ILLINOIS NATURAL HISTORY SURVEY

DATABASE MANAGEMENT AND ANALYSIS OF FISHERIES IN ILLINOIS LAKES

VOLUME 2

1 March 1998 - 28 February 1999

F-69-R
Final Report Segments 10-12
Division of Fisheries
Illinois Department of Natural Resources

Center for Aquatic Ecology

Pacifico J. Perea, David P. Philipp, Todd Kassler, Robert A. Illyes, Ralf Riedel, and Timothy W. Edison

April 1999

Aquatic Ecology Technical Report 99/2

EFFECTS OF ENVIRONMENTAL FACTORS AND SPORT FISHERIES MANAGEMENT PRACTICES ON LARGEMOUTH BASS (*Micropterus salmoides*) FLUCTUATIONS IN ABUNDANCE IN ILLINOIS INLAND LAKES

BY

RALF PETER RIEDEL

B.S., Universidade Federal Rural de Pernambuco, 1987
M.S., The University of Rhode Island, 1993

THESIS

Submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy in Biology
in the Graduate College of the
University of Illinois at Urbana-Champaign, 1999

Urbana, Illinois

EFFECTS OF ENVIRONMENTAL FACTORS AND SPORT FISHERIES MANAGEMENT PRACTICES ON LARGEMOUTH BASS (*Micropterus salmoides*) FLUCTUATIONS IN ABUNDANCE IN ILLINOIS INLAND LAKES

Ralf Riedel
Department of Ecology, Ethology, and Evolution
University of Illinois at Urbana-Champaign, 1999
Peter Bayley, Advisor

Four theoretical models were developed relating environmental factors, anthropogenic factors, productivity (fish caught per hour of electrofishing sampling), and recruitment to several measures of the abundance of largemouth bass (*Micropterus salmoides*) in inland Illinois lakes. Environmental predictors tested were precipitation amounts scaled for lake, watershed size, and land use practice, growing and cooling degree days, snow depth, lake conductivity, and variables for lake morphology. Lake morphology variables were represented by the percent of lake volume in the euphotic zone, shoreline habitat type, and lake inshore mean depth. Anthropogenic predictors tested were largemouth bass stocking, lake rehabilitation events, water level manipulation practices, aquatic vegetation controls, fish length limit changes and fish removal practices.

Four response variables were derived from the number of largemouth bass caught with electrofishing gear during fall sampling. All raw catch-per-effort data were corrected for catchability and logarithm transformed. One-year-old fish (age-1 response variable) was used for all predictors of the anthropogenic component except changes in length limit. Fish 300 mm and larger (adult response variable) was used for changes in length limits. Average lake catch-per-effort was used to derive the response variable for factors potentially explaining differences in lake productivity. Recruitment at age-2 was the response variable for investigating effects of natural factors on recruitment.

Linear regression was used to analyze predictors' effects on the response variables. Each anthropogenic predictor was analyzed for main effects and first-order interactions with the environmental predictors. Multiple-lake (for broad-based treatment effects) and lake-specific analyses of the anthropogenic component were performed. Anthropogenic factors accounted for more variability in response variables than environmental factors. The age-1 response variable decreased the first year and increased the second year following lake rehabilitation. The adult response variable increased following the imposition of all length

limits. None of the predictors analyzed accounted for differences in lake productivity. Recruitment at age-2 correlated only with age-1 abundance.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

models. Abundance = absolute number of age-1 and older fish caught per hour of electrofishing sampling during years when no anthropogenic predictors were implemented. Signs indicate the direction of the effects on the response variable (o = no effect detected), black boxes indicate an effect ($p <= 0.05$).

CHAPTER 1: INTRODUCTION

1.1. Dissertation Format, Summary, and Objectives

The format of this dissertation adheres to the guidelines established by the Graduate College Executive Committee of the University of Illinois at Urbana-Champaign and is comprised of five chapters summarized below (Figure 1).

This Chapter includes a discussion of relevant problems in game fish management in Illinois. The justification for the response variables and the general hypotheses are given. The objective of Chapter 1 is to justify the need of works such as this for the Illinois sport fishery sector.

Chapter 2 presents four verbal models; three describing factors potentially affecting the abundance of largemouth bass (*Micropterus salmoides*) and one for largemouth bass recruitment at two-year-old (age-2). The abundance of largemouth bass was estimated for one-year-old (age-1) and older fish. Chapter 2 also provides the rationale for choosing and estimating the predictors, the response variables, and the data used. Treatment delayed effects used when investigating environmental and anthropogenic predictors are explained together with the general analytical procedures.

Chapter 3 pertains to the analytical methods and results of factors potentially explaining differences in the abundance of largemouth bass among lake and the effects of the environmental and anthropogenic predictors on age-1 largemouth bass.

The objective of Chapter 4 is to present an approach for predicting year-class strength for largemouth bass and to present the results of the impact of environmental factors and changes in size limit regulations on adult fish abundance.

The objective of Chapter 5 is to interpret the results obtained in Chapters 3 and 4 and raise questions based on the conclusions drawn from those results, with possible avenues for addressing those questions.

1.2. Background

The collapse or depression of many fisheries stocks due to anthropogenic factors such as fishing pressure (Coble et al. 1990) and pollution (Longwell et al. 1992; Grosse et al. 1997) are evidence of the strong impact man has on fisheries resources and the need for management for the sustainable exploitation of fish. The efficacy of management practices, however, varies depending on when and where they are conducted, as well as the kind of management practice.

Lake drawdowns have been shown effective for increasing centrarchid growth rates (Hill 1980; Aggus and Elliott 1975), abundance (Meals and Miranda 1991; Martin et al. 1981), and in controlling undesired species of fish (Shields 1957). Among management practices, size regulations are the most widespread for managing fish (Brousseau and Armstrong 1987; Wilde 1997). Fishing regulations have been effective as a tool to restructure population size (Summers 1988; Kurzawski and Durocher 1993; Wynne et al. 1993). Fishing regulations have also been shown to produce variable results on fish. Van Horn et al. (1983) investigated a 45 cm minimum length limit on largemouth bass in four North Carolina reservoirs. The proportion of fish larger than 300 mm increased in two reservoirs and remained unchanged in the other two. Novinger (1987) reported inconsistent results of a 375 mm minimum length on largemouth bass at Table Rock Lake, Missouri. Variation in year-class strength due to environmental factors was the attributed cause of the inconsistencies. Management practices have also been shown to be ineffective (Austen and Orth 1988 for fishing regulations; Howick et al. 1993; Boxrucker 1986 for fish stocking).

Environmental perturbations have been a concern when managing fish stocks (Matsuda et al. 1992) and may influence the efficacy of management interventions. The effects of environmental variables in freshwater systems have mostly been investigated on juvenile fish. Increased vegetative cover has been observed to increase juvenile largemouth bass winter survival (Miranda and Pugh 1997) and growth rates (Olson 1998). Clady (1977) reported mean wind velocity and dissolved oxygen levels to be correlated with abundance and survival of trout-perch (*Percopsis omiscomaycus*) and tessellated darter (*Etheostoma olmstedi*) in Oneida lake, New York. Temperature has been observed to increase egg survival, nesting success (Kramer and Smith 1962), growth rates of young largemouth bass (Kramer and Smith 1960), and to be correlated with adult largemouth bass mortality rates (Beamesderfer and North 1995). Temperature has also been shown to affect first-year growth of smallmouth bass (Serns 1982). Increased silt deposition and declines in water temperature during spawning periods of northern pike (*Esox lucius*) have been correlated with increased fry mortality rates (Hassler 1970).

The relative influence of environmental and anthropogenic factors on fish abundance may estimate the importance of considering uncertainty due to stochastic environmental factors when devising management plans. Because environmental fluctuations, such as changes in weather, cannot be predicted over long periods they are often left unaccounted by managers. If, however, environmental effects are major determinants of fluctuations of fish abundance, management planning is doomed to failure, unless a practice coincides with a favorable environmental condition. When investigating the relative effects of management and environmental factors on fish, the manager may estimate the potential for fisheries management success in an unpredictable environment by recognizing how much control over fisheries resources is possible through management.

1.3. Statement of the Problem

Sport fishing is a major component of the recreational industry and fishing license sales are a significant source of revenue for the Illinois Department of Natural Resources (IDNR). The approximately 84,300 inland lakes in Illinois cover over 122,400 hectares of the state's surface area. A majority of Illinois lakes are man-made providing flood controls, water supply, hydroelectric power plant cooling, or irrigation. Lakes are also used for recreation, which includes boating, hunting, hiking, and fishing (Neely and Heister 1987).

Illinois sport fisheries managers strive to provide high quality fishing to anglers. Management incorporates a variety of activities toward improving game fish population abundance. One of such activities includes sampling to estimate fish abundance. Sampling is usually conducted on a yearly basis and may be used to evaluate management practices. An important concern when evaluating management is the number of years necessary to detect an effect on fish populations.

Erroneous conclusions may be drawn about the efficacy of a management practice if the practice stays in effect for too short a period. Conversely, when an experimental regulation is in effect for too long, identification of a more effective practice may be delayed. The time horizon for a management practice to remain in effect is particularly important when optimization is the goal because an iterative process of successive approximations to the optimal management practice is required. It is, therefore, desirable that a given practice be replaced by a potentially more effective one as soon as the estimated time span for an effect to emerge has elapsed. An optimum practice for a given set of circumstances may be identified sooner when such a time span is adopted as the interval between change of practice.

The effectiveness of management practices in Illinois may also be a function of environmental conditions. Management practices may lead to different results at different lakes and years. Managers in Illinois have not previously had access to data other than that of their own district. This may restrict the understanding of effects of management practices, especially when a spatially broad scale of knowledge is required, as when justification for or against statewide practices, such as fishing regulations, is necessary.

Environmental conditions may interact with management practices (Binet 1982) to produce unexpected outcomes. Environmental effects may also overwhelm the effects of management, making biological parameters such as fish abundance appear to fluctuate unpredictably and irrespective of management interventions when the environmental component is left unaccounted for. The effectiveness of management practices may be more accurately estimated when investigated in light of environmental variation. Furthermore, the relative degree to which management and environmental factors influence fish abundance may determine the degree of uncertainty in management plans.

Research on freshwater fisheries management has mostly been limited to studies that are short-term (Shirley and Andrews 1977; Pasch 1975), spatially restricted (Larimore et al. 1959), or both (Zweiacker et al. 1973), which limits the scope of inference of results and may mislead the manager. Misleading results may occur in situations where a putative effect due to management is confounded by unaccounted factors occurring concurrently with the practice being examined. When temporally and spatially large-scale studies are conducted, unaccounted factors may average out and the effects of confounding factors lessened, provided interactions between management and natural factors are not persistent.

A key objective of sport fisheries in Illinois is the management of game fish species, of which largemouth bass is one of the most important and widespread (Baur 1995; Baur and Rogers 1984). The efficacy of sport fisheries management on largemouth bass is herein investigated, due to the importance of this species for quality angling. Although the quality of sport fishing is a subjective judgment related to anglers' preferences (Knuth and McMullin 1996), which are likely to vary over time and location, quality fishing is generally associated with some combination of fish size and quantity. Management to maximize abundance and size of largemouth bass is a goal because anglers desire some combination of these two properties.

Certain practices are not directly aimed at improving largemouth bass abundance but may affect it. Such practices include aquatic vegetation controls (often done to open access for anglers to fishing areas), small fish removal, and water level manipulations (generally to control excessive abundance of young fish). Practices not directed at largemouth bass will be investigated because they may affect largemouth bass fishing quality.

The response variables chosen to address the problems above were the abundances of age-1 and adult largemouth bass ages 1 and above, and the abundance of recruits at age-2 largemouth bass. Age-1 was the size-class used to investigate the effects on fish abundance due to practices other than changes in size limit regulations. This age class was chosen because age-1 is not subject to angler harvest. Typical harvestable ages of largemouth bass (300 mm and larger) are age-3 and older (Miller 1984; Howells et al. 1995). Even if age-2 and younger largemouth bass are harvestable, as is the case for most slot length limits, anglers tend to release those fish because of their small size (Summers 1990; Gabelhouse 1994; Martin 1995). Young-of-the-year (age-0) largemouth bass was not used because density-dependent population regulating mechanisms (competition for food or winter refugia) may operate more strongly during the first year of a cohort, potentially limiting management effects to short duration (order of weeks) only. It is more likely that management practices will affect older fish, and therefore fishing quality, when the effects of management are first detected on age-1 fish.

Adult largemouth bass were chosen to investigate the effects of size limit regulations. Adult fish were used because they may offer a direct measure of the effects of size limits. Changes in size limits may be more readily reflected on adult fish, because only adult fish are harvested, provided the regulations are observed. In addition, adult fish were used because abundance of spawning fish may determine year class strength.

Recruitment at age-2 was used to evaluate natural effects on year-class strength. Recruitment at earlier year classes was not considered due to density-dependent factors potentially operating more strongly during earlier periods, contributing to high variability of young fish abundance relative to older fish.

1.4. General Hypotheses

The null hypotheses emerging from Section 1.3 are described below. Each problem and related hypothesis are explicitly presented.

Problem 1. The impacts of environmental and anthropogenic factors in determining largemouth bass abundance are unknown.

Null Hypothesis. The abundance of largemouth bass is not affected by either environmental or anthropogenic factors.

Problem 2. The time horizon to detect the effect of management practices is unknown.

Null Hypothesis. There is no impact of management practices over time.

Problem 3. The justification of Illinois statewide management practices is untested.

Null Hypothesis. There is a uniform response to management practices over lakes in Illinois.

The next step of this dissertation will be to develop verbal models based on which the general null hypotheses above will be refined.

