0.1	0.53	0.07	0.11	0.05

B. Otter Lake

Year	Control Seine Density (#/m2)				Refuge Seine Density (#/m2)			
	Total	LMB	BLG	GZS	Total	LMB	BLG	GZS
				Pre Refuge				
2007	0.14	0.03	0.17	0	0.23	0.02	0.21	0
2008	0.27	0.02	0.28	0	0.1	0	0.13	0
2009	0.06	0	0.08	0	0.29	0.27	0.15	0
2010	0.1	0.02	0.09	0	0.05	0	0.05	0
Pre Mean	0.14	0.02	0.15	0	0.17	0.07	0.14	0
				Post Refuge				
2011	0.02	0	0.02	0	0.05	0.01	0.03	0.01
2012	0.07	0.01	0.05	0	1.54	0	0.12	0
Post Mean	0.05	0.01	0.04	0	0.8	0.01	0.08	0.01

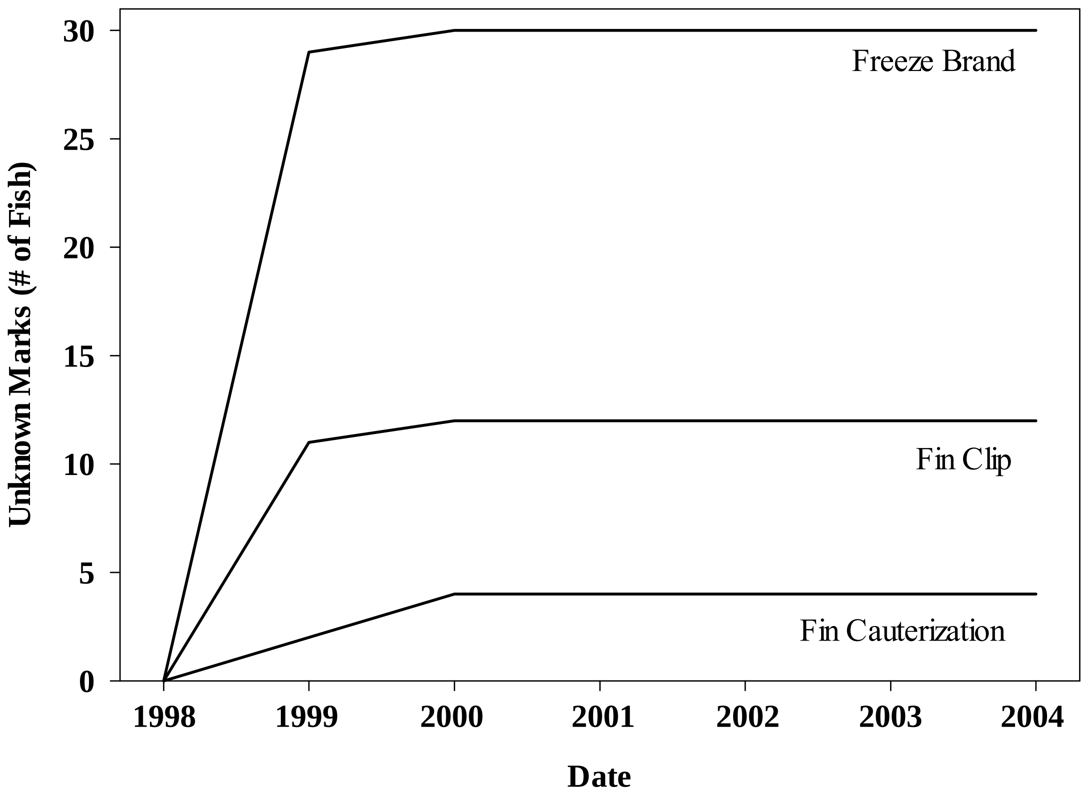

Figure 1-1: Cumulative of 4” largemouth bass with recognizable marks sacrificed and identified 1:1 (Fin Clip, 1:2 (Freeze Brand) of 2:2 (Fin Cauterization) MDH- genotype for each date sampled.

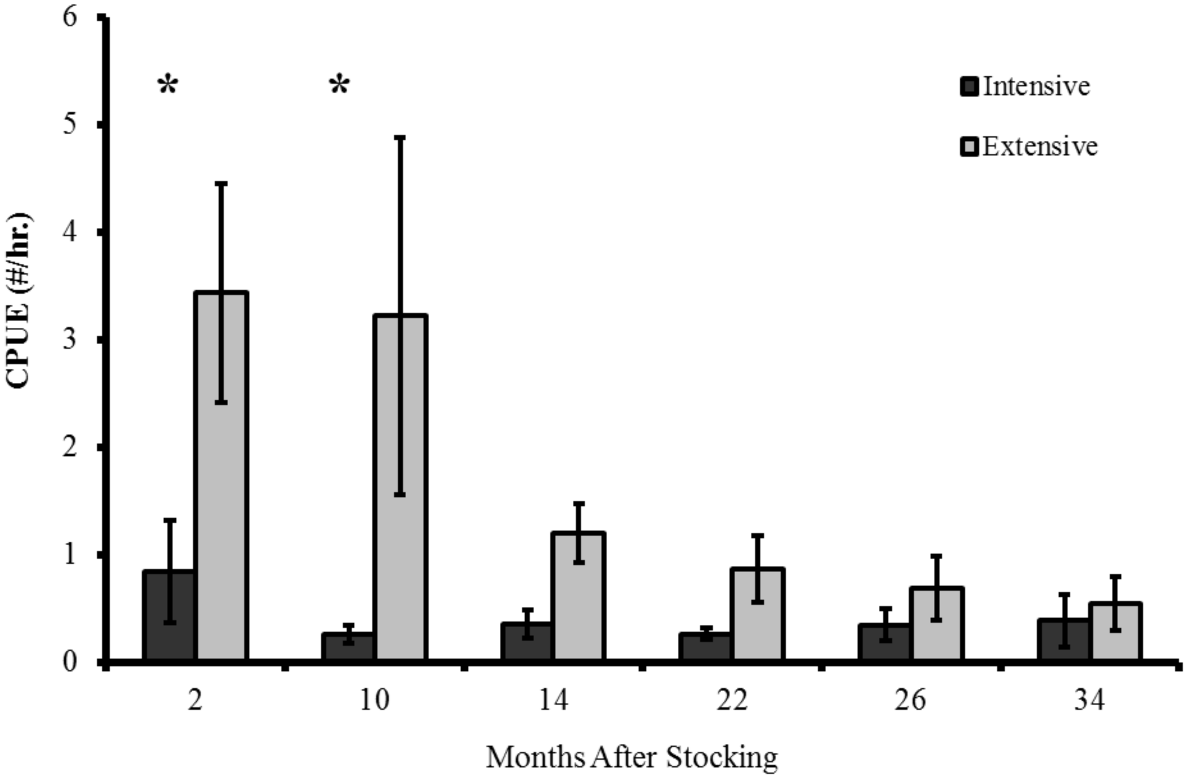

Figure 2-1: Mean CPUE of intensive and extensive fish collected in AC electrofishing samples following stocking. Samples were collected in the fall following stocking and each spring and fall for 5 years thereafter. The stars indicate time periods where there were significant differences in CPUE of intensively and extensively reared fish.

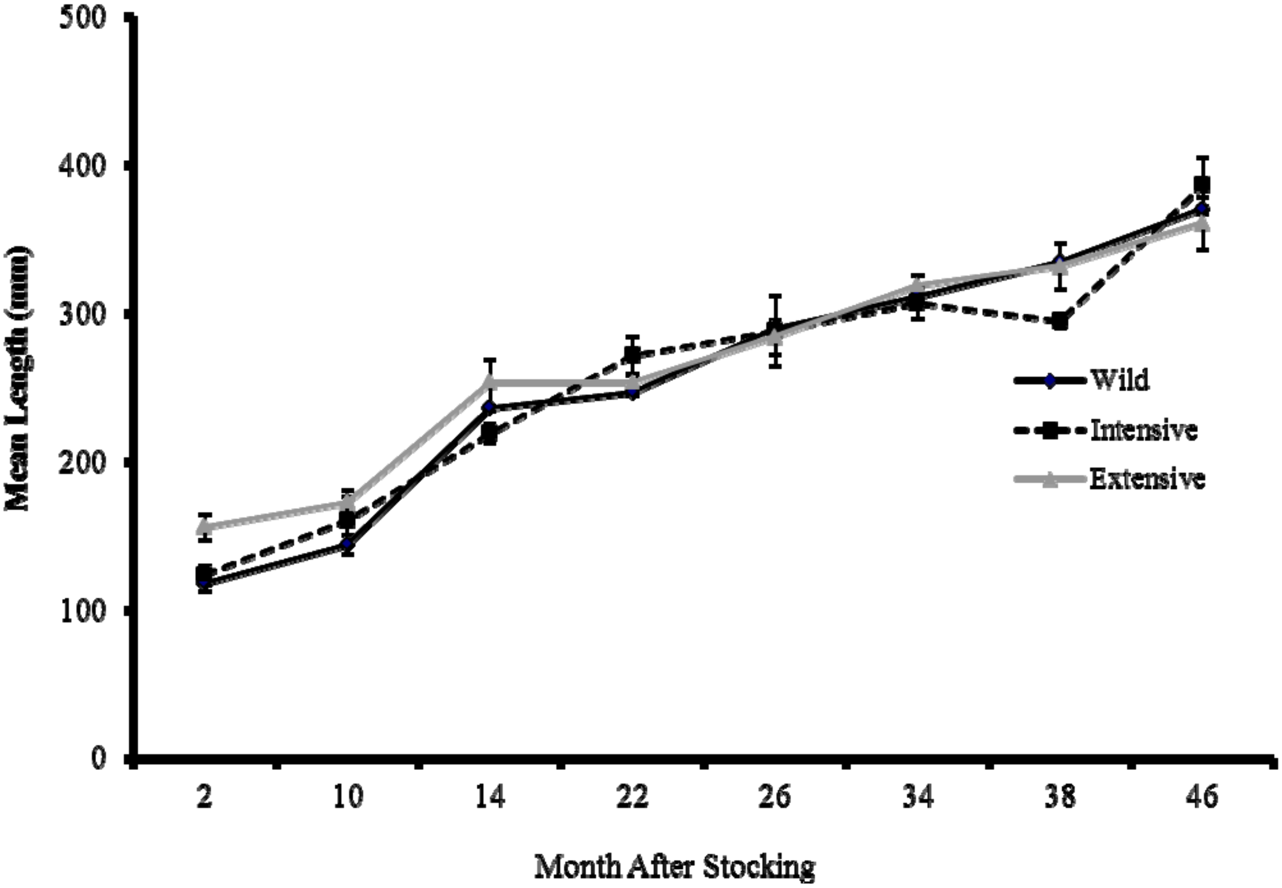

Figure 2-2: Mean length of intensive, extensive, and wild fish collected in AC electrofishing samples in the months following stocking. Samples were collected in the fall following stocking and each spring and fall for 5 years thereafter.

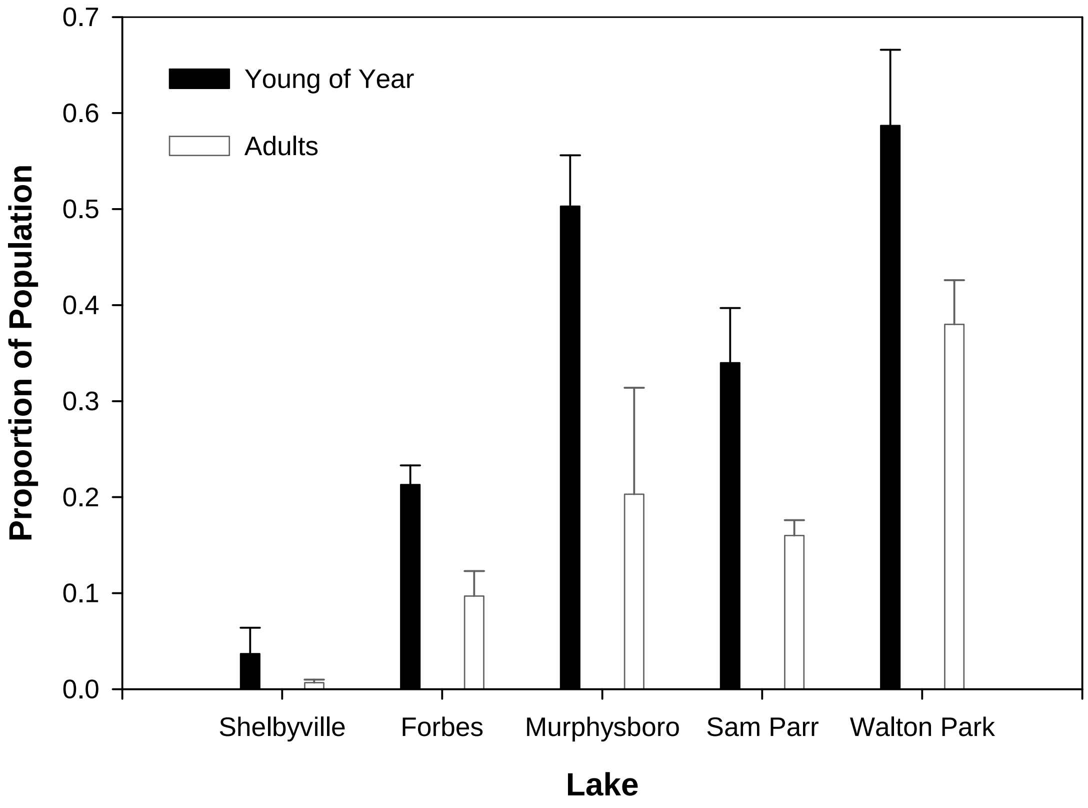

Figure 3-1: Proportion (± SE) of the population in each lake composed of stocked fish as young of year in the fall (2002-2004) and adults (2005-2007). Means represent the same three year classes as young of year and as adults for each lake.

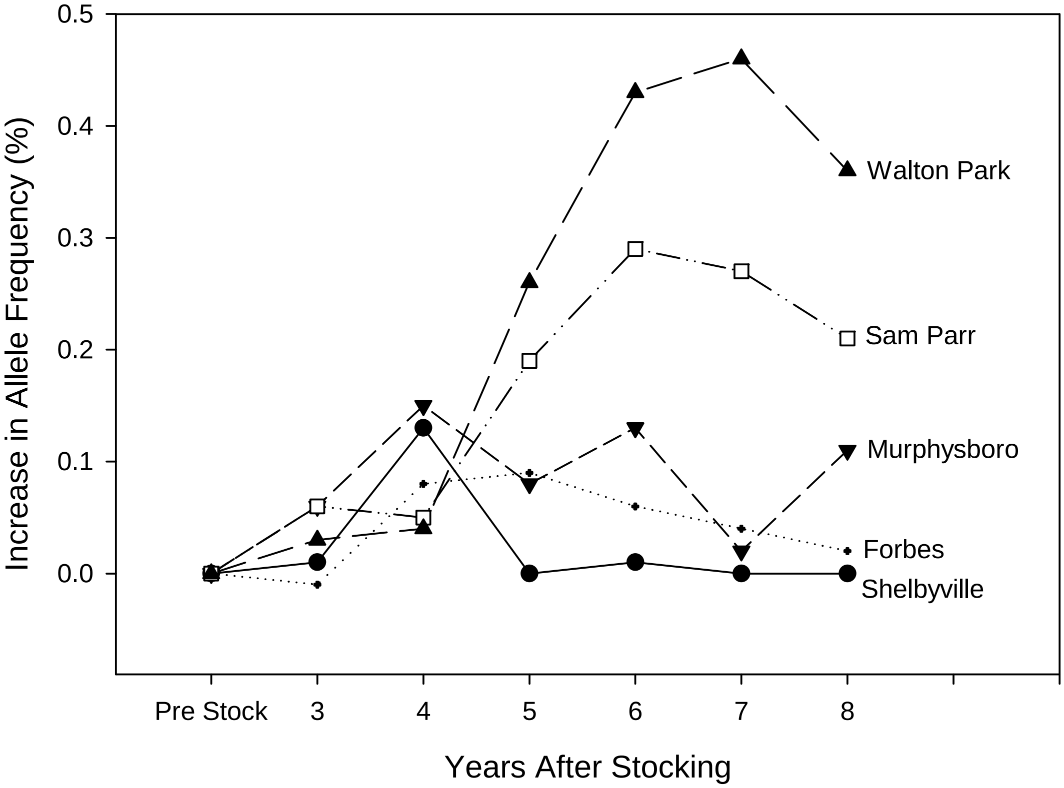

Figure 3-2: Increases in the percent frequency of the B2 allele compared to prestocking frequencies for the five study lakes. Walton Park and Sam Parr lakes showed the greatest increases in B2 frequencies following stocking efforts.

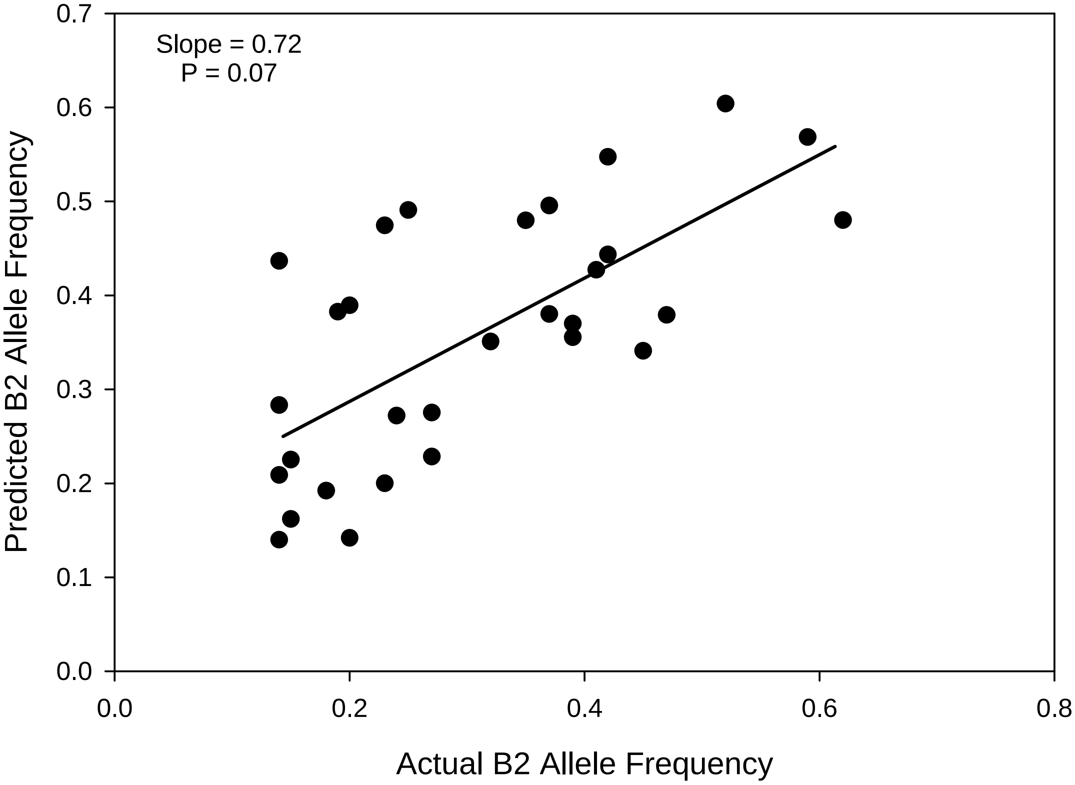

Figure 3-3: Regression of actual and predicted B2 allele frequency based on stocked adult fish for five study lakes for each year from 2002-2007. The null hypothesis tested whether or not the slope = 1 and found that it was not significantly different

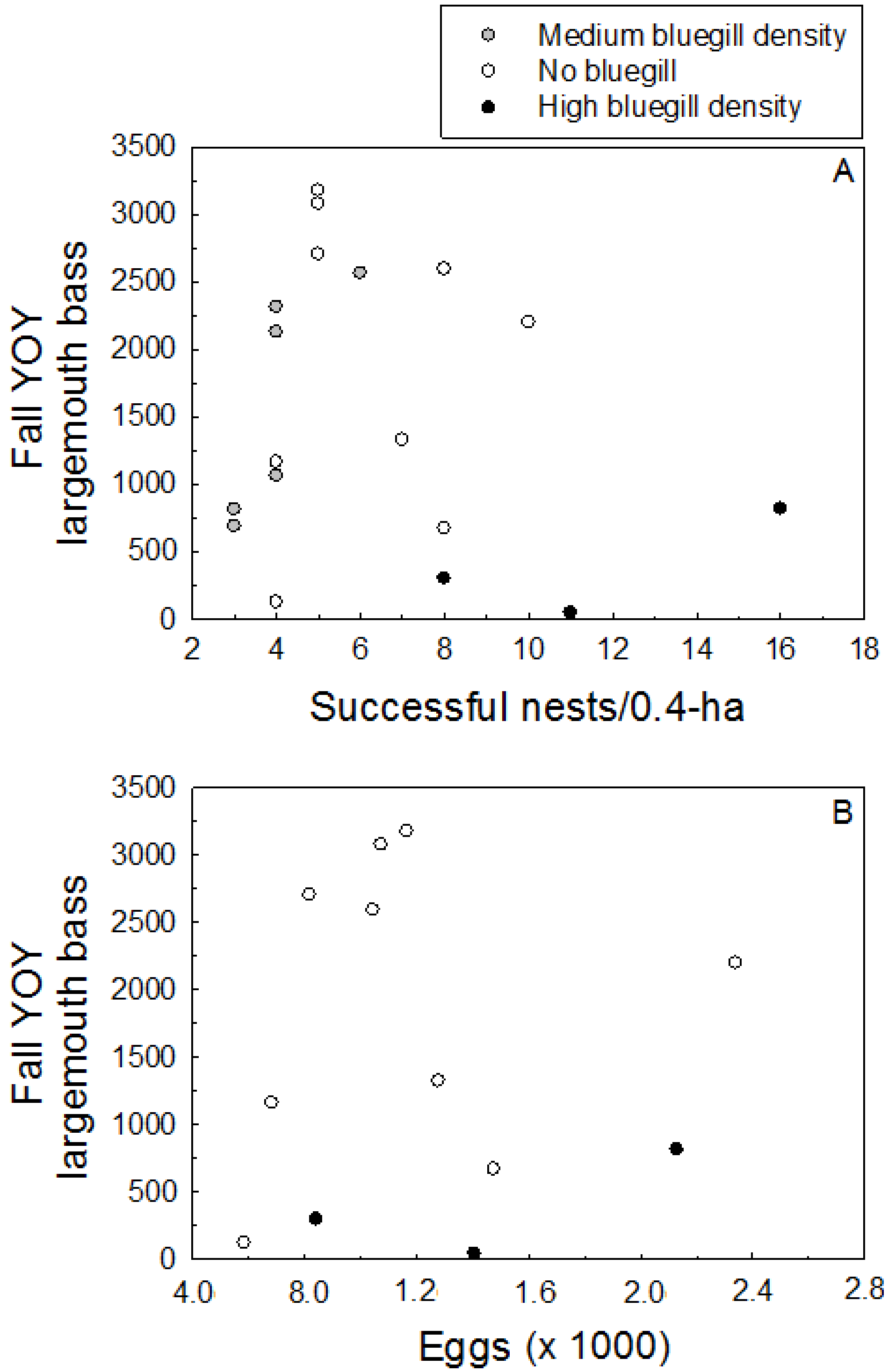

Figure 4-1: Fall young of year (YOY) largemouth bass density (N) in 0.4 ha ponds as a function of either (A) total successful nests or (B) total eggs deposited.

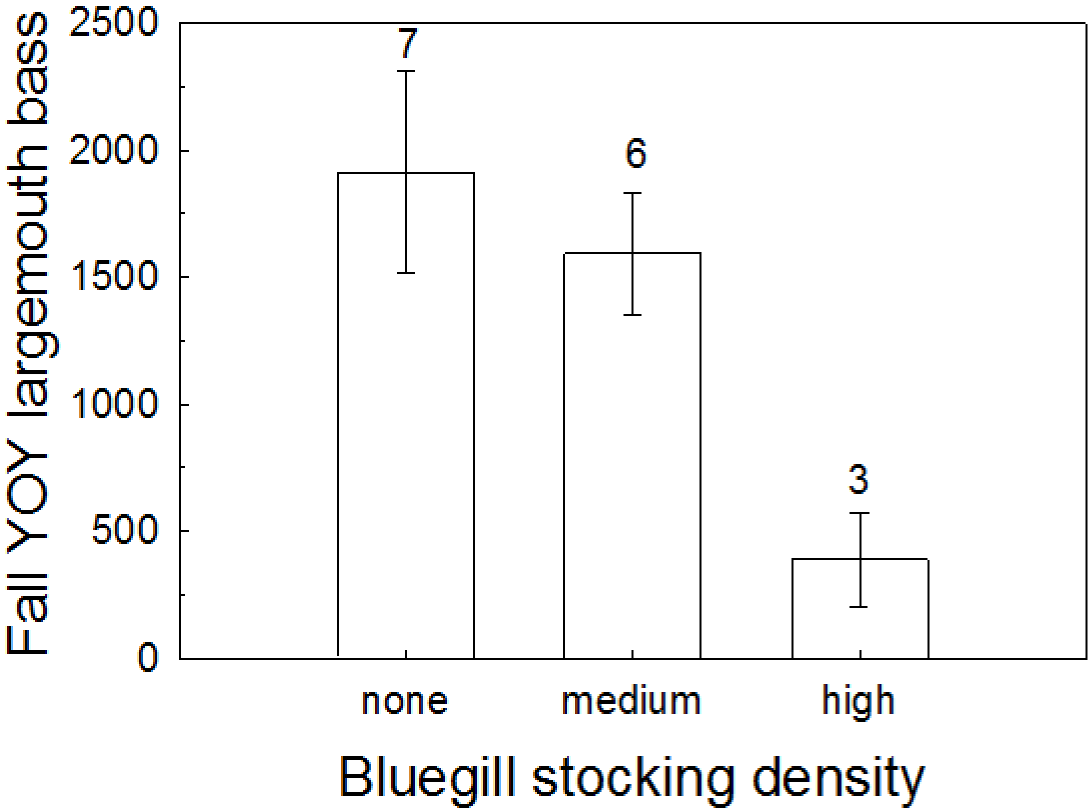

Figure 4-2: Mean (± 1 SE) density of fall young of year (YOY) largemouth bass in ponds with different densities of bluegill stocked in the spring prior to largemouth bass nesting. Densities of bluegill were 0 (none), 954 (medium), and 4123 (high) in each 0.4-ha pond. Numbers above each vertical bar are sample sizes for each bluegill density treatment.

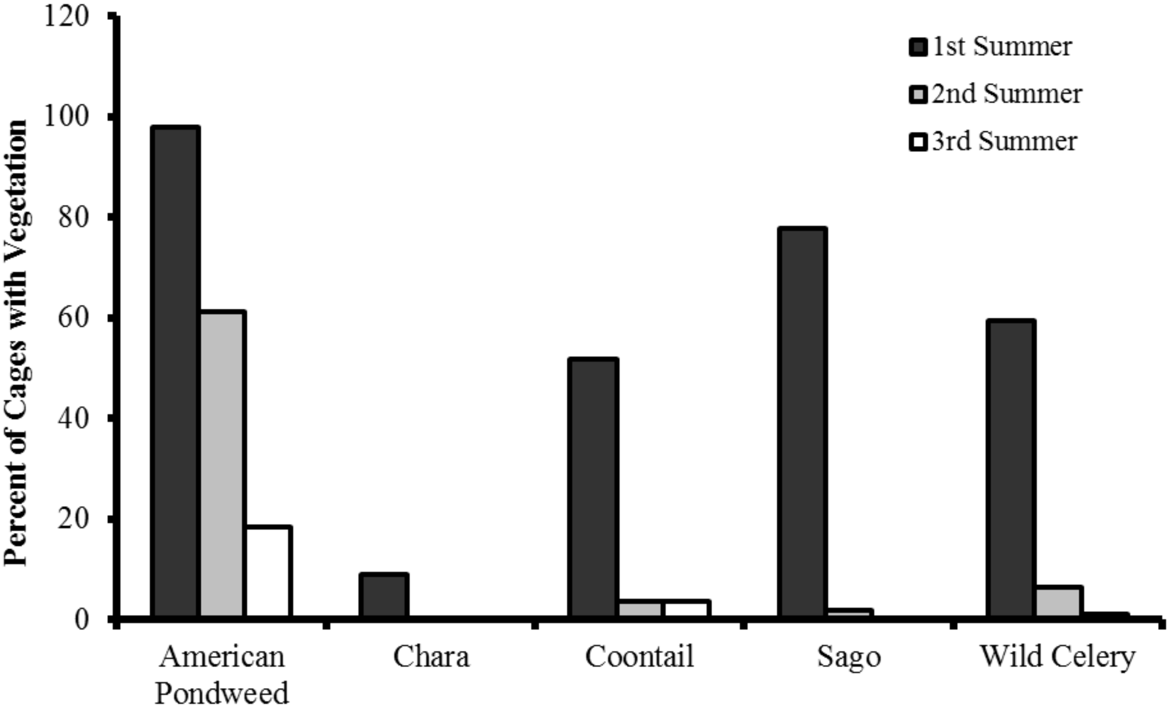

Figure 4-3: The percent of cages that were planted in 2008 and 2009 that had vegetation surviving through the 1st, 2nd, and third summer following planting. A cage was considered vegetated if it had any of the vegetation type planted present. Cages are separated into categories based on the species of vegetation planted.

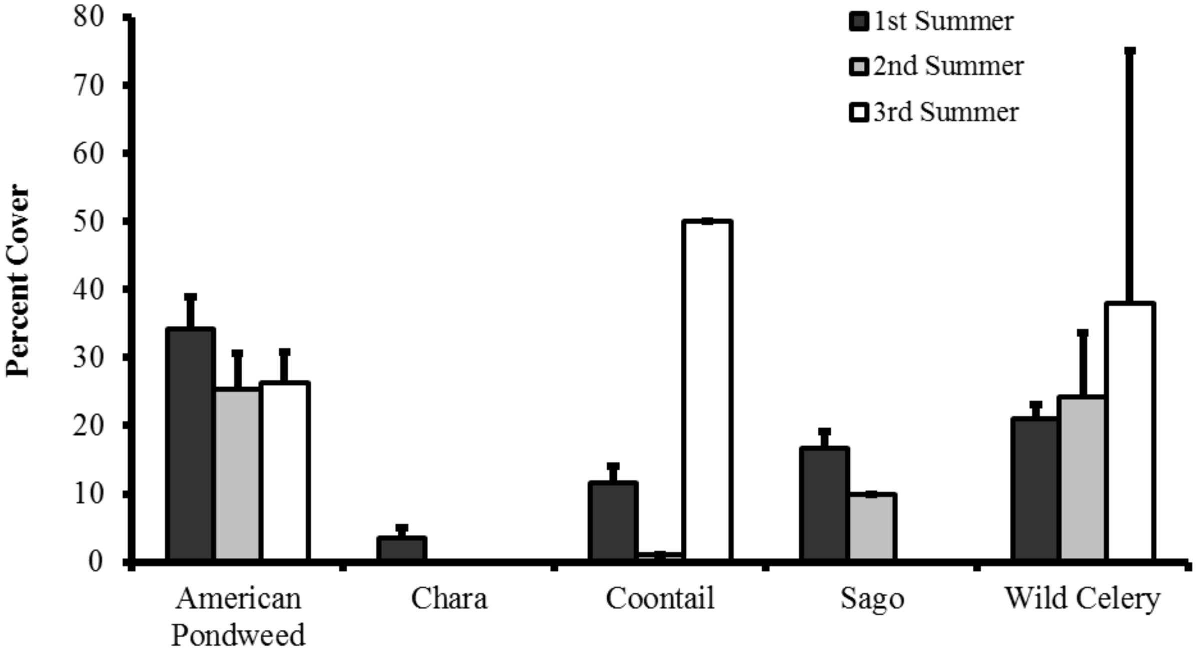

Figure 4-4: Percent cover of vegetation in cages that were vegetated in the 1st, 2nd and 3rd summers following planting. Percent cover was visually assessed in annually in August for three years following planting.

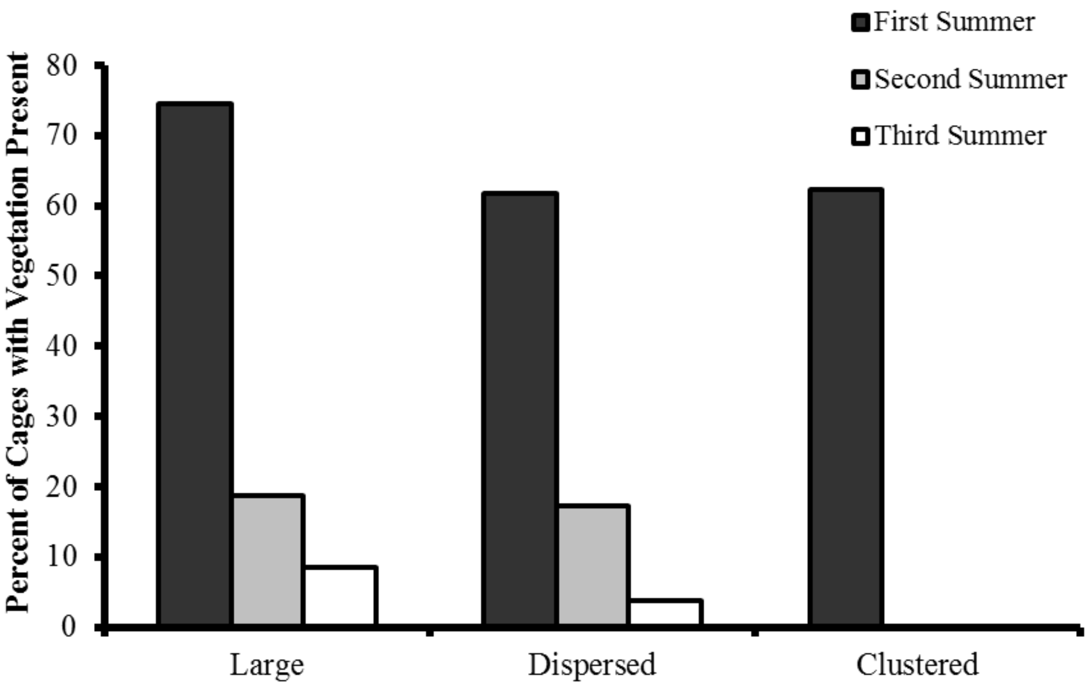

Figure 4-5: The percent of cages that were planted in 2008 and 2009 that had vegetation surviving through the 1st, 2nd, and third summer following planting. A cage was considered vegetated if it had any presence of the vegetation type planted. Cages are separated into categories based on the size and orientation.

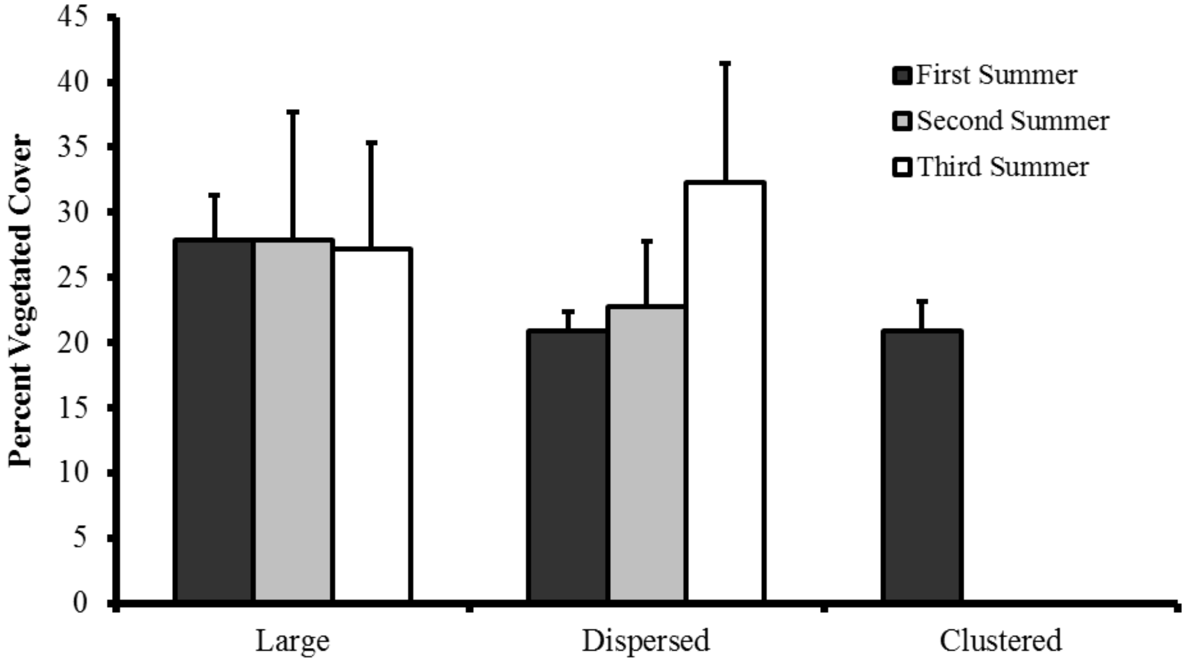

Figure 4-6: Percent cover of vegetation in cages that were vegetated in the 1st, 2nd and 3rd summers following planting. Percent cover was visually assessed in annually in August for three years following planting and compared among size and orientation of the cage.