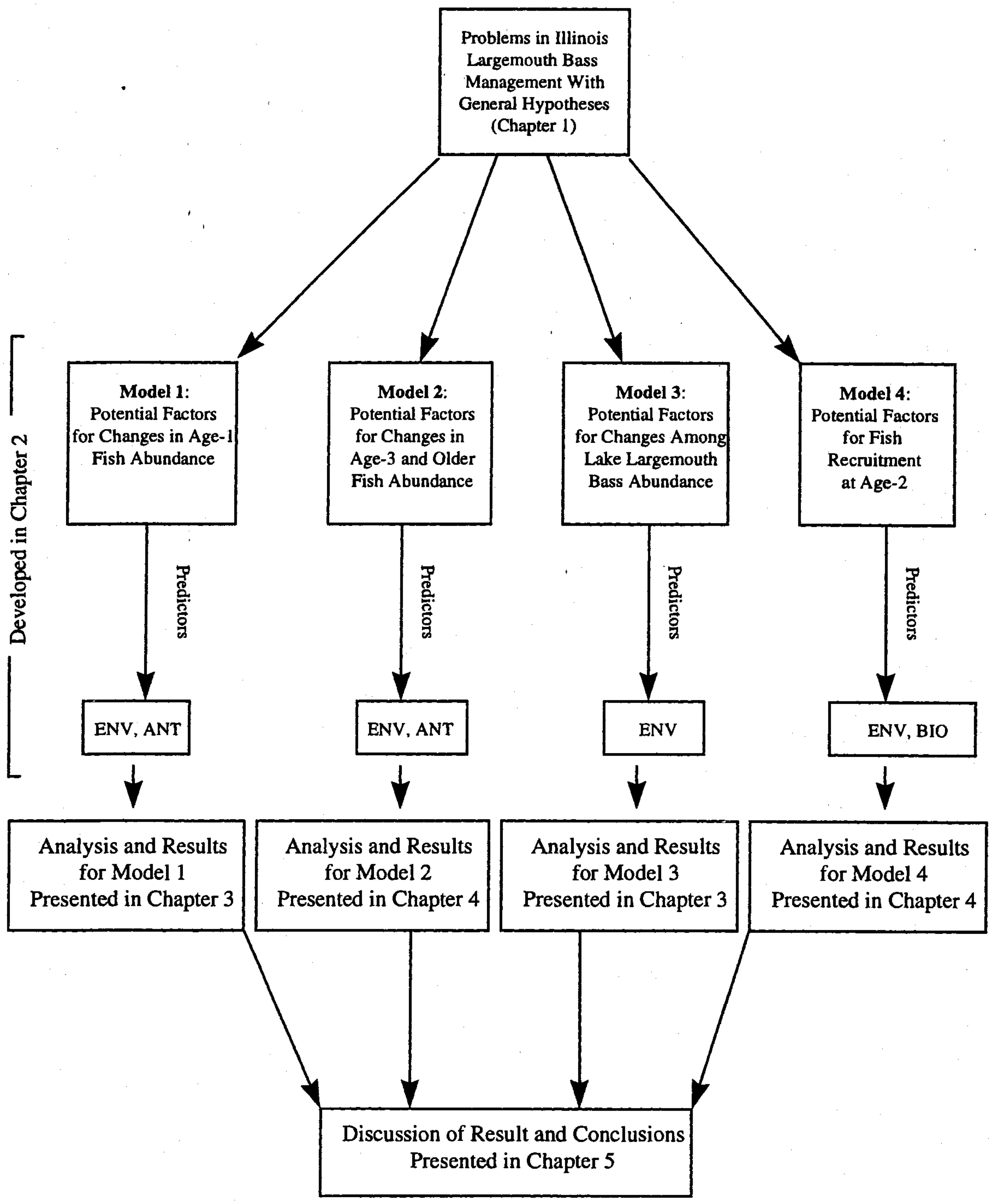

Problems in Illinois Largemouth Bass Management With General Hypotheses (Chapter 1)
Developed in Chapter 2
Model 1: Potential Factors for Changes in Age-1 Fish Abundance
Model 2: Potential Factors for Changes in Age-3 and Older Fish Abundance
Model 3: Potential Factors for Changes Among Lake Largemouth Bass Abundance
Model 4: Potential Factors for Fish Recruitment at Age-2
Predictors
Predictors
Predictors
Predictors
ENV, ANT
ENV, ANT
ENV
ENV, BIO
Analysis and Results for Model 1 Presented in Chapter 3
Analysis and Results for Model 2 Presented in Chapter 4
Analysis and Results for Model 3 Presented in Chapter 3
Analysis and Results for Model 4 Presented in Chapter 4
Discussion of Result and Conclusions Presented in Chapter 5

Figure 1. Schematic representation of the central topics addressed in the five dissertation chapters. ENV = environmental predictors, ANT = anthropogenic predictors, BIO = biological predictors, CPE = corrected electrofishing catch-per-effort (Section 2.3.2).

1.5. List of References

Aggus, L. and G. Elliot. 1975. Effects of cover and food on year-class strength of largemouth bass. Pages 317-322 in R. H. Stroud and H. Clepper, editors. Black bass biology and management, Sports Fishing Institute, Washington, DC.

Austen, D. and D. Orth. 1988. Evaluation of a 305-mm minimum-length limit for smallmouth bass in the New river, Virginia and West Virginia. North American Journal of Fisheries Management 8:231-239.

Baur, R. 1995. Illinois sport fishing survey. Illinois Department of Natural Resources, Report 56.

Baur, R. and R. Rogers. 1984. 1983 Illinois sport fishing survey. Fisheries 11(1):32.

Beamesderfer, R and J. North. 1995. Growth, natural mortality, and predicted response to fishing for largemouth bass and smallmouth bass populations in North America. North American Journal of Fisheries Management 15:688-704.

Binet, D. 1982. Climatic changes related to the *Sardinella aurita* fishery of the Ivory Coast and Ghana: A drought-overfishing relationship. Oceanologica Acta 5(4):443-452

Boxrucker, J. 1986. Evaluation of supplemental stocking of largemouth bass (*Micropterus salmoides*) as a management tool in small impoundments. North American Journal of Fisheries Management 6(3):391-396

Brousseau, C. S. and E. R. Armstrong. 1987. The role of size limits in walleye management. Fisheries 12:2-5.

Clady, M. 1981. Survival and shifts in food of young-of-year *Micropterus* penned at high densities in an Oklahoma pond. Proceedings of the Oklahoma Academy of Science 61:15-22.

Coble, D., R. Brueswitz, T. Fratt, J. Scheirer. 1990. Lake trout, sea lamprey, and overfishing in the upper Great Lakes: A review and reanalysis. Transactions of the American Fisheries Society 119(6):985-995.

Gabelhouse, D. 1984. A length-categorization system to assess fish stocks. North American Journal of Fisheries Management 4:273-285.

Grosse, D., P. Scholz, M. Hirshfield, G. Meaburn, and M. Fletcher. 1997. Fisheries and pollution (Population-level effects of marine contamination, Baltimore, Maryland, USA, October 12-13, 1995). Transactions of the American Fisheries Society 126(3):504-505.

Hassler, T. 1970. Environmental influences on early development and year-class strength of northern pike in lake Oahe and Sharpe, South Dakota. Transactions of the American Fisheries Society 99(2):369-375.

Hill, 1980. Manipulation of bass-bluegill populations by summer drawdown. Iowa Conservation Commission, Project No. F-90-R, Des Moines, IA.

Howells, R., R. Betsill, and J. Prentice. 1995. Age estimation and length back-calculation for known-age largemouth bass. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 49:167-177.

Howick, G., F. Denoyelles, S. Dewey, L. Mason, and D. Baker. 1993. The feasibility of stocking largemouth bass in 0.04-ha mesocosms used for pesticide research. Environmental Toxicology and Chemistry 12(10):1883-1893.

Illinois Department of Natural Resources. 1996. Annual report 1996. Division of Fisheries.

Knuth, B. A. and S. L. McMullin. 1996. Measuring the human dimensions of recreational fisheries. Pages 651-684 in B. Murphy and D. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland, 732 pp.

Kramer, R. and L. Smith. 1962. First-year growth of largemouth bass, *Micropterus salmoides* (Lacepede), and some related ecological factors. Transactions of the American Fisheries Society 89(2):222-233.

Kramer, R. and L. Smith. 1962. Formation of year classes in largemouth bass. Transactions of the American Fisheries Society 91(1):29-41.

Kurzawski, K. and P. Durocher. 1993. Effects of a slot length limit on largemouth bass in a newly opened Texas reservoir. Proceeding of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 47:711-719.

Larimore, R. W., W. F. Childers, and C. Heckrotte. 1959. Destruction and reestablishment of stream fish and invertebrates affected by drought. Transactions of the American Fisheries Society 88:261-285.

Longwell, A., S. Chang, A. Hebert, J. Hughes, D. Perry. 1992. Pollution and developmental abnormalities of Atlantic fisheries. Environmental Biology of Fishes 35(1):1-21.

Martin, C. 1995. Evaluation of slot length limits for largemouth bass in two Delaware ponds. North American Journal of Fisheries Management 15:713-719.

Matsuda, H. T. Kishida, and T. Kidachi. 1992. Optimal harvesting policy for chub mackerel (*Scomber japonicus*) in Japan under a fluctuating environment. Canadian Journal of Fisheries and Aquatic Sciences 49:1796-1800.

Meals, K. and L. Miranda. 1991. Variability in abundance of age-0 centrarchids among littoral habitats of flood control reservoirs in Mississippi. North American Journal of Fisheries Management 11:298-304.

Miller, R. 1975. Comparative behavior of centrarchid basses. Pages 85-94 in R. H. Stroud and H. Clepper, editors. Black bass biology and management, Sports Fishing Institute, Washington, DC.

Miranda, L. and L. Pugh. 1997. Relation between vegetation coverage and abundance, size and diet of juvenile largemouth bass during winter. North American Journal of Fisheries Management 17:601-610.

Neely, R. and C. Heister. 1987. The natural resources of Illinois. Illinois Natural History Survey Special Publication 6, Champaign, Illinois.

Novinger, G. D. 1987. Evaluation of a 15.0-inch minimum length limit on largemouth bass and spotted bass catches at Table Rock Lake, Missouri. North American Journal of Fisheries Management 7:260-272.

Olson, M. 1998. Ontogenetic niche shifts in largemouth bass: variability and consequences of first-year growth. Ecology 77(1):179-190.

Serns, S. 1982. Relation of temperature and population density to first-year recruitment and growth of smallmouth bass in a Wisconsin lake. Transactions of the American Fisheries Society 111:570-574.

Shields, 1957. Experimental control of carp reproduction through water drawdowns in Fort Randall reservoir, South Dakota. Transactions of the American Fisheries Society 87:23-33.

Shirley, K. and A. Andrews. 1977. Growth, production, and mortality of largemouth bass during the first year of life in Lake Carl Blackwell, Oklahoma. Transactions of the American Fisheries Society 106(6):591-595.

Pasch, R. 1975. Some relationships between food habits and growth of largemouth bass in Lake Blackshear, Georgia. Proceeding of the Annual conference of the Southeastern Association of Game and Fish Commissioners 28:307-321.

Summers, G. 1988. Largemouth bass population changes following implementation of a slot length limit. Proceeding of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 42:209-217.

Van Horn, S., W. Chapman, and F. Harris. 1983. Results of a 45-cm (18-in) minimum size regulation on largemouth bass populations. Proceeding of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 35:424-429.

Wilde, G. 1997. Largemouth bass fishery responses to length limits. Fisheries 22(6)14-23.

Wynne, M., A. Little, and K. Nelson. 1993. Evaluation of a protected slot regulation for largemouth bass on Lake Sutton, North Carolina. Proceeding of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 47:686-694.

Zweiacker, P., R. Summerfelt, and J. Johnson. 1973. Largemouth bass growth in relation to annual variations in mean pool elevations in Carl Blackwell, Oklahoma. Proceedings of the Southeastern Association of Fish and Game Commissioners 26(1972):530-540.

CHAPTER 2: THEORETICAL BASIS FOR THE CHOICE OF PREDICTORS AND RESPONSE VARIABLES, DATA SOURCES AND SELECTION, AND GENERAL ANALYTICAL PROCEDURES

This chapter offers a theoretical framework for refining the null hypotheses described in Chapter 1 and for performing the analyses in Chapters 3 and 4. Verbal models describing potential factors determining largemouth bass abundance and productivity are first presented. The verbal models lead to the definition of the environmental and anthropogenic predictors, and the response variables. Lastly, the sources and selection of data are presented, and the general analytical procedures described.

2.1. Models for Largemouth Bass Abundance

A framework for refining the null hypotheses presented in Section 1.4 and for the choice of the predictors potentially affecting the abundance of largemouth bass will be provided in this section by describing the potential effects determining largemouth bass abundance. Three models based on largemouth bass life stages are considered. A model describing factors potentially affecting first-year abundance is first presented, followed by a model for recruitment at age-2 as a function of natural events. Lastly, a model for explaining abundance of adult largemouth bass is described.

2.1.1. Model for Age-1 Abundance

Variations in population density of largemouth bass are common phenomena (Aggus and Elliott 1975; Keith 1975). First-year abundance of largemouth bass may be a function of fish density, as well as physical, chemical, and other biological factors operating at the various life stages described below. The early life history of largemouth bass may be divided into four periods representing key stages determining abundance of age-1 fish (Figure 2). The response variable depicted in Figure 2 is age-1 largemouth bass abundance in the fall because estimates of population density used here are based on fall sampling.

2.1.1.1. Spawning Season

The abundance of age-1 largemouth bass is potentially dependent on the abundance and fecundity of spawners, and the quality of nesting sites. Spawning sites are associated with shoreline areas and built on sandy or silty substrates (Heidinger 1975). A high number of eggs and quality of nesting habitats may increase abundance.

Spawning occurs when the water temperature is between 15 and 24°C. A reduction in temperature may cause largemouth bass to desert the nest and increase the likelihood of fungal infection of the eggs (Kramer and Smith 1960). Alternatively, an increase in temperature increases rates of egg and larval development, which may enhance survival rates (Kramer and Smith 1960). An increase in temperature, may, therefore, be beneficial on spawning (Figure 2).

Water level fluctuations may affect age-0 abundance. Miranda et al. 1984 observed an increase in young largemouth bass survival following a water level increase during spawning, probably due to an increase in habitat and nutrient availability. Similarly, Meals and Miranda (1991) reported an increase in age-0 largemouth bass abundance following high water level years. Conversely, sudden decreases in water level may strand nests (Moyle and Cech 1982) or increase mortality due to predation (Zweiacker et al. 1973) and contribute to a decrease in age-0 abundance. Prolonged periods of low water levels within a year have been observed to correlate with higher growth rates (Aggus and Elliot 1975). Higher growth rates may affect survival if predation on larger age-0 fish is less (Fisher and Zale 1991). Keith (1975) reported an increase in young largemouth bass survival following flooding events. Shirley and Andrews (1977) observed young largemouth bass abundance and higher growth rates following an increase in water level. Water level changes may, therefore, affect spawning in a negative or positive way (Figure 2).

Management practices may affect survival during the spawning season through aquatic vegetation control, stocking of fish, and chemical treatments for controlling small fish abundance. Such activities may positively or negatively affect age-0 abundance through changes in habitat that affect predation and competition (Savino and Stein 1982; Bettoli et al. 1992; Miranda and Pugh 1997; Olson 1998; Figure 2).

Predation on eggs and larvae may be detrimental to spawning of largemouth bass (Heidinger 1975). Insects (chironomids), mollusks (gastropods), and fish (sunfishes) may prey on eggs and larvae (Eipper 1975; Kramer and Smith 1962), potentially decimating nests (Kramer and Smith 1962). Predation, therefore, may be detrimental to egg and larvae abundance (Figure 2).

Largemouth bass spawning sites are usually less than three meters deep in areas protected from wind or wave action (Heidinger 1975). Kramer and Smith (1962) observed wind action to be a major deterrent to spawning success. Wind and wave action potentially destroy nests and, therefore, may negatively affect spawning (Figure 2).

Potential predictors for largemouth bass early life history include precipitation (for natural water level fluctuations), wind speed, management practices, species composition (for predation), and temperature (or related metrics, such as growing-degree-days).

2.1.1.2. First Summer

The abundance of eggs and larvae may determine the abundance of largemouth bass fry entering the next key period (first summer in Figure 2). After about twelve days from egg fertilization, the larva exhausts its yolk-sac reserves and becomes fry, dependent on zooplankton for food. Individual fry growth may be dependent on food quality, quantity, and temperature.

Largemouth bass mostly feed on insects and fish after switching from a zooplankton diet, eventually becoming piscivorous (Heidinger 1975). Aggus and Elliott (1975) observed accelerated growth rates for age-0 largemouth bass shifting early to a piscivorous diet compared to fish remaining insectivorous. They also observed a high correlation between the abundance of rapid growing age-0 fish and recruitment to age-1. Early shift to a piscivorous diet, with a consequent higher growth rate, was the attributed cause of the observed relationship. Accelerated growth rate has also been observed for largemouth bass shifting early to feed on gizzard shad (*Dorosoma cepedianum*) (Miller and Storck 1984; Pasch 1975; Applegate and Mullan 1967). Miranda and Hubbard (1994) observed larger age-0 largemouth bass, with higher energy reserves, to be better able to survive winter months. Mortality differences between smaller and larger age-0 largemouth bass increased with onset of fall and winter. The higher growth rates have been attributed to temperature, food quality, and food quantity. Because larger largemouth bass may be better able to survive winter months, prey availability is indicated as positively affecting age-1 abundance (Figure 2).

Temperature may positively affect growth and fry development (Kramer and Smith 1962), but extremes (above 35°C) may be detrimental to abundance.

Temperature in the summer period is, therefore, indicated in Figure 2 as producing either a positive or a negative effect.

Management practices during the summer are depicted as potentially positive or negative because they may induce changes in predation, competition, and habitat by changing the community or physical structure of lakes.

Predation on young largemouth bass and intraspecific competition may have a negative effect on the abundance of age-1. Interspecific competition for food may affect survival. Planktivorous fish such as threadfin shad (*Dorosoma petenense*) may serve as food for adult largemouth bass, but may compete with fry for zooplankton (Moyle and Cech 1982). Predation and competition are both indicated to be detrimental in Figure 2.

Natural and anthropogenic predictors potentially affecting abundance during the summer may be represented by species composition (predation and competition), nutrient levels (as an indirect measure of food quantity), species abundance and composition of benthos (as a direct measure of food quantity and quality), and temperature (affecting growth).

2.1.1.3. First Winter

Because largemouth bass mortality due to the direct effects of cold temperatures may be rare (Coutant 1975) temperature is not depicted in the winter period of Figure 2. In low temperature tolerance experiments, no mortality due to temperatures below 4°C was reported for largemouth bass (Guest 1982), suggesting temperature not to be a direct factor limiting survival during winter months. Low temperatures, however, may affect tolerance to dissolved oxygen. Largemouth bass has greater requirements for dissolved oxygen than do many other species of warmwater fish (Moore 1942). Minimum tolerable dissolved oxygen under low temperature regimes (4°C) has been observed to be between 2 and 3 ppm (Moore 1942). Tolerance to low levels of dissolved oxygen have been reported to be of 1 ppm for unstressed fish (Johnson 1965) and to vary with temperature (Moss and Scott 1961). Dissolved oxygen is, therefore, a potential limiting factor directly determining survival in the winter through winterkill (Moore 1942; Greenbank 1945; Ricker 1949; Johnson 1965; Figure 2).

Potential predictors which indirectly affect age-1 largemouth bass abundance by influencing levels of dissolved oxygen include temperature levels (or a related metric such as cooling degree days), lake morphology such as mean depth (a potential factor for oxygen depletion), and snow depth (a potential photosynthesis blocking factor).

2.1.1.4. Second Summer

The last period in Figure 2 is when largemouth bass enter their second year (age-1). Prior to its second winter, fish might experience predation and shortage of food. Prey availability and predation are, therefore, indicated in Figure 2 as positive and negative factors, respectively. Fishing mortality (not shown in Figure 2) is probably minimal, unless fish attain legal size, which is unlikely until the end of summer.

Food and predation may be influenced by nutrient levels and species composition, respectively. Species composition of fish may also represent a predictor for food availability because largemouth bass is mostly piscivorous during the second year (Heidinger 1975).

2.1.2. Model for the Recruitment at Age-2

The ability to predict recruitment at harvestable sizes for estimating year-class strength has been a concern when managing fish stocks (Ricker 1954; Gulland 1982). Most fishes invest in numbers (r-selected), rather than size (k-selected) of young. Fluctuations in the abundance of r-selected species tend to be greater than of k-selected species, especially earlier in life (Ricklefs 1990). Predicting fish recruitment to catchable sizes based on the abundance of the spawning stock has been largely unsuccessful (Goodyear and Christensen 1984; Peterman et al. 1988; Mertz and Meyers 1995), partly due to the unexplained high fluctuations in the survival rates of young fish (Gulland 1982).

Large fluctuations in the abundance of age-0 largemouth bass are common and difficult to predict due to the many factors operating during key stages in the early life history of fish (Figure 2). Recruitment at age-1 largemouth bass might be difficult, if not impossible, to predict, especially with the current fish abundance assessment methods. Recruitment at age-2 may prove more predictable and useful for management, given abundance of age-1 fish.

The leftmost column in Figure 3 shows the possible factors directly affecting recruitment at age-2 fish. Abundance of age-1 and prey availability may have positive effects on recruitment to older ages (Figure 3). Extreme weather conditions may cause winterkills by reducing levels of dissolved oxygen. Dissolved oxygen (indicated as positive in Figure 3) may affect recruitment at age-2 as discussed above for age-0 largemouth bass. Competition and predation may similarly affect recruitment as discussed above for age-0 (negative in Figure 3).

Precipitation (for nutrient level changes as when water levels fluctuate), species composition (food quantity and quality), winter conditions (Section 2.1.1.3), and abundance of previous age-classes are possible predictors for addressing fluctuations in recruitment.

2.1.3. Model for Adult Abundance

Adult fish are defined in this dissertation as largemouth bass larger than or equal to 300 mm total length (harvestable at the statewide minimum length limit). Usually fish age-3 and older (300 mm or larger, Carlander 1969) are harvestable under most size limits at lakes in Illinois. Adult fish typically have lower mortality rates due to natural causes than young fish (Gulland 1982). Adult largemouth abundance may be partly determined by the abundance of young fish in past years (the pre-adult period in Figure 3). Similarly, adult abundance may decrease when food is unavailable or when weather conditions are extreme. Increased availability of prey may affect adults as it may young fish. Extremely cold winters, especially in shallow lakes, may induce winterkill due to dissolved oxygen depletion as discussed above. Prey availability and dissolved oxygen are, therefore, potentially positive effects (Figure 3).

Fishing pressure may be an important factor detrimental to the abundance of adult largemouth bass (Figure 3). Paragamian (1982) reported a reduction in the abundance of largemouth bass over 350 mm after the implementation of a 350 mm length limit, possibly due to intensive fishing.

Potential predictors affecting adult fish abundance are precipitation, temperature (for growth), species composition, and winter conditions.

2.2. Development of Predictor Variables

The data available for this dissertation were observational, not gathered to directly test the models described in Section 2.1. Many factors potentially affect largemouth bass mortality throughout life (Figures 2 and 3) and these factors may interact with others. The understanding of these mechanisms provide a challenge due to their complexity. Many factors discussed in Figures 2 and 3 were not available or may not be readily quantifiable, such as predation and competition, making it necessary to develop proxy variables for factors of interest that cannot be addressed directly. Proxy variables were chosen to address common problems in the management of largemouth bass sport fishery (Section 1.2) and to refine the general null hypotheses (Section 1.4). An attempt was made to incorporate the many factors depicted in Figures 2 and 3 in the proxy variables described below. Descriptions of the proxy variables and the resulting null hypotheses follow.

2.2.1. Environmental Predictors

2.2.1.1. Effects of Precipitation

The potential effects of precipitation were investigated by defining a compound variable representing land use practices within the watershed, and the relative sizes of lakes and their watershed. The compound variable was of mean monthly rainfall multiplied by watershed area divided by lake volume and this ratio was divided by an index for the volume development (Cole 1994) and multiplied by an index for land use practice as indicated below:

$PPT = [(RAIN * WSAREA / LVOL) * (1 + LAND / VDI)]$, where

PPT = Precipitation compound variable (unitless)
RAIN = Amount of precipitation
WSAREA = Watershed area
LVOL = Lake volume
LAND = Percent of landuse practice (see below)
VDI = Lake volume development index

The index for land use practice was of the percent of uncovered land (sum of barren land, land for agriculture, and urban) added to one. One was added to the percentage to avoid zero values for watershed covered by land other than uncovered land (precipitation may still affect lakes in watersheds of different vegetation cover). Division by the volume development index was because smaller values of the index may lead to increased flooded areas for the same value of precipitation. Similarly, multiplication by the land use index was because uncovered land may lead to increase in water turbidity. The resulting variable was an estimate of the amount of water and sediment carried into the lake for given levels of precipitation. The relationship of lake to watershed area and watershed vegetation cover may affect the biota differently for the same level of precipitation. The biota may be affected by variations in water turbidity and amount of flooded areas (hypothesized to have an effect on spawning and young survival, Figure 2). Precipitation during the months of May and June was chosen as a surrogate variable incorporating the factors in Figure 2 influencing largemouth bass survival through the spawning season. The months of May and June were chosen because they comprise the period when largemouth bass spawn (Kramer and Smith 1962).

High precipitation may increase water turbidity (Langbein and Schumm 1958) and low precipitation may contribute to nest stranding due to receding water levels (Moyle and Cech 1982). An increase in turbidity after suspended sediments settle may result in silty bottoms, less suitable for spawning compared to nests on hard substrates (Swingle 1949; Robinson 1961). Populations of largemouth bass have been observed to increase following periods of less turbid water, as is the case when rainfall is low (Cross 1967; Miller 1975), possibly due to high egg survival and positive effects on mating (Miller 1975). Buck (1956), as an example, reported lower growth, reproduction rates, and population size as turbidity increased in three Oklahoma lakes.

Precipitation levels within the catchment basin influence nutrient input and water levels. High water levels may increase cover during critical periods in the early life history of fish (Werner et al. 1977). An increase in cover may decrease predation on young largemouth bass. An increase in nutrients may increase food quality and quantity. Higher water levels have also been associated with increases in largemouth bass growth rates (Shirely and Andrews 1977), which may enhance first-winter survival, especially when young fish switch earlier to a piscivorous diet (Miranda and Hubbard 1994; Gutreuter and Anderson 1985).

Direct measures of species composition (for predation and competition), water circulation, and wind speed were not available. Data on turbidity and water level were available for a limited number of lakes (three lakes with water level and two with turbidity data), enough to investigate relationships with precipitation. The relationships of water level and turbidity with precipitation were positive (Figures 4 and 5, respectively), supporting the use of precipitation as a surrogate variable for abundance.

Increased cover and nutrient inputs may occur following high precipitation events, which may increase abundance. Conversely, an increase in turbidity after high precipitation or a decrease in water levels following drought periods may cause a decrease in abundance. Because precipitation may positively or negatively affect largemouth bass abundance, the null hypothesis was that the variable incorporating precipitation is uncorrelated with abundance.

2.2.1.2. Growing-degree-day

Growing-degree-days during the months of April through October were used to represent the potential for largemouth bass growth. Mean air temperature for the months of November through March were excluded from the calculation of growing-degree-days because largemouth bass mostly stays dormant and ceases to grow during this period due to the low water temperatures (Rice et al. 1983; McCauley and Kilgour 1990). When considering the entire year for growing-degree-day calculations, short-term increases in air temperature may bias the effects of growing-degree-days because increases in water temperature do not immediately follow increases in air temperature. A relationship between air and water temperature is depicted in Figure 6.