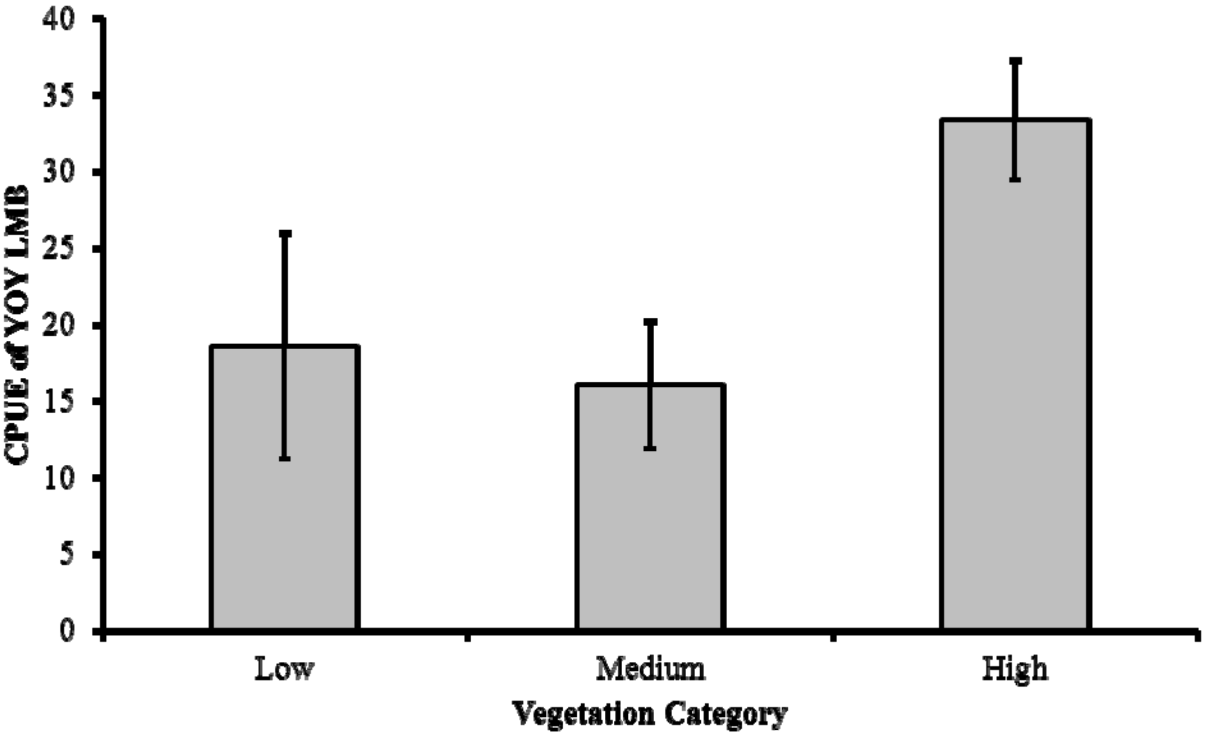

Figure 4-7: Mean CPUE of young-of-year largemouth bass (YOY LMB) from fall electrofishing samples from 2008 through 2011 in 13 lakes in Illinois separated into 3 categories based on the density of vegetation present. Error bars represent the standard error.

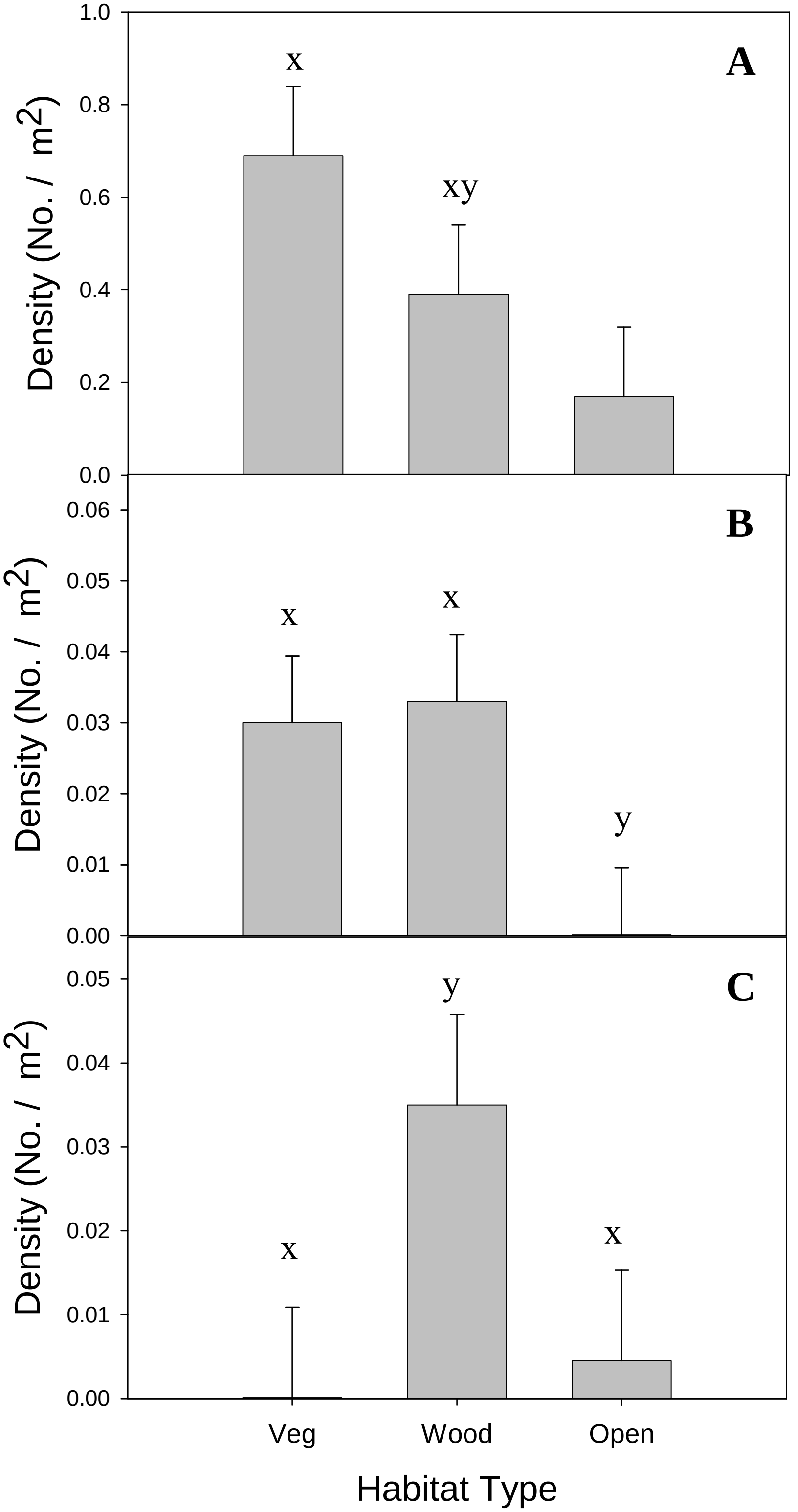

Figure 4-8: Mean densities of bluegills (panel A), and warmouth sunfish (panel B) in Lincoln Trail Lake and white crappie in Lake Paradise (panel C) sampled from vegetated, wooded and open shorelines during August of 2009 and 2010. Each bar represents an average of three sites of each category from each lake for two years (total N = 6 samples per habitat type). Lower case letters indicate significant differences between habitat types.

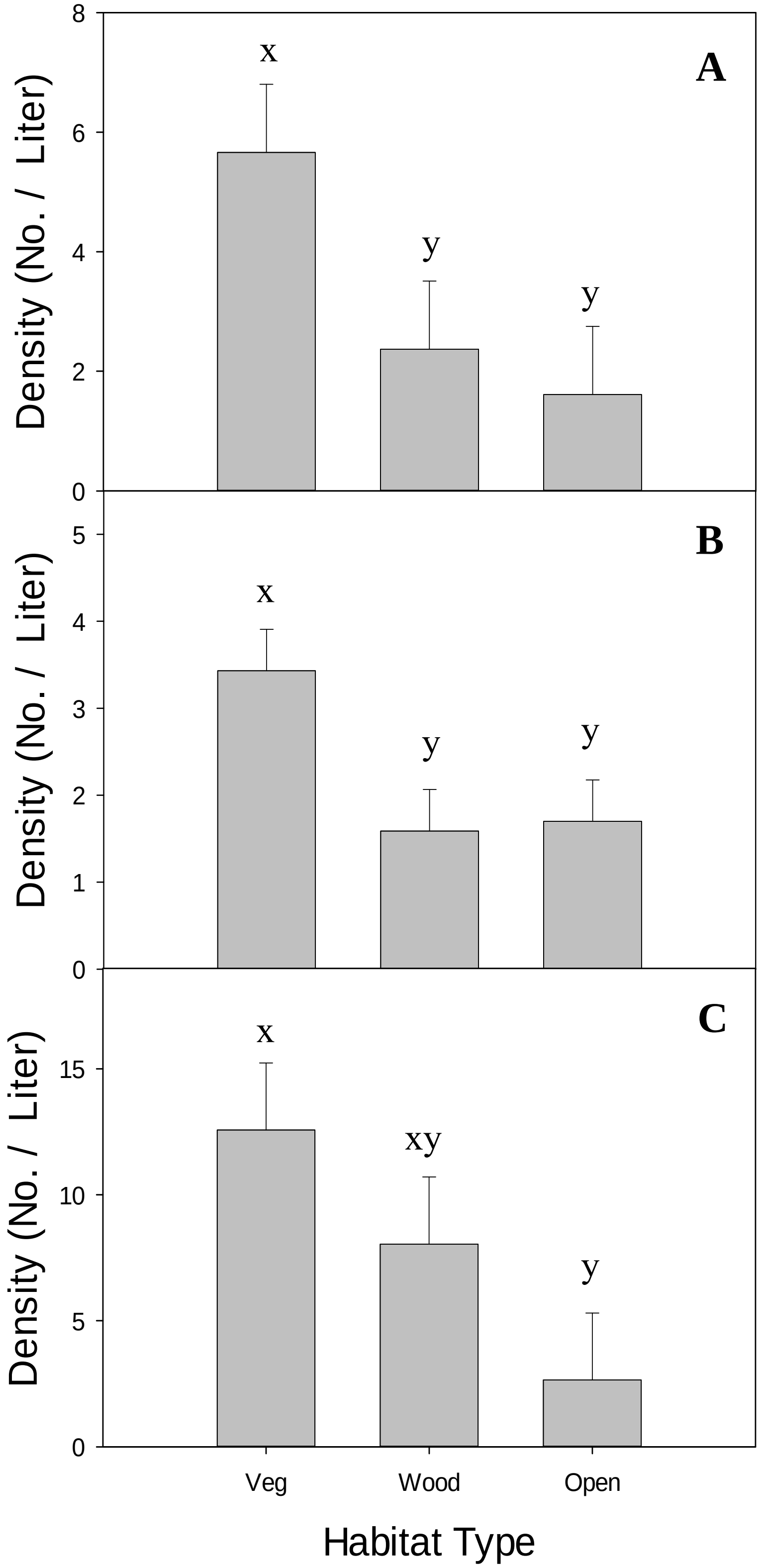

Figure 4-9: Mean densities of cyclopoida (panel A), and chydoridae (panel B) sampled in Lincoln Trail Lake and sididae sampled in Lake Paradise sampled from vegetated, wooded and open shorelines during August of 2009 and 2010. Each bar represents an average of three sites of each category from each lake for two years (total N = 6 samples per habitat type). Lower case letters indicate significant differences between habitat types.

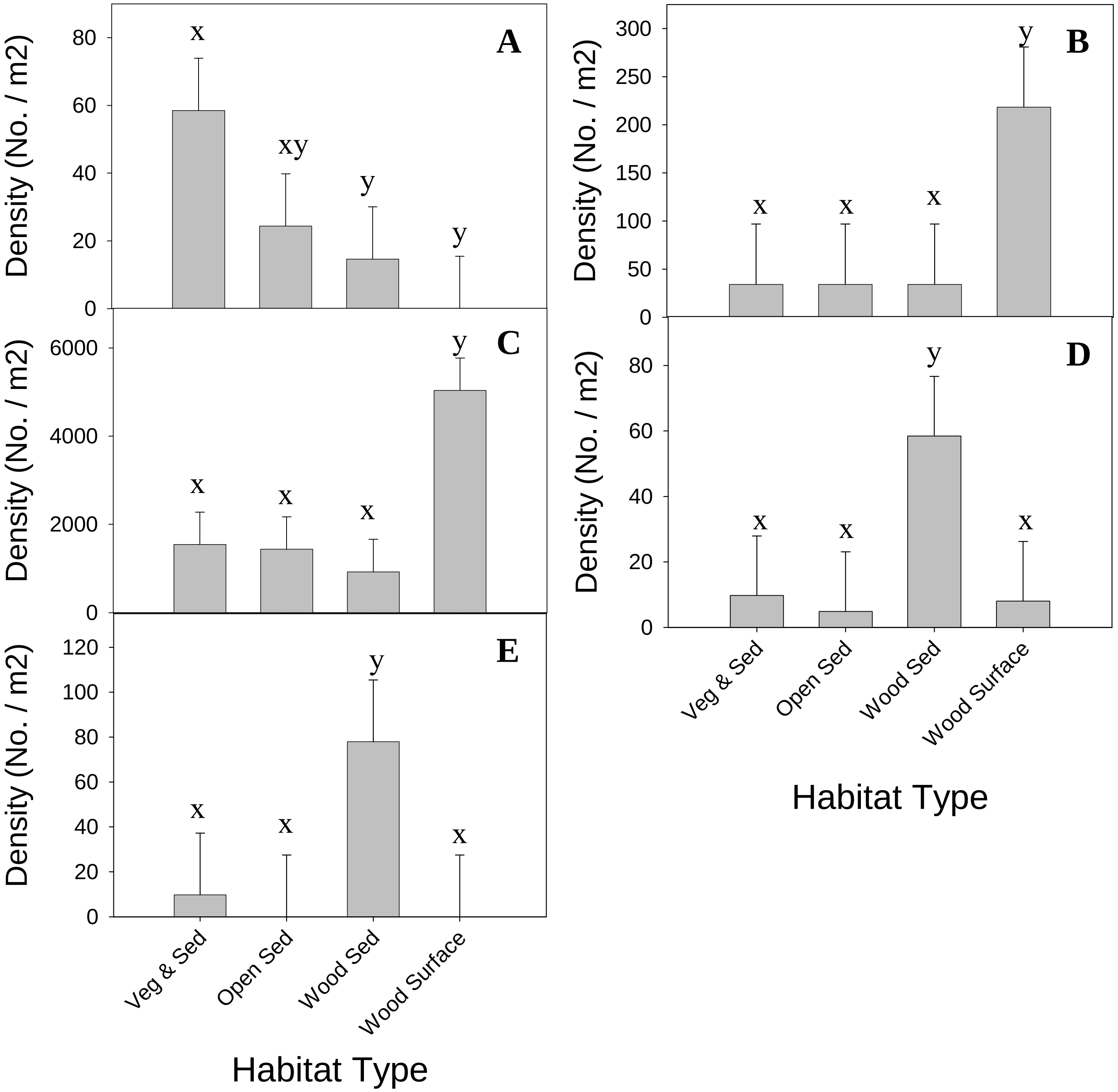

Figure 4-10: Mean density of macroinvertebrates of the family pelecoptera (panel A) and Trichoptera (Panel B) in Lincoln Trail Lake and mean density of chironomidae (panel C), dipteran pupae (panel D) and nematoda (panel E) in Lake Paradise sampled from open sediment, vegetated sediment, wooded sediment and coarse woody debris surfaces sampled during August of 2009-2010. Each bar represents an average of three sites of each category from each lake for two years (total N = 6 samples per habitat type). Lower case letters indicate significant differences among habitat types.

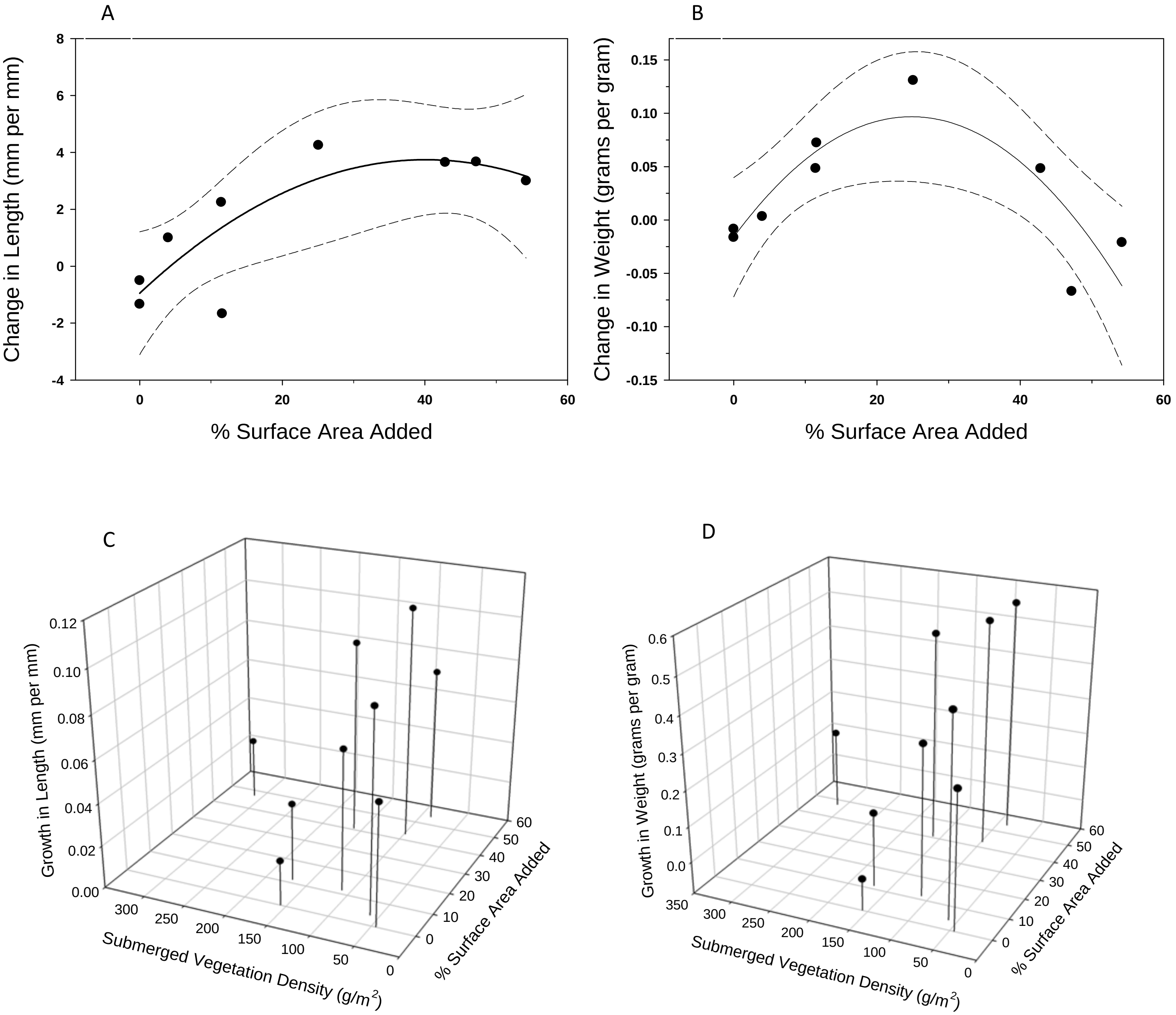

Figure 4-11: Overwinter (October – March; panel A-B) and summer (May-October; Panel C-D) change in adult largemouth bass length and weight after placement in 1/10th acre ponds across a gradient of coarse woody habitat addition. Percent increase in surface area represents the ratio of added wood surface area divided by the area of the pond bottom multiplied by 100. Dashed lines (Panels A-B) represent 95% confidence intervals for the quadratic regression.

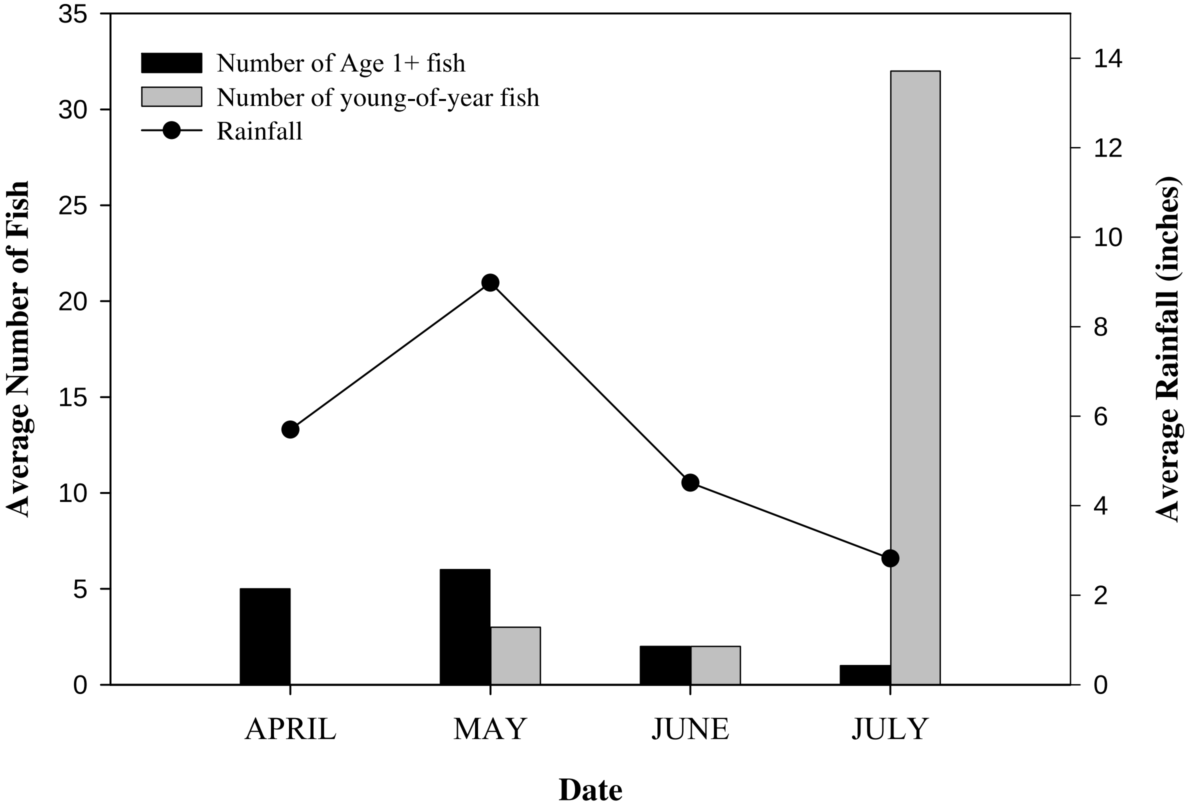

Figure 4-12: Average number of young of year and age 1+ largemouth bass collected by backpack electrofishing and rainfall by month in the Lost Fork stream below Forbes Lake.

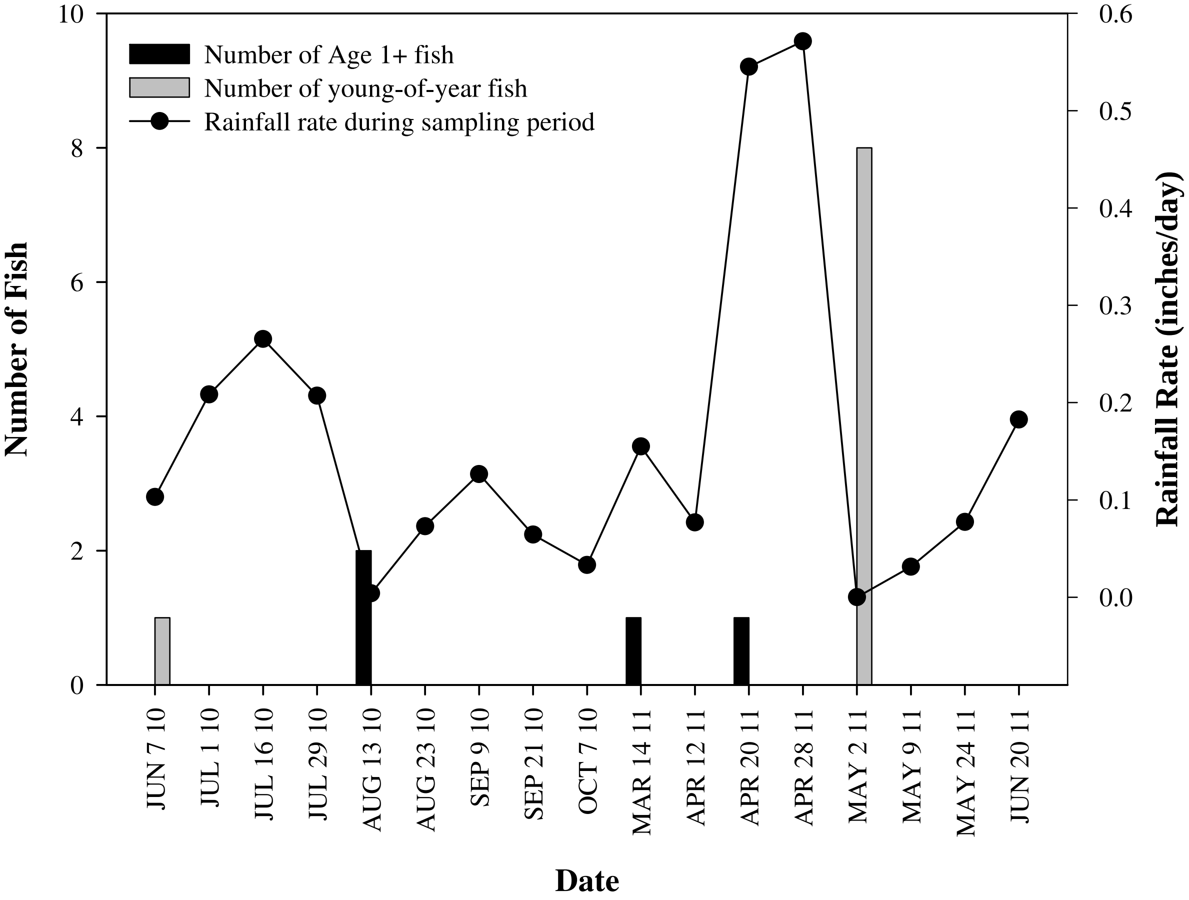

Figure 4-13: Total numbers of adult largemouth bass collected in the catch basin below the dam at Ridge lake during each sampling date related to precipitation. Rainfall rates are the precipitation per day during the sampling period as measured at the Eastern Illinois University rain gauge in Charleston, IL.

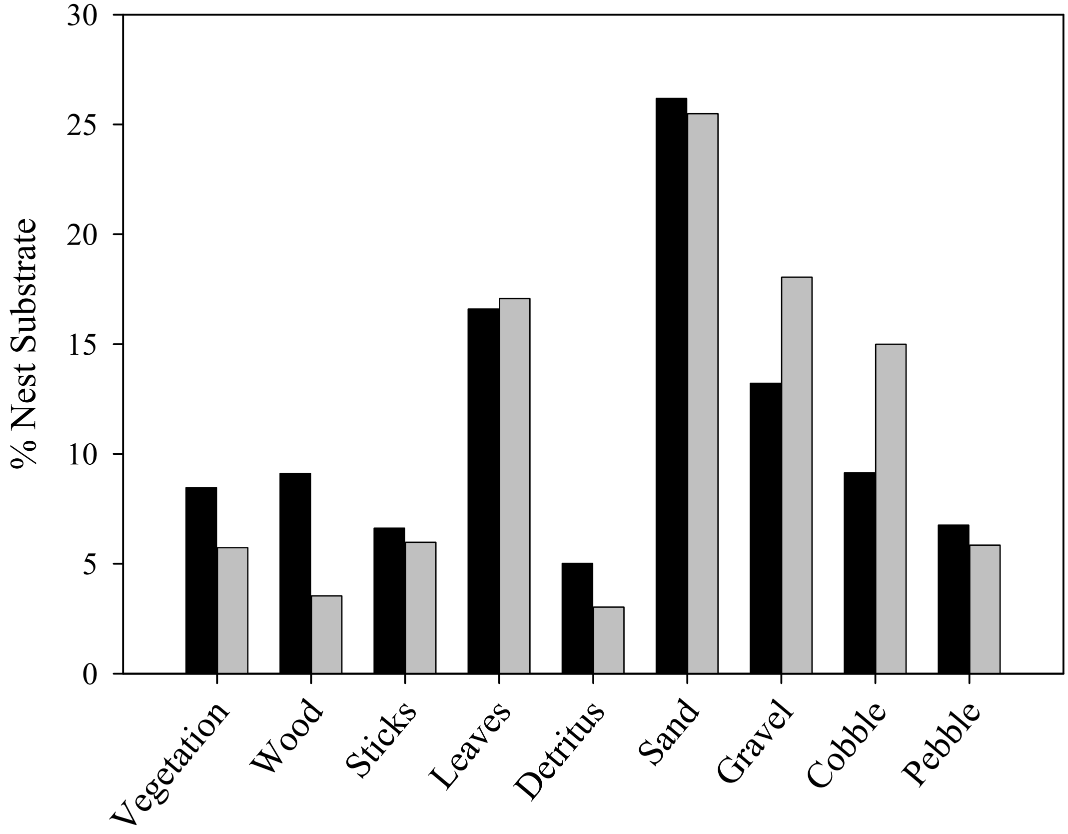

Figure 5-1: Composition of largemouth bass nest habitat in Lincoln Trail Lake with (light bars) and without (dark bars) potential nest predators.

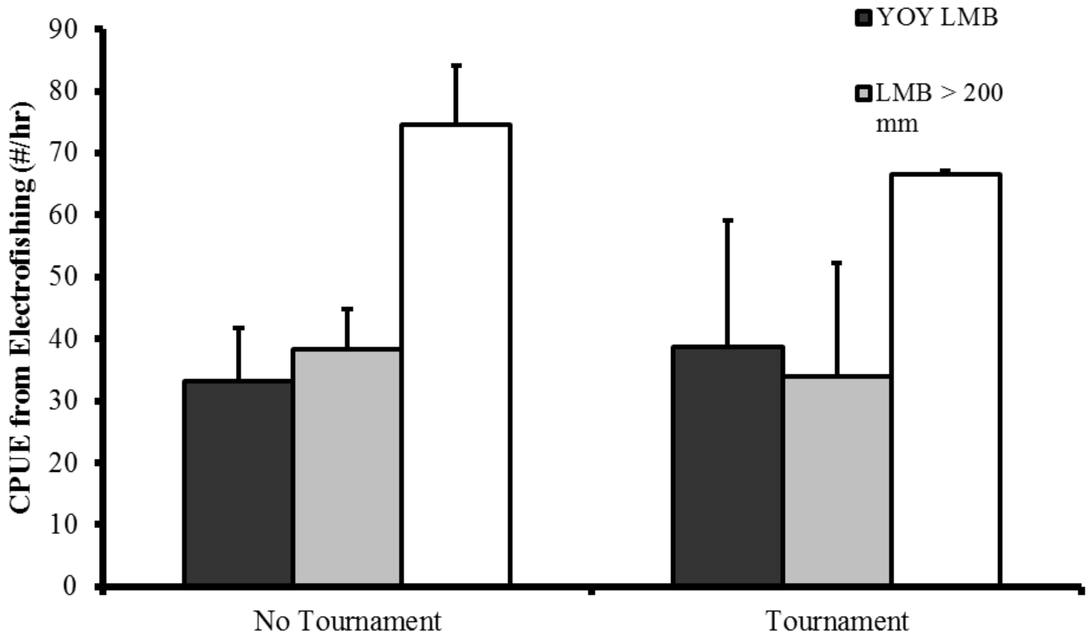

Figure 5-2: Catch per unit effort from fall electrofishing from Ridge Lake in 2006 through 2011 for young-of-year (YOY LMB), adult largemouth bass (LMB > 200mm), and bluegill (BLG). Values are for years where fishing was closed in the spring (2006, 2008, 2009, and 2011; No Tournament) and years where spring tournaments were conducted (2007 and 2010; Tournament). Error bars represent the standard error.

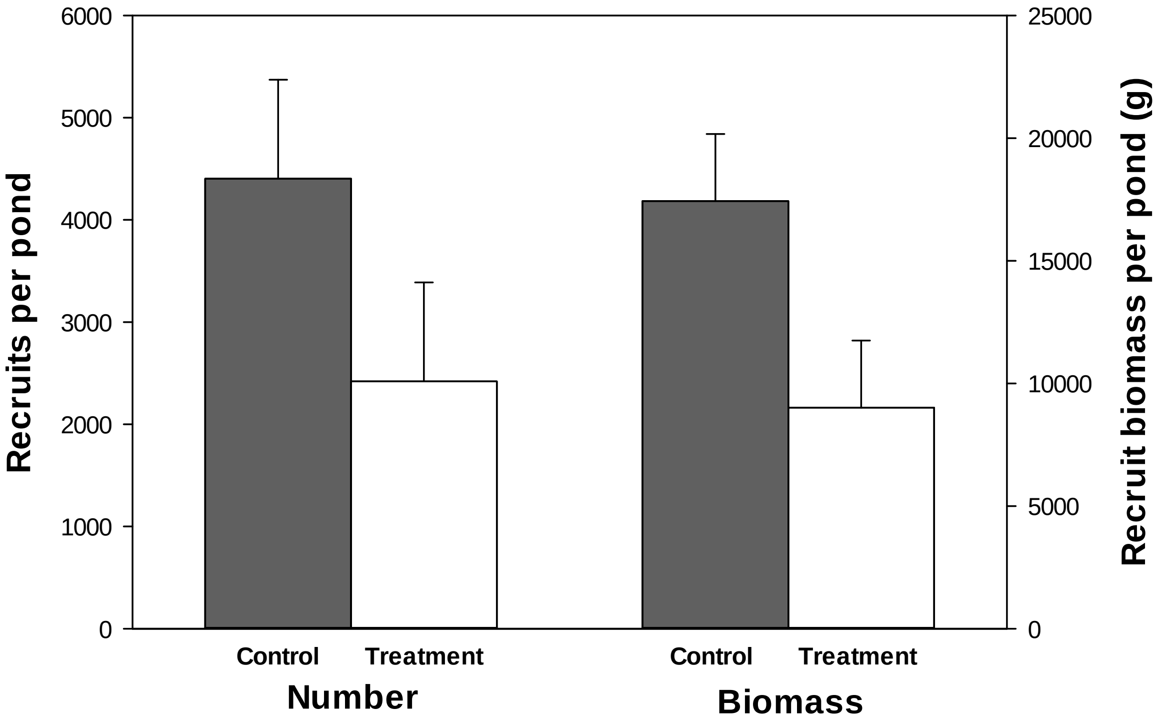

Figure 5-3: Number and biomass of recruits between treatment and control ponds in a replicated pond experiment assessing the effects of tournament angling on largemouth bass recruitment. The adjusted means for the number of recruits were produced from a model incorporating yearly effects and early zooplankton abundance. The means for biomass were adjusted for year only. No significant difference was observed for number of recruits (P = 0.17), but a difference was detected between treatments for recruit biomass (P = 0.05).