Observed changes in the metabolic rates of fish determined the selection of the base air temperature for calculating the growing-degree-days. Savitz (1978) studied the effects of growth and other population parameters of largemouth bass in Illinois and observed growth to cease during October. No specific day was given but a range of temperature between 5 and 16°C for that month was recorded by the National Weather Service. When investigating the relationship between air temperature and somatic growth for largemouth bass, McCauley and Kilgour (1990) reported accumulated degree days over 10°C to best correlate with growth. Rice et al. (1983), when modeling the effects of temperature on largemouth bass, found respiration to be negligible under 10°C. Lemons and Crawshaw (1985) showed a depression of activity measured by food intake of largemouth bass acclimated to temperatures below 10°C. Based on the works above, the base temperature for calculating growing-degree-days was 10°C.

Direct effects of high temperature may reduce largemouth bass survival if persistent and uniform throughout the water column. High temperature tolerances of largemouth bass native to Illinois have been reported to be between the upper 30 to lower 40°C range (Johnson and Charlton 1960; Fields et al. 1987). Storms et al. (1986) observed stress in largemouth bass to increase when water temperatures reached 30°C, leading to death for temperatures above 36°C. In natural conditions, however, behavioral thermoregulations may take place, whereby fish seek habitats of suitable temperatures (Rice et al. 1983). Temperature was, therefore, not used directly because behavior may mask potential effects of extreme temperatures and because moderate temperatures were considered always available in some parts of each lake.

Temperature has been correlated with egg development (Kramer and Smith 1962). Higher recruitment at age-1 has also been associated with larger, faster growing largemouth bass (Aggus and Elliott 1975; Toneys and Coble 1979; Gutreuter and Anderson 1985). The length of the growing season has been observed to affect growth rates (Bennett 1971). The length of the growing season may positively affect growth by extended elevated temperature periods, as measured by growing-degree-days.

Because the effects of temperature on largemouth bass during the summer are probably mostly beneficial, the null hypothesis was that an increase in the growing-degree-days will decrease or not affect largemouth bass abundance.

2.2.1.3. Cooling Degree Days and Snow Depth

Declines in levels of photosynthesis leading to dissolved oxygen deprivation are known to cause winterkill. Fish mortality due to reduced oxygen levels has been reported for largemouth bass (Moore 1942; Ricker 1949; Johnson 1965). Dissolved oxygen depletion has been correlated with amount of snow cover on lakes (Guenther and Hubert 1991). Snow cover blocks incoming light, which in turn lessens dissolved oxygen from primary production (Greenbank 1945; Nickum 1970). Snow removal from lakes may contribute to increases in dissolved oxygen. Müller (1957) obtained an increased oxygen level in lakes of northern Germany after removal of snow cover. Paulin (1960) reported lessened winterkills following snow plowing on a Wisconsin lake.

Data for cooling degree days and snow cover were used because no data for dissolved oxygen were available. Cooling degree days and monthly

average snow depth for December through March were used to represent the effects of low dissolved oxygen on largemouth bass. The base temperature for cooling degree days was 0°C, because no models were found relating ice formation on lakes with air temperature. Because of the potentially detrimental effects of cooling degree days and snow depth on abundance, the null hypothesis was that an increase in snow cover and cooling degree days will increase or not affect largemouth bass abundance.

2.2.1.4. Largemouth Bass Index of Abundance

A largemouth bass index of abundance was estimated here as the absolute number of age-1 and older fish derived from electrofishing sampling and catchability estimates (Section 2.3.2) during years when no anthropogenic action (see below) were implemented. The index was used in an attempt to explain differences in largemouth bass abundance among lakes. Because age-1 and adult fish were combined, the theoretical model for selecting the abiotic predictors in this section is as presented in Sections 2.1.1 and 2.1.3. Differences among lake abiotic factors may lead to differences in productivity. Productivity was analyzed without anthropogenic actions because lakes with different productivity may produce different effects on fish following a similar management practice.

Growing-degree-days, percent of lake volume in the euphotic zone, lake conductivity, shoreline habitat type, and lake inshore mean depth were used in a static model (predictors constant through time) to predict differences in largemouth bass abundance among lakes.

Lake volume in the euphotic zone and inshore mean depth were used to represent lake morphology. Lake primary production may be directly proportional to the amount of littoral euphotic zone (Cole 1994) and may positively affect productivity. The percent of lake volume in the euphotic zone is a function of the amount of light penetrating through the water (Cole 1994). Light may penetrate deeper and reach a higher proportion of the bottom of clear water lakes, which in turn may increase the density of aquatic vegetation in the littoral zone. Denser vegetation may provide additional cover for young or influence predation efficiency of adult largemouth bass and potentially affect productivity (Bettoli et al. 1992; Miranda and Pugh 1997; Olson 1998). Inshore mean depth (see below) and the percent of lake volume in the euphotic zone were used as predictors because largemouth bass live in close association to littoral zones (Miller 1975) most of the growing year.

The shape of the lake basin as represented by inshore mean depth may affect the potential for summer and winterkill. Studies addressing inshore mean depth are rare. Studies addressing mean depth, however, may be used for postulating effects on productivity because mean depth and inshore mean depth correlate (Figure 7), potentially producing similar statisical effects on fish. Shallower lakes may be less suceptible to summerkill and winterkill because wind-induced mixing can reoxygenate the water column down to the substrate. Deeper lakes with a thermocline may have a hypolimnion that can deoxygenate the whole lake when the thermocline is disrupted (Coles 1994). The shoreline steepness is characteristic of lakes with higher inshore mean depth and also influence productivity. Fish in lakes with a steep shore may be less affected by changes in water level than lakes with a more gradual slope. Lakes with a gradual slope will inundate or expose a larger area with similar vertical water level changes, potentially providing for more cover, nesting, and nursing areas.

The effects of temperature and dissolved oxygen may also be affected by lake inshore mean depth. The effects of high temperature in the summer may be ameliorated by wind generated circulation, water turnover during cool nights (Cole 1994), and thermoregulatory responses by fish (Rice et al. 1983). In the winter, lakes with a low mean depth may be more prone to kill fish if depletion rates of dissolved oxygen are higher (Mathias and Barica 1980).

Conductivity is a measure of dissolved solids, which may be indicative of primary production, which in turn may increase productivity (Cole 1994; Moyle and Cech 1988). The shoreline habitat type was represented by amount of hard cover. Lake shoreline habitat structure may influence abundance if dense cover is available, protecting young largemouth bass from predators.

Because the predictors above may increase or decrease survival of largemouth bass, the null hypothesis for all predictors except average growing-degree-days and conductivity was that largemouth bass abundance will remain constant. The null hypothesis for average growing-degree-days and conductivity was that largemouth bass abundance will remain constant or decrease with an increase in those predictors.

2.2.2. Anthropogenic Predictors

Anthropogenic predictors were the following frequent sport fishery management practices at lakes: largemouth bass stocking, lake rehabilitation, water level manipulation, aquatic vegetation control, changes in the fish length limit, and chemical fish removal. The rationale and description of the null hypothesis for each predictor are given below.

2.2.2.1. Stocking

Stocking practices have had detected (Swingle 1950; Buynak et al. 1991; Fielder 1992) and undetected effects (Krumholz 1952; Saila 1952) on fish abundance. However, for largemouth bass, effects for stocking have been generally disappointing. After evaluating stocking densities of 10, 20, 40, and 80 fingerling largemouth bass in two 0.04 ha earthern ponds, Howick et al. (1993) reported a decrease in average size and condition of fish with increasing stocking rate. Boxrucker (1986) evaluated the effectiveness of fingerling largemouth bass stocking in two Oklahoma impoundments. Stocked fish were initially over 70% of the total population, declining to less than 20% at the end of the third growing season. Higher natural mortality of stocked fish was the attributed cause of the ineffective stocking. Ineffective stocking, probably due to the higher natural mortality of hatchery fish compared to naturally reproducing largemouth bass, has also been reported elsewhere (Lawson and Davies 1977; Filipek and Gibson 1986). Survival rates of hatchery fry were reported to be between 35 and 40% in rearing ponds between the months of August and October (Davis 1930). A survival rate of up to 80% in fertilized rearing ponds was reported by Blosz (1952). Much lower survival rates (not reported) were observed in unfertilized ponds. Roseberry (1950) after investigating the effects of largemouth bass stocking, concluded that stocking was ineffective due to low water fertility. Survival of fry and success of stocking, therefore, seems to be closely related with food availability for age-0 fish.

Because adding fish potentially increases abundance, the null hypothesis was of a decrease or an unchanged largemouth bass abundance with an increase in the quantity of fish stocked.

2.2.2.2. Lake Rehabilitation and Water Level Manipulation

Lake rehabilitation is here defined as a major drop in water level followed by removal and subsequent stocking of fish. Water level manipulation is defined herein as any man-made increase or decrease in water level without any additional practice.

Natural fluctuations in water levels are a characteristic of floodplain lakes and rivers and may be emulated by manipulating water levels in artificial lakes. Fluctuations in water level may be caused by annual cycles of wet and dry seasons or by events longer in duration, such as those caused by droughts over multiple years. In artificial lakes, managers may alter water levels for aerating the bottom, facilitating fish removal, controlling excessive macrophytes, and controlling forage or stunted fish (Jenkins 1970).

The sudden reduction of water volume and surface area of a lake may affect the fauna and flora. When subject to stress from extreme crowding, predation, or high temperatures, some fish may die, leaving a population adjusted to the diminished levels of food and space available. As the habitat expands when normal water levels are reached, fish will have opportunities to better grow and reproduce due to the increase in space and food from the reflooded areas (Bennett 1971).

Hill (1980) reported an increase in angler catch rates of largemouth bass, and an increase in average size and young growth rates of largemouth bass and bluegill were shown two years after drawdown. Other studies have shown an increase in catch rates and a restructuring of largemouth bass populations toward larger sizes, probably due to an increase in growth rates following lake drawdowns (Pierce et al. 1965, six months after drawdown; Lantz et al. 1967, one year after drawdown; Paller 1997, nine months after drawdown). Conversely, Zweiacker et al. (1973) reported a decrease in growth rate of largemouth bass one year following a decrease in water level, possibly due to a decrease in food supply.

Water level manipulations and lake rehabilitations were each treated as separate predictors. Because changes in water level may affect many components determining the numbers of largemouth bass (Section 2.1.1.1, Figure 2), the null hypothesis was of largemouth bass abundance fluctuating independently of water level changes. Because lake rehabilitation potentially removes the majority of fish, the null hypothesis for lake rehabilitation was that largemouth bass did not increase.

2.2.2.3. Aquatic Vegetation Control

Production of fish may be related to the type of littoral zone and its associated aquatic vegetation (Werner et al. 1977; Mittelbach 1988; Conrow et al. 1990). Vegetated littoral areas provide habitat, nursery, and refuge for fish (Werner et al. 1977; Hall and Ehlinger 1989). Controlling vegetation growth may be intended to reduce odor and improve aesthetics (Mikol 1984). Indirect biological effects, however, may occur as a consequence. Higher plants often sequester nutrients that would otherwise be available to the fauna in the lake, decreasing the potential for fish production (Bennett 1948; Strange et al. 1975).

Macrophytes may also affect food habits and predation of piscivorous fish. Bettoli et al. (1992) assessed largemouth bass piscivory as a function of habitat complexity. Largemouth bass were shown to shift to a piscivorous diet earlier in life history when in habitats without submersed vegetation. Predation success by largemouth bass has been shown to be a negative function of aquatic vegetation density. Predation success to near zero values were observed at high densities of aquatic vegetation stems (Savino and Stein 1982). Largemouth bass first winter survival has been shown to be optimum at an intermediate level (10-25%) of vegetative cover (Miranda and Pugh 1997). Similarly, Wiley et al. (1984) evaluated the effects of different levels of macrophyte abundance on largemouth bass. Largemouth bass production decreased at low and high levels of macrophytes, again suggesting an intermediate optimum level of vegetative abundance. Olson et al. (1998) observed an increase of growth rates for most age classes of largemouth bass after 20% vegetation removal in four Wisconsin lakes, providing additional support for the benefits of intermediate density of aquatic vegetation.

Because aquatic vegetation may provide protective cover or decrease prey visibility, the null hypothesis tested was that the abundance of largemouth bass remained unchanged after vegetation control practices.

2.2.2.4. Length Limit Regulations

The primary reason for devising length limit regulations in recreational fisheries is to increase yield of harvestable fish by controlling the population size structure. Length regulations include a minimum, an exclusive slot, or a maximum limit. Minimum length limits, whereby a fish below a given size cannot be harvested, are based on the premise that the protection of young fish from fishing will allow them at least to reach a size of first reproduction or to lower the potential for growth overfishing. Slot limit protects fish within (exclusive slot) or outside (inclusive slot) a specified length range. Usually adult fish are protected to bring a population to a desired size structure after slot limit implementations. Maximum length limits are regulations under which all fish above a certain size are not to be harvested. The rationale for maximum length limits is that larger, more fecund fish will more promptly rebuild a population. Maximum length limits are not extensively used due to mostly social, rather than biological, reasons (Brousseau and Armstrong 1987).

Minimum length limits have had impacts on abundance, population structure, and growth of largemouth bass. An increase in electrofishing catch-per-effort (Ager 1989; Buynak et al. 1991) and a population size structure skewed towards larger sizes of largemouth bass (Ager 1989) was observed following an increase in minimum length limits. Conversely, Paragamian (1982) reported a restructuring of population size toward smaller fish after implementation of a 350 mm length limit for largemouth bass. Increased pressure on fish larger than 350 mm was the attributed cause of the observed effect. Increases in growth rates following implementation of a 300 mm minimum length limit have also been observed for largemouth bass (Farabee 1974; Johnson and Anderson 1974). Conversely, Ming and McDonald (1975) reported an increase in sublegal largemouth bass and a decrease in growth rates of adult largemouth bass from a no-regulation to a 300 mm minimum length limit.

Exclusive slot limit regulations have produced changes in largemouth bass population structure and abundance. A trend of population size structure toward larger fish has been the most commonly reported effect of exclusive slot limit regulations (Summers 1988; Novinger 1990; Wynne et al. 1993; Martin 1995). Protected fish measured by catch-per-effort usually increases following exclusive slot limit regulations for largemouth bass (Eder 1984; Summers 1988; Dean et al. 1991; Cofer 1993; Kurzawski and Durocher 1993; Martin 1995), but decreases have also been observed (Martin 1995). Increases (Wynne et al 1993) and decreases (Eder 1984) of catch rates have also been reported after imposition of exclusive slot limit regulations for largemouth bass.

The effects on largemouth bass abundance of changes in length limits were investigated here. The length limit changes investigated consisted of an increase from the statewide minimum length limit of 300 mm to 350 mm, an increase from the statewide minimum length limit to 375 mm, and the substitution of a 350 to 375 mm exclusive slot limit for the statewide minimum length limit. Each of the changes in length limit was treated separately.

Because size limits are dependent on fishing pressure (unavailable), the null hypothesis was that changes in size limits will not affect largemouth bass abundance.

2.2.2.5. Fish Removal

Fish removal practices to control stunted fish populations are widely used as a management tool. The removal of fish is intended to enhance growth of the remaining individuals, restructuring the population towards fewer and larger fish.

Chemical fish removal is the most widely used and most economical means to control stunted fish (Lennon et al. 1970). The success (attainment of desired fish population structure or species composition) of fish removal practices varies widely. Chemical treatments (Avault and Radonsky 1968; Keith 1968; Johnson and Osborne 1977) are apparently more effective than physical methods (Jackson 1966; Scott 1968; Warnick 1977; Goeman and Spencer 1996) and increases in fish growth rates seem to be the most common result of fish removal (Pierce et al. 1965; Johnson 1975; Johnson and Osborne 1977; Davis 1979).

Chemical fish removal is not directed at largemouth bass, but may affect them. Fish affected directly by removal practices may compete with or serve as prey for largemouth bass. The null hypothesis, therefore, was that removal practices had no effect on largemouth bass abundance.

2.3. Response Variables

2.3.1. Definition

Fish numbers caught were corrected for catchability according to Bayley and Austen (1987) to obtain estimates of abundance rather than catch-per-effort to be used for the response variables. The area covered by a unit of time of electrofishing was constant among lakes. The response variables computed were logarithm transformed abundance of largemouth bass caught per hour of fall electrofishing samples. Logarithm transformation was used to normalize the distribution and stabilize the variance (Figure 8).

Response variables based on age-1, age-2, and adult largemouth bass were derived. The response variables were investigated independently because they addressed different models. Age-1 fish was used to address the model in Section 2.1.1 (factors affecting young fish) and age-2 for the model in Section 2.1.2 (recruitment at age-2). The model in Section 2.1.3 (factors affecting adult fish) was assessed using adults. Productivity was assessed using the absolute number of age-1 and older fish caught per hour of electrofishing sampling during years when no anthropogenic predictors were implemented (Section 2.2.1.4).

2.3.2. Catchability

Catchability of fishing gears is defined as the fraction of fish caught by a unit of fishing effort (Ricker 1975). Catchability is a function of biotic and abiotic factors and may, therefore, vary when sampling different fish sizes and species, habitats, or the same habitat at different times. When catchability varies, estimates of fish abundance become unreliable and may lead to erroneous conclusions of management or natural effects on fish. Mortality estimates, as an example, may yield impossible outcomes if catchability for younger fish is lower than for older age-classes. Comparison of data across systems, especially in situations when different gears and sampling protocols are used, is only meaningful with correction for catchability.

To correct for catchability, data from fall electrofishing sampling were calibrated based on a quasi-likelihood, logistic model with inshore mean depth, macrophyte density, fish length and length squared as predictors (Bayley, personal communication; Bayley and Austen 1987). A simplified model based on fish length was used herein because an inshore mean depth effect for the ranges studied was not detected for largemouth bass (Bayley, personal communication) and information on macrophyte density was not available. A peak of efficiency of 0.08 was estimated for largemouth bass 30 cm long in a defined inshore zone (Figure 9).

2.3.3. Caveats on Past-Fish Sampling

1. Fish populations in Illinois inland lakes have been assessed since the early 1960s using a variety of sampling gear, principally boat electroshockers. Boat electrofishing is the only sampling method consistently used. Prior to 1985, sampling data were not always reported with regard to the type of sampling gear. Data were frequently reported as pooled catches from various gears, making it difficult to identify

the proportion of the sample caught with electroshockers. Since 1985 there has been more consistent recording of the type of gear used to sample each fish species, allowing the estimation of the proportion of largemouth bass caught with electrofishing prior to 1985. Analysis of the annual percentage sampled with electrofishing gear in post-1985 data, indicate that largemouth bass are caught almost exclusively with that type of fishing gear (Table 1). At Lake Defiance (in 1991), Lake Pierce (in 1985 and 1986), and Ramsey Lake (in 1988), the catches using gears other than electrofishing gear were large enough to warrant concern about possible confounding of largemouth bass abundance estimates with that of fish species other than largemouth bass. The large amount of data where largemouth bass is proportionately high, however, may mask the potential bias during those four instances. Pooled data by gear, therefore, were used even though they may overestimate largemouth bass catches. The extent to which data prior to 1985 may overestimate largemouth bass catches, however, cannot be identified and ignoring such data would probably be harmful, because they comprise over 75% of the total data.

2. No direct age information was used to determine size at age of largemouth bass. Length-frequency distributions were used to define largemouth bass age classes using a likelihood-based method for analyzing multiple data sampled at different times (Fournier et al. 1990). Largemouth bass has well defined spawning seasons (Heidinger 1975), which potentially makes age estimation from length-frequency data more accurate than for species that have multiple spawning periods (such as bluegill). A chi-square test was used to estimate the best fitting likelihood model. The likelihood model fitted over a series of years was used to control for observer bias which might have occurred if relying on length-frequency plots alone when estimating size ranges for the age-1 and age-2 classes. The length range at age was established by adding and subtracting two standard deviations from the mean length at age estimated from the likelihood model. Two standard deviations were used to minimize overlap between age classes yet include over 95% of the fish of an age class in the estimated interval for that age class. When the lower limit for age-2 fish overlapped with the upper limit of age-1 fish the upper limit for age-1 fish (lower for age-2) was taken to be the midrange of the overlap area (Figure 10, panel A).

Fish from IDNR fall electrofishing catches are frequently subsampled for age determination of fish. Only a range of size by age is recorded in IDNR final reports. The resulting likelihood estimates were compared with the observed IDNR range of size for age-1 and age-2 largemouth bass to determine if there was disagreement between estimates (Figure 10, panel B). Disagreement occurred only in cases two years after complete lake rehabilitation events were performed, potentially due to an increase in growth rates of fish following those practices. Size at age in years following rehabilitation practices were larger than estimated by the model. Size ranges were determined by direct examination of length-frequency plots for these events.

2.4. Data Sources and Selection

2.4.1. Environmental Data

Climatic data were obtained from the Midwest Climate Center. This information was accessed through the Midwest Climate Information System, a computer-based application for storing climatic data from the National Climatic Data Center, the Climate Analysis Center, National Weather Service stations and state weather networks. Data regarding the environmental predictors were obtained first from the closest weather station located within the same catchment basin as each lake. If information was unavailable from the nearest weather station, data were collected from the weather station which was next closest to the lake, as long as the station was located in the same catchment basin. Data were only occasionally obtained from the second and third closest weather station. Data for lake inshore mean depth, conductivity, and shoreline habitat type were obtained from Austen et al. 1993. Data for the proportion of lake in the euphotic zone were obtained from Austen (personal communication).

2.4.2. Anthropogenic Data

Any intervention (management practices discussed in Section 2.2.2) to lakes is reported by district biologists. The reports follow a standard format dependent on the kind of intervention and are archived by year for every lake. All of the data pertaining to management practices except fishing regulations were gathered from standard reports archived in the fisheries district offices. Fishing regulations were collected from the Illinois State Library and the Illinois Register. A summary of the anthropogenic predictors by lake and year is presented in Table 2.

2.4.3. Fishery Data

Sport fishery data are archived in the 26 IDNR fisheries district offices located throughout the state and are stored in the IDNR Fisheries Analysis System (FAS) database (Austen et al. 1993; Bayley and Austen 1989). The FAS database system includes data on management practices, fish sampling, and length-frequency information since 1985, whereas the IDNR district offices archive recent as well as historical data. Historical data were collected from IDNR district offices and appended to the existing FAS database, generating a source database for this work. One hundred and eighty seven lakes are stored in the source database and 42 lakes have historical information starting as early as the 1960s.

Forty two lakes in Illinois with data since 1960 were used (Figure 11; Table 3). Data pertaining to the environmental and anthropogenic predictors and the response variable were obtained only for those lakes with management and sampling information dating back at least to the mid-1970s and with at least yearly sampling frequency (Table 3). Lakes in Table 3 were chosen because regular annual sampling at those lakes provided more continuous and extensive historical data than sporadically managed and sampled lakes. Only lakes at which a management practice was conducted were selected to investigate the effects of that practice. Fall samples were collected from years and lakes without management in analyses incorporating natural effects only.

2.5. General Analytical Procedures

2.5.1. Introduction

General linear models were used to investigate the effects of the predictors and their first-order interactions on each response variable. Higher order interactions were excluded in the interest of result interpretability. Interactions were investigated because loss of information or loss of statistical power may occur (Zar 1996) in addition to misinterpretations of main effects if only main effects are considered.

2.5.2. Regression Model Assumptions

2.5.2.1. Autocorrelation

Serial autocorrelation is a concern when analyzing fisheries data (McAllister and Peterman 1992). High or low abundance in one year may persist in subsequent years, making regression results questionable due to an underestimation of residual variance (Green 1987) or an overestimate of the effective degrees of freedom. Data were tested for autocorrelation to investigate violations of independence and to determine where corrections for independence were necessary.

The effects of autocorrelation were tested separately for each lake that provided at least three consecutive data points separated by as many years as the lag being tested. Time-lagged regression was used to test the degree to which previous years (predictor) affected an observation of the age-1 and adult response variable. The age-2 response variable was not tested for autocorrelation because it did not provide enough data to warrant analysis. Each response variable was tested independently. The datum observed for the response variable in one year was regressed against the datum from a previous year. To avoid treatment confounding, only years were used in which none of the management practices considered herein (Section 2.2.2) was conducted. A one-year lag regression was initially tested (current year regressed against the previous year), followed by a two-year lag regression if the one-year lag test was statistically significant. The time lags between the observations of the response variable were increased until the effects for autocorrelation were no longer present.

The results of the serial autocorrelation showed violation of independence for two out of the 38 lakes tested for the age-1 response variable (Table 4). Both lakes were corrected for autocorrelation after introducing a time lag of two years (Table 4). The adult response variable showed four lakes out of 31 to violate independence. Two lakes were corrected for independence after introducing a time lag of two years and the other two after a time lag of three years (Table 5).

2.5.2.2. Multicollinearity

Multicollinearity may decrease the reliability of regression models and bias the assessment of model predictors (Pedhazur 1982; Cohen and Cohen 1983). Furthermore, multicollinearity may cause instability in parameter estimates, limiting the explanatory power of regression models (Stevens 1992; Phillipi 1993).

The effects of multicollinearity were examined by constructing correlation matrices and by determining the variance inflation factor (VIF; Weisberg 1985; Stevens 1992). The VIF provides a measure of the stability of model parameters by estimating the degree of intercorrelation among the predictors in the model. VIF values larger than 10 are taken as evidence of multicollinearity among predictors (Chatterjee and Price 1991).

The degree of association between pairs of predictors was determined using Pearson's r. The VIF was estimated in order to identify multicollinearity which may go undetected by relying on pairwise correlations only. The estimates of multicollinearity and pairwise correlations among the predictors are shown in Table 6.

2.5.3. Delayed Effects of the Predictors

Three delay lags based on delayed treatment effects were used to measure the effects of the predictors on the response variable. This was done because the predictor variables were hypothesized to affect the response later. Even though the predictors have a potential direct effect on fish, the effect on the response variable may not be immediate. An example is age-0 fish stocking in Illinois. Stocking as a predictor will not be detected immediately if a response variable based on age-1 fish in that year is used, even though it has an immediate effect on age-0 fish (an increase in age-0 fish).

A zero delay (lag 0) was defined for predictors potentially affecting fish during the same year a management practice was implemented or a datum for an environmental predictor observed. A one-year delay (lag -1) and a two-year delay (lag -2) were used for predictors affecting the response one and two years, respectively, after being implemented or observed. As an example for a lag -2, lake rehabilitation is done during the fall by completely draining the lake and leaving it without water until the next spring. Stocking of age-0 fish is done during the spring following rehabilitation. A potential increase of age-1 fish following lake rehabilitation, therefore, will only be detected in the second year after lake draining.

The main reason for not considering longer lags was the lack of any potential mechanism justifying lags over two years. It makes intuitive sense to postulate that the effects of the predictors on fish will be age or time dependent, as discussed for stocking and lake rehabilitation above, and immediately reflected on fish of certain ages. There is no evidence, however, that the effects will be latent and reflected at a later time only.

2.5.4. Regression Model Selection

Analyses were conducted on groups of lakes (multiple-lake) and separately for each lake (lake-specific). Multiple-lake analyses provided an estimate of treatment effect of a wider scope of inference, sometimes statewide. Lake-specific analyses consisted of estimating treatment effects specific for each lake. Power analysis for both, multiple- and lake-specific analyses was conducted using Fisher z transformation (Zar 1996), and an r^2 of zero as the null hypothesis and the observed r^2 as the alternative hypothesis.

2.5.4.1. Multiple-Lake Analyses

The variable selection criterion used to decide which interaction terms to retain was the same for each of the three treatment delayed effects above. The criterion was based on Residual Sums of Squares (RSS) tests for each coefficient.