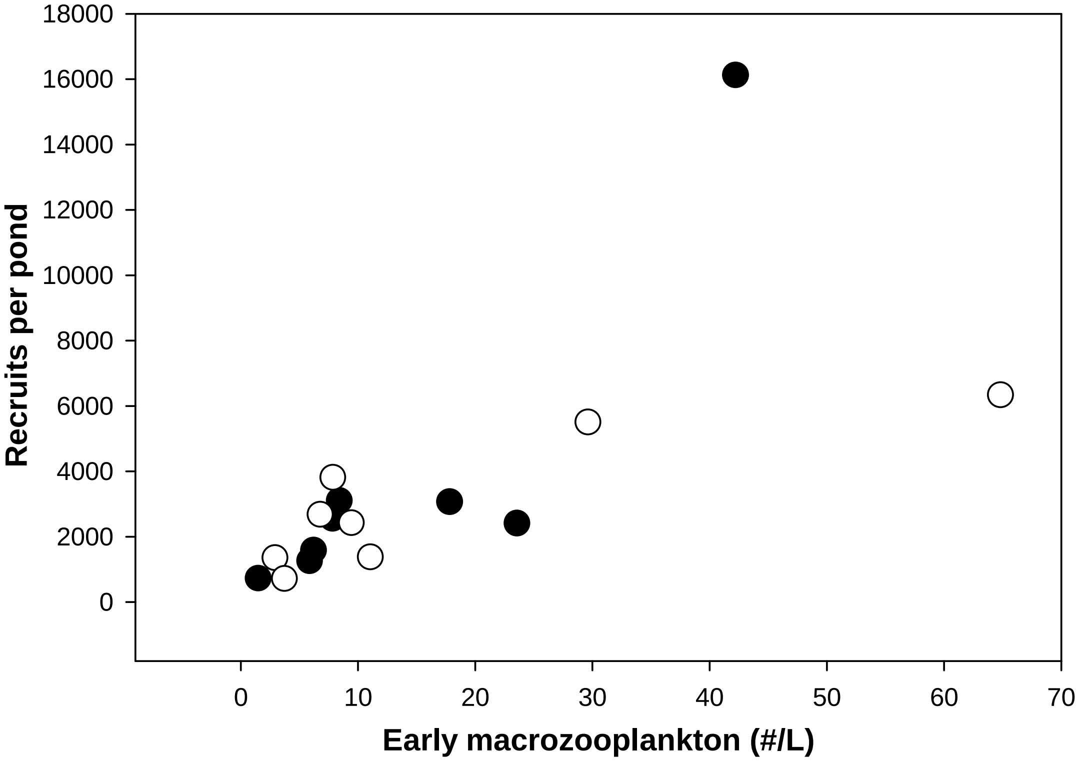

Figure 5-4: The relationship between early summer (May-June) macrozooplankton density and the number of recruits produced in each pond in a manipulative pond experiment examining the effects of tournament angling on largemouth bass recruitment. Control ponds are represented by darkened circles and treatment ponds are represented as open circles.

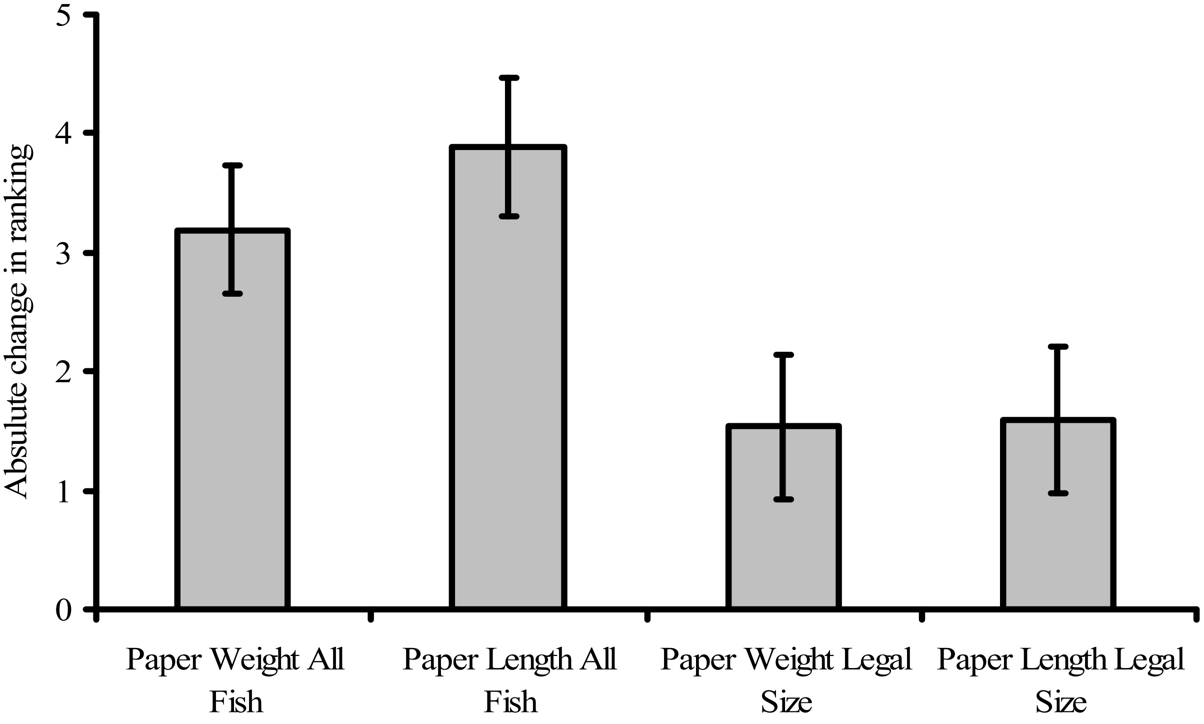

Figure 5-5: Mean absolute change in ranking from a typical weigh-in for 4 different paper tournament scenarios. The length of each fish caught was recorded by anglers to produce paper length. Length-weight regressions were used to convert paper length to paper weight. All fish refers to the cumulative of all fish caught by an angler, where legal size only included fish caught that were larger than the legal limit for the lake on which the tournament was held. Error bars represent the standard error.

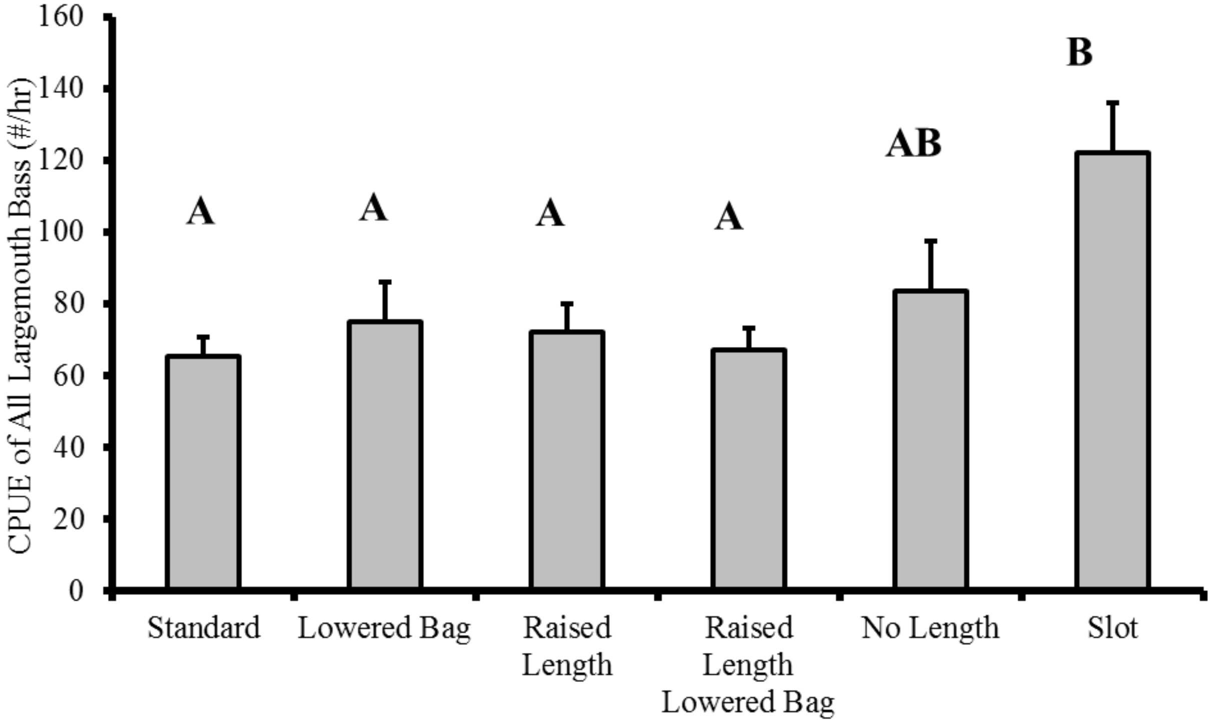

Figure 6-1: Catch per unit effort of all largemouth bass from fall electrofishing in 218 lakes in Illinois sampled from 2000 to 2007 in 6 different regulation categories. Letters indicate bars that are not significantly different (P > 0.05). Error bars represent the standard error.

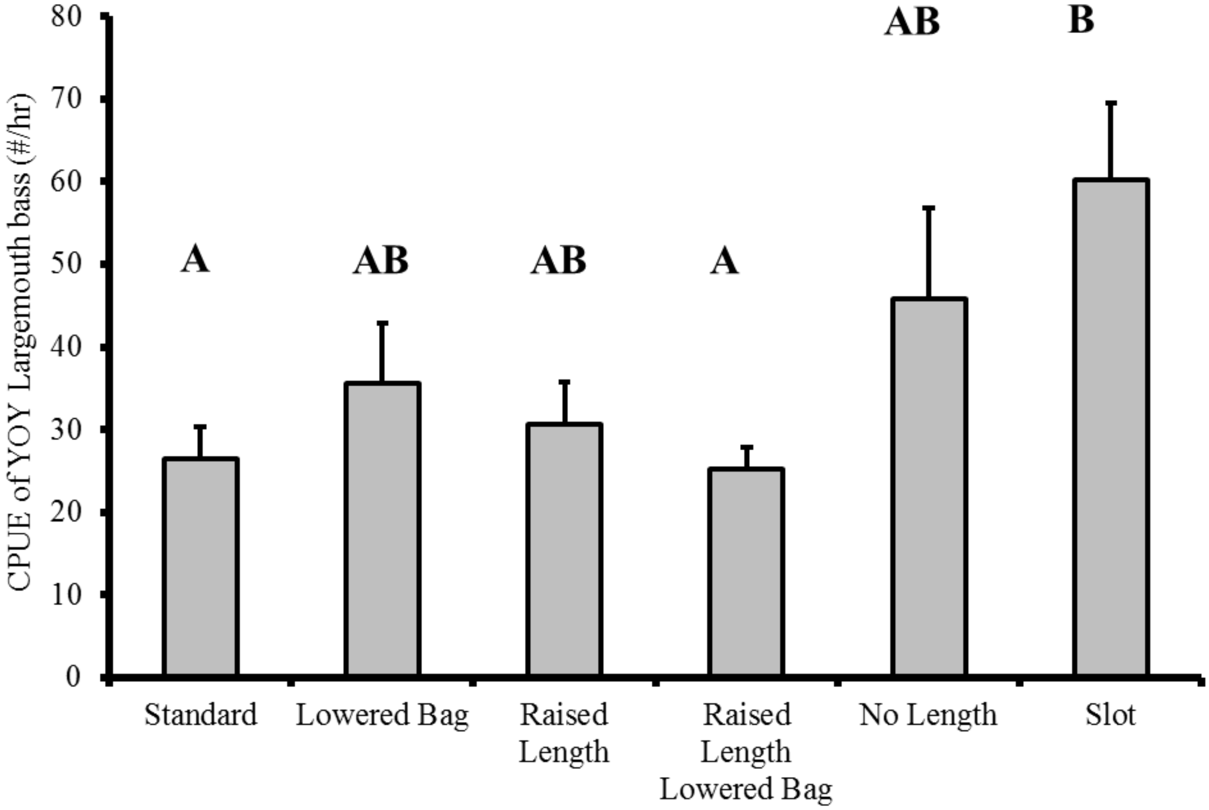

Figure 6-2: Catch per unit effort of young of year largemouth bass from fall electrofishing in 218 lakes in Illinois sampled from 2000 to 2007 in 6 different regulation categories. Letters indicate bars that are not significantly different ($P > 0.05$).

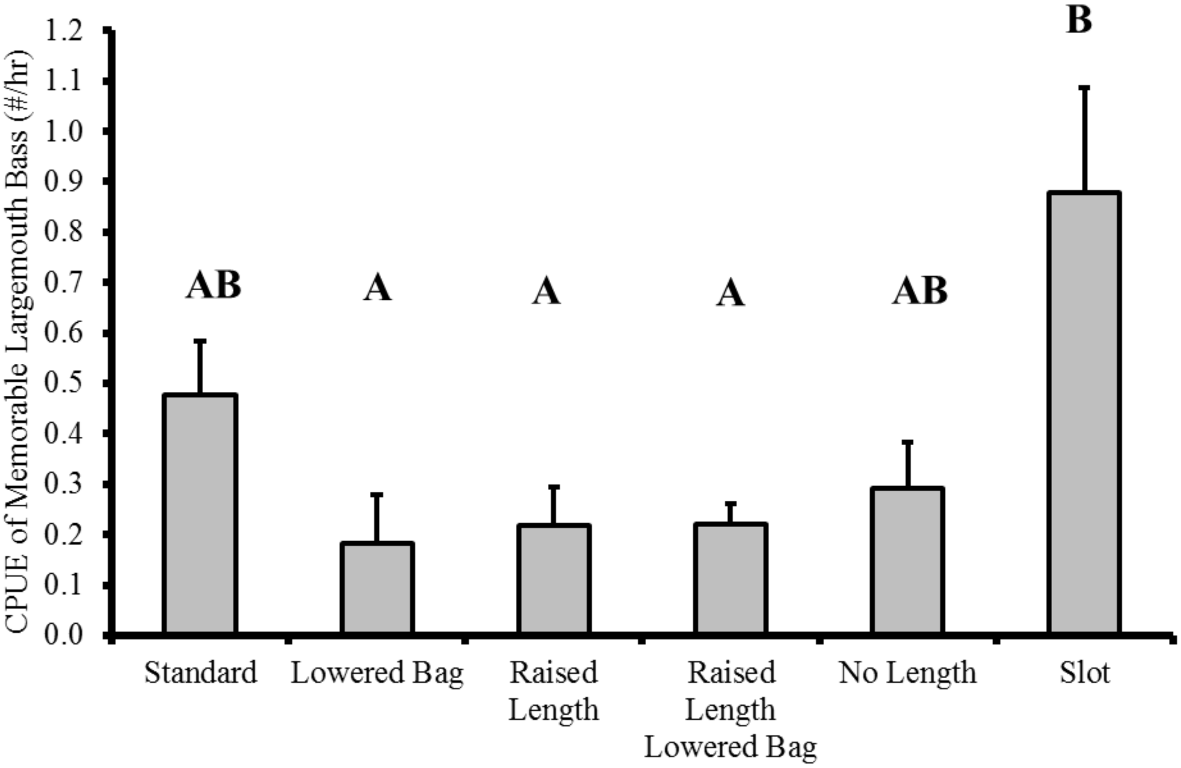

Figure 6-3: Catch per unit effort of memorable sized largemouth bass from fall electrofishing in 218 lakes in Illinois sampled from 2000 to 2007 in 6 different regulation categories. Letters indicate bars that are not significantly different (P > 0.05).

Appendix A

Diana, M.J. and D.H. Wahl. 2008. Long-Term Stocking Success of Largemouth Bass and the Relationship to Natural Populations. Pages 413-426 in M.S. Allen, S. Sammons, and M.J. Maceina. Balancing Fisheries Management and Water Uses for Impounded River Systems. American Fisheries Society, Symposium 62, Bethesda, Maryland.

Long-Term Stocking Success of Largemouth Bass and the Relationship to Natural Populations

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Abstract

Despite the widespread use of supplemental stocking, survival of age-0 and age-1 stocked fish is often variable and stocking success is not commonly evaluated through adult sizes classes. We evaluated the long-term contribution of stocked largemouth bass *Micropterus salmoides* from three annual stockings in 15 reservoirs in Illinois. Stocked largemouth bass were marked with fin clips and sampled for five years. Contribution of stocked fish to the population was highest for age-0 (21%) and age-1 largemouth bass (17%), but decreased significantly in adult fish (5%). There were no differences in contribution of stocked bass associated with either populations of wild largemouth bass or latitude. Survival of stocked fish was similar to survival of wild fish through age-1. Age-0 abundance of wild and stocked largemouth bass were positively correlated in the fall following stocking, suggesting that similar factors may influence initial survival. Survival of stocked fish from age-1 to adult ages decreased significantly compared to wild fish resulting in the low contribution of stocked bass to the adult population. Adult and age-1 CPUE of stocked largemouth bass were positively correlated with the mean size of stocked bass in the first fall after stocking and the following spring, indicating that lakes with higher growth rates have increased contribution of stocked fish. We found limited contribution of stocked fish to adult largemouth bass populations due to low survival from age-1 to adult ages. Assessments of fish stocking success should evaluate survival of stocked fish through adult ages or they may omit a critical period for mortality.

Introduction

Fish stocking is a common practice used to introduce a species to a new system (Dauwalter and Jackson 2005), sustain fish species in areas where there is no natural reproduction (Santucci et al. 1994), supplement wild populations where they have been reduced by angling and habitat degradation (Wingate 1986), or alter genetics of a population (Maceina et al 1988; Buckmeier et al. 2003). Survival of stocked fish has been related to a number of variables including stocking size (Gunn et al. 1987; Santucci et al. 1994; Szendrey and Wahl 1996; Farrell and Werner 1999; Yule et al. 2000; Brooks et al. 2002), stocking density (Fielder 1992), competition with other fish (Gunn et al. 1987) abundance and type of available prey (Stahl et al. 1996; Szendrey and Wahl 1996; Donovan et al. 1997; Sutton and Ney 2001), and density of resident predators (Santucci et al. 1994; Stahl et al. 1996; Szendrey and Wahl 1996; Yule et al. 2000; Michaelson et al. 2001). Initial survival is often assessed; however, few studies have evaluated long-term survival of adult stocked fish. Factors related to long-term survival have been evaluated for esocids through age-5 (Wahl and Stein 1993), however esocids are long-lived species and older adults were not included. Because the goal of most stocking is to increase adult abundance, understanding the survival of stocked fish through adult ages is important. Recruitment of stocked fish may or may not be set in the initial months after stocking; therefore, it is critical to assess long-term stocking success.

Stocking is a tool for managing reservoir largemouth bass *Micropterus salmoides* populations and fish are often stocked on top of naturally reproducing populations. This practice is used when a weak year class is expected (Boxrucker 1986), to alter genetics (Maceina et al. 1988; Buckmeier et al. 2003) or because of public pressure to stock largemouth bass (Buynak et al. 1999). Several studies have examined supplemental stocking of largemouth bass in large lentic systems, and typically the contribution of stocked fish to year-class strength is low (Loska 1982; Boxrucker 1986; Ryan et al. 1998; Buynak and Mitchell 1999; Buckmeier and Betsill 2002; Porak et al 2002; Hoffman and Bettoli 2005). Most previous studies evaluating stocking success have been conducted in one or two lakes. A few studies have been conducted on a large number of lakes, but they have only measured success through the first year after stocking (Hoxmeier and Wahl 2002; Porak et al. 2002). Because the goal of many stocking programs is to increase the harvestable population, there is a need to examine the contribution of stocked largemouth bass to adult sizes or that are catchable. Estimates from creel surveys of the contribution of stocked fish to the adult population have varied by individual reservoir from no survival (Boxrucker 1986) to moderate contribution (11.6%; Buynak and Mitchell 1999). To our knowledge no studies have examined variation in adult stocked largemouth bass survival across a number of reservoirs to assess factors that could influence success.

Because largemouth bass are stocked in reservoirs with naturally reproducing populations, wild fish could affect recruitment of stocked fish. Natural largemouth bass can compete with stocked fingerlings for prey resources and habitat (Neal et al. 2002) or stocked fish may displace native fish if a system is close to carrying capacity (Buynak and Mitchell 1999; Buckmeier and Betsill 2002). Largemouth bass are also the most abundant predator in many lakes and reservoirs and have been shown to prey heavily on other stocked fish species contributing to low stocking success (Santucci and Wahl 1993; Stein et al. 1981; Wahl and Stein 1989; Hoxmeier and Wahl 2002; Schlechte et al. 2005).

Prey species and abundance could also influence long-term growth and survival of stocked largemouth bass and have been shown to influence growth and survival of age-0 fish (Stone and Modde 1982; Hoxmeier and Wahl 2002). Competition with other fish species for prey resources could reduce largemouth bass stocking success. Stocked largemouth bass can have difficulty switching to natural prey, which can also contribute to low growth or survival (Porak et al. 2002). Managers must also consider the ecological risks of stocking including how stocked fish can affect the fish community (Olsen et al. 1995; Pearsons and Hopley 1999; Brenden and Murphy 2004). Stocked largemouth bass have the potential to be affected by the native fish community through either competition or predation.

The objectives of this study were to 1) evaluate recruitment of stocked largemouth bass to adult age, 2) compare survival of stocked and wild fish, 3) identify how survival and contribution of stocked fish is influenced by wild bass populations and latitude and 4) determine when recruitment of stocked fish to the adult population can be determined. We observed wild and stocked largemouth bass from initial introduction into the adult life stage in 15 Illinois reservoirs. Lakes were chosen to include a range of wild largemouth bass abundances. We examined lake-to-lake differences in contribution of stocked fish to the population to determine how stocking success can vary within a lake. We also examined variation in stocking success among lakes to determine how reservoir specific differences may influence stocking success. We use these analyses to make management recommendations regarding how long supplemental stockings should be monitored to determine success and stocking is an appropriate tool for manipulating largemouth bass populations in a particular lake.

Methods

Largemouth bass were stocked in 15 reservoirs in Illinois (Figure 1). Each reservoir was stocked with largemouth bass fingerlings in 1999, 2000, and 2001. Largemouth bass were the main predator in all of the reservoirs and the primary forage fish were bluegill *Lepomis macrochirus* and gizzard shad *Dorosoma cepedianum*. Stockings occurred in the 15 reservoirs in an attempt to increase predator abundance as a means to control bluegill populations. Lakes were chosen in order to include a range of wild largemouth bass population abundances, growth, and recruitment. Stockings occurred in mid-July to mid-August and the target stocking size was 100 mm with a density of 60 fish per hectare (Table 1). Each fish was marked with a pelvic fin clip in order to identify stocked fish in future samples. All fins were clipped by the Illinois Natural History Survey (INHS) staff and care was taken to remove the fin as close to the origin as possible to prevent regrowth. Clips were identifiable for the duration of the study based on concurrent work in experimental ponds with these sizes of fish (Ostrand and Wahl, unpublished data). Over a five year period a low proportion of fish (10.4%) had fin regeneration and those that did, marks were still identifiable due to distortion in the fin rays. Pelvic fin clips were left or right in alternating years to aid in determining which year each fish was stocked when it was recaptured.

Relative abundance of stocked and wild largemouth bass was assessed using 3 phase AC electrofishing for a minimum of 5 years and continued until no marked fish were observed in electrofishing samples. AC electrofishing was used because of historical use in Illinois on the study lakes. Each lake was electrofished on two dates in the spring and two in the fall. Three transects of one half hour each and standard locations were electrofished on each lake on each date. Half hour transects were chosen to ensure high probability of collecting stocked largemouth bass on a transect and to standardize sampling effort among lakes. One transect in each lake was located at the stocking site and the remaining two were evenly spaced across the remaining shoreline. All largemouth bass collected were measured for total length, examined for clips, and assigned a year class based on clip, length frequency, and aging from scales (for age-0 and age-1 fish). Catch per unit effort (CPUE) of stocked and wild largemouth bass was calculated for age-0 in the fall, age-0 the following spring, age-1 in the second fall, and adult fish in subsequent falls. CPUE of adult largemouth bass was calculated for each stocking at combined ages of 3, 4, and 5 years. Adult ages could not be delineated into individual years due to the lack of age data and the inaccuracy of using length frequency analysis to determine age for these larger largemouth bass. CPUE was averaged across years for each reservoir using reservoir as the experimental unit to evaluate differences among reservoirs and examined for relationships with reservoir characteristics using Pearson correlation analysis. Sampling fish populations through electrofishing can result in variation from lake to lake or select for larger individuals (Jackson and Noble 1995). As a result, we calculated the proportional contribution of stocked fish to the total largemouth bass population. CPUE of stocked largemouth bass from electrofishing samples was divided by the CPUE of all largemouth bass sampled for each date of sampling. Using a proportion rather than CPUE alone will allow us to better compare values across lakes because regardless of catch rates, the ratio of stocked to wild fish should be accurately represented.

To further study differences in contribution of stocked fish we examined change in survival between stocked and wild largemouth bass. Survival was estimated as the proportion of change in catch per unit effort from electrofishing at three time steps, from the first fall following stocking to the subsequent spring (age-0 fall to age-0 spring), from the first spring following stocking to the subsequent fall (age-0 spring to age-1), and from the second fall following stocking to the adult age (age-1 to adult). Using these metrics, we could examine differences in declines in CPUE between wild and stocked fish.

We also examined differences in contribution of stocked largemouth bass with latitude. We divided the study lakes into North (n=5), Mid (n=5) and South (n=5) regions within Illinois (Figure 1). A repeated measure ANOVA was used to determine differences in stocking contribution among these regions at different ages (age-0 fall, age-0 spring, age-1, and adult). To determine the influence of wild largemouth bass populations, we examined differences in contribution of stocked fish and survival of both stocked and wild fish between lakes with varying largemouth bass populations. Lakes were categorized as high, medium, and low largemouth bass populations using natural separations in CPUE of adult and age-0 largemouth bass in the population of each lake. We then examined differences in contribution and survival between these designated groups using repeated measures ANOVA. Using these analyses, we evaluate changes in survival through time and differences in survival between stocked and wild largemouth bass.

Results

Contribution of stocked fish to the total largemouth bass population varied among lakes. Proportion of stocked largemouth bass in the first fall following stocking ranged from 3 to 50 percent of the total population across lakes. Stocked largemouth bass CPUE was lower than wild fish for all age classes and declined through time (Table 2). Percent contribution of stocked fish to adult largemouth bass was the lowest of all age classes, ranging from 0 to 18 percent of the total largemouth bass collected in electrofishing samples.

Similar factors appeared to influence initial abundance of stocked and wild largemouth bass, but not older fish. The initial period following stocking can be critical to survival of stocked largemouth bass. Stocked largemouth bass CPUE in the first fall following stocking was significantly correlated with that of CPUE for wild age-0 largemouth bass ($r = 0.55$; $P = 0.03$). However, adult stocked largemouth bass CPUE was not correlated with CPUE of stocked largemouth bass in the first fall after stocking ($r = 0.17$, $P = 0.55$) or the first spring ($r = 0.26$, $P = 0.34$). Abundance of stocked adult fish was not related to stocked age-0 abundance both before and after the first winter and recruitment may not be set until a later time. Wild fish recruitment, however, did appear to be set at an early age. Age-0 wild fish abundance was correlated with the abundances of all older wild fish age classes. CPUE for age-0 wild fish was positively correlated with age-0 in the spring (r = 0.63; P = 0.01), age-1 (r = 0.92; P < 0.0001), and adult (r = 0.63; P = 0.01) wild fish. Wild fish abundance in the first fall was a good predictor of wild adult fish abundance. Unlike abundance, the mean size of age-0 stocked largemouth bass in the fall was related to abundance of older stocked fish. Mean size of stocked largemouth bass in the first fall after stocking was positively correlated with CPUE of age-1 (r = 0.74, P = 0.002; Figure 2A.) and adult (r = 0.68; P = 0.006; Figure 2B.) stocked largemouth bass. Lakes with faster growth rates immediately after stocking have greater adult stocked bass relative abundances.

We examined variation between years within a lake using ANOVA. Years were blocked by lake and examined for significant differences in percent contribution of stocked largemouth bass for each time step. There were no significant differences between years for percent of stocked largemouth bass for age-0 in the fall (F = 0.22; df = 2; P = 0.80), age-0 in the spring (F = 1.19; df = 2; P = 0.32), age-1 (F = 0.16; df = 2; P = 0.85), or adult (F = 3.20; df = 2; P = 0.06) fish. Because there were no significant differences in stocking contribution in lakes among years, for additional analysis we used the mean contribution and survival of stocked largemouth bass and focused the analysis on examining variation between lakes.

We also examined differences in contribution of stocked fish by latitudinal regions. There were no significant difference in stocking contribution in separate regions (F = 3.28; df = 2; P = 0.07) nor was there a significant interaction between region and age (F=0.56; df = 6; P = 0.76). There was a significant difference in contribution of stocked largemouth bass by age group (F = 11.42; df = 3; P < 0.0001; Figure 3). Adult contribution of stocked largemouth bass was significantly lower than age-0 in the fall (t = -4.68; P < 0.001), age-0 in the spring (t = -5.38; P < 0.001), and age-1 fish (t = -3.42; P = 0.008). The proportion of stocked largemouth bass in the population decreased significantly between the age-1 and the adult stage.

Abundance of wild fish large enough to prey on stocked fish was not correlated to stocked largemouth bass abundance. The CPUE of wild largemouth bass predators (> 250 mm) was not correlated with the CPUE of age-0 stocked fish in the first fall following stocking (r = 0.13; P = 0.65) or the following spring (r = 0.10; P = 0.73). CPUE of wild adult bass was also not related to stocked adult bass numbers (r = -0.35; P = 0.20). Similar trends existed when examining the influence of wild bass populations (high, medium or low) and contribution and survival of stocked and wild fish. No significant differences in stocking contribution existed between high, medium and low bass populations (F = 1.10; df = 2; P = 0.36) nor was there a significant interaction with age (F = 1.36; df = 6; P = 0.26). There was again a significant difference in contribution among age groups (F = 12.82; df = 3; P < 0.0001) with contribution of stocked adult fish being significantly lower than age-0 fall (t = -4.96; P < 0.0001), age-0 spring (t = -5.70; P < 0.0001) and age-1 (t = -3.62; P = 0.005) fish. There were significant differences in survival of largemouth bass. There were no significant differences in survival for lakes with high, medium and low wild largemouth bass populations (F = 1.15; df = 2; P = 0.35), however stocked fish had significantly lower survival than wild fish (F = 29.77 df = 1; P < 0.001). The interaction between stocked and wild survival with age was also significant (F = 6.4; df = 2; P = 0.0062) due to survival of adult wild largemouth bass being greater than survival of stocked adult fish (t = 5.88; P < 0.0001; Figure 4). In general, there was low survival of stocked fish from the age-1 to the adult age resulting in a decrease in contribution of stocked fish to the adult age class.

Discussion

Initial survival of stocked and wild young-of year largemouth bass followed similar patterns in our study lakes. Both CPUE and mean total length of age-0 of stocked and wild largemouth bass were correlated the first fall after. Similar factors may influence first year survival and growth of stocked and wild largemouth bass. Also, factors that cause low recruitment of wild fish may also be limiting stocked largemouth bass survival. Other studies have also shown no differences in mortality of stocked and wild largemouth bass in the first year following stocking (Buckmeier and Betsill 2002; Hoxmeier and Wahl 2002; Jackson et al. 2002; Hoffman and Bettoli 2005). Stocked largemouth bass are surviving better in those lakes that have favorable conditions for wild young-of year largemouth bass survival and growth. Unfortunately, lakes with good wild largemouth bass survival and growth are not usually the target of supplemental stocking efforts.

Overwinter survival was high for both stocked and wild fish. We observed high survival of both stocked and wild largemouth bass over the first winter following spawning/stocking and there was no change in contribution of stocked bass over this time period. Estimates of overwinter mortality for wild largemouth bass have varied from extensive (Mirranda and Hubbard 1994; Garvey et al. 1998; Post et al 1998) to minimal (Kohler et al. 1993; Garvey et al. 1998; Jackson and Noble 2000a; Fuhr et al. 2002; Ostrand et al. 2005). Similar variation has been shown for stocked largemouth bass with overwinter mortality ranging from low (Boxrucker 1986; Hoxmeier et al. 2002) to high (Gilliand 1992). Overwinter mortality was not a major factor influencing survival of stocked fish in this study and survival did not differ between stocked and wild fish.

We attempted to identify when the recruitment of stocked and wild largemouth bass to the adult population was determined. Recruitment of wild fish was determined by the first fall. The relative abundance of age-0 fish was related to that of all older age classes of wild fish and no significant mortality occurred in older fish. Recruitment of wild largemouth bass is commonly established by the first fall for wild largemouth bass (Jackson and Noble 2000a; Jackson and Noble 2000b; Sammons and Bettoli 2000). We did not, however, observe any relationship between relative abundance of age-0 stocked fish (both fall and spring) and relative abundance of stocked fish as adults. We observed a decrease in survival of stocked bass from age-1 to adult age that we did not observe in the wild fish. This decrease in survival was also evident through a significantly lower contribution of adult stocked fish to the adult largemouth bass population. There appears to be substantial continued mortality in stocked fish during the second year that affects recruitment to adulthood. Similar high mortality has been reported in individual lakes for stocked largemouth bass after the first year following stocking (Boxrucker 1986; Neal 2002). Our results provide evidence that the abundance of adult stocked fish differs from wild fish and is not determined until the fish reach adulthood. Stocked fish may be more vulnerable to predation or susceptible to starvation than wild fish. If resources for larger fish are limited, wild fish may out compete stocked largemouth bass. We believe it is important to evaluate stocked fish past the first year in order to fully determine stocking success.

This study provides evidence that size of stocked fish in the first fall may be important to long-term survival. Relative abundance of both age-1 and adult stocked largemouth bass was related to the mean size of age-0 stocked fish during the first fall following stocking. There may be either size selective survival of larger fish or lakes with higher growth rates may also yield higher abundance and contribution of stocked largemouth bass. Overwinter mortality is often size selective for largemouth bass, resulting in larger fish surviving at higher rates than smaller fish (Miranda and Hubbard 1994; Garvey et al. 1998; Post et al. 1998). Larger fish are less vulnerable to predation (Miller et al. 1988; Miranda and Hubbard 1994) and have greater energy reserves (Miranda and Hubbard 1994; Ludsin and DeVries 1997; Post et al. 1998). Growth of stocked fish immediately following stocking may influence the long-term survival of stocked largemouth bass.

Latitude, within lake variation, and preexisting largemouth bass populations did not influence stocking contribution or survival in this study. We did observe greater contribution of stocked fish the lakes that were further south, but differences were not significant. We need to further examine the role of latitude on survival of stocked fish, but it does not appear to greatly influence stocking success in this study. Contribution of stocked fish showed greater variation from lake-to-lake than within lakes. Lakes with high contribution of stocked fish in one season, tended to have high contribution throughout the study. This suggests that certain lakes may have characteristics that are conducive to stocking such as prey or habitat availability. Identifying these factors will allow managers to increase stocking success in a lake. Preexisting largemouth bass populations did not appear to influence stocking success through either competition or predation. We observed no differences in survival or contribution of stocked bass in lakes with high, medium or low wild largemouth bass populations. Similarly, predators did not affect survival of age-0 stocked largemouth bass in a previous study in Illinois (Hoxmeier and Wahl 2002). The influence of predators on stocked fish appears to vary by species. Low survival of stocked fish has been related to predator abundance for stocked esocids (Carline et al. 1986; Wahl and Stein 1989; Szendry and Wahl 1996) and walleye (Santucci and Wahl 1993, Hoxmeier et al. 2006). Conversely, predation was minimal or had no influence on survival and stocking success of saugeye (Stahl et al. 1996), channel catfish (Santucci et al. 1994) and striped bass (Michaelson et al. 2001). We found that predator abundance does not have a strong influence on survival of stocked largemouth bass.