Each of the three treatment delays was tested independently. The interaction terms for which the RSS analysis yielded non-significant results were individually excluded from analysis, starting with the term with the highest probability value associated with the RSS test (which contributed the least to the overall significance of the multiple regression model). Main effects were always kept in the model when examining the effects of interactions. The main effects were dropped if not significant and not part of any significant interaction term. Each time an interaction term was dropped, the RSS F-value for each of the remaining predictors was recalculated. This was repeated until the retained interaction terms had probability values of less than 0.05 or until all of the interaction terms were dropped. The anthropogenic predictor was never dropped from the model to allow for estimation of the efficacy of management practices. Multiple-lake analyses yielded a model for the effects the management practice being examined accounting for natural factors for each of the response variables defined in this dissertation (Section 2.2).

2.5.4.2. Lake-Specific Analyses

Following significant multiple-lake analysis, a lake-specific regression analysis was conducted for predictors significantly affecting the response variable. Only significant predictors were used because of the low number of observations within each lake would not allow for analyses of all predictors (low degrees of freedom). Because of the low number of observations for each lake, a more relaxed alpha level of significance of 0.1 was used for lake-specific tests.

LAKE	1985	86	87	88	89	90	91
ARGYLE LAKE				96			99
AUGUSTA LAKE			100	100			
CARTHAGE LAKE							100
DAWSON LAKE			98	97			
DEFIANCE LAKE							50
HORTON LAKE	100	100	100	100	100	100	100
JONES STATE LAKE	100					100	
LAKE CARLTON							100
LAKE LE-AQUA-NA	100			100	100		100
LAKE MURPHYSBORO						100	100
LAKE SANGCHRIS	100		97	99	100	97	98
LAKE STOREY							100
LINCOLN TRAIL LAKE	96	91	92	94	96	98	95
MCCULLOM LAKE			100	100	100	100	84
MILL CREEK LAKE	95	98	97	92	96	99	99
PIERCE LAKE	80	80	100	100		100	
RAMSEY LAKE		97	93	81	100	100	100
RED HILLS	89					100	
WELDON SPRINGS		98	97	92	92	96	99
WOLF LAKE	100	100	100	100		100	100

Table 1. Percent of largemouth bass caught with electrofishing gear during fall samples.

LAKE	DISTRICT	1960	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92
APPLE CANYON LAKE	1																																		
RM																													RM							
VG																																			
ST													ST																							
WL																												WM	WM							
RH																																			
R4																																			
R5																																			
RS																																			
LAKE LE-AQUA-NA	1																																		
RM																																			
VG					VG																			VG	VG	VG	VG									
ST												ST																								
WL						WM	WM						WM				WM		WM																	
RH															RH					RH															
R4																									R4	R4	R4	R4	R4	R4	R4	R4	R4	R4	R4	R4
R5																																			
RS																																			
PIERCE LAKE	1																																		
RM																						RM	RM			RM	RM		RM	RM						
VG																																			
ST																																			
WL																																			
RH																																			
R4																			R4	R4	R4	R4	R4	R4	R4	R4	R4	R4	R4	R4	R4	R4	R4	R4	R4
R5																																			
RS																																			
SHABBONA LAKE	1																																		
RM																						RM	RM													
VG																										VG	VG									
ST																		ST						ST												
WL																																			
RH																																			
R4																									R4	R4	R4	R4	R4	R4	R4	R4	R4	R4	R4	R4
R5																																			
RS																																			
LAKE CARLTON	2																																		
RM																																			
VG															VG	VG	VG		VG		VG		VG				VG	VG	VG	VG					
ST													ST									ST		ST					ST							
WL																																			
RH																																			
R4																			R4	R4	R4	R4	R4	R4	R4	R4	R4	R4	R4	R4	R4	R4	R4	R4	R4
R5																																			
RS																																			
SAUK TRAIL	2																																		
RM																																			
VG			VG	VG	VG								VG						VG			VG	VG						VG	VG		VG	VG		
ST									ST			ST												ST					ST							
WL						WM				WM	WM			WM				WM				WM				WM		WM			WM				
RH							RH																												
R4																			R4	R4	R4	R4	R4	R4	R4	R4	R4	R4	R4	R4	R4	R4	R4	R4	R4
R5																																			
RS																																			
ARGYLE LAKE	4																																		
RM									RM		RM	RM			RM	RM	RM		RM	RM		RM														
VG						VG																												
ST																					ST			ST					ST							
WL							WM	WM	WM				WM									WM											
RH													RH																					
R4																																			
R5																																			
RS																					RS	RS	RS	RS	RS	RS	RS	RS	RS	RS	RS	RS	RS	RS	RS
GLADST NE LAKE	4																																		
RM																								RM											
VG																																			
ST																						ST														
WL							WM				WM																			WM					
RH																					RH															
R4																																			
R5																																			
RS																							RS	RS	RS	RS	RS	RS	RS	RS	RS	RS	RS	RS	RS

Key:
RM - Fish removal practices
VG - Aquatic vegetation controls
ST - Largemouth bass stocking
WM - Water level maniulations
RH - Lake rehabilitation events
R4 - Fishing regulation changes from the Statewide 300 mm minimum length limit to a 350 mm minimum length limit
R5 - Fishing regulation changes from the Statewide 300 mm minimum length limit to a 375 mm minimum length limit
RS - Fishing regulation changes from the Statewide 300 mm minimum length limit to a 300-375 mm slot length limit

Table 2. Selection of management practices by lake. Example of coding system interpretation: Apple Canyon Lake is an Illinois Department of Natural Resources lake located in District 1 and had fish RM oval practices in 1985, water level manipulation in 1984 and 1985, and largemouth bass ST cking in 1970.

LAKE	DISTRICT	1960	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	89	90	91	92	
LAKE ST REY	4																																	
RM															RM																			
VG																VG																		
ST																																		
WL					WM	WM	WM						WM				WM			WM	WM	WM	WM			WM	WM	WM	WM	WM		WM		
RH						RH					RH																							
R4																																		
R5																																		
RS																												RS	RS	RS	RS	RS	RS	RS
ANDERSON LAKE	5																																	
RM																																		
VG																																		
ST																																		
WL									WM				WM																					
RH																																		
R4																																		
R5																																		
RS																																		
DEFIANCE LAKE	7																																	
RM																	RM																	
VG																																		
ST																																		
WL															WM																			
RH																																		
R4																							R4	R4	R4	R4	R4	R4	R4	R4	R4	R4	R4	R4
R5																																		
RS																																		
MCCULLOM LAKE	7																																	
RM																																		
VG																																		
ST													ST						ST	ST	ST													
WL																	WM																	
RH												RH																						
R4																																		
R5																												R5	R5	R5	R5	R5	R5	R5
RS																																		
LAKE OF THE WOODS	8																																	
RM																RM																		
VG																																		
ST					ST																													
WL																WM																		
RH																																		
R4																																		
R5																							R5	R5	R5	R5	R5	R5	R5	R5	R5	R5	R5	R5
RS																																		
WELDON SPRINGS	8																																	
RM											RM																		RM			RM		
VG		VG					VG	VG	VG										VG	VG	VG	VG				VG	VG	VG			VG			
ST																																		
WL				WM						WM								WM					WM											
RH																																		
R4																																		
R5																							R5	R5	R5	R5	R5	R5	R5	R5	R5	R5	R5	R5
RS																																		
WOLF LAKE	9																																	
RM								RM																										
VG																																		
ST																ST																		
WL																																		
RH																				RH														
R4																												R4	R4	R4	R4	R4	R4	R4
R5																																		
RS																																		
SILOAM SPRINGS	10																																	
RM																																		
VG		VG	VG												VG	VG				VG														
ST							ST																											
WL								WM																										
RH				RH																														
R4																																		
R5																																		
RS																													RS	RS	RS	RS	RS	RS

Key:

RM - Fish removal practices

VG - Aquatic vegetation controls

ST - Largemouth bass stocking

WM - Water level maniulations

RH - Lake rehabilitation events

R4 - Fishing regulation changes from the Statewide 300 mm minimum length limit to a 350 mm minimum length limit

R5 - Fishing regulation changes from the Statewide 300 mm minimum length limit to a 375 mm minimum length limit

RS - Fishing regulation changes from the Statewide 300 mm minimum length limit to a 300-375 mm slot length limit

Table 2. (Continued).

LAKE	DISTRICT	1960	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92
WEINBURG - KING LAKE #1	10																																	
RM																																		
VG																		VG		VG	VG													
ST																																		
WL																	WM	WM			WM				WM									
RH																																		
R4																																		
R5																																		
RS																																		
HOMER LAKE	12																																	
RM														RM																				
VG																																		
ST																																		
WL																																		
RH																																		
R4																							R4	R4	R4	R4	R4	R4	R4	R4	R4	R4	R4	R4
R5																																		
RS																																		
WALNUT POINT LAKE	12																																	
RM														RM	RM																			
VG																VG							VG	VG	VG			VG	VG	VG	VG	VG	VG	
ST																																		
WL													WM																					
RH																						RH												
R4																							R4	R4	R4	R4	R4	R4	R4	R4	R4	R4	R4	R4
R5																																		
RS																																		
DAWSON LAKE	13																																	
RM													RM		RM																			
VG							VG	VG	VG	VG	VG	VG							VG			VG				VG								
ST					ST																								ST					
WL																																		
RH																RH																RH		
R4																																		
R5																																		
RS																										RS	RS	RS	RS	RS	RS	RS	RS	RS
LINCOLN TRAIL LAKE	14																																	
RM											RM			RM	RM																			
VG		VG	VG	VG				VG	VG				VG							VG	VG	VG					VG	VG	VG	VG	VG	VG	VG	
ST																																		
WL										WM			WM	WM			WM	WM								WM								
RH						RH																												
R4																																		
R5																																		
RS																																		
MILL CREEK LAKE	14																																	
RM																																		
VG																																		
ST																																		
WL																																		
RH																																		
R4																																		
R5																																		
RS																												RS	RS	RS	RS	RS	RS	RS
AUGUSTA LAKE	15																																	
RM																																		
VG													VG			VG																		
ST																																		
WL								WM							WM	WM	WM			WM														
RH																																		
R4																																		
R5																																		
RS																																		
CARTHAGE LAKE	15																																	
RM									RM	RM	RM			RM	RM																			
VG																																		
ST																																		
WL										WM			WM					WM	WM	WM	WM													
RH																	RH																	
R4																																		
R5																																		
RS																																		

Key:
RM - Fish removal practices
VG - Aquatic vegetation controls
ST - Largemouth bass stocking
WM - Water level maniulations
RH - Lake rehabilitation events
R4 - Fishing regulation changes from the Statewide 300 mm minimum length limit to a 350 mm minimum length limit
R5 - Fishing regulation changes from the Statewide 300 mm minimum length limit to a 375 mm minimum length limit
RS - Fishing regulation changes from the Statewide 300 mm minimum length limit to a 300-375 mm slot length limit

Table 2. (Continued).

LAKE	DISTRICT	1960	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92
HORTON LAKE	15																																	
RM																																		
VG																																		
ST																																		
WL																					WM				WM									
RH													RH																					
R4																																		
R5																																		
RS																																		
PITTSFIELD LAKE	15																																	
RM							RM			RM																								
VG																																		
ST																				ST														
WL																					WM													
RH																																		
R4																																		
R5																																		
RS																																		
RED HILLS	15																																	
RM																	RM																	
VG		VG						VG	VG	VG	VG	VG		VG	VG			VG		VG	VG	VG	VG		VG									
ST																																		
WL																				WM														
RH					RH															RH														
R4																																		
R5																													R5	R5	R5	R5	R5	R5
RS																																		
SCHUY-RUSH LAKE	15																																	
RM																																		
VG																																		
ST																	ST																	
WL																					WM													
RH																																		
R4																																		
R5																																		
RS																																		
DOLAN STATE LAKE	16																																	
RM											RM		RM					RM	RM		RM													
VG								VG	VG	VG																								
ST																																		
WL						WM	WM							WM	WM	WM	WM	WM																
RH																																		
R4																												R4	R4	R4	R4	R4	R4	R4
R5																																		
RS																																		
LAKE SANGCHRIS	17																																	
RM																																		
VG																																		
ST							ST																											
WL																		WM				WM												
RH																																		
R4																																		
R5																							R5	R5	R5	R5	R5	R5	R5	R5	R5	R5	R5	R5
RS																																		
BEAVER DAM LAKE	18																																	
RM														RM	RM	RM	RM																	
VG																							VG				VG		VG	VG				
ST						ST	ST											ST																
WL																																		
RH																																		
R4																																		
R5																							R5	R5	R5					R5	R5	R5	R5	R5
RS																										RS	RS	RS	RS					
BALDWIN LAKE	21																																	
RM												RM																						
VG																																		
ST																																		
WL																																		
RH																																		
R4																							R4	R4	R4									
R5																																		
RS																																		

Key:
RM - Fish removal practices
VG - Aquatic vegetation controls
ST - Largemouth bass stocking
WM - Water level maniulations
RH - Lake rehabilitation events
R4 - Fishing regulation changes from the Statewide 300 mm minimum length limit to a 350 mm minimum length limit
R5 - Fishing regulation changes from the Statewide 300 mm minimum length limit to a 375 mm minimum length limit
RS - Fishing regulation changes from the Statewide 300 mm minimum length limit to a 300-375 mm slot length limit

Table 2. (Continued).

LAKE	DISTRICT	1960	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92
RANDOLPH COUNTY LAKE	21																																	
RM													RM											RM										
VG									VG										VG										VG	VG	VG			
ST												ST					ST																	
WL						WM																												
RH																																		
R4																							R4	R4	R4	R4	R4	R4	R4	R4	R4	R4	R4	R4
R5																																		
RS																																		
WASHINGTON COUNTY LAKE	21																																	
RM															RM		RM																	
VG																																		
ST				ST									ST																					
WL						WM					WM							WM							WM									
RH												RH																						
R4																										R4	R4	R4	R4	R4	R4	R4	R4	R4
R5																																		
RS																																		
FORBES LAKE	22																																	
RM													RM	RM		RM	RM	RM																
VG																																		
ST						ST																				ST	ST			ST	ST	ST		
WL																																		
RH																																		
R4																												R4	R4	R4	R4	R4	R4	R4
R5																																		
RS																																		
LAKE SARA	22																																	
RM																																		
VG																																		
ST																																		
WL																																		
RH																																		
R4																																		
R5																											R5	R5	R5	R5	R5	R5	R5	R5
RS																																		
RAMSEY LAKE	22																																	
RM																RM	RM				RM													
VG									VG		VG	VG		VG	VG										VG	VG	VG	VG	VG	VG	VG			
ST																			ST						ST	ST								
WL					WM			WM		WM			WM																					
RH				RH																														
R4																										R4	R4	R4	R4	R4	R4	R4	R4	R4
R5																																		
RS																																		
JONES STATE LAKE	24																																	
RM							RM				RM	RM									RM	RM	RM	RM	RM	RM	RM							
VG									VG	VG																								
ST																																		
WL													WM	WM	WM	WM		WM																
RH																																		
R4																												R4	R4	R4	R4	R4	R4	R4
R5																																		
RS																																		
LAKE MURPHYSBORO	25																																	
RM																								RM										
VG						VG	VG	VG	VG	VG		VG												VG		VG	VG		VG	VG				
ST						ST																												
WL							WM														WM	WM	WM											
RH					RH																													
R4																														R4	R4	R4	R4	R4
R5																														R5	R5	R5	R5	R5
RS																																		
CARLYLE LAKE	32																																	
RM																																		
VG																																		
ST							ST	ST									ST	ST	ST	ST	ST	ST	ST	ST	ST									
WL																																		
RH																																		
R4																										R4	R4	R4	R4	R4	R4	R4	R4	R4
R5																																		
RS																																		

Key:
RM - Fish removal practices
VG - Aquatic vegetation controls
ST - Largemouth bass stocking
WM - Water level maniulations
RH - Lake rehabilitation events
R4 - Fishing regulation changes from the Statewide 300 mm minimum length limit to a 350 mm minimum length limit
R5 - Fishing regulation changes from the Statewide 300 mm minimum length limit to a 375 mm minimum length limit
RS - Fishing regulation changes from the Statewide 300 mm minimum length limit to a 300-375 mm slot length limit

Table 2. (Continued).

LAKE	DISTRICT	1960	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	'91	92
LAKE SHELBYVILLE	32																																	
RM																																		
VG																																		
ST													ST					ST	ST				ST						ST					
WL																																		
RH																																		
R4																				R4	R4	R4	R4	R4	R4	R4	R4	R4	R4	R4	R4	R4	R4	R4
R5																																		
RS																																		
REND LAKE	32																																	
RM																																		
VG																																		
ST													ST	ST		ST							ST	ST			ST							
WL																																		
RH																																		
R4																										R4	R4	R4	R4	R4	R4	R4	R4	R4
R5																																		
RS																																		

Key:

RM - Fish removal practices
VG - Aquatic vegetation controls
ST - Largemouth bass stocking
WM - Water level maniulations
RH - Lake rehabilitation events
R4 - Fishing regulation changes from the Statewide 300 mm minimum length limit to a 350 mm minimum length limit
R5 - Fishing regulation changes from the Statewide 300 mm minimum length limit to a 375 mm minimum length limit
RS - Fishing regulation changes from the Statewide 300 mm minimum length limit to a 300-375 mm slot length limit

Table 2. (Concluded).

LAKE (DISTRICT)	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91
APPLE CANYON LAKE (1)											*	*	*	*	*	*	*	*	*	*	*	*	*			*	*
LAKE LE-AQUA-NA (1)	*	*	*	*	*	*	*		*	*	*	*	*	*	*	*	*	*	*	*	*	*		*	*		*
PIERCE LAKE (1)							*	*	*	*	*	*	*	*	*	*	*		*	*	*		*	*		*	
SHABBONA LAKE (1)												*	*	*	*	*	*			*	*			*	*		*
LAKE CARLTON (2)						*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
SAUK TRAIL (2)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		*
ARGYLE LAKE (4)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*			*
GLADSTONE LAKE (4)	*	*	*	*	*	*	*	*	*	*	*	*	*		*	*	*	*	*	*	*	*	*			*	
LAKE STOREY (4)			*			*	*	*	*	*	*	*	*	*	*	*	*	*		*	*	*	*			*	*
ANDERSON LAKE (5)				*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*						
DEFIANCE LAKE (7)						*		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
MCCULLOM LAKE (7)		*		*				*			*		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
LAKE OF THE WOODS (8)					*		*		*	*	*	*	*	*	*		*	*	*	*	*	*		*			
WELDON SPRINGS (8)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		*	*	*	*	*	*	*	*	*
WOLF LAKE (9)	*	*	*	*	*		*	*	*	*	*	*		*	*	*	*				*	*	*	*	*	*	*
SILOAM SPRINGS (10)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		*				
WEINBURG - KING LAKE #1 (10)											*	*	*	*	*	*	*	*	*		*	*	*	*			
HOMER LAKE (12)						*	*	*	*	*				*		*			*		*	*		*			
WALNUT POINT LAKE (12)			*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
DAWSON LAKE (13)	*	*	*	*	*	*	*	*	*		*	*	*	*	*	*	*	*	*	*	*	*	*	*		*	*
LINCOLN TRAIL LAKE (14)		*	*	**	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
MILL CREEK LAKE (14)																	*	*	*	*	*	*	*	*	*	*	*
AUGUSTA LAKE (15)	*	*	*	*	*	*		*		*	*			*	*			*	*				*	*		*	
CARTHAGE LAKE (15)		*	*	*	*	*	*	*	*		*	*	*	*	*			*					*	*	*	*	*
HORTON LAKE (15)								*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
PITTSFIELD LAKE (15)	*		*		*				*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
RED HILLS (15)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		*	*	*	*	*		*	
SCHUY-RUSH LAKE (15)												*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
DOLAN STATE LAKE (16)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*				*	*		*
LAKE SANGCHRIS (17)							*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		*	*	*	*	*
BEAVER DAM LAKE (18)								*	*	*	*						*		*		*	*	*	*	*	*	*
BALDWIN LAKE (21)					*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		*	*	*		
RANDOLPH COUNTY LAKE (21)		*	* *	*	*	*	*	*	*	*	*	*			*	*	*	*	*								
WASHINGTON COUNTY LAKE (21)		*	**	*	*		*	*	*	*	*	*	*	*	*	*	*	*	*	*		*	*		*		
FORBES LAKE (22)								*	*	*	*	*				*	*	*	*	*	*	*	*	*	*	*	*

LAKE SARA (22)			*				*		*				*						*	*	*	*			*	*	*
RAMSEY LAKE (22)	*	*	*	*	*	*	*	*			*	*			*		*	*	*	*	*	*	*	*	*	*	*
JONES STATE LAKE (24)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		*	
LAKE MURPHYSBORO (25)	*	*	*	*	*	*	*	*		*	*	*	*	*	*	*	*	*	*	*		*	*	*	*	*	*
CARLYLE LAKE (32)		*	*	*	*	*	*	*	*	*	*	*	*	*		*	*	*	*	*	*	*	*	*	*		*
LAKE SHELBYVILLE (32)							*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		*	*	*		*
REND LAKE (32)							*	*	*	*	*	*	*	*	*	*	*	*	*	*	*		*	*	*		*

Table 3. List of lakes by district with years of available information (asterisks) for fish fall electrofishing catch per effort.

LAKE	Results (one-year lag)				Correction			
	(r^2	slope	p-value	df)	(r^2	slope	p-value	df)
ANDERSON LAKE	0.01	+0.08	0.7401	13				
APPLE CANYON LAKE	0.03	+0.15	0.6603	08				
ARGYLE LAKE	<0.01	+0.01	0.9635	15				
BALDWIN LAKE	0.34	+0.59	0.0175	14	0.05	+0.17	0.4454	13
BEAVER DAM LAKE	0.15	-0.44	0.7450	01				
CARLYLE LAKE	0.18	+0.40	0.0558	19				
CARTHAGE LAKE	0.01	-0.10	0.8365	05				
DAWSON LAKE	0.05	+0.23	0.6814	04				
DEFIANCE LAKE	0.01	+0.09	0.7337	15				
DOLAN STATE LAKE	0.07	-0.28	0.4972	07				
FORBES LAKE	0.13	+0.43	0.1984	12				
GLADSTONE LAKE	0.22	+0.45	0.0376	18	0.05	+0.22	0.4466	11
HOMER LAKE	0.32	-0.10	0.4328	02				
HORTON LAKE	0.07	+0.29	0.3182	14				
JONES STATE LAKE	0.07	-0.21	0.4169	10				
LAKE CARLTON	0.83	+2.39	0.2749	01				
LAKE LE-AQUA-NA	<0.01	-0.01	0.9932	01				
LAKE MURPHYSBORO	0.24	-0.46	0.3263	04				
LAKE OF THE WOODS	0.16	-0.50	0.3237	06				
LAKE SANGCHRIS	0.24	+0.58	0.0552	14				
LAKE SARA	0.01	-0.07	0.9411	01				
LAKE SHELBYVILLE	0.01	+0.26	0.3265	12				

LINCOLN TRAIL LAKE	0.17 -0.40 0.4209 04
MCCULLOM LAKE	<0.01 +0.02 0.9488 10
MILL CREEK LAKE	<0.01 +0.02 0.9256 08
PITTSFIELD LAKE	0.11 +0.32 0.2048 14
RANDOLPH COUNTY LAKE	<0.01 +0.09 0.7736 09
RED HILLS	0.21 -0.71 0.6953 01
REND LAKE	0.45 +0.20 0.4665 12
SAUK TRAIL	0.77 +0.25 0.8213 01
SCHUY-RUSH LAKE	<0.01 +0.03 0.9319 02
SHABBONA LAKE	0.47 -0.70 0.2003 03
SILOAM SPRINGS	<0.01 +0.06 0.8483 12
WALNUT POINT LAKE	0.40 +0.05 0.1278 14
WASHINGTON COUNTY LAKE	0.21 +0.45 0.0778 14
WEINBURG - KING LAKE #1	0.21 -0.40 0.6975 01
WELDON SPRINGS	<0.01 -0.01 0.8976 05
WOLF LAKE	0.12 +0.03 0.1149 20

Table 4. Regression results for lake serial autocorrelation for the age-1 largemouth bass response variable. First value - r-square, second value - slope coefficient, third value - probability -value, fourth value - degrees of freedom. Values in the correction column are only for lakes with statistically significant one-year lag autocorrelations.

LAKE	Results (one-year lag)				Correction			
	(r^2	slope	p-value	df)	(r^2	slope	p-value	df)
ARGYLE LAKE	0.01	+0.14	0.6576	12				
BEAVER DAM LAKE	0.26	-0.50	0.6628	01				
CARLYLE LAKE	0.22	+0.33	0.0803	13				
DAWSON LAKE	0.04	+0.18	0.4464	15				
DEFIANCE LAKE	0.01	-0.05	0.8544	06				
DOLAN STATE LAKE	0.01	-0.12	0.5766	19				
FORBES LAKE	0.57	+0.79	0.0183	07	0.21	+0.66	0.6954	01*
HOMER LAKE	0.74	-1.87	0.1407	02				
JONES STATE LAKE	<0.01	-0.01	0.9667	19				
LAKE CARLTON	0.56	+0.67	0.1486	03				
LAKE LE-AQUA-NA	0.01	+0.11	0.7512	08				
LAKE MURPHYSBORO	0.01	+0.07	0.7412	15				
LAKE OF THE WOODS	0.17	-0.45	0.4231	04				
LAKE SANGCHRIS	0.02	+0.13	0.7474	07				
LAKE SHELBYVILLE	0.54	+0.44	0.0958	04				
LAKE STOREY	0.41	+0.38	0.0336	09	0.09	+0.14	0.3645	09
MILL CREEK LAKE	0.51	-0.60	0.2848	02				
PIERCE LAKE	0.25	+0.43	0.5054	02				
RAMSEY LAKE	0.13	-0.47	0.3818	06				
RANDOLPH COUNTY LAKE	0.07	+0.26	0.4301	09				
RED HILLS	0.05	+0.24	0.3730	15				
REND LAKE	0.34	+0.34	0.0459	10	0.02	-0.06	0.7150	09
SAUK TRAIL	<0.01	+0.04	0.8993	10				
SHABBONA LAKE	0.18	+0.20	0.5793	02				

SILOAM SPRINGS	<0.01 +0.08 0.7430 18	
WALNUT POINT LAKE	0.24 +0.46 0.0864 11	
WASHINGTON COUNTY LAKE	0.03 +0.16 0.5110 16	
WELDON SPRINGS	0.38 +0.63 0.0051 17	
WOLF LAKE	0.02 -0.12 0.6189 14	0.16 +0.34 0.1118 15*

Table 5. Regression results for lake serial autocorrelation for the adult largemouth bass response variable. First value - r-square, second value - slope coefficient, third value - probability-value, fourth value - degrees of freedom. Values in the correction column are only for lakes with statistically significant one-year lag autocorrelations. Asterisks are indications for lakes needing three years in between observations for correction of effects of autocorrelation.