Our results suggest the need to evaluate long-term survival of stocked largemouth bass when evaluating stocking success. Although stocked fish may exhibit similar survival to wild fish in a system initially following stocking, significant mortality can occur through the adult age. Stocking success could be evaluated incorrectly if long-term survival is not considered. We have shown that recruitment of at least one fish species (largemouth bass) is not determined in the first year after stocking. Many previous evaluations of stocking success have not examined stocking success beyond the first spring. These studies may omit a critical period for determining survival of stocked fish. For largemouth bass, success of stocked fish in the first year is often not reflected in creel data providing further evidence for variable survival following the first year after stocking (Boxrucker 1986; Neal et al. 2002). Managers should consider the survival of age-1 and adult fish when managing a lake or reservoir. Considering the availability of appropriate prey and habitat for larger stocked fish may reduce the mortality and increase recruitment to the fishery. We did observe a large range in stocking success with some lakes exhibiting no survival of stocked fish whereas others had stocked fish collected in substantial numbers (as high as 21% of the adult population) up to 5 years following stocking. Because of the high variation in stocking survival among lakes, there is a need for additional studies examining factors influencing stocking success. We focused on differences in survival of wild and stocked largemouth bass and the role of and predator populations in determining stocking success. Other factors such as prey abundance and availability, available habitat, thermal regimes, and fishing pressure may also be important. Future studies should examine variation among lakes in order to further explore what factors may play a role in determining growth and survival of stocked fish.

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Table 1. Characteristics of 15 Illinois lakes stocked annually in July and August with fingerling largemouth bass from 1999 - 2001. Information is based on the mean of stockings in each reservoir. Angler pressure is the number of angler hours per hectare estimated from creel census performed by the Illinois Natural History Survey Creel project in 1996-2000. Secchi depth is the mean annual secchi depth measured monthly at a designated station through 1999-2001.

Lake	Size (ha)	Mean Depth (m)	Secchi Depth (m)	Stocking Density #/ha	Percent of 60 m lake buffer as urban	Angler Pressure (Hours/ha)
Bloomington	250		0.54	60	1.1	156
Charleston	113	2.4	0.45	60	17.1	No Data
Forbes	212	4.6	0.64	60	8.2	207
Homer	32	2.5	0.63	60	No Data	815
Jacksonville	198	3.8	0.90	59	15.4	119
Kakusha	21	1.3	0.53	73	3.2	306
LeAquaNa	16	3.2	0.90	71	2.5	1833
McLeansboro	30		0.89	60	4.1	148
Mingo	69	3.7	0.85	60	6.0	492
Murphysboro	58	4.2	0.89	60	0.0	282
Pierce	66	3.4	0.88	60	0.3	1005
Sam Parr	73	3.1	0.84	60	47.3	536
Spring South	247	1.2	0.68	60	No Data	371
Walton Park	12	1.6	0.55	107	2.4	264
Woods	11	2.2	0.68	60	0.0	373

Table 2. Lake size and stocking densities for 15 Illinois lakes stocked with fingerling largemouth bass. CPUE was determined from fall and spring AC electrofishing transects in each lake for age-0 in fall after stocking and the following spring, age-1 the following fall and adults (> 250 mm) in subsequent years through age-5.

Lake	Mean Stocked CPUE (#/hr)				Mean Natural CPUE (#/hr)			
	Age-0 Fall	Age-0 Spring	Age-1 Fall	Adult	Age-0 Fall	Age-0 Spring	Age-1 Fall	Adult
Bloomington	5.1	0.7	0.2	0.0	42.9	5.1	10.0	26.7
Charleston	6.0	0.9	0.1	0.1	6.0	8.3	1.1	8.7
Forbes	4.7	5.3	0.7	0.8	19.1	9.2	6.1	15.2
Homer	0.7	0.5	0.1	0.0	22.4	10.2	5.5	17.7
Jacksonville	7.5	12.6	3.2	0.6	10.5	6.1	2.4	17.0
Kakusha	3.8	1.3	0.7	0.5	45.0	7.5	8.3	12.3
LeAquaNa	3.4	2.7	0.1	0.1	10.8	10.7	1.7	12.2
McLeansboro	3.6	4.4	0.9	0.8	11.6	6.4	2.6	7.0
Mingo	2.7	0.8	0.8	0.1	20.0	10.8	6.2	11.2
Murphysboro	3.3	3.9	1.6	0.6	18.6	7.9	2.8	12.3
Pierce	14.3	12.7	2.0	0.4	61.4	24.4	15.8	18.2
Sam Parr	4.2	4.2	3.3	2.0	20.7	14.5	5.3	13.9
Spring South	0.7	1.0	0.0	0.0	15.5	11.9	1.8	25.3
Walton Park	5.2	4.0	1.0	2.3	7.7	5.7	4.3	10.8
Woods	0.3	0.3	0.8	0.0	9.7	3.8	3.1	11.8

Figure Captions:

Figure 1. Location of 15 lakes in Illinois stocked with fingerling largemouth bass in 1999, 2000, and 2001 (from Hoxmeier and Wahl 2002). Dashed lines indicate the separation of lakes into regions (North, Mid, South) based on latitude.

Figure 2. Relationship between and mean total length of age-0 stocked largemouth bass in electrofishing samples in the fall following stocking and CPUE of age-1 (age 1; A.) and adult (age 2-5; B.) stocked largemouth bass in fall electrofishing samples in 15 lakes in Illinois. Values are means from three annual stockings.

Figure 3: Contribution of Stocked largemouth bass to the total population through time. Age-0 Fall is the first fall after stocking. Age-0 spring is the following spring. Age-1 refers to the second fall following stocking and Adult is the mean of fall contribution from the third, forth and fifth fall following stocking. Different letters represent bars that are significantly different ($P < 0.05$) and error bars represent the standard error.

Figure 4: Mean proportion of fish surviving to a specific age class based on decreases in CPUE from electrofishing. Age-0 represents survival from the first fall following spawn/stocking to the first spring. Age-1 represents survival from the first spring through the second fall following spawn/stocking. Adult represents the survival from the second fall to adult age. The asterisk represents a significant difference ($P < 0.05$) between stocked and wild fish. Error bars represent the standard error.

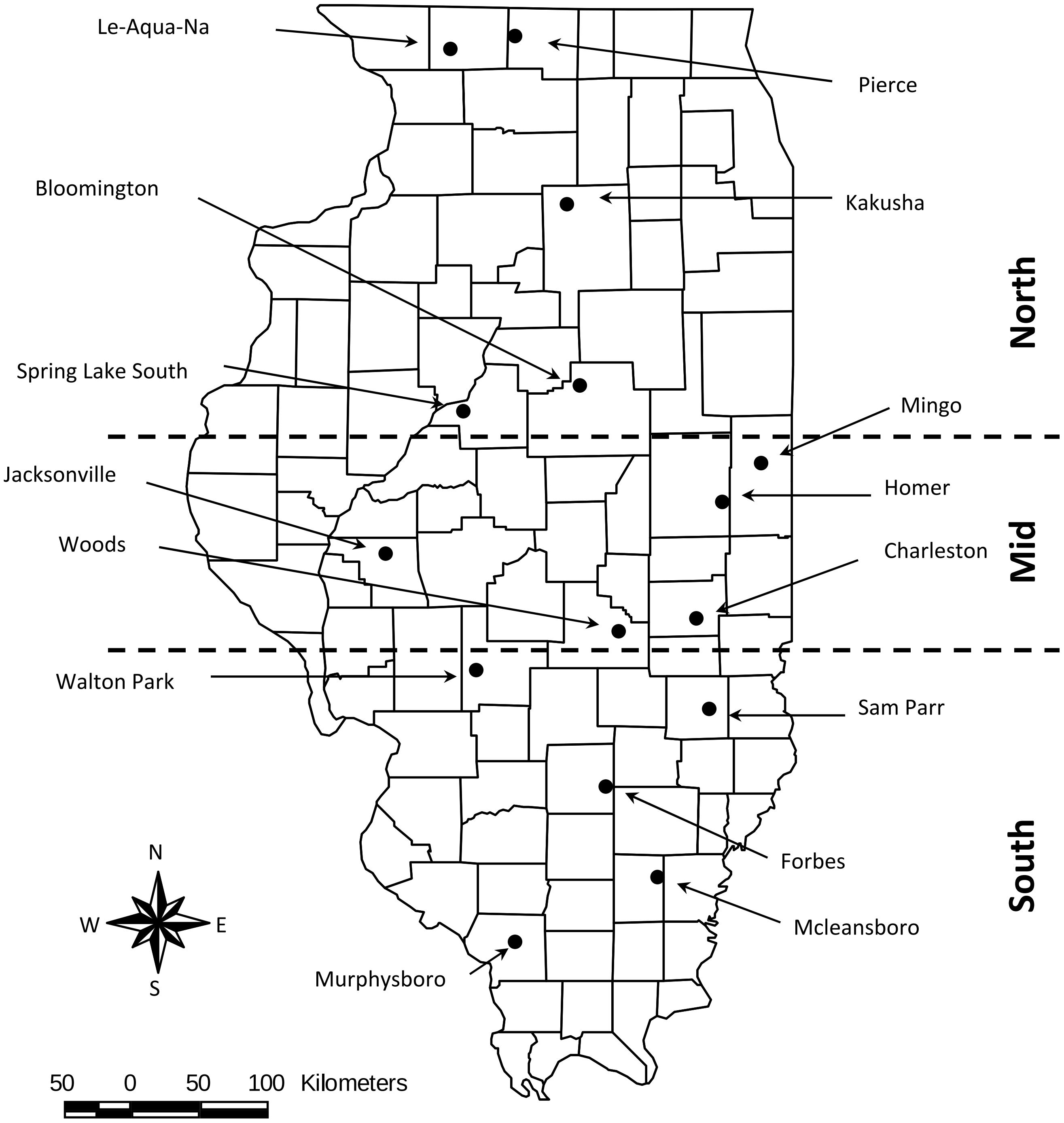

Le-Aqua-Na
Pierce
Bloomington
Kakusha
North
Spring Lake South
Mingo
Jacksonville
Homer
Woods
Charleston
Mid
Walton Park
Sam Parr
Forbes
South
N
W
E
S
Mcleansboro
Murphysboro
50 0 50 100 Kilometers

Figure 1.

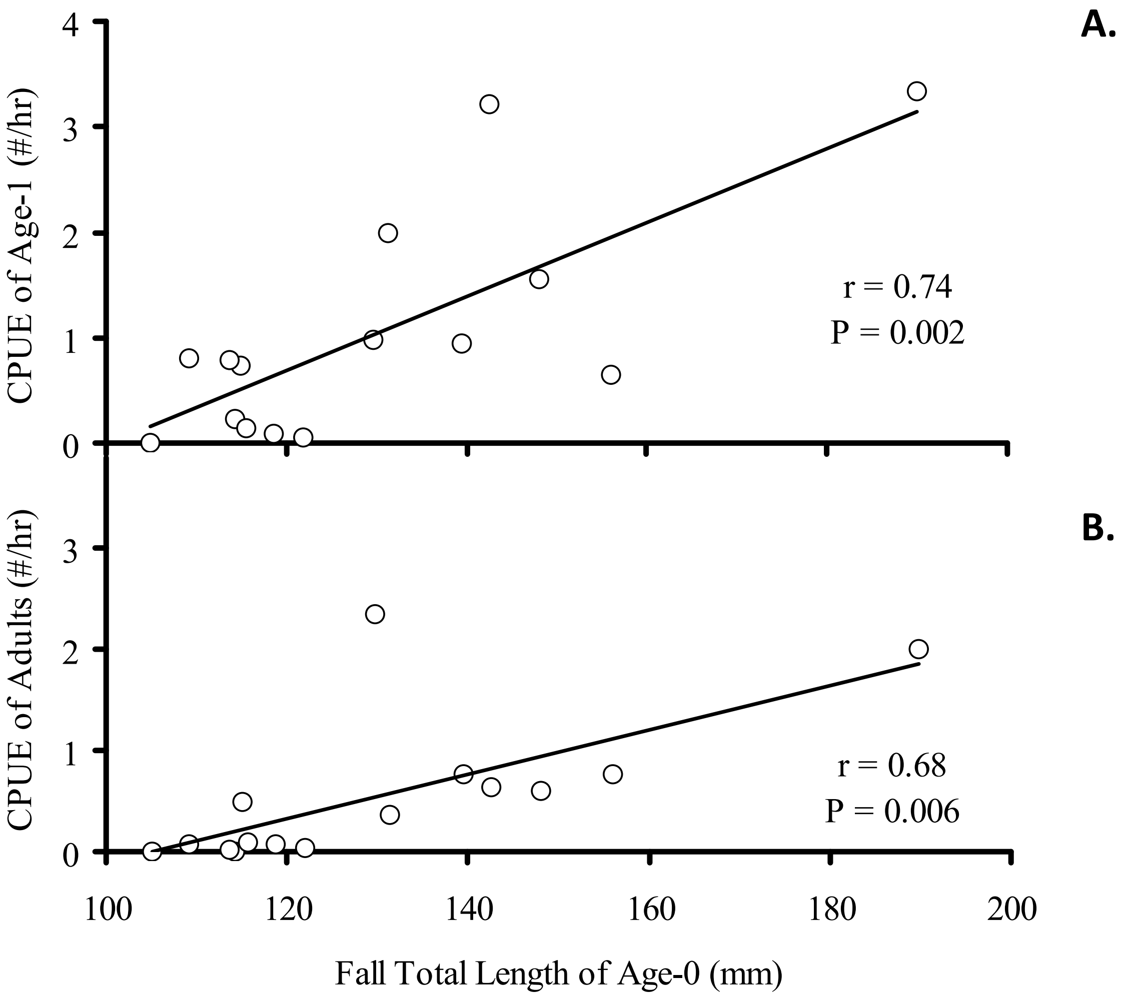
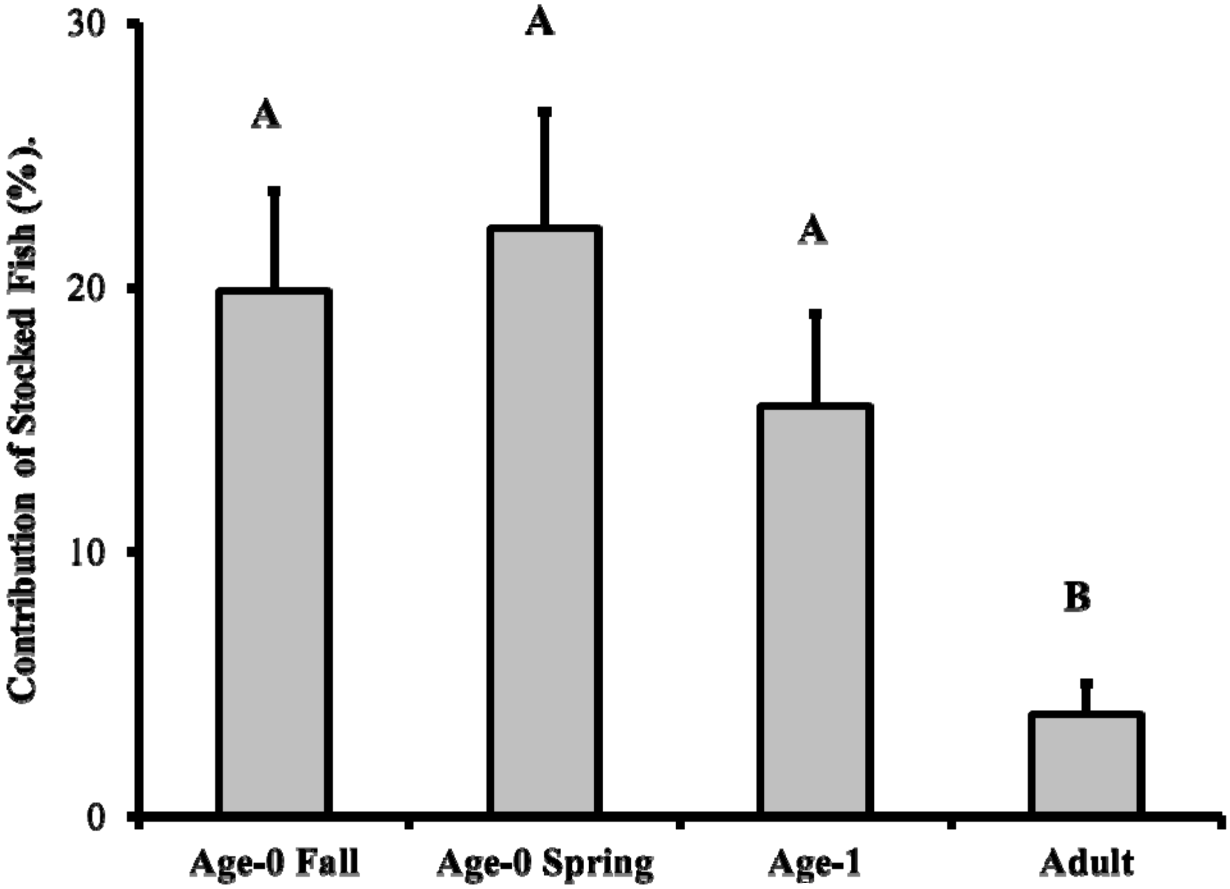

A.
B.
CPUE of Age-1 (#/hr)
CPUE of Adults (#/hr)
r = 0.74
P = 0.002
r = 0.68
P = 0.006
0
1
2
3
4
100
120
140
160
180
200
Fall Total Length of Age-0 (mm)

Figure 2.



Contribution of Stocked Fish (%).
30
20
10
0
A
A
A
B
Age-0 Fall
Age-0 Spring
Age-1
Adult

Figure 3.

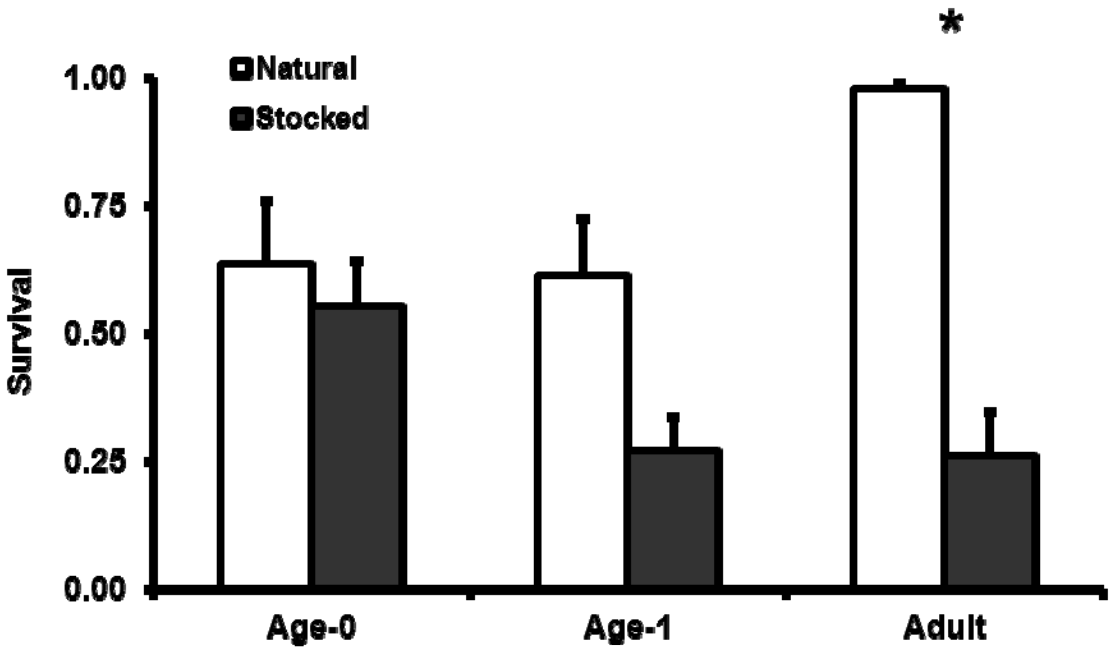

*
□Natural
■Stocked
Survival
1.00
0.75
0.50
0.25
0.00
Age-0
Age-1
Adult

Figure 4.

Appendix B

Diana, M.J., D.H. Wahl. 2009. Growth and survival of four sizes of stocked largemouth bass. North American Journal of Fisheries Management 29:1653–1663.

Growth and Survival of Four Sizes of Stocked Largemouth Bass

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Abstract

We compared growth, and survival including losses to stocking stress and predation of four sizes of largemouth bass *Micropterus salmoides* in four Illinois reservoirs. Fish were stocked as small fingerlings (55 mm) in July, medium fingerlings (100 mm) in August, large fingerlings (150 mm) in September, and advanced fingerlings (200 mm) the following spring. Survival of small fingerlings was very low (CPUE < 1/hr of electrofishing in fall after stocking) and they were not observed in electrofishing samples after the spring following stocking. Large and advanced fingerlings were larger and more abundant than other sizes initially following stocking. However in subsequent sampling, there were no differences in size or survival of the medium, large, and advanced fingerlings. Long-term growth of stocked fish was similar to wild fish, but survival of stocked fish was low for all sizes. Mean initial stocking mortality for fish held in cages was variable but generally low (0 – 5.6%) and related to lake temperature at stocking. Predator diets (primarily adult largemouth bass) contained high numbers of small, medium and large sized fingerlings following stocking, but no predation was observed on advanced fingerlings. Cost of producing fish increased with size and cost benefit analysis determined medium (100 mm) fish had the greatest return per cost. We recommend stocking medium fingerlings due to no increase in survival of larger fingerlings.

Introduction

Largemouth bass *Micropterus salmoides* are one of the most popular sport fish in North America. Because of their popularity, the management of largemouth bass populations has been a primary objective of numerous agencies. Stocking largemouth bass is a common management practice used to introduce them into ponds (Dillard and Novinger 1975; Modde 1980; Stone and Modde 1982) or to supplement wild populations (Mesing et al. 2008). Benefits of supplemental stocking include increasing harvest rates (Boxrucker 1986; Buynak and Mitchell 1999), supplementing weak year classes of wild fish (Boxrucker 1986), altering genetics of an existing population (Rieger and Summerfelt 1978; Maceina et al. 1988; Mitchell et al. 1991; Gilliland 1992; Terre et al. 1993; Buckmeier et al. 2003), or increasing the number of predators to control an overabundant forage population (Mundahl et al 1998, Boxrucker 2002, Schneider and Lockwood 2002). However, in order for these positive benefits to occur, stocked fish must contribute to the natural population. The success of supplemental stocking has been reported as variable and often times the contribution of stocked fish to year-class strength is low (Boxrucker 1986; Ryan et al. 1998; Buynak and Mitchell 1999; Buckmeier and Betsill 2002; Hoxmeier and Wahl 2002; Porak et al 2002; Hoffman and Bettoli 2005, Diana and Wahl 2008). There are some exceptions, in one southern lake 37 percent of electrofishing catch of age-3 fish were stocked fish (Mesing et al. 2008). Estimates from creel surveys of the contribution of stocked fish to the adult population have varied by individual reservoir from no survival (Boxrucker 1986) to moderate contribution (11.6%; Buynak and Mitchell 1999, 20%; Mesing et al. 2008). Many factors can influence the survival of stocked fish (Wahl and Stein 1993) and may be the cause of variable stocking success for largemouth bass.

Factors influencing stocking success may include predation, prey availability, and abiotic variables such as handling, confinement, and temperature change that fish experience during stocking (Wahl et al. 1995). Resident predators have been shown to greatly influence the survival of stocked channel catfish (Storck and Newmann 1988), walleye (Santucci and Wahl 1993; Hoxmeier et al. 2006), saugeye (Stahl et al. 1996), esocids (Stein et al. 1981; Carline et al. 1986; Wahl and Stein 1989; Szendrey and Wahl 1996), rainbow trout (Yule et al. 2000), striped bass (Michaelson et al. 2001) and largemouth bass (Hoxmeier and Wahl 2002; Schlechte et al. 2005). Older age classes of largemouth bass may be especially important predators given that they have been shown to prey heavily on stocked fish (Stein et al. 1981; Wahl and Stein 1989; Santucci and Wahl 1993) and are highly cannibalistic (Post et al. 1998). The importance of predation on the survival of stocked fish can vary by species being stocked, the size at stocking, as well as the composition of the predators in a system (Wahl 1995).

The size at which fish are stocked has been shown to be related to survival for a number of different species including channel catfish *Ictalurus punctatus* (Storck and Newmann 1988, Santucci et al. 1994), walleye *Sander vitreus* (Brooks et al. 2002; Hoxmeier et al. 2006), lake trout *Salvelinus namaycush* (Gunn et al. 1987), and esocids *Esox spp.* (Szendrey and Wahl 1996; Farrell and Werner 1999; McKneown et al. 1999). Stocking fish at different sizes also requires them to be stocked at different times of year depending on growth rates in the rearing facility. Because of this, varying stocking size also affects the water temperature at stocking, the amount of time a stocked fish is in the lake before winter, the abundance and type of available prey, and vulnerability to predation. High water temperatures at time of stocking have been shown to increase stocking stress and subsequent mortality of stocked fish (Mather and Wahl 1989; Clapp et al. 1997; Hoxmeier et al. 2006). Fish stocked at the appropriate time may have more abundant prey resources (Kolar et al. 2003; Mesing et al. 2008). Large fish have been shown to be less vulnerable to predation from gape-limited predators (Miller et al. 1988; Wahl and Stein 1989; Miranda and Hubbard 1994). In addition, holding fish in the hatchery overwinter has been successful in increasing survival of stocked muskellunge (Hoff and Sterns 1986; Margenau 1992). The size of largemouth bass fingerlings produced and the timing of their release into recipient populations could greatly affect the success of stocking efforts. Determining which of these factors is most important to stocking success has important implications for deciding the appropriate size of fish and times to stock largemouth bass.

The objective of this study was to compare size specific survival and growth of stocked largemouth bass. We examine the influence of predation from resident fish and lake conditions at the time of stocking on the success of four sizes of largemouth bass. We also compare the contribution of the different sizes of fish to the wild largemouth bass in the population. Cost benefit analyses were used to make recommendations of which size of largemouth bass is most appropriate to stock based on cost of production, survival, and growth.

Methods

We evaluated the success of four sizes of stocked largemouth bass in four lakes (Charleston, Homer, Mingo and Woods) in central Illinois during a seven year period (3-4 stockings in each lake) (Figure 1). The four lakes were small (surface area 11 – 113 ha) with existing largemouth bass (the primary predator), bluegill *Lepomis macrochirus* and gizzard shad *Dorosoma cepedianum* populations. The four lakes eutrophic to hypereutrophic (Forsberg and Ryding 1980) and relatively turbid with high productivity (Table 1). Largemouth bass were stocked in each lake at four sizes at differing times of the year. Largemouth bass were stocked as small fingerlings (mean = 57 mm, SE = 0.4 mm) in July at a target density of 120 per hectare (118 ± 5), medium fingerlings (102 ± 1) in August at 60 per hectare (59.0 ± 2), large fingerlings (152 ± 2) in September at 30 per hectare (26 ± 2), and advanced fingerlings (201 ± 6) in May the following spring at 15 per hectare (14 ± 3). Woods and Mingo were stocked in three years (1999, 2001, and 2003) and Charleston (1998, 2000, 2002, and 2004) and Homer (1999, 2000, 2002, and 2004) were stocked in four years. Advanced fingerlings were not included in the 2000. For the first four years (1998-2002), all sizes of largemouth bass were raised in raceways and fed artificial diet (Brecka et al. 1996; Bio-Oregon® BioVita Starter, 1mm to 4mm) until they grew to 55 millimeters. The medium, large and advanced fingerlings were then placed in ponds at 55 mm and fed fathead minnows *Pimephales promelas* until they reached the desired size. In the final two years (2003 and 2004), rearing techniques for the medium, large and advanced fingerlings were adjusted to reduce hatchery costs. The medium fingerlings were reared entirely in raceways on artificial diet, whereas the large and advanced fingerlings were held in raceways on artificial diets until they reached about 110 millimeters. These fish were then moved to ponds and fed minnows until they grew to the desired size. Because of the changes in rearing technique, we examined growth and survival separately between the first four and last two years of stocking. Repeated measures ANOVA was used to determine if differences existed among size groups in mean total length and CPUE in the three years following stocking.
Each size group was given a distinctive mark for identification during subsequent sampling. Small fingerlings were immersed in oxytetracycline (OTC; Brooks et al. 1994), whereas larger fingerlings were marked with distinctive fin clips (left pelvic, right pelvic or both pelvic). Preliminary studies were conducted to evaluate retention of fin clips in experimental ponds with these sizes of fish (Ostrand and Wahl, unpublished data). A low proportion of fish (10.4%) had fin regeneration over a five year period and fish that experienced fin regeneration were still identifiable due to distortion in the fin rays. All fish used in this study were clipped by the Illinois Natural History Survey (INHS) staff that were trained to remove the fin as close to the origin as possible to prevent regrowth. INHS staff was also trained to identify fin regrowth to ensure marked fish were correctly identified in the field. All sizes of fish were transported to the stocking location using aerated tanks on hauling trucks, tempered on the truck to within five degrees of lake temperature, and point stocked in one location near a boat ramp.

Following stocking, we evaluated the importance of stocking stress, physicochemical properties, and losses to predation on the success of the different size groups of stocked largemouth bass. Lake and hatchery truck water temperatures were measured at the time of stocking. Initial stocking mortality was estimated by placing 30 fish into each of three floating mesh cages. Largemouth bass were taken directly from the hatchery truck and placed immediately into the three cages. Cages were 3 m deep and 1 m in diameter with 3.2 mm mesh and were placed in at least 3 m of water. The cages were checked after 24 and 48 hours and the number of live and dead fish was recorded.

Predation on stocked bass was estimated by sampling diets of potential predators. Fish were collected by electrofishing during the day using a 3-phase AC electrofishing boat (250V, 9-12 A). Three shoreline transects were identified on each lake, one centered on the stocking location, and two dispersed evenly around the lake. Each transect was electrofished for 0.5 hours during mid-day (10AM to 2PM) on each sampling date and the same transects were used throughout the duration of the study. Diet contents were removed from all potential predators by the use of clear acrylic tubes (Van Den Avyle 1979) and the number of stocked bass as well as size and type of other prey were recorded. Predators were collected the day before stocking to evaluate the background level of predation on natural largemouth bass prior to stocking. During these samples, almost no largemouth bass (n=2 of 730 examined diets) were recovered from predator diets. As a result, we assumed that largemouth bass found in the diets were stocked fish in cases where they were digested to a point where clip identification was not possible. In addition, stocked fish would generally not be confused with natural bass due to size differences. Electrofishing samples were then conducted two hours after stocking and continued daily for the first five days after stocking and weekly thereafter until no stocked bass were observed in predator diets on two consecutive sample dates. The total number of stocked fish that were lost to predation was calculated using population estimates from mark recapture data collected in the fall through electrofishing. During the fall of each year of stocking, all largemouth bass were collected, measured for total length, checked for previous clips, and given a caudal fin clip. Three 0.5 hour electrofishing transects were conducted each sampling trip. We continued electrofishing sampling through the fall until the number of recaptured fish was large enough (5 to 16 sampling dates) to calculate the size of the population using Schnable mark recapture estimates from multiple censuses (Ricker 1975). The daily total number of stocked largemouth bass that were consumed was calculated as the percent of predators with stocked largemouth bass in the diet from electrofishing multiplied by the estimated number of largemouth bass in the population large enough to feed on the stocked fish (Wahl and Stein 1989). The size of largemouth bass predators large enough to feed on stocked fingerlings was estimated as the smallest predator observed feeding on each size of stocked largemouth bass throughout the duration of the study. Population estimates of potential predators were calculated separately for each stocking size. Number of fish consumed between sample dates was estimated using linear extrapolation. The estimated number of stocked bass consumed by predators for each day was then summed for the duration that stocked bass were found in predator diets to yield the total estimated proportion of stocked bass lost to predation.

Survival and growth was assessed through time for the different sizes of stocked bass. Largemouth bass were collected each spring and fall for two years after stocking by electrofishing samples. The same three shoreline transects on each lake used in the assessment of predation were electrofished for 0.5 hours each on each sampling date and all largemouth bass collected were measured for total length and examined for clips. In order to examine survival and growth of small fingerlings, all unclipped bass captured were taken to the laboratory where otoliths were removed for identification of OTC marks. Otoliths were mounted on a microscope slide, ground if necessary, and examined for the presence/absence of OTC marks using an epiflorescent ultraviolet light mounted on a microscope. Catch per unit of effort (CPUE) was calculated as the number of stocked fish collected per hour of electrofishing and was used as a relative measure of survival across lakes. CPUE for each size of largemouth bass stocked was adjusted to account for different stocking rates by dividing total CPUE by the number of largemouth bass stocked and multiplying by 1000 (Brooks et al. 2002). Growth was determined using the mean length (mm) for each size group through time. Differences in the survival and growth of stocked fish were examined using repeated measures ANOVA (Proc Mixed in SAS).

Cost of producing each size of fish was used to determine the economic value of stocking each size of largemouth bass. Hatchery costs were obtained from the Illinois Department of Natural Resources (Jake Wolf Memorial Fish Hatchery). Costs of producing each size was estimated as direct costs, which included the cost of maintaining brood stock, feed (pellets and minnows), and prorated use of the ponds and raceways. The estimated cost per fish was multiplied by the number of fish stocked per hectare to provide the total cost of stocking by area.

Results

No differences were observed in long-term growth or survival between fish from the two rearing techniques. We found no significant differences in growth (F = 0.37, P = 0.55) between rearing techniques nor was there a significant interaction between rearing technique and stocking size (RM-ANOVA, F = 0.58, P = 0.63). Similarly there were no significant differences in survival between the two rearing techniques (RM-ANOVA, F = 0.77, P = 0.39) nor an interaction between stocking size and rearing technique (RM-ANOVA, F = 1.03, P = 0.38). Because there were no statistical differences based on rearing technique, we combined all years in comparisons of the effects of stocking size. Mean mortality related to stocking stress was low for largemouth bass (0 - 5.6%; Figure 2) and no significant differences in mortality were observed among sizes (F = 1.81, P = 0.16). Small fingerlings had the highest mortality related to stocking stress and mortality was also more variable. All stocking mortality observed occurred when temperatures exceeded 24 C (Figure 3). Mortality was not observed at all stockings with high temperatures; however the potential for increased mortality appears to be greater when temperatures are high. Advanced fingerling (200 mm) stockings took place in the spring with cooler temperatures (< 23 ^{o}C) and no stocking mortality was observed for these fish. A total of 3,807 predator diets were examined for presence of stocked largemouth bass. The most abundant predator in these lakes with diets that contained stocked fish were largemouth bass (n = 3455, 7.9% with stocked fish found in diet), channel catfish (n = 164, 1.4%), white crappie *Pomoxis annularis* (n = 71, 1.4 %), and northern pike *Esox lucius* (n = 10, 10%). Largemouth bass were responsible for a majority of the predation and other species examined only consumed four stocked largemouth over the duration of this study. Because largemouth bass were responsible for 99% of the total observed predation on the stocked fingerlings we focused solely on this species for estimating the total stocked fish lost to predation. Population estimates of all natural largemouth bass (>150 mm) were calculated each year and ranged from 44 fish/ha in Lake Charleston to 156 bass/ha in Woods Lake (Table 1). Population estimates were then calculated for the smallest largemouth bass predator observed feeding on small fingerlings (150 mm), for medium fingerlings (188 mm), and for large fingerlings (294 mm). Based on population estimates for these sizes, we determined that stocked fingerlings were lost to predation (8 – 25%) except for advanced sizes where no predation was observed (Figure 4). Significant differences were observed in losses to predation among size groups (ANOVA, F = 3.24, P = 0.03). Medium fingerlings had the greatest proportion of fish lost to predation being significantly higher than advanced fingerlings (Tukey, P = 0.04), but similar to small and large fingerlings (Tukey, P = 0.96 and 0.23 respectively). Survival of fingerlings though time was low for all sizes however there were some initial differences in CPUE (RM-ANOVA, F = 9.95, P < 0.0001; Figure 5). CPUE for small fingerlings declined to near zero in the spring following stocking and none of this size group were found in later electrofishing samples. Large fingerlings had a significantly greater CPUE in the first fall after stocking than small (Tukey-Kramer (T-K), t = 10.02, P < 0.0001) and medium fingerlings (T-K, t = -8.33, P < 0.0001). Adjusted CPUE showed similar patterns with higher CPUE of large fingerlings than other sizes (small T-K, t = 5.71, P < 0.0001; medium T-K, t = -5.44, P = 0.0001). Due to high overwinter mortality, CPUE of large fingerlings was no longer significantly different from small (T-K, t = 2.57, P = 0.62) and medium fingerlings (T-K, t = -1.85, P = 0.97) the spring following stocking. Adjusted CPUE was also no longer significantly different between large, small, and medium fingerlings (P > 0.99) in the spring following stocking. CPUE of advanced fingerling in the first spring was significantly greater than medium (T-K, t = 4.77, P = 0.001), but not large fingerlings (T-K, t = 2.92, P = 0.36) but by the second fall dropped to levels that were no longer different from medium fingerlings (T-K, t = 1.67, P = 0.99). Advanced fingerlings also had significantly higher adjusted CPUE than medium (T-K, t = 4.11, P = 0.01) but not large (T-K, t = 282, P = 0.43) fingerlings shortly after stocking in the spring, but were no longer significantly different the following fall (medium, T-K, t = 2.19, P = 0.87; large, T-K, t = 1.80, P = 0.98). After the first spring following stocking, no significant differences existed in CPUE or adjusted CPUE among medium, large and advanced fingerlings.

Initial differences in growth existed between the four sizes of fingerlings (RM_ANOVA, F = 15.96, P < 0.0001; Figure 6). Small fingerlings were significantly smaller than both medium fingerlings (T-K, t = 2.77, P = 0.007) and natural largemouth bass (t-K, t = 0.37, P = 0.0004) in the first fall after stocking. Medium fingerlings were similar in size to natural fingerlings in the first fall (T-K, t = -0.84, P = 0.40) and remained similar in size in the following two years. Large fingerlings were significantly larger in mean total length in the first fall than small fingerlings (T-K, t = 7.33, P < 0.0001), medium fingerlings (T-K, t = -4.75, P < 0.0001) and natural largemouth bass (T-K, t = -4.10, P < 0.0001). However, the following spring the large fingerlings were similar in size to medium fingerlings (T-K, t = -1.66, P = 0.10). Large fingerlings were larger than natural bass in the first spring (T-K, t = -3.41, P = 0.001), but were no longer different in size the following fall (T-K, t = 0.82, P = 0.41). Small fingerlings (55 mm) were smaller than large fingerlings the first spring (T-K, t = 4.79, P < 0.0001) but sample sizes were low. Advanced fingerlings were significantly larger than all other largemouth bass in the spring shortly after stocking (T-K; small t = 6.74, $P < 0.0001$; medium t = 6.00, $P < 0.0001$; large t = 4.87, $P < 0.0001$; natural t = 8.13, $P < 0.0001$). In the following fall however, the advanced fingerlings were similar in size to the medium (T-K, t = -1.23, P = 0.23), large (T-K, t = -0.38, P = 0.70) and wild largemouth bass (T-K, t = -1.32, P = 0.19). All stocked and natural bass (excluding small fingerlings) were similar in size after 1 year post stocking and no differences in long-term growth were observed.

Cost was reduced when fingerlings were fed prepared pellets for longer periods (after 2002). Because of the lack of differences in growth and survival between rearing methods, we used cost estimates after 2003 because they better represent the cost of rearing these fish with current capabilities and knowledge. Cost of producing fish increased exponentially with fish size (Table 2); with advanced fingerlings being the most expensive to produce due to overwintering in the hatchery ponds.

Discussion

Survival of largemouth bass fingerlings varied with stocking size. We observed low long-term survival of small fingerlings with low relative abundance the first fall following stocking and very poor overwinter survival. Stocked largemouth bass fingerlings of similar size to the small fish we used have also been shown to have low survival in other studies, resulting in little to no contribution to wild populations (Buckmeier and Betsill 2002; Hoffman and Bettoli 2005). However, other studies have shown some success when stocking small sizes of largemouth bass (Boxrucker 1986; Buynak et al. 1999; Buckmeier et al. 2003; Colvin et al. 2008), however all of these studies examined success based on only one year of stocking. In general, we found low long-term survival of all sizes of stocked largemouth bass. Low survival of stocked largemouth bass has also been observed in previous studies (Ryan et al. 1998; Buckmeier and Betsill 2002; Porak et al 2002; Hoffman and Bettoli 2005, Diana and Wahl 2008).

We did not observe an increase in survival of stocked largemouth bass with stocking size. Initial survival differed among the medium, large and advanced fingerlings, but long-term contribution to the wild population was low and did not vary among sizes stocked. Few studies have assessed survival of different sizes of stocked largemouth bass in the same system and those that have also showed no differences between small and medium fish (Colvin et al. 2008). Survival of stocked fish has been shown to increase with size for other species including esocids (Carline et al. 1986; Wahl and Stein 1993; Szendry and Wahl 1996; McKeown et al. 1999), walleye (Santucci and Wahl 1993), and lake trout (Gunn et al. 1987). Similar to largemouth bass, no differences were observed in survival of different sizes of stocked channel catfish (Santucci et al. 1994). Walleye of intermediate sizes have been recommended for stocking due to a lack of increased survival of larger fish and cost-benefit analyses (Brooks et al. 2002). Largemouth bass stocked at advanced sizes have experienced low survival and contribution to the wild population in some studies (Porak et al. 2002; Buynak et al. 1999), but advanced Florida largemouth bass *Micropterus salmoides floridanus* fingerlings constituted up to 40 percent of age-1 fish and 37 percent of age-3 fish in a Florida reservoir (Mesing et al. 2008). Poor survival of advanced fingerlings and high cost of production result in no advantage of stocking fish of this size in our study. Based on our results, stocking fish of larger size (>159 mm) does not increase survival and long-term catch rates of largemouth bass.

Initial relative abundance of the large and advanced fingerlings was higher than other sizes, but these differences were short lived. Differences observed relative abundance occurred shortly following stocking of large and advanced fingerling. Additional mortality seems to occur following stocking for these two size classes. Delayed mortality not related to stocking stress and initial predation has been observed for largemouth bass (Boxrucker 1986; Neal 2002, Diana and Wahl 2008) and could be due to starvation or inability of stocked fish to compete with the existing natural population.

We observed no differences in growth or survival of fish raised using the two rearing techniques. Stocked largemouth bass have been shown to have difficulty switching to natural prey, which can contribute to low growth or survival (Porak et al. 2002). Feeding experience on natural prey prior to stocking has also been shown to increase the survival of other stocked fishes (Suboski and Templeton 1989; Szendrey and Wahl 1995, Wahl et al. 1995). We expected that differences in growth or survival might occur, especially in the medium fingerlings where rearing technique was changed from being fed minnows prior to stocking, to feeding entirely on a diet of pellets. Apparently the differences in the length of time fed pellet diets was not substantial enough to influence growth and survival for largemouth bass.

Stress at the time of stocking appeared to influence mortality accounting for up to 50% of the stocked fish. We observed no mortality in cages at temperatures less than 24 C, with increased but more variable mortality at warmer temperatures. Temperature has been suggested to influence stocking related stress and mortality for largemouth bass in other studies (Carmichael et al. 1984; Porak et al 2002). Similar effects of temperature have been observed for small sizes of stocked walleye (Clapp et al. 1997; Hoxmeier et al. 2006) with mortality directly related to the temperature difference between the hatchery truck and lake. Mortality may be reduced by tempering fish for extended periods prior to stocking (Clapp et al. 1997) and could also be reduced by stocking fish at cooler times of year. Fish in our study were tempered to within five degrees of lake temperature, however, small largemouth bass fingerlings were stocked during summer at the warmest temperatures and experienced the greatest stocking related mortality. Mortality from stocking stress did not account all of the losses observed for small fingerlings, and in some stocking events, mortality at stocking was low. In areas or lakes where temperature at stocking is of concern, it may be advantageous to stocking larger sizes of fish in order to avoid periods of high temperature and reduce stocking mortality. For other sizes of stocked largemouth bass, stocking stress did not account for significant amounts of mortality.

Predation on small, medium, and large stocked fingerlings varied with stocking size with 8 to 25 percent of stocked fish of these sizes lost to predation. Resident predators have previously been shown to greatly influence the survival of medium sized stocked largemouth bass (Hoxmeier et al. 2002; Schlechte et al. 2005). Largemouth bass predation has also contributed to low survival of stocked fish of other species (Stein et al. 1981; Storck and Newmann 1988; Carline et al. 1986**;** Wahl and Stein 1989; Santucci and Wahl 1993; Szendrey and Wahl 1996; Yule et al. 2000; Hoxmeier et al. 2006). Conversely, predation had no or minimal effect on survival of stocked channel catfish (Santucci et al. 1994), saugeye *Sander vitreus x Sander Canadensis* (Stahl et al. 1996) and striped bass *Morone saxatilis* (Michaelson et al. 2001). Other studies have shown a decrease in predation with increased size of stocked fish for walleye (Santucci and Wahl 1993; Hoxmeier et al. 2006) tiger muskellunge (Carline et al. 1986), muskellunge (Szendrey and Wahl 1996; McKeown et al. 1999) and channel catfish (Storck and Newman 1988; Santucci et al. 1994). Similarly, we did not observe any predation on the largest stocked sizes of largemouth bass (advanced fingerling). Stocking larger fish in systems with high abundances of predators may decrease mortality and increase stocking success. Predation may have been underestimated because only largemouth bass predators were included and other predators may not have been efficiently captured in electrofishing samples. However, largemouth bass are the most important predators in these systems as indicated by a variety of other methods (e.g. creel surveys). Although we observed high levels of predation, losses did not account for differences in stocking success of the various sizes of stocked largemouth bass.

We observed no difference in long-term growth among medium, large, and advanced fingerlings. In contrast, small fingerlings remained smaller than all other sizes throughout their lives. Few previous studies have directly compared growth of different sizes of stocked largemouth bass, the exception being a study in the Arkansas River that showed no differences in the first year of growth between small and medium fingerlings (Colvin et al. 2008). However, in this study, different sized fish were stocked in different backwaters in a single year and long-term growth was not assessed. Differences in growth appear to vary among stocked species, ranging from higher growth of smaller stocked muskellunge (Szendrey and Wahl 1996), no differences for two sizes of stocked channel catfish (Santucci et al. 1994), to higher growth for larger stocked lake trout (Gunn et al. 1987). Large and advanced fingerling largemouth bass were larger than wild and medium sizes at the time of stocking, but both experienced a lag in growth that resulted in no long-term differences in size. Because the large fingerlings were larger than other fish going into the first winter following stocking, we expected that they might experience higher rates of survival. Overwinter mortality is often size selective for largemouth bass, resulting in larger fish surviving at higher rates than smaller fish (Miranda and Hubbard 1994; Garvey et al. 1998; Post et al. 1998). Fish of larger size should have greater energy reserves (Miranda and Hubbard 1994; Ludsin and DeVries 1997; Post et al. 1998) and be less susceptible to predation (Miller et al. 1988; Miranda and Hubbard 1994). However, large fingerlings experienced the highest mortality over winter.

The lag in growth observed in large and advanced fingerlings occurred simultaneously with the decrease in relative abundance shortly following stocking. Stocked largemouth bass are often larger than wild fish, but still have poor growth and survival (Bunyak and Mitchell 1999; Hoffman and Bettoli 2005). Slow growth and low survival could be due to a number of factors, including conversion to natural forage (Wahl et al. 1995; Porak et al. 2003). Stocked largemouth bass may not compete with native fish, resulting in lower growth rates. Hatchery fish may also fail to recognize predators during early life that could cause high mortality (Suboski and Templeton 1989). Stocked bass have shown increased ability to avoid predation when habituated to various habitats before stocking (Schlechte et al. 2005). Further research is needed to determine the cause for the lag in growth and low survival of large and advanced fingerlings and could be used to increase the contribution of these stocked fish.

Cost of producing fish for stocking increased substantially with size. Other than the poor survival of small fingerlings, we observed no differences in long-term growth or survival of the different sizes of stocked largemouth bass. As a result, due to the lower cost of production, medium fingerlings are more cost effective. Our recommendation is based on the lack of increase in growth or survival when stocking larger sized fish. Studies with other species have also proposed stocking fish of an intermediate size due to high cost and low survival and growth benefit of stocking larger fish (Brooks et al. 2002). Unfortunately, we could not produce data to estimate the cost per fish that contributed to the adult population due to low numbers of recaptures of adult stocked fish. Stocking size influences losses to predation and thermal stress, but we observed little advantage of stocking larger fish and survival was low for all sizes of stocked largemouth bass. Alternate strategies (other than stocking larger fish) may be effective at increasing survival of stocked largemouth bass such as providing feeding experience on natural prey and habituation (Suboski and Templeton 1989; Szendrey and Wahl 1995; Schlechte et al. 2005). We demonstrate that altering stocking size will not increase survival or growth of stocked largemouth bass. Future work should consider the potential of other approaches for increasing growth and survival such as conversion to natural prey and predator habituation.

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Table 1: Population estimates and 95% confidence intervals for largemouth bass large enough to prey on stocked fish from mark recapture data from fall electrofishing transects in four Illinois lakes over seven years. Water chemistry values (chlorophyll a [Chl a], phosphorous [Phos], and Secchi depth) are the mean of samples taken bimonthly from June through September 1999 through 2004. Trophic state was estimated using the criteria described by Forsberg and Ryding (1980).

Lake	Lake Size (ha)	Trophic State	Chl a (ug/L)	Phos (ug/L)	Secchi (m)	Year	Population Estimate	95 % CI		N/ha
								low	high	
Charleston	113	Hypertrophic	48.2	212.6	0.45	1998	7402	5188	10993	66
						2000	6798	4651	10397	60
						2002	5142	1753	25708	46
						2004	551	98	5510	5
Homer	32	Eutrophic	30.9	97.3	0.64	1999	4854	3298	7491	152
						2000	4988	3823	6509	156
						2002	3583	2434	5530	112
						2004	6377	1771	63765	199
Mingo	69	Eutrophic	20.2	63.0	0.89	1999	7260	4765	11728	105
						2001	6421	4819	8791	93
						2003	13493	5766	42165	196
Woods	11	Eutrophic	37.4	188.6	0.68	1999	1159	888	1513	105
						2001	802	643	999	73
						2003	698	367	1570	63

Table 2: Cost of production for four sizes of stocked largemouth bass. Cost was estimated as food, space and hatchery equipment required to rear each size of fish. Stocking cost per hectare is averaged for the four study lakes.

Stocking Size	Cost per Fish	Mean Stocking Cost (per hectare)
Small	\$0.03	\$3.51
Medium	\$0.15	\$8.81
Large	\$0.72	\$18.65
Advanced	\$4.05	\$55.91

Figure Captions

Figure 1. Location of four lakes in Illinois stocked with four sizes of fingerling largemouth bass during seven years (1998 – 2004). Lake size (ha) is provided in parentheses.

Figure 2. Mean mortality of small, medium, large and advanced sizes of stocked largemouth bass following stocking. Mortality was estimated as the percent of fish that died in three net cages over 48 hours following stocking. Bars represent standard error.

Figure 3. Percent mortality for four sizes of stocked largemouth bass as related to water temperature at the time of stocking. All mortality occurred at temperatures higher than 24 ^{o}C.

Figure 4. Estimated proportion of four sizes of stocked largemouth bass that were lost to predation after stocking in four lakes in Illinois over seven years. Size groups with different letters are statistically different (ANOVA, $P < 0.05$). Values are mean +/- 1 standard error.

Figure 5. Mean (+/- 1 S.E.) catch per unit effort for four sizes of stocked largemouth in four lakes in Illinois over seven years. Adjusted values are calculated as the CPUE from electrofishing divided by the total number stocked. Size groups with different letters are statistically different (ANOVA, $P < 0.05$).

Figure 6. Mean total length (+/- 1 S.E.) of four sizes of stocked and wild (natural) largemouth bass over the first two years of growth. Fish were collected by 3 phase AC electrofishing in the spring and fall from four lakes over ten years. Asterisks represent a mean that is significantly different than others within a season.

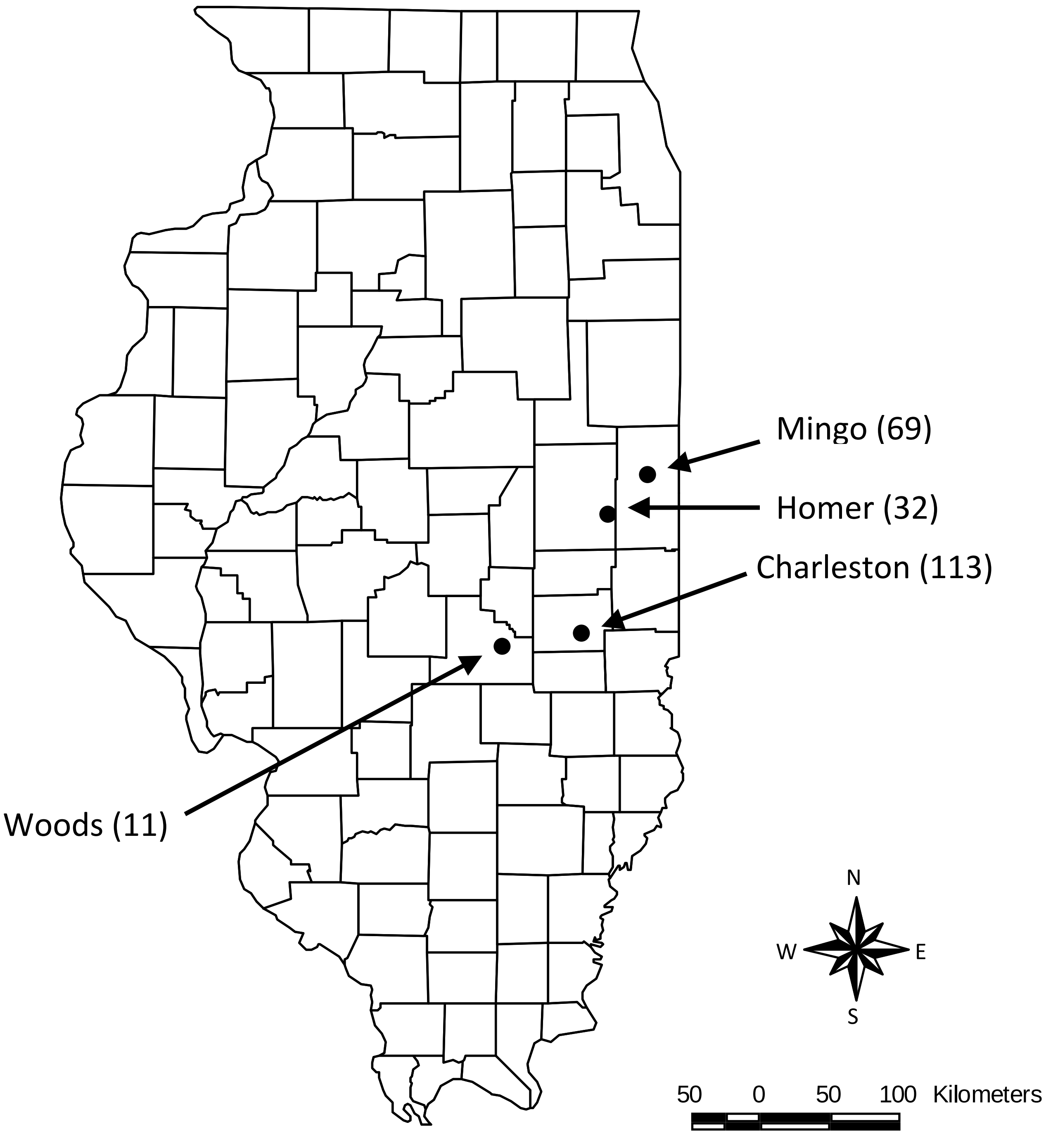
Mingo (69)
Homer (32)
Charleston (113)
Woods (11)
N
W
E
S
50
0
50
100
Kilometers

Figure 1.

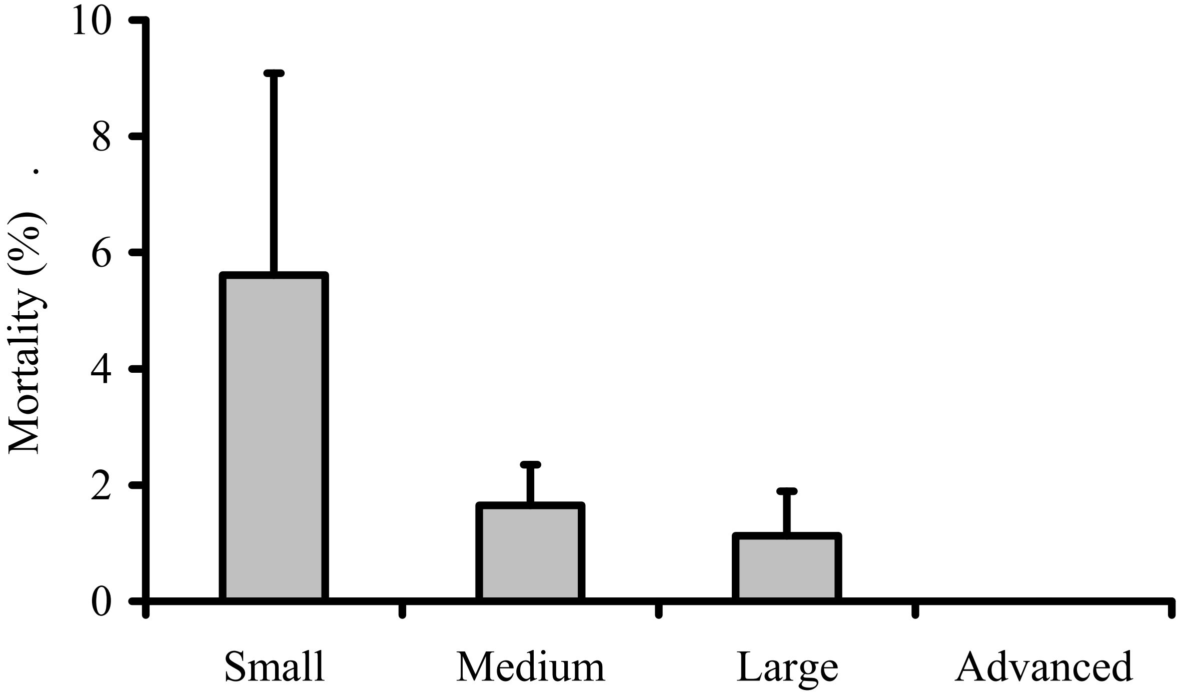

Figure 2.

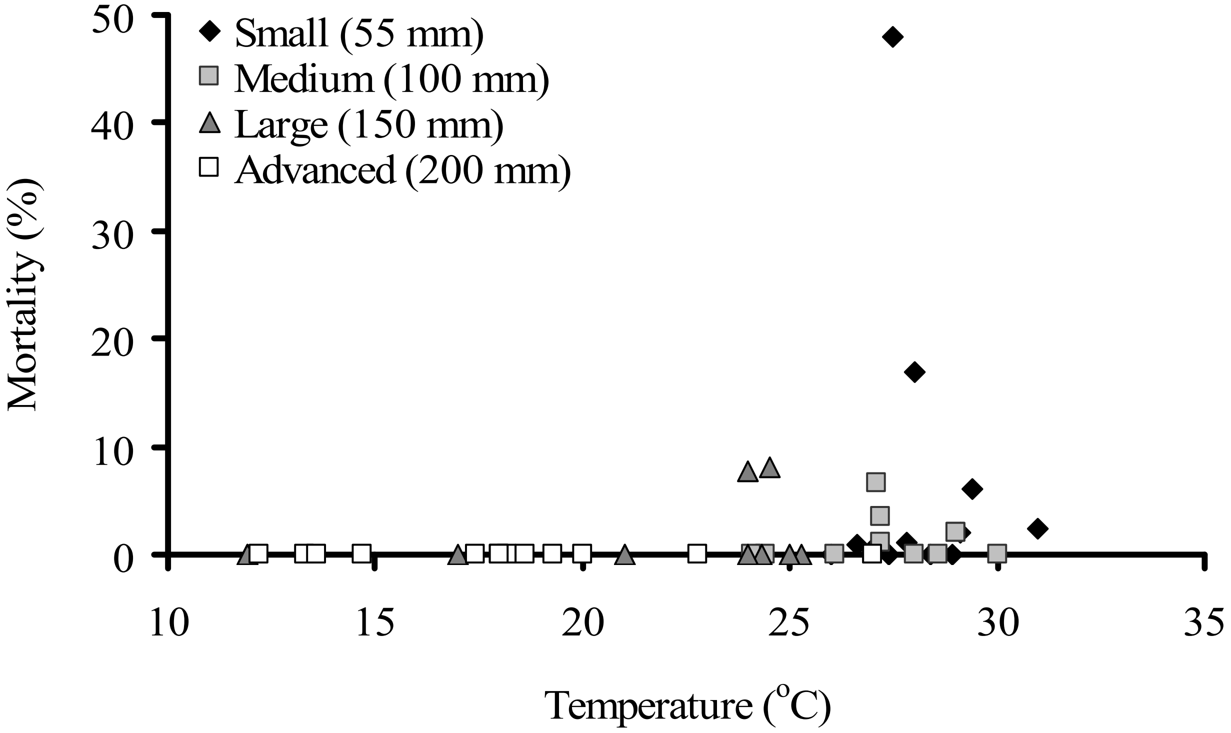
◆ Small (55 mm)
▨ Medium (100 mm)
▲ Large (150 mm)
☐ Advanced (200 mm)
Mortality (%)
0
10
20
30
40
50
10
15
20
25
30
35
Temperature (oC)

Figure 3.

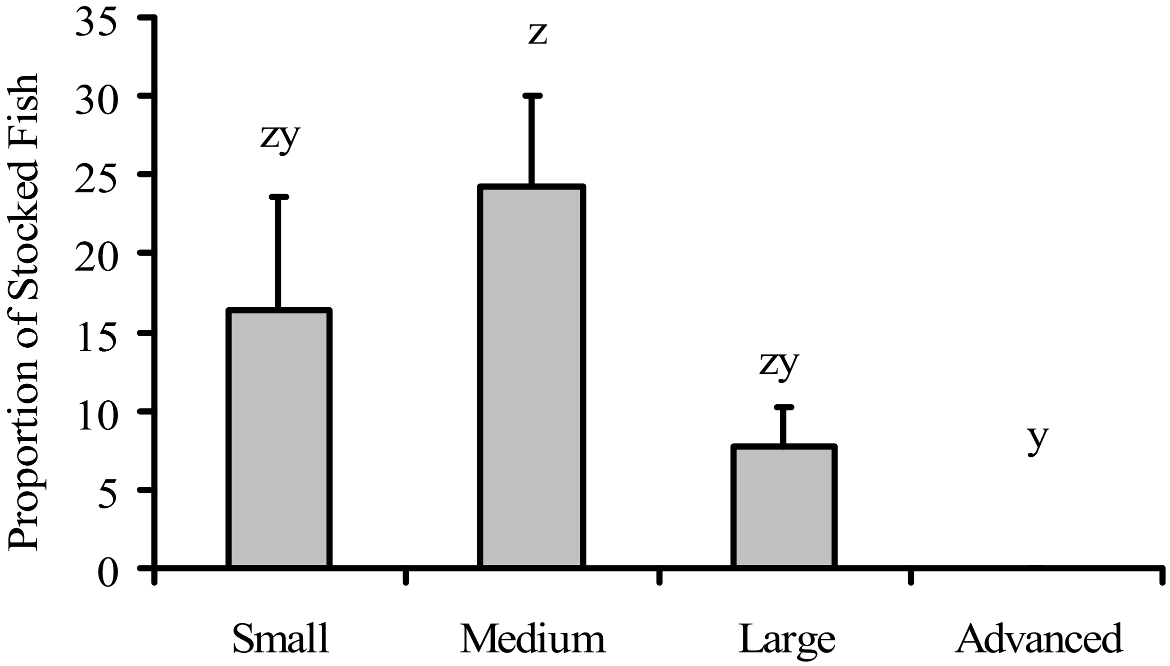
Proportion of Stocked Fish
35
30
25
20
15
10
5
0
zy
z
zy
y
Small
Medium
Large
Advanced

Figure 4.

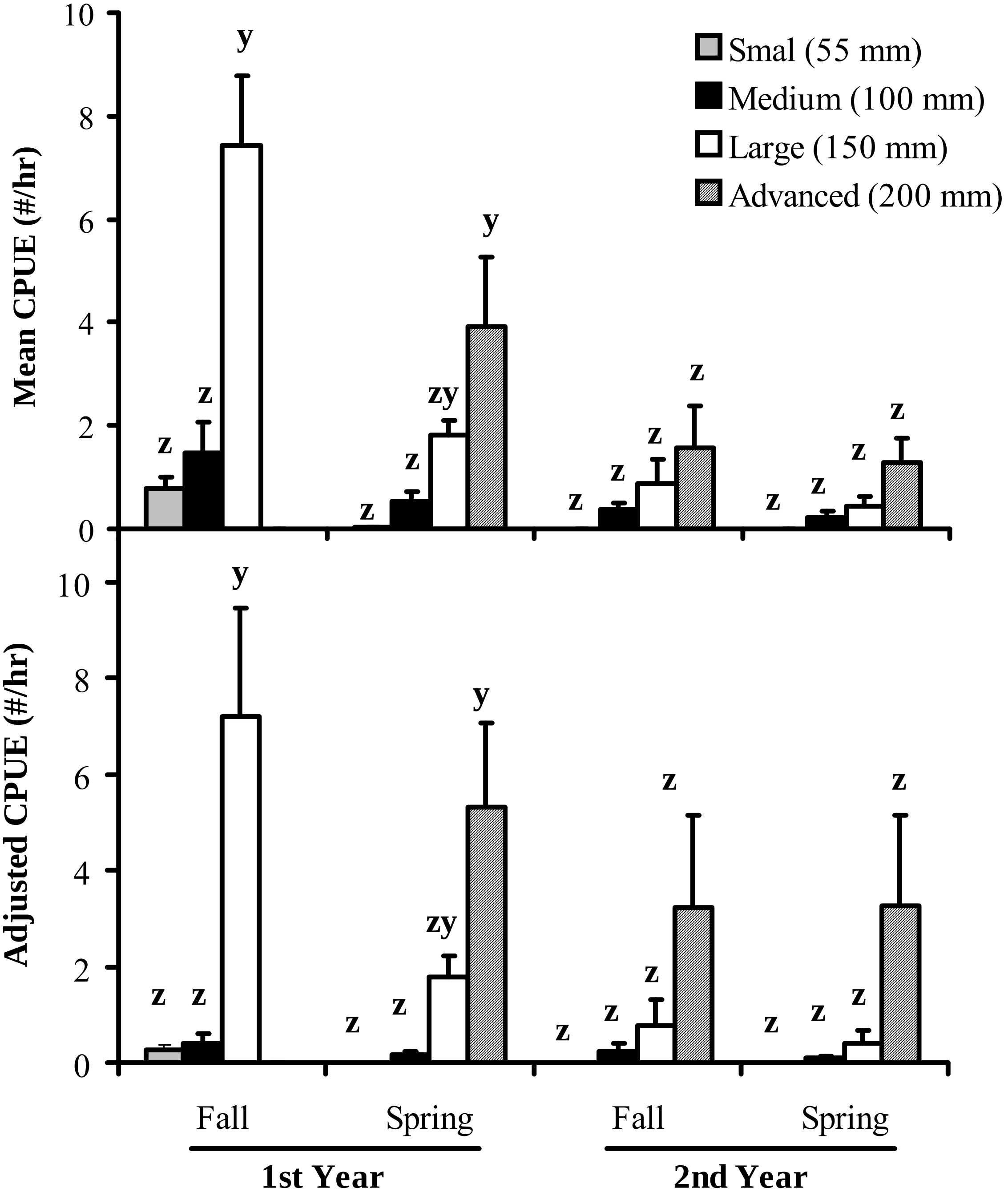
10
8
6
4
2
0
Mean CPUE (#/hr)
Smal (55 mm)
Medium (100 mm)
Large (150 mm)
Advanced (200 mm)
z
z
y
z
z
zy
y
z
z
z
z
z
z
z
z
10
8
6
4
2
0
Adjusted CPUE (#/hr)
z
z
y
z
z
zy
y
z
z
z
z
z
z
z
z
Fall
Spring
Fall
Spring
1st Year
2nd Year

Figure 5.

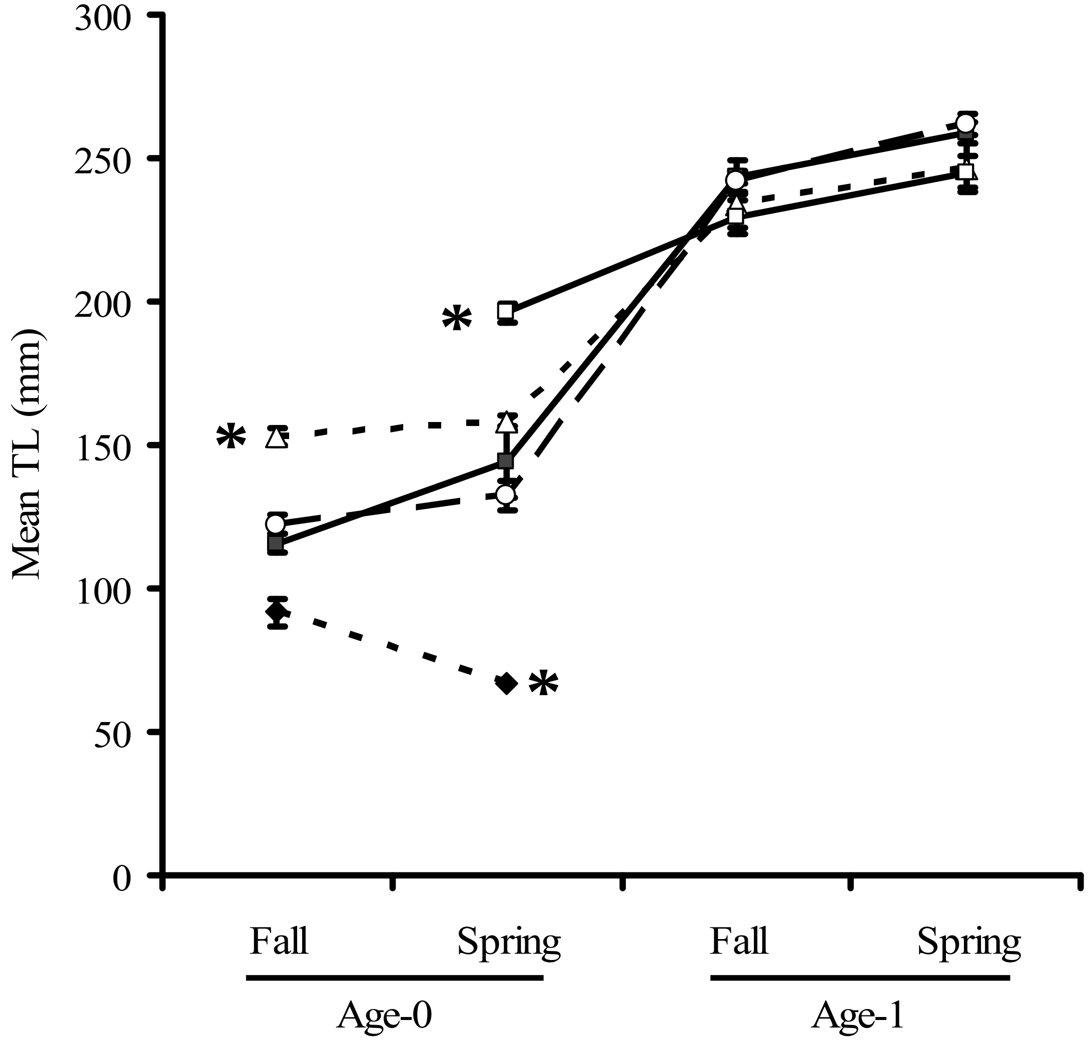
300
250
200
150
100
50
0
Mean TL (mm)
*
*
*
Fall
Spring
Fall
Spring
Age-0
Age-1

Figure 6.

Appendix C

Parkos, J.J., III, and D.H. Wahl. 2010. Intra- and intersystem variation in largemouth bass recruitment: reproduction, prey availability, and the timing of year-class establishment. Transactions of the American Fisheries Society 139:1372-1385.

Intra- and inter-system variation in largemouth bass recruitment: reproduction, prey availability, and the timing of year class establishment.

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Abstract

Incorporating potentially important events during the first year of life across multiple environmental conditions is needed to generalize models of fish recruitment. Using previous conceptual models as a framework, we quantified sources of intra- and inter-system variation in recruitment of largemouth bass. We measured young-of-year (YOY) abundances, first year growth, and potentially important environmental variables across 12 populations and five to seven year-classes. Inter-population differences in average recruitment to age 1 were set by variation in number of YOY surviving to fall. Survival to fall was in turn positively related to density of juvenile bluegill. First year growth was positively related to turbidity and abundance of adult largemouth bass. For individual lakes, variables explaining a significant amount of intra-population variation in recruitment strength were factors associated with either production of YOY from the parental care stage (peak density of YOY largemouth bass) or prey fish abundance (densities of larval and juvenile bluegill). Abundance of larval bluegill was higher in systems where largemouth bass recruitment to age 1 was not related to bluegill abundance than in lakes where recruitment strength was sensitive to annual fluctuations in prey fish abundance. The relationship between output from the parental care stage and recruitment strength suggests that management should focus on actions designed to influence nest success. Where recruitment is also limited by prey fish availability, management actions can also be directed towards community attributes that influence the growth and production of important prey species.

Introduction

Recruitment variation in fishes is often a process driven by survival during the earliest life stages (Hjort 1914; Houde 1987). Starvation and predation are two of the primary sources of mortality during early life stages and factors that influence relative losses to these two causes of death generally determine year class strength (Cowan and Shaw 2002). Spawning behavior can play a role in probability of starvation by determining when and where newly hatched larvae will emerge. Probability of starvation will be high if a larva emerges in either an environment or time where food is limiting (Cushing 1990). In addition, material investment by the mother into each egg will determine whether or not individuals will have the energetic reserves necessary to survive initial lean times (Berkeley et al. 2004). Losses to predation are also important because during early life stages, fish have not fully developed the sensory, locomotory, and behavioral abilities needed to successfully avoid predators (Brown 1984; Blaxter 1986; Jonas and Wahl 1998). Furthermore, young fish are also small and therefore available to a wider range of larger, gape-limited predators (Juanes 1994). High vulnerability to predation of fish in early life stages means that variation in factors that affect exposure and availability to predators can influence recruitment (Houde 1987). Due to the size-specific nature of both starvation and vulnerability to predators, conditions that influence first-year growth can be critical for recruitment strength (Miller et al. 1988).

Depending on the important sources of mortality, recruitment can be driven by processes occurring during specific developmental stages of fish early life history. One of the earliest models of fish recruitment predicts that food availability when larvae make the transition from yolk-derived to exogenous nutrition is the most important source of recruitment variation (Hjort 1914). Other models have gone on to modify this concept by extending the mechanism to other larval stages of development and by addressing the various processes that can influence availability of food to larval fishes. For example, variation in the timing of fish hatch relative to plankton blooms result in either a match or mismatch between larval fish and their earliest sources of exogenous food (Cushing 1990). Other researchers have proposed a variety of mechanisms to explain how food availability can vary for larval individuals, thereby resulting in recruitment variation (e.g., Lasker 1981). Houde (1987; 1994) changed the focus of fish recruitment studies by emphasizing predation as an important source of mortality and by proposing that the identity of critical life stages may vary across different aquatic environments. Critical periods of mortality for recruitment were proposed to occur during larval stages in marine environments and the juvenile stage in freshwater systems (Houde 1994).

Freshwater species that become piscivorous as young-of-year (YOY) are generally proposed to experience recruitment bottlenecks later in their early life history than either marine fishes or species with little or no piscivory during their first year of life (DeVries et al. 2009). Relative to non-piscivores, piscivirous species typically spawn early in the year and produce few, high quality offspring (DeVries et al. 2009). These life history features are likely adaptations for increasing foraging opportunities for offspring, because YOY that fail to develop a piscivorous diet have reduced fitness (Mittelbach and Persson 1998; Aday et al. 2009). In addition, parental care behavior could also push back timing of recruitment bottlenecks because parental protection reduces loss of eggs and larvae to predators. Largemouth bass *Micropterus salmoides* has a life history that combines both parental protection of offspring and development of a piscivorous diet by YOY (Olson 1996; DeVries et al. 2009). From the model of Winemiller and Rose (1992), largemouth bass life history is characterized by elements of both a periodic (delayed maturity, synchronous reproduction) and an equilibrium strategy (large eggs, parental care). Synchronous reproduction would increase the sensitivity of largemouth bass recruitment to conditions during nesting (Parkos and Wahl 2002), whereas parental care and high quality offspring should lead to increased importance of mortality during post-larval life stages relative to mortality during egg and larval stages.

Ludsin and DeVries (1997) outlined a conceptual model of recruitment that focused on the linked importance of four events during the early life history of largemouth bass. These events were hatching, onset of piscivory, fall lipid accumulation, and first winter. Fish that hatched early had a higher chance of making a transition to a piscivorous diet, resulting in faster growth and higher lipid reserves, and ultimately, improved survival through winter. This model was used primarily to explain variation in recruitment probability of early- and late-hatched cohorts within a year class, but the model can also be extended to larger-scale variation in recruitment (i.e., among year classes and populations; Ludsin and DeVries 1997). Hatch time, an important component of individual recruitment success, can be extended to entire populations and cohorts by considering the overall timing of YOY largemouth bass hatching relative to that of important prey species (Adams and DeAngelis 1987). For onset of piscivory, conditions favorable for an early and consistent shift to piscivory may not be found in all populations and year classes (Olson 1996). Conditions favorable for a large proportion of either a population or a cohort to develop sufficient lipid reserves and survive their first winter will vary as forage, predators, and winter weather varies (Miranda and Hubbard 1994a; Miranda and Hubbard 1994b; Ludsin and DeVries 1997; Fullerton et al. 2000). Though events as early as hatch have an effect on recruitment, the model of Ludsin and DeVries (1997) presents winter survival of juveniles as the main survival bottleneck determining year class strength.

Parkos and Wahl (2002) provided a conceptual model of largemouth bass recruitment that extended the model of Ludsin and DeVries (1997) to include more potential recruitment mechanisms. In particular, this model accounted for the importance of parental care to survival of the earliest life stages (embryo and larva) of largemouth bass. In the absence of parental protection, offspring mortality from brood predators can be high (Siepker et al. 2009). Events that can interfere with parental care of developing offspring, such as extreme weather events and removal of nesting males by angling (Kramer and Smith 1962; Philipp et al. 1997), were hypothesized to have the potential to negatively affect overall year class strength. Parkos and Wahl (2002) concluded that for some populations and cohorts, processes operating during the earliest developmental stages of YOY largemouth bass (i.e., survival of embryos and larvae) have a larger effect on overall recruitment strength than patterns of mortality occurring towards the end of the first year of life (i.e., first summer and winter survival of juveniles). Unfortunately, examples of recruitment studies that consider mechanisms operating at multiple developmental stages during the first year of life are rare. Incorporating all potentially important events during the first year of life across multiple environmental conditions (i.e., multiple year classes and populations) are needed to generalize models of recruitment.

To address these issues, we examined largemouth bass recruitment to age 1, first year growth and survival, and potentially important environmental variables across 12 populations and five to seven year-classes. The conceptual models of Ludsin and DeVries (1997) and Parkos and Wahl (2002) were used as a framework to guide assessment of largemouth bass recruitment variation (Figure 1). Analyses focused on important processes during the early life history of largemouth bass by measuring variables indicative of reproductive potential and survival through the parental care stage (spawning stock size, peak YOY density), early foraging conditions (spring zooplankton, benthos), conditions for diet switch to piscivory (abundance of larval and juvenile prey fishes), survival through the first growing season (fall YOY largemouth bass abundance), and survival potential over the first winter (fall size of YOY largemouth bass, winter temperatures). In addition, other potentially important community characteristics, such as gizzard shad abundance (Stein et al. 1995; Garvey et al. 1998) and lake primary productivity (Bunnell et al. 2006), were also included (Figure 1). The data set was used to address questions regarding critical periods in largemouth bass recruitment, processes determining differences in recruitment potential among populations and year classes, and community traits that influence the relative importance of different recruitment mechanisms.

Methods

We sampled 12 lake populations of largemouth bass in order to assess the influence of various abiotic and biotic variables on recruitment strength of eight year-classes (1999-2006). These lake environments represented a range of physical and biological conditions (Table 1) and occupied a range of latitudes (Figure 2). For eight lakes, some variables were measured twice a month in spring only (spawn stock, zooplankton, age 1 recruits), twice a month in fall only (fall YOY largemouth bass CPUE and TL, gizzard shad CPUE), and twice a month spring through summer (chlorophyll a, YOY largemouth bass density, larval and juvenile prey fish density). In four lakes (Clinton, Dolan, Pierce, Sterling), sampling took place once a month, following the same seasonal pattern as the other eight lakes. In all lakes, benthos was sampled once in June and once in August. Due to lack of access in some years, we sampled only five year-classes in Dolan

Lake and seven in Lake of the Woods (Table 1). Climatic conditions during spring nesting and winter were obtained from archived records of the Illinois State Water Survey (www.sws.uiuc.edu/warm). Deviation of spring (March-May) and winter (December-February) temperatures from normal (mean temperature since 1895) and total spring precipitation (total mm in March-May) were recorded for districts that included study lakes.

Largemouth bass abundance measures included adult stock during the spring spawning season, YOY from spring through fall, and recruits to age 1 the following spring (Figure 1). Seining was conducted to estimate densities of YOY largemouth bass by using a 9.2-m bag seine with 0.32-cm mesh pulled parallel to the shoreline for 10 meters followed by a sweep to shore at four to six fixed transects per lake. Transect locations were sites that were dispersed throughout a lake and represented available largemouth bass habitats. The two lakes over 1000 hectares in area contained six transects in order to cover enough habitat to accurately estimate fish abundance. All captured fish species were enumerated and up to 50 fish of each species were measured to the nearest total length (mm). Seine surveys began after the majority of nesting would be complete in each lake (late May). YOY largemouth bass were not large enough to be vulnerable to collection by seine until shortly after completion of parental care. These early samples of YOY largemouth bass were the highest recorded densities for the year, and therefore, we used peak density as an index of the number of YOY largemouth bass produced by nesting males. Electrofishing was used to collect fish that were too large to be effectively sampled by seining. Sampling involved using a boat-mounted 240-V A.C. electrofisher unit with bow-mounted droppers and a single netter at the bow. For each lake, three shoreline-transects of a 0.5-hour each were conducted, covering on average 52% ± 9% of available shoreline. Transect locations were fixed and electrofishing collections were conducted each spring and fall. Spring surveys were used to assess the relative abundance of both sexually mature largemouth bass and individuals from the previous year class that had recruited to age 1. Based on previous surveys, we considered adult largemouth bass 300 mm TL and larger to be part of the population's potential spawning stock (Parkos unpublished data). Based on otolith-derived ages, all largemouth bass 150 mm TL or smaller collected in the spring were considered to be recruits from the cohort of the previous year. Abundance and size structure of YOY largemouth bass that survived through their first growing season were estimated by conducting electrofishing surveys in October and November along the same transects used in the spring.

Due to the potential importance of a diet shift to piscivory, measurements were taken of the abundance of both larval and juvenile fish prey. Based on analysis of YOY largemouth bass diets from a sub-set of study lakes, we focused measures of fish prey availability on abundance of *Lepomis* species, especially bluegill *Lepomis macrochirus*, the predominant fish prey in diets (53-100% of fish prey: Parkos 2008; see also Olson 1996). Push net collections were conducted to determine larval *Lepomis* density (Claramunt et al. 2005) and seine samples were used to estimate densities of juvenile bluegill. Larval sunfish were collected at six sites on each lake by pushing a bow-mounted 0.5-m diameter push net with 500-μm mesh for 5 minutes inshore and 5 minutes offshore (target sample volume = 85 m^3; Claramunt et al. 2005). Larval fish samples were preserved in ETOH, brought to the laboratory, identified to genus, and enumerated. A late pulse of bluegill reproduction is an important predictor of age 0 piscivory (Parkos 2008); therefore, density of larval sunfish in August was also included. Because of the difficulty in distinguishing the larvae of different *Lepomis* species, we combined all larvae of this genus in our estimates of abundance. Based on previous studies of bluegill populations in Illinois lakes, all individuals less than or equal to 60 mm total length were considered YOY or juveniles. Due to previous documentation of indirect effects of gizzard shad *Dorosoma cepedianum* on growth of YOY largemouth bass (Garvey et al. 1998), fall electrofishing surveys were used to assess the size of the gizzard shad population in each lake.

Abundance of prey resources for YOY largemouth bass that had not switched to piscivory was measured by quantifying densities of benthic macroinvertebrates and crustacean zooplankton, excluding nauplii. Zooplankton was collected at four inshore sites with a 0.5-m diameter zooplankton net with 64-µm mesh pulled vertically to the surface (Hoxmeier et al. 2006). At these sites, samples were collected from either 1-m depth, or if the site was shallower, from the bottom to the surface. Zooplankton samples were preserved in 4% Lugol's solution, and all zooplankton were identified to suborder or family and enumerated in subsamples until at least 200 organisms from the two most common taxa in that sample were counted (Welker et al. 1994). Because copepod nauplii and rotifers rarely occurred in YOY largemouth bass diets (< 1% diets), they were not included in zooplankton density estimates (Parkos unpublished data). Analysis of crustacean zooplankton abundance without nauplii was restricted to the spring season when age 0 largemouth bass would be planktivorous. A general index of benthic invertebrate abundance was estimated for each lake by collecting benthos samples in June and August at six sites in each lake by using a modified stovepipe sampler (McPeek 1990). Benthos samples were sieved through a 250-µm mesh bucket and preserved in ETOH and stained with rose Bengal. Benthic macroinvertebrates were sorted, identified to order, and enumerated in the laboratory. For purposes of analysis, only those benthic taxa previously found in YOY largemouth bass diets were included in estimates of benthic macroinvertebrate abundance. These taxa included amphipods, chironomids, hemiptera, zygoptera, and ephemeroptera (Parkos 2008). Abundance of prey resources should be related to primary production; therefore, on each sampling trip, chlorophyll *a* concentration was measured at the deepest fixed sites in each lake. Water samples were collected with an integrated tube sampler lowered to twice the secchi depth, and chlorophyll *a* concentration was estimated flurometrically with an acetone extraction (Welschmeyer and Naughton 1994). Secchi depth was significantly correlated with chlorophyll *a* concentration ($r = -0.85$; $P = 0.0005$); therefore, chlorophyll *a* also approximated turbidity level.

Univariate correlations and multiple regression analyses were used to identify variables that significantly explained inter- and intra-system variation in recruitment to age 1. For each analysis (i.e., inter-lake and each individual lake), the complete set of potential variables was reduced to a smaller subset by retaining those variables correlated at $\alpha < 0.10$ with largemouth bass recruitment to age 1. Correlation analyses consisted of either Pearson correlations, or if the data were non-normally distributed, Spearman correlations. A $\log_{10}(X)$ transformation was used on predictor variables whenever this transformation was able to normalize the distribution. If any of the variables contained zeros, a constant was added to all values for that variable before applying the $\log_{10}$ transformation. The choice of constant added was the smallest possible value for each variable (electrofishing CPUE: $X + 0.7$; seine density: $X + 0.001$; larval fish density: $X + 0.01$; zeros not present in any other variables). Only predictive variables whose correlations represented plausible biological relationship with recruitment were included in the regression analyses. Linear regression models were built by subjecting the reduced set of variables to a stepwise selection procedure, with significance level necessary for entry into a model set at $P = 0.05$ (SAS 2001). All predictor variables were checked for collinearity and correlations before being used in model selection. These analyses were performed for individual largemouth bass populations (temporal analysis; N = 5-8 year classes per lake; Table 1) in order to identify variables responsible for the majority of within-lake variation in largemouth bass recruitment. These analyses were also done on mean values for each lake (spatial analysis; N = 10 populations; Table 1) in order to determine which variables were associated with among lake differences in growth and recruitment to fall and age 1. Dolan and Lake of the Woods were omitted from the spatial analysis in order to restrict the data set to lakes with means based on the same number of year classes (8 year classes per lake). Models were considered significant at $\alpha = 0.05$.

Results

A great deal of variability in extrinsic and intrinsic factors associated with largemouth bass populations was present among lakes and years. Abundances of age 0 and age 1 largemouth bass were more variable among year classes than spawning stock abundance (Table 2). A similar pattern of variability was also apparent among populations, with generally decreasing variability in abundances from the earliest life stages to spawning stock. Peak density of age 0 largemouth bass was highly variable both within and among lakes. Among populations, peak density varied as much as 248 YOY largemouth bass/m^2 (Table 2). Abundance of age 0 largemouth bass surviving to the end of their first growing season (i.e., fall YOY bass) varied more among than within populations (mean CV within lakes = 80%; among lakes CV = 100%). Average size of age 0 largemouth bass at the end of their first growing season ranged from 93-126 mm total length and varied more among populations than among years. In contrast to fall age 0 abundance, variability in both spawning stock abundance (mean CV within lakes = 52%) and recruitment to age 1 (mean CV within lakes = 94%) was higher within than among systems (Table 2). Inter-system variation in recruitment was high, however, with highest mean abundance of age 1 largemouth bass almost 12 times higher than the lowest abundance (Table 2). Neither recruitment to age 1, fall YOY, nor fall total length was significantly correlated with lake area ($P > 0.12$ in all cases).

Primary productivity and abundance of potential prey resources also varied a great deal (mean CV of chlorophyll *a* among lakes = 54 and CV's ≥ 100 for prey in many cases) within and between lakes (Table 3). All of the lakes had high primary productivity, with three hyper-eutrophic (> 40 µg/L chlorophyll *a*) and nine eutrophic systems (8-40 µg/L chlorophyll *a*; trophic classification per Bachman et al. [1996]). Chlorophyll *a* concentration was negatively related to mean depth ($r = -0.79$; $P = 0.004$). Zooplankton, benthos, and larval fish varied considerably in abundance between populations and years. In particular, abundance of fishes, such as bluegill and gizzard shad was highly variable. Where gizzard shad were present they were generally very abundant, except in Sterling Lake (Table 3).

Inter-system differences in recruitment of age 1 largemouth bass were set by the end of the growing season (fall YOY largemouth bass abundance; Figure 3). Variability in recruitment to age 1 decreased with lake depth (CV in recruitment and mean lake depth; $r = -0.64$; $P = 0.03$). Among lakes, abundance of YOY largemouth bass in the fall was positively related to density of juvenile bluegill (Figure 4), and size attained by the end of the growing season was negatively related to secchi depth and positively related to abundance of spawning stock (Figure 5).

For eight out of twelve populations, variables explaining a significant amount of within-population variation in recruitment strength were factors associated with either an index of YOY produced from the parental care stage (peak density of YOY largemouth bass) or conditions for ontogenetic development of piscivory (densities of larval *Lepomis* and juvenile bluegill sunfish; Table 4). These models explained 52-91% of recruitment variation among years for each population (Table 4). Except for Lake of the Woods, relationships between recruitment strength and peak density of YOY largemouth bass were positive. Relationships between recruitment strength and abundance of either larval *Lepomis* or juvenile bluegill were also positive. Populations where recruitment variation is a function of survival through the parental care stage had significantly higher abundance of larval *Lepomis* than populations where recruitment variation was driven by fluctuations in prey fish abundance (nest output mechanism: 322 ± 161 larval *Lepomis*/m^3; fish prey mechanism: 12 ± 6 *Lepomis*/m^3; $t = -3.52$, $P = 0.01$). For two of the largemouth bass populations, none of the measured variables significantly explained among-year class variation in recruitment strength (Shelbyville, Woods; Table 4). The only significant correlations with recruitment strength in Woods Lake were negative correlations with benthos and fish prey abundance and likely were indicative of the response of prey organisms to fluctuating predator abundance. For Pierce Lake, recruitment strength was positively related to fall abundance of YOY largemouth bass (Table 4). Ridge Lake was the only largemouth bass population where recruitment to age 1 was related to meteorological conditions, with recruitment strength positively related to winter temperature (Table 4).

Discussion

As fishes pass through developmental stages during their first year of life, they experience highly variable growth and survival. Success during each developmental step influences growth and survival during subsequent life stages (Ludsin and DeVries 1997), but the relative importance of stage-specific performance on overall recruitment strength will vary by life history strategy and community context (Bremigan and Stein 2001; Lidicker 2002). By encompassing a variety of lakes, years, and developmental stages, we were able to assess the relative influences of factors influencing survival during different stages in the first year of life on recruitment to age-1 in largemouth bass. Inter-lake differences in relative year class strength were established by fall, with recruitment positively related to number of juvenile bluegill. The relative importance of either reproductive output or prey fish in explaining intra-system variation in recruitment differed among lake environments. Some lakes always had high production of fish prey; therefore, there were few limitations on the opportunities for YOY largemouth bass to switch to piscivory. Other lakes had years where there was insufficient production of prey fish, resulting in lower recruitment even when largemouth bass reproductive success was initially high. Recruitment strength in the smallest lake in this study was influenced by winter temperatures. The strong influence of both reproductive output and prey fish abundance on largemouth bass recruitment reflects the importance of nest success for a species with elements of both a periodic (seasonal, synchronous reproduction) and equilibrium (parental care) life history (Winemiller and Rose 1992), and the importance of a successful diet shift to fish prey for a species adapted for piscivory (Mittelbach and Persson 1998; Aday et al. 2009).

Reproduction and nest success

Reproductive potential of a population is a function of both the number and quality of spawning individuals. Stock-recruitment relationships are the cornerstone of most fish population models and often serve as the framework for models of environmental relationships with survival during early life stages (e.g., Bunnell et al. 2006). Stock-recruitment relationships are also controversial as they often provide a poor fit to recruitment strength (Hall 1988), but overall, there is support for at least a weak relationship between spawning stock abundance and recruitment (Myers and Barrowman 1996). For largemouth bass, we did not find a relationship between recruitment strength and abundance of spawning-sized adults. We did measure a positive relationship between mean size of YOY largemouth bass at the end of the growing season and stock abundance, but the mechanism underlying this association is unclear. A more recent approach to stock-recruitment relationships is to account for age- and weight-specific differences in reproductive potential of populations (Rutherford 2002). If lakes with large spawning populations also have higher quality adults than lakes with low stock abundance, parental effects on offspring quality may account in part for the measured differences in fall YOY total lengths. Larger, older males and females often have higher reproductive success as well as higher quality offspring (Berkeley et al. 2004; Suski and Philipp 2004). From an examination of brood-specific contribution to recruitment, Parkos (2008) found higher contribution of recruits from parental males age-7 and older; therefore, positive correlations with year class strength and previous cohorts may occur over a lag of several years. The time series of the present study was too short to measure the strength of temporal autocorrelation of recruitment within lakes. Unlike stock abundance, variation in numbers of YOY largemouth bass emerging from the nesting stage of their life history was positively associated with largemouth bass recruitment.

Peak density of age 0 largemouth bass may have been the result of variation in not only reproductive output, but also survival during parental care. Survival of the earliest life stages often drives recruitment strength in fish populations (Hjort 1914; Kramer and Smith 1962), and recruitment variation in four of the study populations was related to production of offspring from the parental care phase of development. In the smallest of these four populations (Lake of the Woods), recruitment was negatively related to peak abundance of YOY perhaps due to high mortality from large piscivores when YOY largemouth bass are an abundant prey resource (Raborn et al. 2003). Parental care by male largemouth bass ameliorates mortality of the earliest life stages (egg, larva, early post-larval juvenile) and factors that interfere with parental care will also affect survival through these early stages of development (Philipp et al. 1997; Suski et al.2003; Steinhart et al. 2004; Siepker et al. 2009).

In addition to losses from brood predators, extreme fluctuations in abiotic conditions typically occur during the time of year that largemouth bass nests are initiated (spring) and in shallow, inshore habitats where nests are generally located. Spring in temperate environments is often characterized by variable and potentially extreme levels of rain, wind, and cold temperatures. Furthermore, shallow habitats are characterized by more rapid changes in temperature and higher exposure to wave action. Sudden drops in temperature can lead to nest abandonment by parental males and high winds generated by storm events often result in egg mortality (Kramer and Smith 1962; Steinhart et al. 2005). In lakes with large watersheds relative to system size, heavy rains lead to increased discharge and subsequent loss of age 0 largemouth bass (Garvey et al. 2000). However, in systems with low availability of nesting sites and habitat for age 0 juveniles, high rainfall can increase spawning success and survival by flooding larger areas of vegetation (Aggus and Elliott 1975; Miranda et al. 1984). Though no significant models for recruitment to age 1 in Lake Shelbyville could be developed from our data, it is possible that water level during nesting could be important as the highest correlation with recruitment in this system was a positive correlation with spring rainfall ($r = +0.62$, $P = 0.10$) and a previous study by Kohler et al. (1993) in Lake Shelbyville identified variable water levels as influencing survival during the nesting stage. Metrics more sensitive to changes in water level than spring precipitation might have revealed more significant relationships with recruitment as the majority of the populations in this study were in impoundments, systems often characterized by variable water levels in spring. However, impoundments can differ in their degree of variability in water level, and therefore, the significance of water level to temporal variation in recruitment will also vary (Parkos and Wahl 2002).

Trophic conditions

The availability of prey is often a strong determinant of fish recruitment strength, and in the case of largemouth bass, availability of fish prey was important in both inter-system and within lake variation in year class strength. During their first year of life, largemouth bass exhibit an increasing tendency towards piscivory (Olson 1996). After becoming piscivorous, the physiological condition of largemouth bass juveniles improves, enhancing their survival prospects (Ludsin and DeVries 1997). Availability of appropriate zooplankton prey for first-feeding fish larvae is often critical for survival (Mayer and Wahl 1997; Graeb et al. 2004) and growth during invertebrate feeding stages can be important for a later switch to piscivory (Olson 1996). However, because the offspring of specialist piscivores are relatively inefficient foragers on invertebrate prey compared to species that are not specialist piscivores (Persson and Brönmark 2002; Graeb et al. 2005), selection has favored a piscivore life history strategy that minimizes the time to transition to a piscivorous diet (Juanes et al. 1994). Consequently, broad-scale patterns of zooplankton and macroinvertebrate abundance did not have a significant influence on variation in overall recruitment strength.

Bluegill, the primary fish prey of YOY largemouth bass (Olson 1996), was an important predictor of largemouth bass recruitment patterns. Bluegills typically have a protracted period of reproduction (Garvey et al. 2002a; Santucci and Wahl 2003), whereas largemouth bass have some variation in the timing of spawning, but this variation is much more compressed in time (Keast 1985; Aday et al. 2009). When the fish prey of largemouth bass have small temporal variation in reproductive activity, differences in hatch times can have large effects on YOY largemouth bass growth and survival (Adams and DeAngelis 1987; Goodgame and Miranda 1993; Ludsin and DeVries 1997). When protracted reproduction produces vulnerable-sized fish prey throughout the growing season of the YOY predator, late season availability of fish prey may improve the survival of late-hatched largemouth bass, increasing year class strength. For example, variation in late summer production of prey fish influenced temporal variation in recruitment of largemouth bass in Clinton Lake. In general, abundance of bluegill influenced both spatial differences among Illinois lakes in average survival of YOY largemouth bass through the first growing season and the driving mechanism behind temporal variation in recruitment of largemouth bass within lakes. Gizzard shad were also abundant in populations where recruitment strength was influenced by density of bluegill, and yet, fluctuations in gizzard shad abundance did not influence largemouth bass recruitment. Despite previous evidence that larval gizzard shad can negatively influence growth of juvenile largemouth bass (Garvey et al. 1998), post-larval gizzard shad juveniles may have a smaller effect on predator growth than juvenile bluegill (Aday et al. 2005). Furthermore, gizzard shad are potentially not an important diet item for age 0 largemouth bass in Illinois because YOY gizzard shad are known to quickly outgrow vulnerability to small predators (Stein et al. 1995).

Variation in abundance of fish prey may also have positively influenced largemouth bass recruitment by providing an alternative prey resource for predators that would otherwise consume age 0 largemouth bass. Consumption of YOY individuals by older, larger largemouth bass can be extensive enough to influence year class strength (Post et al. 1998; Swenson 2002). Typically, cannibalism has been identified as an important component of mortality in either smaller systems (e.g., ponds; Parkos and Wahl 2002) or fish assemblages where largemouth bass are the only abundant fish species (e.g., Post et al. 1998). However, cannibalism has also been found to be a significant source of mortality in some large systems (Swenson 2002; Raborn et al. 2003). If gizzard shad are not vulnerable to predators, then fluctuations in availability of juvenile bluegill may also influence predation pressure on YOY largemouth bass with predators selecting the more abundant prey in the environment. Otherwise, positive relationships between largemouth bass recruitment and juvenile bluegill are the result of predator-prey interactions between these species.

Winter survival.

In general, winter was not an important survival bottleneck for largemouth bass cohorts in this study. Recruitment strength of largemouth bass in Ridge Lake was driven in part by winter severity, but pre-winter size structure and winter severity did not influence recruitment in any of the other 11 populations. Furthermore, inter-system differences in recruitment strength were set by fall. Several studies have demonstrated that mortality of largemouth bass during their first winter is size-specific, but evidence for the importance of this mortality to overall recruitment strength is equivocal (Parkos and Wahl 2002). The extent of size-specific mortality during winter can vary among systems at similar latitudes (Garvey et al. 1998) and be conditional on energetic demand, predation risk, and system productivity (Garvey et al. 2004). Another potential cause of variability in the importance of winter mortality to recruitment strength in previous studies may be the spatial scales examined. Many of the studies cited as evidence of winter as the primary survival bottleneck of largemouth bass have been done in ponds and other small systems (e.g., Gutreuter and Anderson 1985; Ludsin and DeVries 1997; Post et al. 1998), though there are some exceptions (Aggus and Elliott 1975; Miranda and Hubbard 1994a). In the present study, the only population where recruitment was significantly affected by winter conditions was in fact the smallest system, Ridge Lake. Studies of largemouth bass recruitment in larger systems have often found year class strength to be set previous to winter (e.g., Kramer and Smith 1962; Jackson and Noble 2000; Fuhr et al. 2002; the current study). Temporal scale of previous studies may also be a source of variability as the importance of mortality during different life stages to recruitment is likely to vary among years and conditions (Post et al. 1998).

Other sources of variability in the importance of winter in setting year class strength include system-specific conditions, such as community composition and climate. In the study system of Post et al. (1998), the fish assemblage consisted almost entirely of largemouth bass; therefore, few largemouth bass were able to switch to piscivory during their first growing season (Post 2003). Limited opportunities for piscivory resulted in smaller than usual size structure going into winter, but even under these conditions, recruitment strength was sometimes set previous to winter (Post et al. 1998). Examples of winter mortality setting recruitment strength of bass populations are often from either the northern or southern limits of the largemouth bass and smallmouth bass native ranges (Shuter et al. 1980; Ludsin and DeVries 1997; Post et al. 1998; Miranda and Hubbard 1994a). Losses to predation during winter may be more extreme at lower latitudes where warmer water temperatures result in higher activity and consumptive demand of large predators (Miranda and Hubbard 1994b). Near the northern extent of the centrarchid range, severe winter conditions produce high largemouth bass mortality (Fullerton et al. 2000; Shuter et al. 1980). Largemouth bass populations in Illinois occupy the center of the largemouth bass native range; therefore, winters may be severe enough to limit losses to predators but not enough to cause heavy losses of juveniles.

Management recommendations and future directions.

Community context will influence the relative importance of different recruitment mechanisms (Lidicker 2002) and the ability to group systems by either an important ecological factor or an environmental gradient helps to facilitate management of fisheries resources within these systems (Bremigan and Stein 2001; Garvey et al. 2002b). In general, we found most lakes to group into systems where recruitment to age 1 was related to either survival through the parental care stage or abundance of fish prey. Where productivity of prey needed by YOY largemouth bass to complete and sustain a diet switch to piscivory was low, recruitment to age 1 was sensitive to fluctuations in the availability of fish prey. Abundance of bluegill also defined inter-system differences in survival of YOY largemouth bass through the first growing season, itself an important factor identifying among-lake differences in average recruitment. Managing survival of YOY largemouth bass through the nesting stage of their life can include regulating the recreational fishery for largemouth bass during nesting (Suski et al. 2002), providing adequate habitat (Hunt et al. 2002), and if the system is an impoundment, managing water levels (Kohler et al. 1993). In systems where it is desirable, these same factors can be manipulated to limit largemouth bass recruitment. Managing largemouth bass recruitment through availability of bluegill as prey for YOY largemouth bass can take the form of enhancing bluegill reproduction through harvest regulations, adequate nesting habitat, and reduction of competitors such as gizzard shad. Even if bluegill abundance promoted higher largemouth bass recruitment indirectly through reduced predation on YOY largemouth bass individuals, efforts to enhance bluegill reproductive success should provide benefits for largemouth bass recruitment.

Within Illinois, there was a large enough range of environmental contexts (e.g., lake size, prey abundance, gizzard shad presence or absence) for us to test and find differing mechanisms of recruitment; therefore, expanding this type of study to other portions of the largemouth bass range, encompassing community and environmental contexts not found in our study, would deepen our understanding of recruitment even further. The general environmental setting of the largemouth bass populations in our study was eutrophic impoundments within the central portion (mid-latitudes) of the largemouth bass range. The inhabited range of largemouth bass is expansive enough to cover environments with very different growing season lengths and winter severity (e.g., Ontario, Canada versus Alabama, USA), resulting in potential differences in timing and duration of nesting and in community composition (e.g., presence or absence of gizzard shad; Aday et al. 2009). These latitudinal differences in seasonality could lead to differences in the timing of year class establishment as well as the mechanisms involved (e.g., predation versus starvation during winter; Garvey et al. 1998; Fullerton et al. 2000). Systems with very different growing seasons and productivities should exhibit spatial variation in growth rate, leading to potential differences in largemouth bass life history (e.g., age at maturity; Aday et al. 2009) that could alter pathways of recruitment. In addition, the outcome of complex food web interactions should also change along latitudinal and productivity gradients (e.g., relative influence of gizzard shad and predator-prey relationship with bluegill; Garvey et al. 2002b;

DeVries et al. 2009). Timing of year class establishment will likely vary with the severity of disturbance (e.g., angling pressure, storms, water level fluctuation) during largemouth bass nesting (Parkos and Wahl 2002), with the frequency and severity of these disturbances varying among system types (e.g., natural lakes vs. impoundments) and latitude (e.g., high versus low latitudes). To continue making progress in the study of recruitment, more studies are needed that simultaneously address multiple potential mechanisms influencing recruitment and account for spatial and temporal variation in the environmental context of early life history.

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Table 1. Physical characteristics of 12 lakes containing largemouth bass populations. Total area (hectares) and mean and maximum depth (meters) are from Austen 1993. Lakes were sampled for 5-8 years on a twice monthly (bimonthly) or monthly basis. Secchi depths are mean values for the study period.

Lake	Area (ha)	Mean depth (m)	Max. depth (m)	Secchi (m)	Sampling frequency	Years
Clinton	1981	3.35	12.19	0.71	monthly	8
Dolan	29	1.9	5.18	0.48	monthly	5
Forbes	226	4.62	9.45	0.67	bimonthly	8
Lake of the Woods	11	2.86	6.7	1.38	bimonthly	7
Lincoln Trail	57	4.84	10.7	2.02	bimonthly	8
Paradise	57.6	2.59	4.88	0.43	bimonthly	8
Pierce	61.2	3.41	10.06	0.92	monthly	8
Ridge	7	3	7.6	0.95	bimonthly	8
Shelbyville	4492	5.76	24	1.06	bimonthly	8
Sterling	28.6	4.37	7.01	2.08	monthly	8
Walnut Point	22	3.82	9.75	0.97	bimonthly	8
Woods	11.21	2.23	5.79	0.65	bimonthly	8

Table 2. Mean values and (coefficients of variation) for largemouth bass spawning stock (N/hr), peak density of young-of-the-year (N/m^2), fall abundance of young-of-the-year (N/hr), total length of fall young-of-the-year (mm), and abundance of age-1 recruits (N/hr). Values are based on 5-8 years of sampling (see Table 1 for lake-specific sampling information).

Lake	Spawning Stock	Peak YOY	Fall YOY	Fall TL	Age-1
Clinton	8.8 (50)	0.1 (110)	6.4 (80)	113 (10)	2.7 (90)
Dolan	6.5 (40)	0.1 (160)	3.3 (50)	126 (10)	4.1 (170)
Forbes	8.6 (50)	0.3 (80)	17.3 (60)	121 (10)	4.5 (110)
Lake of the Woods	1.0 (50)	1.8 (90)	10.6 (90)	101 (10)	6.1 (80)
Lincoln Trail	9.2 (50)	1.1 (200)	32 (50)	110 (10)	15.1 (70)
Paradise	7.9 (60)	0.04 (150)	9.8 (130)	122 (10)	1.4 (90)
Pierce	10.3 (50)	1.0 (200)	32 (120)	121 (10)	16.4 (90)
Ridge	5.7 (20)	11 (270)	25.9 (70)	100 (20)	8.9 (100)
Shelbyville	9.9 (90)	0.1 (150)	6.0 (70)	115 (4)	3.9 (60)
Sterling	5.6 (60)	0.6 (150)	10.2 (60)	93 (10)	3.2 (80)
Walnut Point	3.7 (50)	9.9 (100)	67.3 (120)	96 (10)	14.1 (80)
Woods	7.3 (40)	2.3 (240)	6.2 (60)	112 (10)	2.4 (100)
Inter-system	7.8 (30)	2.4 (160)	18.9 (100)	111 (10)	6.9 (80)

Table 3. Mean values and (coefficients of variation) for chlorophyll *a* concentration (µg/L), spring density of zooplankton (N/L), density of benthos (N/m^2), total density of larval *Lepomis* (N/m^3), August density of larval *Lepomis* (N/m^3), summer density of juvenile bluegill (N/m^2; bluegill TL $\leq$ 60 mm), and fall abundance of gizzard shad (N/hr). Values are based on 5-8 years of sampling (see Table 1 for lake-specific sampling information).

Lake	Chlorophyll *a*	Spring Zooplankton	Benthos	Total Lepomis larvae	August Lepomis larvae	Juvenile Bluegill	Gizzard shad
Clinton	36 (40)	115 (190)	6583 (90)	2.9 (130)	0.4 (160)	0.2 (210)	254 (60)
Dolan	55.8 (30)	59 (40)	2561 (100)	22.3 (90)	6.3 (70)	0.2 (40)	20.1 (30)
Forbes	28.1 (60)	75 (80)	1014 (40)	23.5 (110)	2.6 (140)	2.1 (100)	39.2 (50)
Lake of the Woods	28.8 (70)	198 (150)	16851 (120)	74.8 (70)	12.8 (110)	2.7 (210)	44.7 (50)
Lincoln Trail	18.4 (60)	101 (200)	5165 (70)	715 (230)	34.9 (80)	3.4 (60)	0
Paradise	51.2 (20)	98 (200)	4287 (90)	84.9 (80)	13.3 (130)	0.3 (70)	279 (70)
Pierce	29.5 (50)	253 (200)	5974 (70)	41.5 (210)	23.1 (280)	1.4 (60)	101 (90)
Ridge	23.5 (60)	114 (90)	8674 (140)	99.6 (130)	12.5 (160)	10.1 (100)	0
Shelbyville	21 (70)	125 (130)	2549 (100)	3.2 (70)	0.1 (110)	0.1 (140)	750 (70)
Sterling	8.3 (100)	50 (70)	5381 (100)	0.7 (120)	0.1 (170)	0.3 (150)	11.9 (70)
Walnut Point	40.3 (50)	180 (160)	12654 (90)	528 (120)	139 (100)	1.9 (80)	0
Woods	44.1 (40)	90 (140)	7215 (130)	30.4 (60)	5.0 (100)	0.3 (50)	161 (70)
Inter-system	32.1 (40)	122 (50)	6576 (70)	136 (170)	20.8 (190)	1.9 (150)	138 (160)

Table 4. Multiple linear regression models for largemouth bass recruitment to age 1 in 12 study lakes in Illinois. All models were significant at 0.05.

Lake	Adjusted R^2	Variables	Coefficients	P-values
Clinton	0.63	August Lepomis larvae	0.32	0.02
Dolan	0.91	Total Lepomis larvae	0.02	0.03
Forbes	0.52	$\log_{10}$(Juvenile Bluegill)	0.58	0.03
Lake of the Woods	0.73	$\log_{10}$(Peak YOY bass+0.001)	-0.33	0.02
Lincoln Trail	0.53	$\log_{10}$(Peak YOY bass+0.001)	14.6	0.03
Paradise	0.84	$\log_{10}$(Peak YOY bass+0.001)	2.19	0.001
Pierce	0.59	$\log_{10}$(Fall YOY bass)	0.65	0.03
Ridge	0.53	Winter temperature deviation	2.3	0.03
Shelbyville	-	none	-	-
Sterling	0.68	$\log_{10}$(Total Lepomis larvae)	3.37	0.01
Walnut Point	0.52	$\log_{10}$(Peak YOY bass+0.001)	11.9	0.03
Woods	-	none	-	-

Figure 1. Conceptual model of factors affecting recruitment of largemouth bass to age-1. Three general classes of factors are examined: reproductive output, trophic conditions, and winter survival. In each box are the measured variables associated with each factor. Recruitment is conceptualized to occur in three stages: peak young-of-year (YOY) indexes output from spring nesting stage, fall YOY catch-per-unit-effort measures survival from first growing season, and age-1 CPUE measures recruitment to the spring following the first winter.

Figure 2. Locations of twelve study populations in Illinois used to evaluate mechanisms determining recruitment in largemouth bass.

Figure 3. Relationship between the abundance of YOY largemouth bass in the fall (N/hr) and the abundance of the same year class as age-1 recruits the following spring. Data are from spring and fall electrofishing surveys. Values are mean abundances across 8 year classes for each of 10 populations.

Figure 4. Relationships between fall abundance of YOY largemouth bass and summer density of juvenile bluegill (N/m^2). Data for fall abundance of YOY largemouth bass are from electrofishing surveys and data for juvenile bluegill density are from seine samples. Values are means across 8 year classes for each of 10 populations.

Figure 5. Relationships between fall mean total lengths (mm) of YOY largemouth bass and mean (A) secchi depth (m) and (B) largemouth bass spawning stock (N/hr). Data for spawning stock abundance and fall size structure of YOY largemouth bass are from electrofishing surveys. Secchi depth values are based on twice monthly to monthly measurements depending on the lake (see Table 1). Values are means across 8 year classes for each of 10 populations.

Figure 1

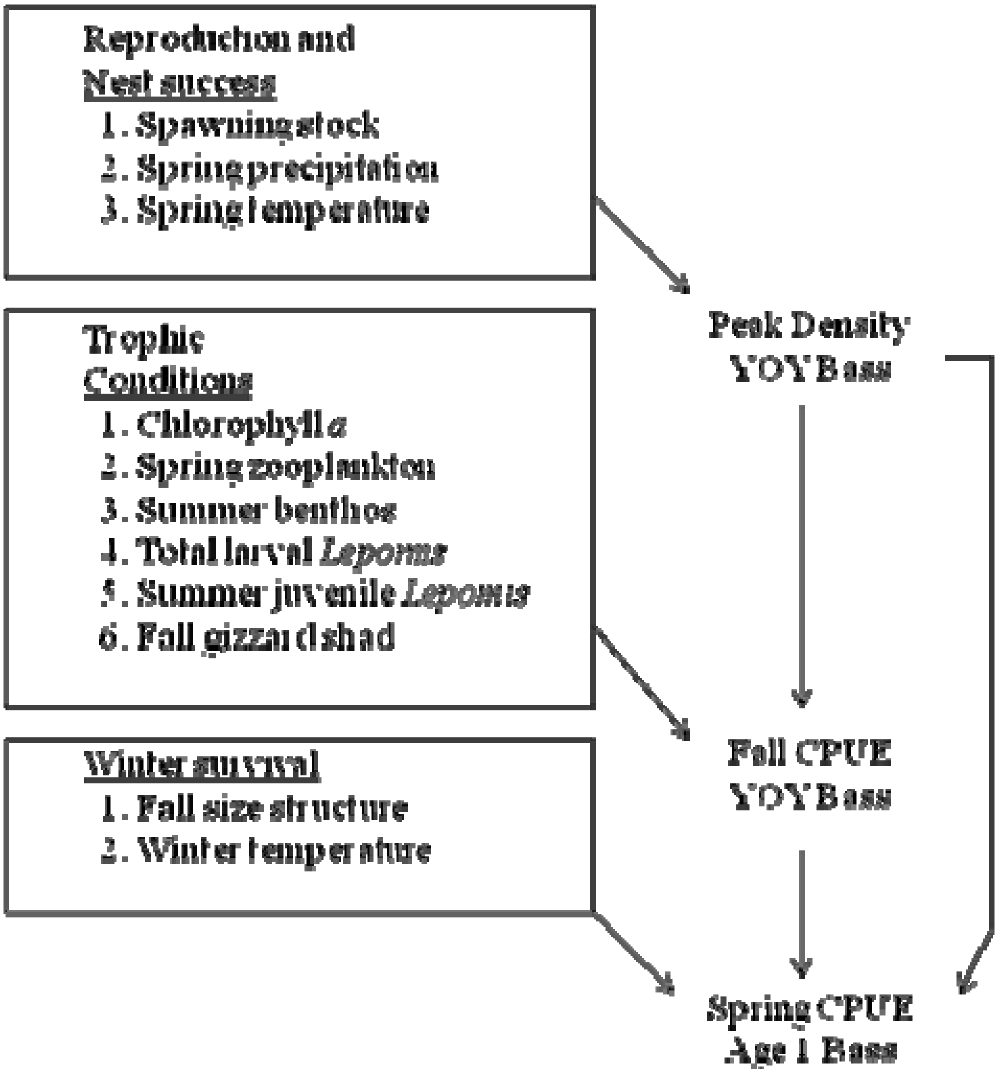

Reproduction and Nest success
1. Spawning stock
2. Spring precipitation
3. Spring temperature
Trophic Conditions
1. Chlorophyll *a*
2. Spring zooplankton
3. Summer benthos
4. Total larval *Lepomis*
5. Summer juvenile *Lepomis*
6. Fall gizzard shad
Winter survival
1. Fall size structure
2. Winter temperature
Peak Density YOY Bass
Fall CPUE YOY Bass
Spring CPUE Age 1 Bass

Figure 2

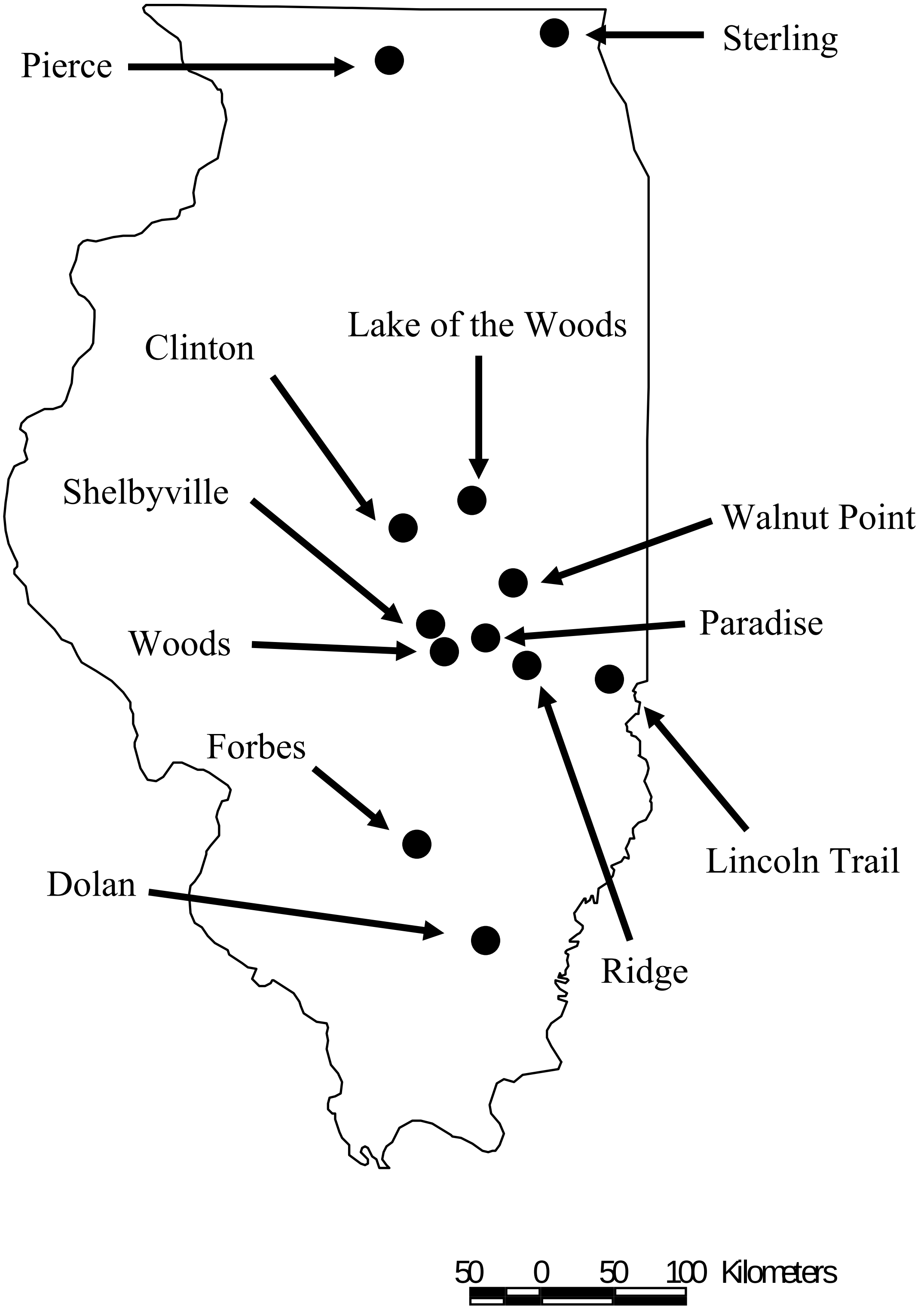

Sterling
Pierce
Lake of the Woods
Clinton
Shelbyville
Walnut Point
Paradise
Woods
Forbes
Lincoln Trail
Dolan
Ridge
50 0 50 100 Kilometers

Figure 3

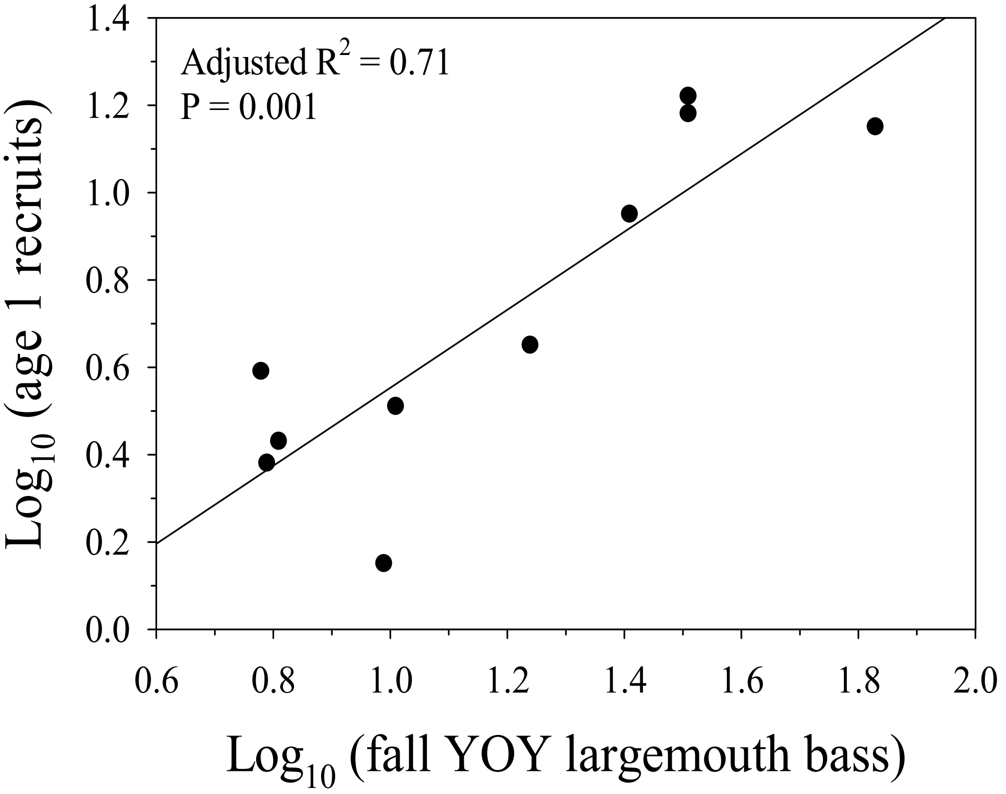

Adjusted $R^2 = 0.71$
$P = 0.001$
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
Log_{10} (age 1 recruits)
Log_{10} (fall YOY largemouth bass)

Figure 4

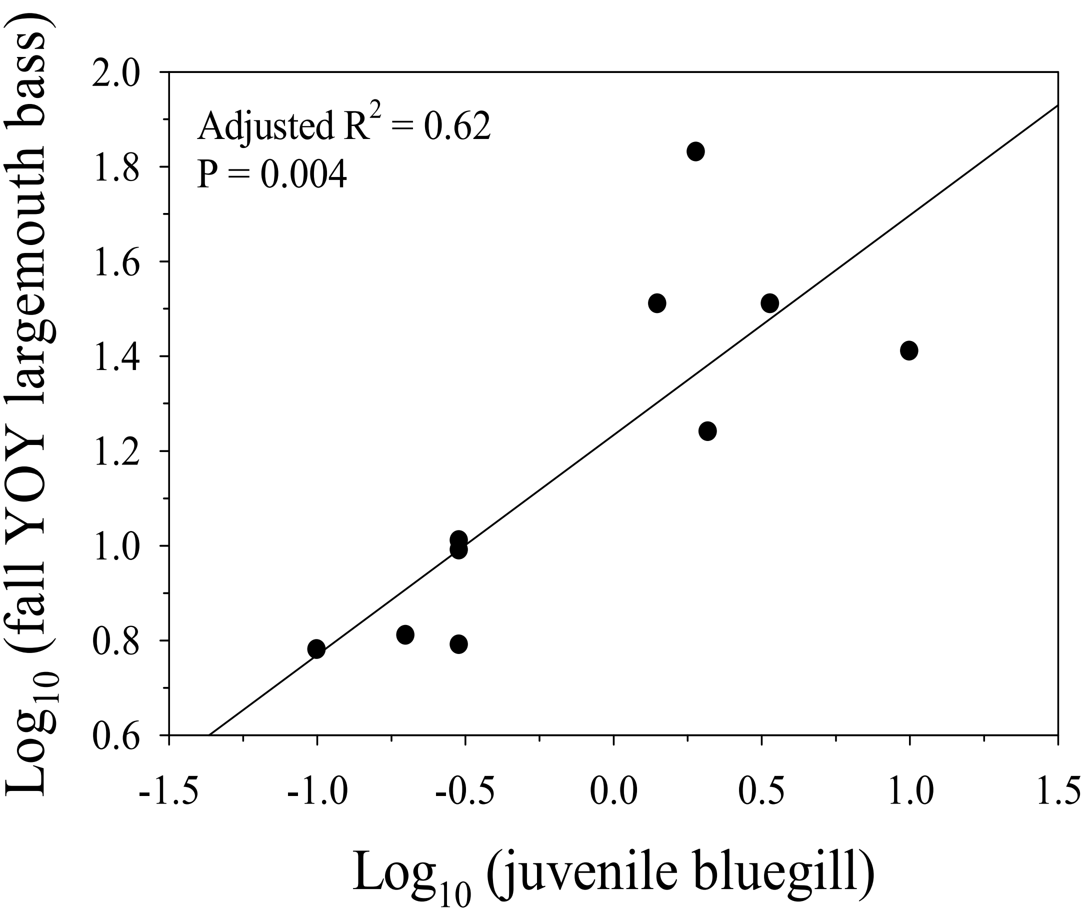
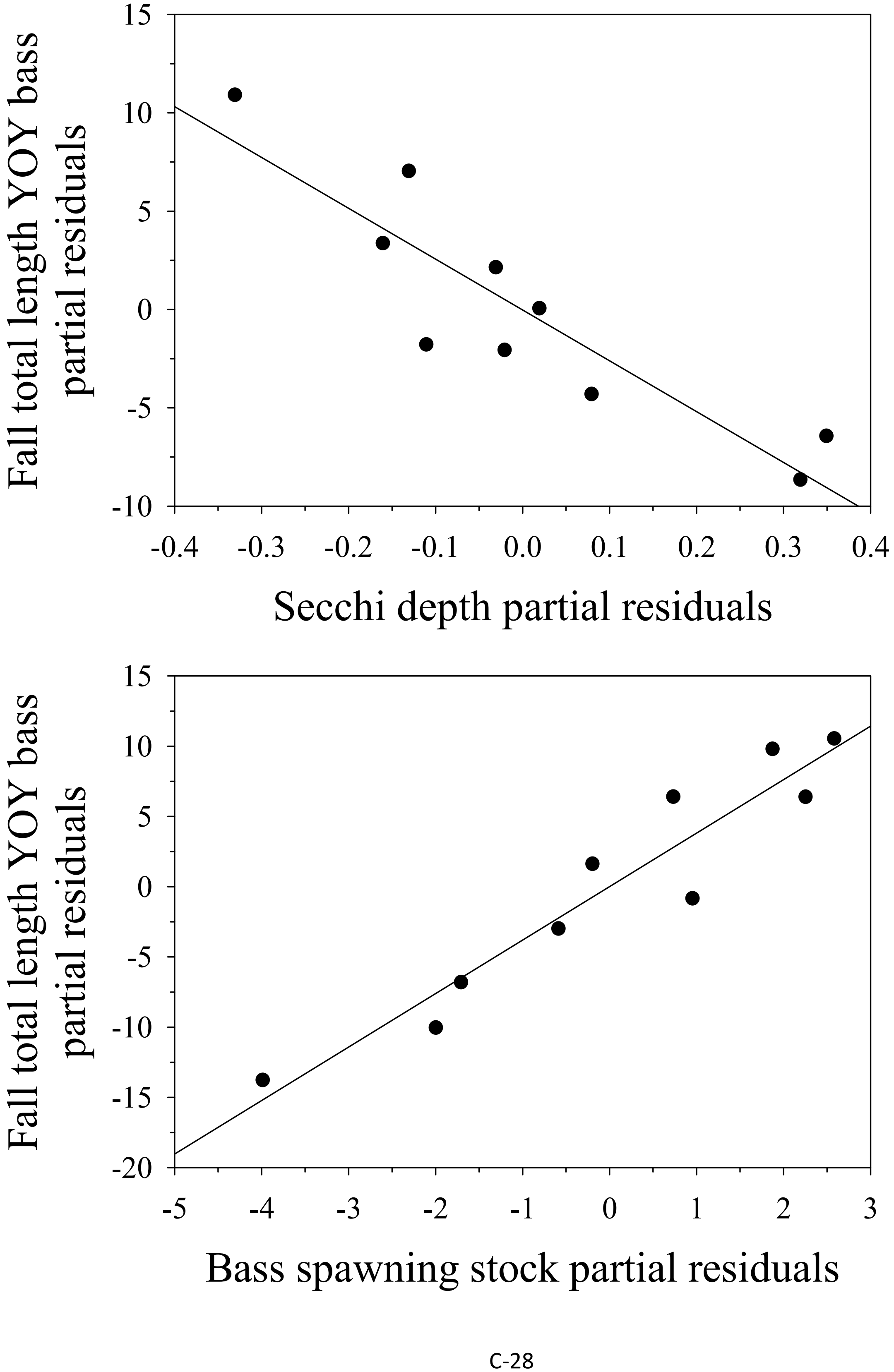

Adjusted $R^2 = 0.62$
P = 0.004
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
Log$_{10}$ (fall YOY largemouth bass)
Log$_{10}$ (juvenile bluegill)

Figure 5


Fall total length YOY bass partial residuals
15
10
5
0
-5
-10
-0.4
-0.3
-0.2
-0.1
0.0
0.1
0.2
0.3
0.4
Secchi depth partial residuals
Fall total length YOY bass partial residuals
15
10
5
0
-5
-10
-15
-20
-5
-4
-3
-2
-1
0
1
2
3
Bass spawning stock partial residuals

Appendix D

Diana, M.J., A.L. Larsen, M.J. Siepker, and D.H. Wahl. 2012. Effects of tournament compared with catch and release angling on nest abandonment of largemouth bass. North American Journal of Fisheries Management 32(5):832-837.

Effects of Tournament Compared to Catch and Release Angling on Nest Abandonment of Largemouth Bass

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Abstract

The popularity of tournament angling for largemouth bass *Micropterus salmoides* remains high, leading to concerns about the effects on populations. Catch-and-release angling and its effects on nest abandonment have been well documented, but few studies have examined the effects of competitive angling on nest abandonment. Nest-guarding male largemouth bass were subjected to one of three treatments: no angling controls, catch-and-release angling, and simulated tournament angling. Abandonment rates were assessed at 24 h following angling. Both angling treatments experienced higher abandonment rates than the control group (3%) with tournament-angled males abandoning their nests at a higher rate (90%) than catch-and-release males (33%). Additional research will be required to determine the population-level consequences of these angling practices. Until then, a conservative recommendation would be for organizers to consider alternative tournament formats during the reproductive season for largemouth bass.

Introduction

Largemouth bass *Micropterus salmoides* are an extremely popular sport fish and populations can experience high amounts of angling pressure. Of particular concern is the effect of angling on spawning success of largemouth bass and how this can influence recruitment (Schramm et al. 1991a; Philipp et al. 1997; Siepker et al. 2007; Siepker et al. 2009). Male largemouth bass are aggressive and vulnerable to angling in the spring while guarding nests (Colgan and Brown 1988; Philipp et al. 1997; Cooke et al. 2002a; Suski and Philipp 2004) and they will guard a nest and young for up to 4 weeks (Brown 1984; Colgan and Brown 1988). Removal of spawning males by angling has been shown to reduce individual largemouth bass reproductive success in a variety of angling scenarios (Philipp et al. 1997; Suski et al. 2003a; Wagner et al. 2006; Hanson et al. 2007; Siepker et al. 2009). Catch-and-release angling of nesting largemouth bass results in increased brood predation and increased nest abandonment rates (Philipp et al. 1997; Suski et al. 2003a). Catch and release angling also has been shown to have physiological effects on largemouth bass (Gustaveson et al. 1991; Cooke et al. 2000; Cooke et al. 2002b) that may also reduce the potential for successful brood production of individuals (Ostrand et al. 2004). In addition to catch-and release angling, harvest permanently removes fish from the nest. In modeling simulations, fishing closures during the spawning season resulted in increased abundance of adult fish, although only under extreme harvest levels (Gwinn and Allen 2010). It is likely that substantial angling for nesting bass would have negative effects on reproductive success.

Competitive angling tournaments for largemouth bass commonly occur during the period when fish are nesting and have the potential to increase the effects of angling beyond those of catch and release on individual reproductive success. During competitive angling events, fish are held in livewells for several hours in some instances, and then transported to a central location where they are subjected to the weigh-in procedure and released. Each of the components of a tournament (confinement, transportation, and weigh-in) can increase stress in largemouth bass (Furimsky et al.

2003; Suski et al. 2003b; Suski et al. 2004). Previous studies have considered how abandonment rates of largemouth bass are affected by individual components of tournament angling (Siepker et al. 2009), but none have examined a typical tournament in its entirety including the weigh-in. Nest abandonment of largemouth and smallmouth bass *Micropterus dolomieu* increases as both time away from the nest and distance released from the nest increase (Hanson et al. 2007; Siepker 2009). However, the weigh-in process has not been considered for largemouth bass and has been identified as one of the most significant stressors for tournament angled fish resulting in significant metabolic disturbances and reduced physiological condition (Suski et al. 2004). Smallmouth bass experience higher abandonment rates than largemouth bass when subjected to tournament angling that includes a weigh-in (Hanson et al 2008). In another study, Hanson et al. (2007) found that largemouth bass subjected to weigh-in procedures and that had their broods manually reduced by 90% during their confinement had higher abandonment rates than individuals that did not experience the weigh-in or brood reductions. At this time, abandonment rates of largemouth bass subjected to an entire tournament event (including weigh-in but without artificially decreased broods) are not known.

Previous studies of black bass nest abandonment have primarily focused on smallmouth bass (Kieffer et al. 1995; Suski et al. 2003a; Hanson et al. 2008; Lunn and Steinhart 2010) or been conducted at northern latitudes (Kieffer et al. 1995; Philipp et al. 1997; Suski et al. 2003a; Hanson et al. 2007; Siepker et al. 2009; Lunn and Steinhart 2010). In one study, Hanson et al. (2008) noted a difference in nest abandonment rates when simulated tournament procedures were applied to smallmouth bass across varying latitudes, suggesting that latitudinal variation in nest abandonment likelihood may exist. Therefore, to better understand the effects of tournament angling on black bass, nest abandonment needs to be evaluated for largemouth bass in middle latitudes.

We examined nest abandonment rates resulting from tournament angling of largemouth bass in the middle latitudes of their range. Treatment fish were subject to typical tournament angling events that included angling, live well confinement, displacement from the nest, and weigh-in. We compared abandonment rates of these individuals to those of catch-and-release and unhandled control groups. The objectives of our study were to determine the level of nest abandonment associated with tournament angling and weigh-in procedures relative to the abandonment rates of fish subjected to catch-and-release angling. We also discuss how our findings compare to other studies conducted at differing latitudes and potential implications for black bass management.

Methods

Snorkel surveys were used to assess largemouth bass spawning activity, nest site selection by males, and the effects of angling on nesting success in Lincoln Trail Lake in east central Illinois. Lincoln Trail Lake contains a variety of known nest predators (e.g., bluegill *Lepomis macrochirus*, redear sunfish *Lepomis microlophus* and black crappie *Pomoxis nigromaculatus,* Colgan and Brown 1988). Six transects were monitored for largemouth bass nests throughout the spawning season (generally April 10 through May 30) over 3 years. Nests were identified by snorkelers, marked using a white PVC nest tag, and assigned an egg score (1-5) depending on the number of eggs present in the nest

(1= low number of eggs, 5= high number of eggs; Kubacki 1992; Parkos et al. 2011). Egg scores are positively related to the number of eggs in a nest with egg score 1 = 9,000 ± 3,100, egg score 2 = 13,100 ± 2,200, egg score 3 = 14,700 ± 1,900, egg score 4 = 29,100 ± 6,300, and egg score 5 > 35,000 (Parkos et al. 2011). The water depth of each nest, the water temperature and the developmental stage of the offspring were measured and recorded. Only nests containing eggs with egg scores of 4 or 5 were included in this study to standardize the effects of brood size and developmental stage on parental investment levels.

Once nest locations were identified, they were randomly assigned to one of three treatments: catch-and-release, tournament (competitive angling), and no angling controls. Treatments were evenly distributed on each date of snorkeling. Males were removed from the nest by snorkelers using a 2-m fishing pole rigged with 2 m of monofilament tied to a treble hook. Fish were then brought to a boat located 10 m from the nest where they were removed from the hook, measured for total length (TL) and the appropriate treatment was administered. Males from the catch-and-release treatment were held for a two-minute air exposure (from the moment it was removed from the water) and released 10 m from the nest to simulate release from an angler's boat. Males from the tournament treatment were held for a 2 min air exposure then placed into an aerated holding tank and held for 2 h to simulate live well confinement of fish during a tournament (Siepker et al. 2009). After 2 h had elapsed, the fish were placed in a weigh-in bag with 7 L of water for two minutes and then exposed to air in an open cooler for two minutes, to simulate typical tournament handling during weigh-in (Suski et al. 2004). Tournament fish were then released 1 km from their nesting site. Both the distance of release from the nest and the time the fish were held in the livewell were conservative and actual tournaments may far exceed these conditions. All angled fish were given an upper caudal clip in order to identify an experimental fish returning to the nesting location. Due to the low number of experimental fish marked on each date, if a clipped fish was observed returning to the nest, there was a high probability that it was the original fish removed from the nest. Control treatment nests were located, marked, and assigned an egg score, but were otherwise not disturbed. Two-way ANOVA was used to test for differences in starting egg score, water depth, and temperature among treatments to ensure random assignment of treatments. Each nest was revisited 24 h after treatment and checked for presence or absence of the nesting male through snorkeling surveys and each nest was again given an egg score based on the number of eggs remaining in the nest. If the male was not present initially, the nest was observed from a distance for 5 min to determine if the nest was indeed abandoned. The number of nests with males present or absent at the end of each treatment was used to calculate proportion abandonment. A logistic regression model was used to examine the relationship between the binary response variable, male abandonment, and angling treatment (SAS 2002). We then tested differences among treatments using Wald chi-square statistics. Model fit was verified using a Hosmer and Lemeshow goodness-of-fit test. Error for abandonment rates were determined by Clopper-Pearson estimates of 95% confidence intervals. Each treatment was examined for differences among treatments in starting egg score, depth, and temperature. One-way ANOVA was used to test for differences in egg score after 24 h to determine if nests that were abandoned resulted in a reduced number of eggs in the nest compared to nests that were not abandoned.

Results

A total of 101 male largemouth bass were observed guarding nests in the experiment. Fifty nine nesting males were not angled and observed as controls. Of the experimentally angled fish, 22 were subjected to simulated catch and release and 20 were subjected to simulated tournament angling. Mean total length of all fish caught was 361 mm ± 6.2 (± 1SE) and Total Length did not vary among treatments (ANOVA; $F = 0.32$; $df = 1, 3$; $P = 0.57$). No significant differences existed either in initial egg score among treatments or between nests that were abandoned and not abandoned following treatment (2-Way ANOVA; $df = 3, 30$; $F = 0.66$; $P = 0.58$). Water depth at nesting location varied from 0.25 to 2.50 meters and did not vary by treatments or among nest that were abandoned and not abandoned (2-Way ANOVA; $F = 0.49$; $df = 3, 30$; $P = 0.69$). Water temperature varied from 16.8 to 23.2 ^{o}C and no significant differences were found in temperature among treatments or among nests that were abandoned or not abandoned (2-way ANOVA; $F = 1.56$; $df = 3, 31$; $P = 0.22$). Since initial egg score, depth and temperature were similar among treatments and between nests that were abandoned or not, we did not include them as covariates in subsequent analyses.

Differences were observed among treatments in the abandonment rates of males guarding the nest ($\chi^2 = 57.6$, $P < 0.001$). Males subjected to the simulated tournament abandoned the nest more often than those exposed to catch-and-release angling (Wald $\chi^2 = 11.4$; $P < 0.001$; Figure 1). Males in control treatments abandoned the nest less often than either of the angling treatments (Wald $\chi^2 > 9.2$; $P < 0.002$). Change in egg score 24 h after the treatment was administered differed among treatments and between abandoned and non-abandoned nests (2-way ANOVA; $F = 49.0$, $P < 0.0001$). When fish abandoned the nest, the resulting change in egg score (-2.8 ± 0.2) was greater than for nests where the guarding male remained or returned (-0.2 ± 0.1). There was a significant interaction between nest abandonment and treatment for egg score (2-way ANOVA; $F = 8.2$; $P = 0.0006$). For all treatments, when largemouth bass abandoned the nest, egg score declined dramatically (Figure 2) and there were no significant differences among treatments ($P > 0.05$). When fish returned to the nest, change in egg score was the highest for the tournament treatment compared to catch-and-release ($t = 3.5$; $P = 0.009$) and control treatments ($t = 5.2$; $P <0.0001$). The tournament treatment nests had a large decrease in egg score for both nests that were abandoned and nests where the male returned and remained to guard the nest. Few tournament treatment nests had males return ($n = 2$) and were away from the nest for a longer period of time than other treatments. Catch-and-release treatments where the male returned to the nest had significantly greater change in egg score than control nests ($t = 3.04$; $P = 0.04$). Changes in egg score were related to the length of time the fish was removed from the nest with the tournament treatment nests experiencing the greatest decline followed by catch-and release and control nests.

Discussion

Male largemouth bass abandoned nests at a high rate when subjected to simulated tournament angling. We found higher abandonment rates for largemouth bass subjected to a complete tournament (90%) than in a previous study where only the distance from and time away from the nest, but not the weigh-in were evaluated (65%; Siepker et al. 2009). Abandonment rates were similar to those observed by Hanson et al. (2007) where a large portion of eggs were removed from the nest in lakes in southern Ontario. In combination, these results suggest that the weigh-in procedure associated with tournaments can increase abandonment rates for male largemouth bass beyond those from other components of a tournament alone. Similarly, tournament weigh-in procedures have been shown to significantly increase the level of physiological stress and reduce fitness in black bass (Furimsky et al. 2003; Suski et al. 2003b; Ostrand et al. 2004; Suski et al. 2004). Largemouth bass have been shown to have higher abandonment rates associated with increased duration of time they are removed from the nest due to the increased level of nest predation (Philipp et al. 1997; Siepker et al. 2009). The weigh-in associated with tournaments adds additional physiological stress as well as distance and time away from the nest resulting in a higher probability of nest abandonment. Largemouth bass captured in some live release tournaments have been shown to be displaced greater distances than the 1 km we used for this experiment (Wilde 2003) suggesting even greater abandonment rates from tournaments are possible.

Catch and release angling caused increased nest abandonment when compared to controls, but were significantly lower than fish that experienced tournament angling. Catch-and-release fish were removed from the nest for a much shorter duration than tournament treatment fish and did not experience the increased stress of weigh-in and displacement from nesting location. The abandonment rate of catch-and-release fish in our study (32%) was higher than that observed in similar studies with largemouth bass (~10%; Siepker et al. 2009) and smallmouth bass (0 to 10%; Suski et al. 2003a; Hanson et al. 2008; Siepker et al. 2009). However, Philipp et al. (1997) measured higher abandonment rates (44%) of catch-and-release angled smallmouth bass and largemouth bass than in our study when fish were removed from nests for a similar time duration as we used.

Most studies examining nest abandonment have focused on smallmouth bass (Kieffer et al. 1995; Suski et al. 2003a; Hanson et al. 2008; Lunn and Steinhart 2010). However, there may be differences in nest guarding and abandonment between largemouth and smallmouth bass. Lower levels of nest abandonment have been observed for nest guarding smallmouth bass (~0%) than largemouth bass (10% - 55%) when exposed to catch and release (Hanson et al. 2007; Siepker et al. 2009). Abandonment rates from these studies were measured for populations of largemouth bass at the northern extent of their range in southern Ontario and may vary by latitude. Climate, nest predators, condition of fish and angling pressure can vary with latitude and may influence abandonment rates. Smallmouth bass have higher abandonment rates when exposed to tournament conditions in Missouri (similar latitudes to this study) when compared to two populations in Ontario (Hanson et al. 2008). Similarly, abandonment rates of largemouth bass in our study (34%) were higher than from four lakes in Ontario (10%) during catch and release angling (Siepker et al. 2009). Combined, these results suggest the potential for latitudinal and species interactions to influence nest abandonment due to angling. Our study at mid-latitudes provides a measure of abandonment rates for catch-and release and tournament angling for largemouth bass for future comparisons at other latitudes. Regardless of the outcome of these studies, largemouth bass that experience tournament angling have an elevated probability of nest abandonment, much higher than from catch-and-release angling when fish are released at the site of capture within minutes of being angled.

Largemouth bass nests that were abandoned had significantly lower egg scores than those that were not abandoned. When a nest is left unguarded, significant nest predation occurs (Kieffer et al. 1995; Philipp et al. 1997; Steinhart et al. 2004) and we observed large decreases in egg scores when a nest was abandoned, most likely due to nest predation. Nest predation or the reduction of brood in a nest has been shown to directly influence nest abandonment rates of parental male black bass (Suski et al. 2003a; Siepker et al. 2007). Nests may have been abandoned due to the decrease in egg numbers when the fish was removed from the nest or from stress caused by angling. We were unable to separate these potential causes in the current study because we did not evaluate the egg score at the time the fish returned to the nest. However when male largemouth bass abandoned the nest, the eggs were left unguarded and we observed a significant decrease in the egg score. When the eggs are left unguarded and we observed a significant decrease in the egg score, which reduces the reproductive potential from the individual nest.

Despite evidence from this study and others that angling fish from the nest can result in brood loss, the population wide effects on recruitment are unknown. The potential for decreased recruitment resulting from nest abandonment and brood loss could be affected by several factors. A strong relationship between stock and recruitment is required, however many studies failed to show a link and any relationship is probably nonlinear (Reynolds and Babb 1978; Weidel et al. 2007; Zipkin et al. 2008; Allen et al. 2011). Compensatory mechanisms could occur where surviving juveniles from unaffected nests experience greater growth and survival due to a release of resources through density dependent processes (Weidel et al. 2007; Zipkin et al. 2008). However, if brood loss is great enough, lake-wide recruitment may decline.

The level of nest abandonment as a result of angling may need to be very high to have an effect on recruitment. Modeling has shown that abundance of adult bass was only decreased under very high and potentially unrealistic fishing pressures (Gwinn and Allen 2010). Capture would also have to occur during the short time when largemouth bass are guarding the nest in order to result in brood loss. It is unknown what proportion of a population is captured during fishing tournaments and probability of capture would be affected by the angling pressure and the catchability of the fish. Removing individuals that are susceptible to angling from the recruiting population could result in a reduction in angling vulnerability of the entire population (Cooke et al. 2007; Philipp et al. 2009; Nannini et al. 2011). Larger individuals that are more aggressive nest defenders and more susceptible to angling (Suski and Philipp 2004) are also preferred by tournament anglers. Future research should focus on determining if the level of angling that occurs on nesting largemouth bass is great enough to influence population level recruitment.

While angling during the spring spawning season is permitted in many areas (Quinn 2002), our study, along with others (Phillip et al. 1997; Suski et al. 2003, Siepker et al. 2009), provide evidence that angling has negative effects on the reproductive success of individual black bass. Some fisheries management agencies have limited competitive tournaments, or invoked closed fishing periods, catch-and-release regulations, and various length and harvest limits in different combinations in an attempt to limit angling of largemouth bass during the spawning season (see Schramm et al. 1995). These measures leave some portion of the spawning population unexposed to angling practices. We provide evidence that there is substantial nest abandonment associated with angling, especially during tournaments. Catch and release angling can increase abandonment rates in largemouth bass guarding a nest, but at significantly lower levels than tournament angling. The most cautious approach is for anglers and managers to consider limiting tournaments during the reproductive periods or consider alternative tournament formats (e.g. paper tournaments) where the weigh-in is removed from the process.

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Figure Captions

Figure 1. Abandonment rates of male largemouth bass from controls with no angling, catch-and-release angling, and simulated tournament angling in Lincoln Trail Lake, Illinois. Values in parentheses are the number of nests in each treatment. Error bars represent Clopper-Pearson 95% estimated confidence intervals.

Figure 2. Mean change in egg score of each nest from first observation until 24 h later. Nests were separated into those where the nesting male continued to guard following treatment (returned, solid circles) and nests where the males were not present 24 h later (abandoned, open squares) for each of the three administered treatments. Similar letters indicate bars that are not significantly different ($P > 0.05$). Error bars represent standard errors.

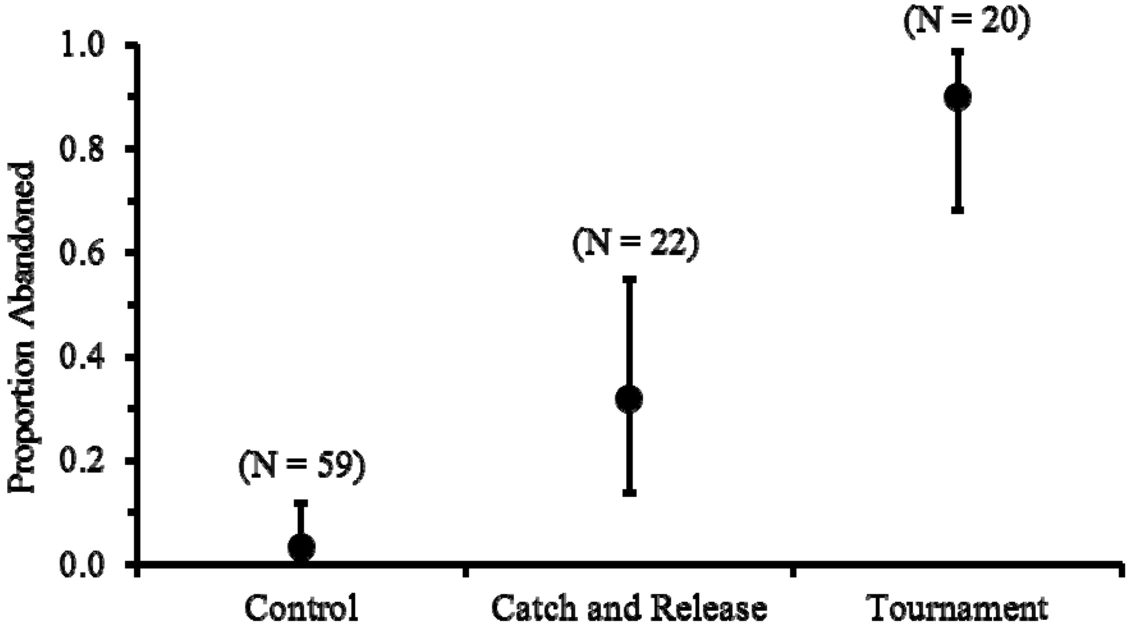
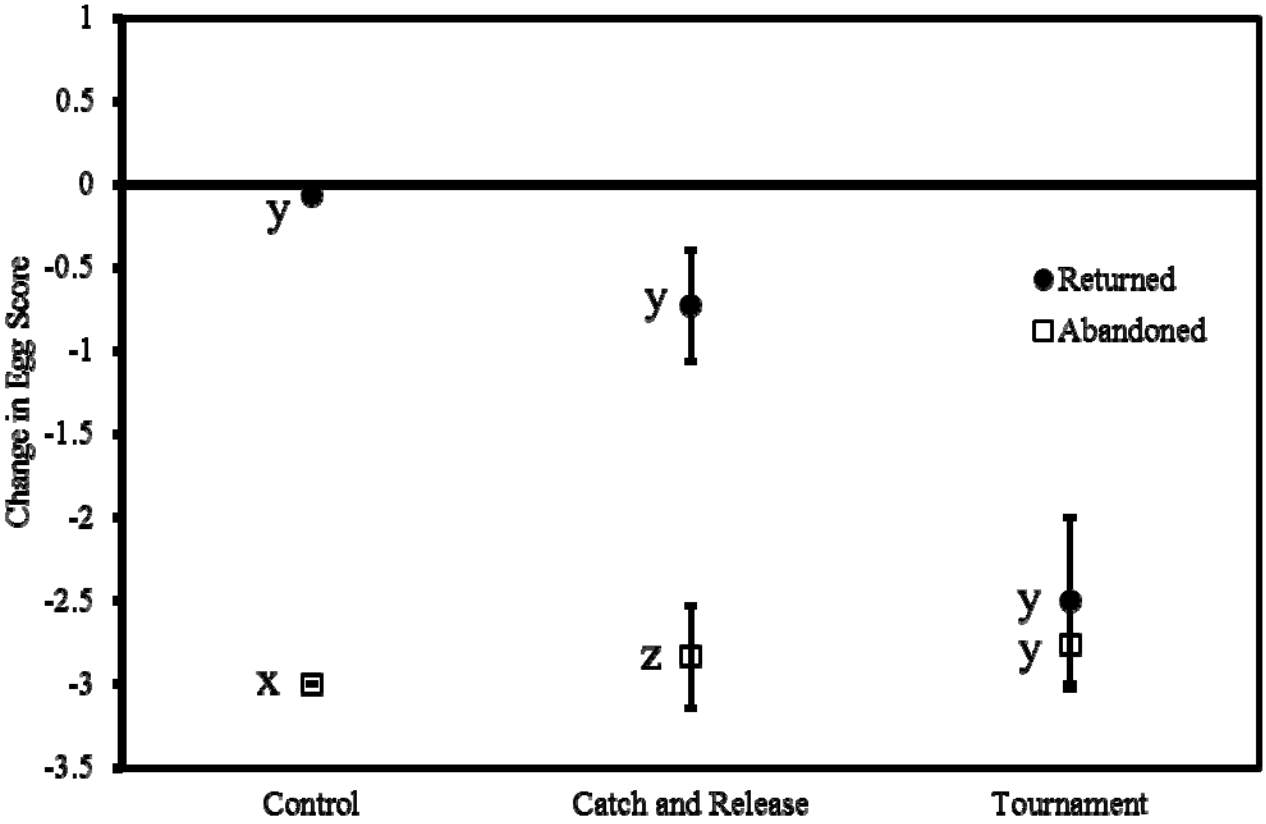

Proportion Abandoned
1.0
0.8
0.6
0.4
0.2
0.0
(N = 59)
(N = 22)
(N = 20)
Control
Catch and Release
Tournament

Figure 1.


1
0.5
0
-0.5
-1
-1.5
-2
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-3
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Change in Egg Score
y
y
y
y
x
z
● Returned
□ Abandoned
Control
Catch and Release
Tournament

Figure 2

Appendix E

Ostrand, K. G., M. J. Siepker, D. H. Wahl. 2011. Effectiveness of livewell additives on largemouth bass survival. Journal of Fish and Wildlife Management 2: 22-28.

Effectiveness of Livewell Additives on Largemouth Bass Survival

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Keywords:

Largemouth bass; Tournament; Competitive Angling; Livewell; Water Conditioners

Abstract

Livewell conditions during competitive angling events are thought to affect fish mortality. We examined the effects of livewell additives on initial and delayed mortality of largemouth bass *Micropterus salmoides.* We applied three treatments (salt, ice, or salt and ice) to livewells during tournaments conducted on lakes in Illinois as well as in laboratory and pond experiments designed to examine the effects of fish size and ambient water temperature on mortality. Fish were collected after weigh-in and monitored for delayed mortality every 24 h for 5 d. Initial mortality did not differ among livewell additives during field evaluations. Although delayed mortality was high it was not significantly different among livewells that contained salt (56%), ice (48%), ice and salt (40%) and controls (30%) suggesting that additives may have a null or possibly a negative effect as compared to controls. Additives administered during laboratory evaluations, at cool water temperatures, resulted in significantly lower delayed mortalities than those observed during the field evaluations when ambient water temperatures were warmer. Initial and delayed mortality did not differ among livewell additives during the laboratory evaluations. Larger fish in field evaluations had significantly greater delayed mortality than smaller fish even though initial and delayed mortality did not differ among livewell additives. Our results suggest that that fish size and ambient water temperature have a greater influence on delayed mortality observed during competitive angling events than the specific livewell additives (i.e. salt and ice or their combination) studied here.

Introduction

Black bass (*Micropterus* spp.) are a commonly sought species in the United States that are often targeted during competitive angling events (Schramm et al. 1991; Paukert et al. 2007). Since the rate of competitive angling events continues to increase (Kerr and Kamke 2003; Schramm and Hunt 2007), interest in minimizing mortality is an issue of concern among anglers and fisheries biologists alike (Siepker et al. 2007; Schramm and Hunt 2007). Acting on these interests, researchers have examined the effects that fish size (Meals and Miranda 1994; Weathers and Newman 1997; Neal and Lopez-Clayton 2001), water temperatures (Schramm et al. 1987; Meals and Miranda 1994; Neal and Lopez-Clayton 2001), various tournament procedures (Weathers and Newman 1997; Suski et al. 2004), and livewell conditions (Carmicheal et al. 1984; Plumb et al. 1988; Cooke et al. 2002; Gilliland 2002; Suski et al. 2004) have on black bass survival rates after competitive angling events. Indeed black bass mortality associated with these events can be relatively low (0 to 28%) whereas other events result in mortality rates as high as 98% (Champeau and Denson 1988; Lee et al. 1993; Wilde 1998; Neal and Lopez-Clayton 2001; Gilliland 2002; Wilde et al. 2002; Edwards et al. 2004; Seipker et al. 2007). Even with continued research and literature available to anglers on improving survival of their catches (see Gilliland and Schramm 2002; Tufts and Morlock 2004), mortality rates have not been substantially reduced since the 1980's (Wilde 1998).

Water quality in livewells during these events has been considered a contributing factor to black bass mortality (Plumb et al. 1998; Gilliland 2002). As a result, tournament anglers have been encouraged to use livewell additives such as ice, commercially available water conditioners, and antibacterial treatments (including salt) as a means to reduce mortality rates (Gilliland and Schramm 2002; Gilliland 2002). However, current research provides equivocal support regarding the benefits to fish of using livewell additives. Plumb et al. (1988) examined livewells with or without water conditioners and found that water conditioners enhanced survival. Gilliland (2002) reported that diffused pure oxygen added to livewells reduced mortality compared to combinations of salt and ice or control groups with continuous or intermittent water flow through. Conversely, Cooke et al. (2002) found delayed physiological recovery of fish held in livewells containing chemical conditioners compared to fish held in livewells containing only lake water, suggesting conditioners were detrimental to fish recovery. Still others have shown that physiological recovery is delayed when fishes are placed in water cooler than from where they were captured (Suski et al. 2006). How sublethal physiological responses affect mortality of fish held in livewells is still unknown. At present, there is disparate information available to anglers regarding whether or not to use chemical additives or chill livewell water. Additionally, many studies examining livewell additives combine several treatments, including fungicides, anesthetics, ice, and salt which makes it difficult to assess the merits of using these products independently.

We conducted a field experiment to compare initial and delayed mortality of competitively angled largemouth bass that had been confined over a period of time (up to eight hours) in livewells that contained either ice, salt, salt and ice (treatments), or recirculated lake water (control). Given the evidence that water temperature (Schramm et al. 1987; Meals and Miranda 1994; Neal and Lopez-Clayton 2001) and fish size (Meals and Miranda 1994) are positively related to tournament mortality, we also conducted lab and pond studies comparing survival of fish subjected to these treatments at differing water temperatures and across differing sizes of largemouth bass.

Methods

Field Evaluation

We contacted largemouth bass tournament organizers and received permission to randomly place additives within boat livewells during competitive angling events (N = 3). The three separate field experiments occurred on June 28th (surface water temperature at weigh-in = 25.1 °C), July 21st (surface water temperature at weigh-in = 34.5 °C), and August 4th (surface water temperature at weigh-in = 30.8 °C) at Lake Shelbyville, IL (Latitude: 39º 40' 84.0 N, Longitude: 88º 77' 78.0 W). We chose tournaments that had manageable numbers of participants (< 50 boats) and that launched from locations near cooperating marinas where holding net pens could be secured for five days.

Boats were randomly given both appropriate livewell additives and instructions on their use. We instructed anglers assigned the salt treatment to add 109 g of non-iodized salt, hereafter referred to as salt, per 18 L of water to make approximately a 5% solution (Gilliland and Schramm 2002) at the onset and then again at the midpoint (i.e., 4 hours from tournament onset) of the tournament if they flushed their livewell. We instructed those assigned the ice treatment to fill livewells and add a 3.8 L block of ice to cool the water by approximately 5 °C (Gilliland and Schramm 2002) adding additional ice approximately every two hours in order to maintain temperature. Anglers that were assigned a combination treatment added both salt (5% solution) and ice (quantity to cool the water by approximately 5 °C) to their livewells as outlined above. Lastly, we instructed individuals that were assigned the control treatment to operate livewells without the addition of any livewell additives. We also asked all participants to restrict the use of any commercially available livewell treatments that they might normally use during competitive events.

At the weigh-in anglers were asked if they deviated from instructions. Anglers that deviated from the instructions or those unable to capture fish were excluded from analysis. Following the weigh-in live fish were given a unique fin clip designating their respective livewell and treatment, weighed (g) and measured (total length, TL), and placed in holding tanks on boats before being transported to the holding net pens. We measured, weighed, and recorded the livewell number of dead fish at the weigh-in. We determined delayed mortality by visually inspecting net pens for expired fish every 24 hours for five days following each competitive angling event.

Laboratory Experiment-Water Temperature

We conducted a second experiment in the laboratory to determine if livewell additives affect competitively angled largemouth bass mortality at cool ambient water temperatures. Largemouth bass (mean = 360 ± 7.78 mm TL) were acclimated in 445 L indoor tanks at the Homer Buck Laboratory, Sam Parr Biological Station at water temperatures significantly (t-value = 15.8; $P < 0.01$) cooler (mean = 22.7 ± 0.41°C) than ambient water temperatures observed during the field evaluations (mean = 30 ± 0.24°C).

To simulate angling exhaustion, we manually chased fish for 60 s (Cooke et al. 2002), exposed them to air for 60 s, introduced them to livewells and held them at a density of 3 fish per livewell for 8 h. Livewells were circular tanks (0.91 m diameter) that contained 100 L of water and one of four treatments: salt (5% solution; Gilliland and Schramm 2002), ice (to reduce water temperature by approximately 5 °C; Gilliland and Schramm 2002), salt and ice (5% solution and ice to reduce water temperature by 5 °C), or control. We replicated all treatments four times. Dissolved oxygen (mg/L) and temperature (°C) were monitored every hour in a subset of livewells throughout the experiment. We disturbed livewells (i.e., water agitation, opening lid) every hour to simulate wave action and culling. Water agitation was achieved by shaking the livewell for 60 s. Fish were then removed from the livewell, exposed to air for 10s, and placed in a plastic weigh-in bag (0.66 m x 0.86 m) containing about 7 L of water for 120 s. Following removal from the weigh-in bag, fish lengths and weights were taken subjecting individuals to air for 120 s. These methods simulated a typical tournament weigh-in and fish transport back to the lake before they were released into their respective tanks.

We recorded mortality throughout the experiment. We recorded initial mortality when fish exhibited a loss of gill color, stopped respiration, and/or was unable to volitionally maintain equilibrium and swim after release. We visually inspected tanks for delayed mortality daily beginning 24 hours after the event and continuing for five days.

Pond Experiment-Fish Size Experiment

We conducted a third experiment to determine if fish size influenced mortality rates of competitively angled largemouth bass. We subjected fish to livewell treatments in two simulated tournaments in 0.14 ha clay-lined experimental ponds at the Sam Parr Biological Station, Kinmundy, Illinois in late June and early July. We stocked largemouth bass in ponds 12 months prior to the simulated tournaments. The ponds supported sparse aquatic vegetation and had populations of small (≤ 120 mm TL) bluegill *Lepomis macrochirus*, naturally colonized invertebrates, and fathead minnows *Pimephales promelas* that were stocked monthly (3,750 minnows/ha). We angled largemouth bass when ambient water temperatures (mean = 28.9 ± 0.49°C) were similar (t-value = 2.04; *P* = 0.07) to those observed during the field evaluations (mean = 30 ± 0.24°C).

Anglers fished from shore with standard angling gear typified by medium action rods, 10 lb test line, and commercially available “J” style aberdeen hooks. We constructed livewells from coolers modified with small pumps to allow for intermittent pond water flow-though during the confinement period. Once angled, three fish were placed in each livewell for 8 hours. Livewells contained one of four water treatments: salt (109 g salt per 18 L water, 5% solution; Gilliland and Schramm 2002), ice (3.8 L blocks added to reduce water temperature by approximately 5 °C; Gilliland and Schramm 2002), salt and ice combination (5% solution and quantity to reduce water temperature by 5 °C), or control (recirculated pond water only). All livewell treatments were replicated five times during each of the two simulated tournaments. We monitored dissolved oxygen (mg/L) and temperature (°C) every hour in a subset of livewells throughout the simulated tournaments. In addition, we disturbed all livewells (i.e. water agitation, opening lid) every hour to simulate wave action and culling as described in the laboratory experiment. Fish were then removed from the livewell and subjected to a weigh-in as described in the laboratory experiment before they were released into net pens within the experimental ponds. Fish lengths (mean = 207.17 ± 1.72 mm, TL) were significantly (*P*'s < 0.01) smaller than fish captured during the field evaluations (mean = 402 ± 3.4 mm, TL) and the laboratory experiment (mean = 360 ± 7.78 mm TL). After release, we monitored all angled largemouth bass for mortality and every 24 hours post-release. We used the same criteria to determine initial and delayed mortality as that described above for field evaluations.

We used a completely randomized experimental design and two-way analysis of variance (ANOVA) to test for differences (*P* < 0.05) in initial and delayed mortality and dissolved oxygen and temperature among tournaments and among livewell additive treatments. To meet assumptions of the ANOVA, the percentages of initial and delayed mortalities were arcsine-square-root transformed. Fisher's LSD mean separation tests for pairwise comparisons followed significant ANOVAs.

Results

Field Evaluation

Livewell additives did not affect initial and delayed mortality during competitive angling events. Of the 65 boats that collectively participated during the three tournaments 48 captured largemouth bass. Largemouth bass captured during the tournaments were similarly sized (mean = 402 ± 3.4 mm TL; F = 0.26, *P* = 0.77). The number of fish caught did not significantly differ (F = 1.49; *P* = 0.24) among the June (N = 23 boats, mean = 2.6 ± 0.48 fish per livewell), July (N = 21 boats, mean = 2.5 ± 0.42 fish per livewell), and August (N = 21 boats, 1.7 ± 0.33 fish per livewell) tournaments or among treatments added to livewells (F = 1.63; *P* = 0.19).

Across all tournaments, self reported and observed initial mortality at the weigh-in was low (mean = 1.9 ± 1.2 %) and did not differ among tournaments (F = 1.16; *P* = 0.33) or livewells treatments (F = 0.65; *P* = 0.59). Delayed mortalities varied among the tournaments (F = 6.22, *P* < 0.01) with the event conducted in July (55.8 ± 8.36%) having the highest delayed mortality as compared to the August (29.9 ± 9.75%) and June (12.4 ± 5.22%) tournaments that did not differ. Delayed mortality for fish held in livewells containing salt (52.4 ± 11.6%), ice (32.4 ± 14.7%), salt and ice (31.6 ± 10.7%), and controls (25.5 ± 7.5%) were not significantly different (F = 0.99; *P* = 0.41).

Laboratory Experiment-Water Temperature

Additives administered to livewells containing cooler water during the laboratory experiments resulted in no initial or delayed mortalities. As a result, the initial mortality of largemouth bass did not differ (F = 0.54; *P* = 0.65) among livewell additive treatments or from the field evaluations (F = 0.9; *P* = 0.35). Delayed mortality also did not differ among the treatments during the laboratory experiment (F = 1.13; *P* = 0.35). Conversely, delayed mortality in the laboratory experiment was significantly lower than those observed following tournaments in the field (F = 15.1; *P* < 0.01).

Pond Experiment-Fish Size Experiment

Size of largemouth bass appears to have a greater influence on mortality than livewell additives. There were no significant differences in initial mortality between small sizes of largemouth bass and the larger sized fish used in the field evaluations or the laboratory experiments (F = 1.6; $P = 0.21$). Likewise, initial mortality of the smaller fish in pond experiment did not differ among livewell treatments when compared to the larger fish used in the field evaluations or the laboratory experiments (F = 0.52; $P = 0.67$). Although we observed some delayed mortalities (salt = 12.5%, ice and ice and salt = 4.2%, and controls = 0%) for smaller sized bass in the pond experiment it was significantly lower when compared to the larger fish angled during the field evaluations (F = 20.9; $P < 0.01$). Conversely delayed mortality for smaller fish used in the pond experiment was similar to the larger fish in the laboratory experiment that were subjected to livewell additives at cooler laboratory water temperatures (F = 1.57; $P = 0.20$).

Dissolved oxygen and temperature within livewells varied throughout the duration of the pond experiment and among livewell treatments. Dissolved oxygen levels (mean = 6.17 ± 0.05 mg/L) fluctuated in the livewells but did not approach anoxic levels and did not significantly differ among treatments (F = 1.34; $P = 0.26$; Figure 1a). Water temperatures in the livewells gradually increased throughout the day reaching the highest level at weigh-in. Water temperatures in the livewells that had ice added cooled and warmed compared to the other treatments (Figure 1b). Water temperatures within the livewells containing ice (mean = 24.3 ± 0.34 °C) and salt and ice (mean = 25.2 ± 0.34 °C) were significantly (F = 20; $P < 0.01$) cooler than control (mean = 27.3 ± 0.28 °C) or salt (mean = 27.0 ± 0.29 °C) treatments that did not differ. Water temperatures were also significantly cooler within livewells containing the ice than the salt and ice treatment (F = 20; $P < 0.01$).

Discussion

Our results suggest that the use of livewell water additives such as salt and ice or their combination will not significantly reduce tournament related mortality. Largemouth bass may recover from capture, handling, and livewell confinement stress if water quality is good (Furimsky et al. 2003, Suski et al. 2004), regardless of livewell additives. Although we did not find significant differences in delayed mortality among the livewell treatments the consistent trend of higher mortality with livewell treatments during the field experiment suggests that additives may impart additional negative stressors that increase mortality. Our results also suggest that fish size and ambient water temperature may have a greater influence on delayed mortality observed during competitive angling events than specific livewell additives. Fish appear to have greater long term survival following tournaments that were conducted when ambient water temperatures were cooler. Further, smaller sized fish appear to be more resilient to tournament related stressors that result in mortality as compared to larger fishes regardless of ambient water temperature or livewell additive. Collectively these results suggest that the addition of livewell additives do not enhance fish survival following competitive angling events. As a result, we encourage anglers to practice proper fish handling practices as well as maintain good water quality within livewells as opposed to altering water quality with additives.

Initial mortality observed during all tournaments was low (mean = 1.9%); however, delayed mortality was relatively high (mean = 35%) and concurred with previously reported levels (Wilde 1998). Although we surmise that tournament related mortality was related to fish size and ambient water temperature, observers were not present with every angling team during the actual tournaments. As a result, we are unable to examine alternative mechanisms that may be correlated with the observed mortality such as angling, handling, and culling practices. During our laboratory and pond experiments each practice (i.e. angling, handling, disturbance, air exposure, weigh-in procedures) were timed and carefully monitored. Since these experiments afford individual attention to fish, sublethal stress may have been minimized leading to lower mortality rates. Nevertheless, subtleties in these practices do not appear to be dramatic enough to be overcome by the addition of livewell additives during fish confinement.

In contrast to Gilliland and Schramm (2002), our results suggest the use of salt and ice are not warranted. The use of salt during periods of acute stress may result in better osmoregulatory balance (Carmichael et al. 1984; Harrell 1992) and lower the risk of fungal infections in fish (Plumb 1991), but our results do not support this general paradigm for fish subjected to tournament angling. More specifically, our results suggest that additives may not reduce mortality for larger fish that have been angled from high water temperatures, confined to livewells, and subjected to weigh-in procedures prior to release. Fish angled from waters that have significantly different water temperatures than livewells that contain ice may be subjected to temperature changes that potentially can cause rapid physiological changes, prolonging recovery (Cooke et al. 2002; Suski et al. 2006). Although the stress caused by these temperature and salinity changes within livewells may not cause initial mortality, these effects coupled with the weigh-in process may result in higher rates of delayed mortality than simply aerating and flushing livewells as much as possible. Thus we hypothesize that both initial and delayed mortality is the result of a linear, additive sequence of acute stressors throughout the duration of the tournament that may not be substantially lowered by the manipulation of a single factor such as livewell water temperature or salinity.

Many organizations continue to sponsor black bass tournaments during late spring and summer months when ambient water temperatures are at the highest. Although a variety of practices have been adopted to reduce initial and delayed tournament mortality, our results suggest the benefits of livewell additives on post-release survival of competitively angling largemouth bass are minimal; water temperature when tournaments are conducted and the size of fish angled appear to be more important. Our results suggest that tournament organizers should consider conducting events when ambient water temperatures are cooler. In addition, tournament organizers should consider alternative rules and formats that may result in less physiological stress on fish such as reduced creels or paper tournaments, where captured fish are immediately measured and released at their capture location (Ostrand et al. 1999).

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Figure

Figure 1. a) Dissolved oxygen (mean ± 1 SE; mg/L) within livewells that contained lake water (controls) and either noniodized salt, ice, or noniodized salt and ice. Dissolved oxygen levels were not significantly different among livewell treatments. b) Water temperature (mean ± 1 SE; ºC) within livewells that contained lake water (controls) with either salt, ice, or salt and ice. Water temperatures within the livewells containing ice and salt and ice were significantly ($P < 0.05$) cooler than control or salt treatments that did not differ. Livewells containing ice had significantly ($P < 0.05$) cooler water temperatures than the salt and ice treatment.

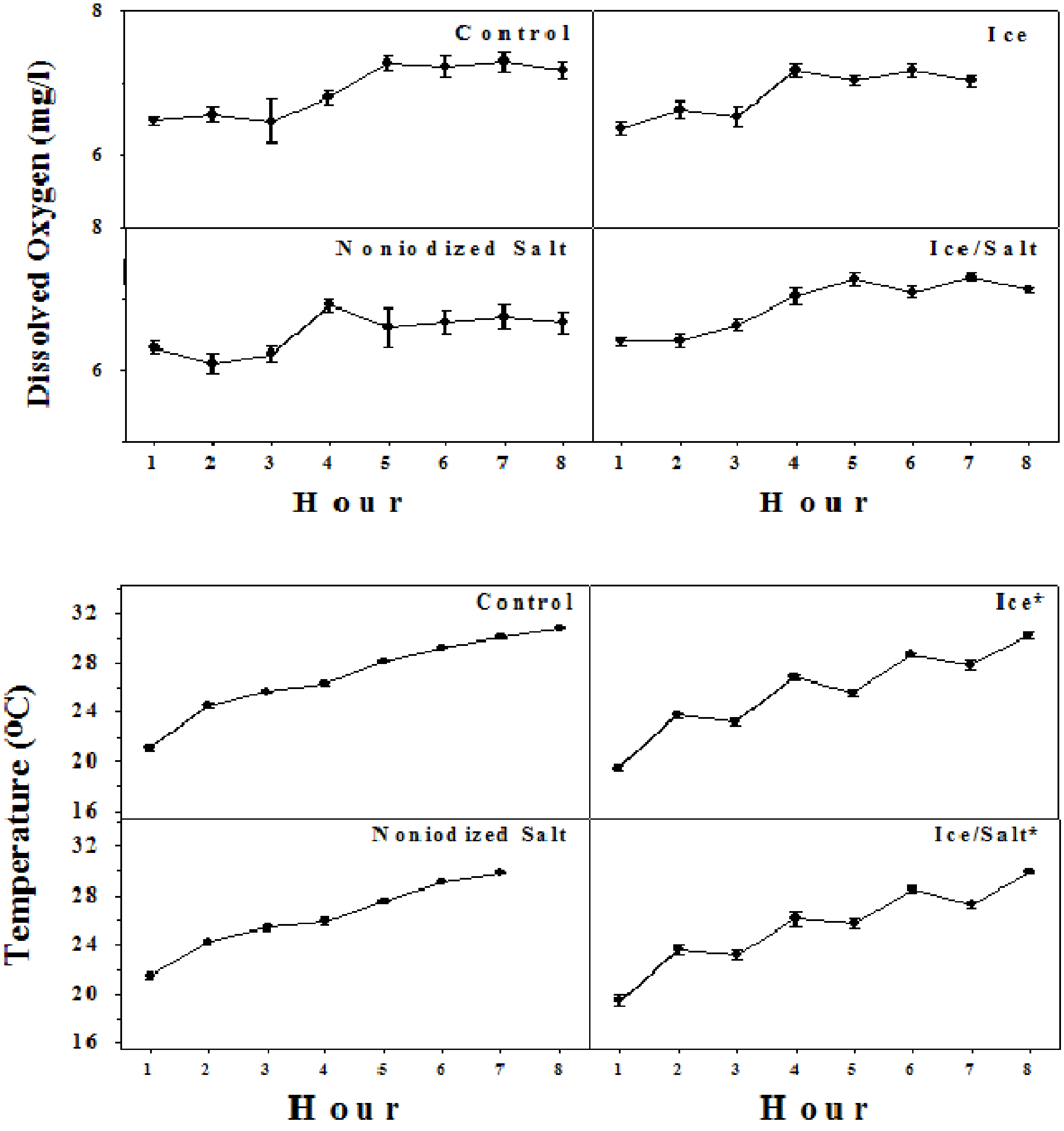
Dissolved Oxygen (mg/l)
8
6
8
6
Control
Ice
Nonioidized Salt
Ice/Salt
1
2
3
4
5
6
7
8
Hour
Hour
Temperature (oC)
32
28
24
20
16
Control
Ice*
Noniodized Salt
Ice/Salt*
Hour
Hour

Figure 1.