PREDICTOR	X	STD	Min	Max	Skew	Kurt	VIF
ENVIRONMENTAL							
PRECIPITATION PREDICTOR*	0.07	0.20	0.0	1.79	6.9	57.8	1.4
GROWING-DEGREE-DAY (°C)	3423	451	1994	4671	-0.2	-0.2	1.7
COOLING DEGREE DAY (°C)	616	324	23	1827	0.8	0.7	2.1
SNOW DEPTH (millimeters)	37.2	43.2	0.9	439.3	3.5	18.6	1.1
LAKE AVERAGE CATCH PER EFFORT (fish/hour)	3.3	0.3	2.6	4.10	-0.6	0.4	1.3
LAKE AVERAGE GROWING-DEGREE-DAYS	3422	368	2694	3984	-0.5	-0.6	1.5
VOLUME OF LAKE IN EUPHOTIC ZONE (%)	0.39	0.26	0.01	0.95	0.45	-0.69	1.2
LAKE CONDUCTIVITY (mohs/cm)	326.6	110.9	125	547	0.5	-0.6	1.4
LAKE INSHORE MEAN DEPTH (meters)	2.1	0.9	0.6	4.3	0.8	<0.1	1.3
LAKE HABITAT TYPE (hard cover rating)	1.1	0.5	<0.1	2.8	1.3	2.8	1.3
ANTHROPOGENIC							
Continuous variables							
LARGEMOUTH BASS STOCKING EVENTS (fish/hectares)	7.6	58.5	0.0	1110	11.9	173.0	1.0
WATER LEVEL MANIPULATIONS (centimeters)	7.8	38.8	0.0	457.2	6.7	51.1	1.0
Dichotomous variables							
FISH REMOVAL PRACTICE			0.0	1.0	4.0	14.1	1.0
AQUATIC VEGETATION CONTROL			0.0	1.0	2.7	5.5	1.0
LAKE TOTAL REHABILITATION			0.0	1.0	8.7	74.3	1.0
350 mm MINIMUM LARGEMOUTH BASS LENGTH REGULATION			0.0	1.0	1.9	1.6	1.1
375 mm MINIMUM LARGEMOUTH BASS LENGTH REGULATION			0.0	1.0	4.1	14.9	1.0
300-375 mm LARGEMOUTH BASS SLOT LENGTH REGULATION			0.0	1.0	4.6	18.8	1.0

Pearson Product-Moment for Pair-Wise Correlations
(* - significant at 0.05 alpha level)

(environmental predictors)

	PPT	GDE	CDE	SND
PPT	1			
GDE	-0.1*	1		
CDE	-0.1*	-0.5*	1	
SND	trace	-0.3*	0.6*	1

(environmental predictors for the static model)

	GDE	CON	HAB	IMD	EUP
GDE	1				
CON	-0.7*	1			
HAB	0.1	trace	1		
IMD	0.4*	-0.4	0.3	1	
EUP	-0.3	0.3	-0.1	-0.2	1

Key:
* - [(precipitation*watershed area)*(1+percent uncovered land)]/(lake volume*volume development index)
X - Mean
STD - Standard deviation
Max - Maximum value
Min - Minimum value
Skew- Skewness
Kurt- Kurtosis
VIF - Variance inflation factor
PPT - Precipitation predictor
GDE - Growing-degree-days
CDE - Cooling degree days
SND - Snow depth
GDE - Average growing-degree-days(*)
CON - Average conductivity(*)
HAB - Inshore habitat type(*)
IMD - Inshore mean depth(*)

EUP - Volume of lake in the euphotic zone(*)

Table 6. Summary statistics and summary diagnostics for predictors for the environmental and anthropogenic components (N = 1428; N = 28 for predictors with asterisks).

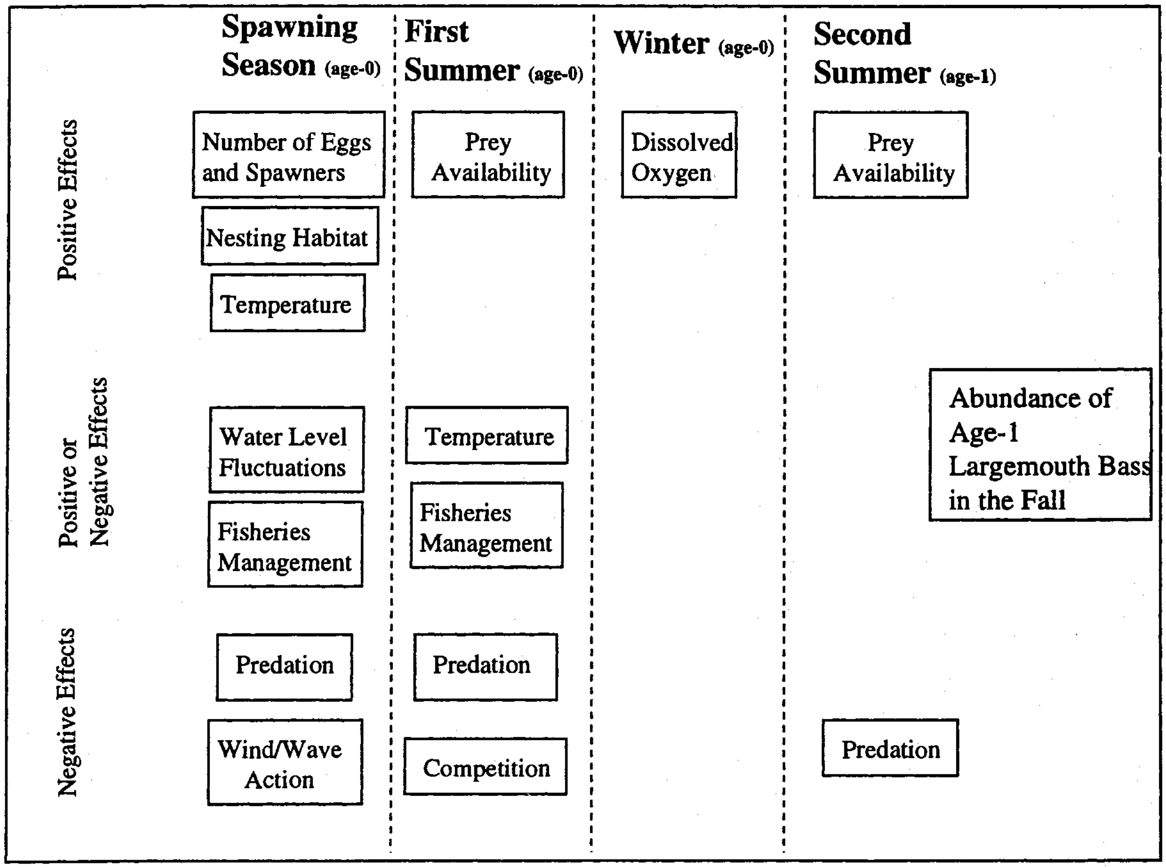


Figure 2. A schematic representation of potential effects on largemouth bass influencing first year abundance.

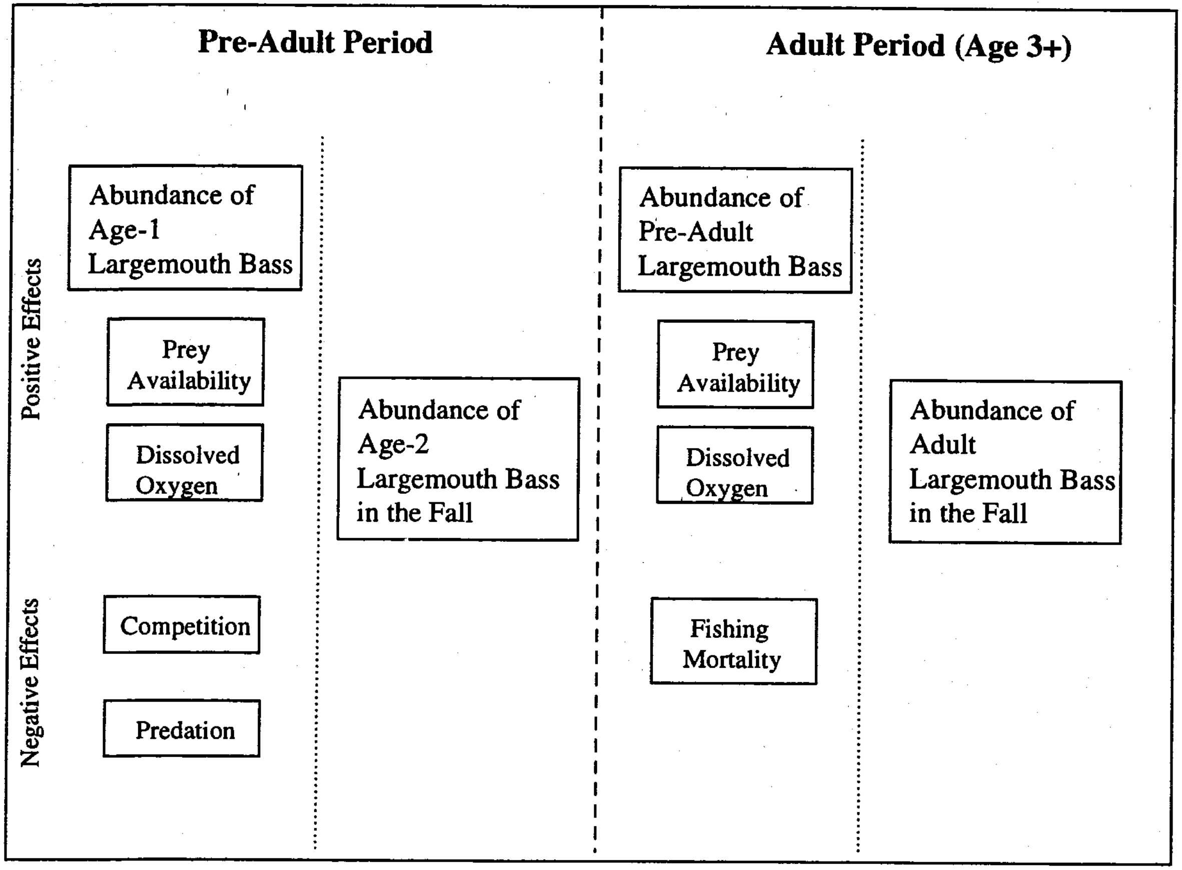
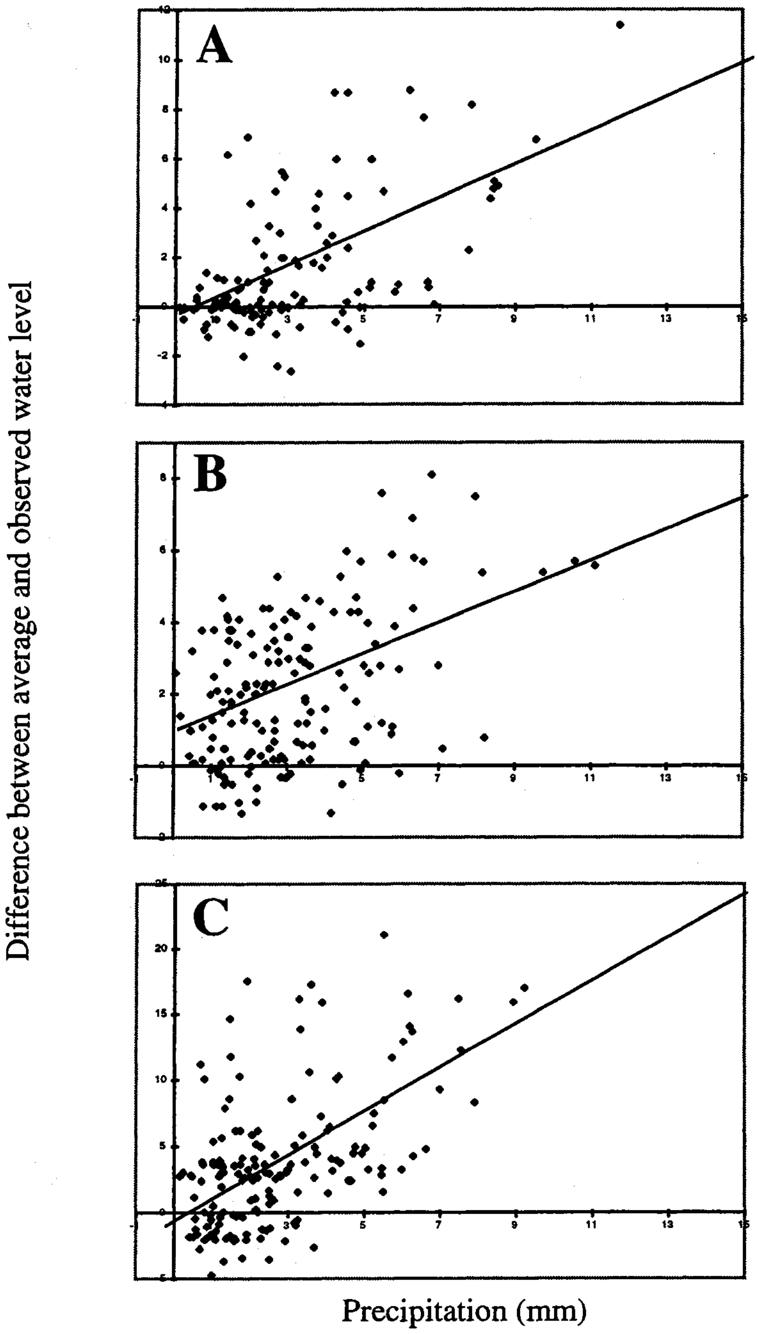

Pre-Adult Period
Adult Period (Age 3+)
Positive Effects
Negative Effects
Abundance of Age-1 Largemouth Bass
Prey Availability
Dissolved Oxygen
Competition
Predation
Abundance of Age-2 Largemouth Bass in the Fall
Abundance of Pre-Adult Largemouth Bass
Prey Availability
Dissolved Oxygen
Fishing Mortality
Abundance of Adult Largemouth Bass in the Fall

Figure 3. A schematic representation of potential effects influencing recruitment at age-2 largemouth bass and largemouth bass adult abundance (age-3+).



R^2 = 0.33
Slope = 0.69
N = 123
p-value < 0.0001

R^2 = 0.21
Slope = 0.46
N = 166
p-value < 0.0001

R^2 = 0.30
Slope = 1.48
N = 148
p-value < 0.0001

Figure 4. Relationship between mean monthly water level and monthly precipitation for three Illinois lakes. Panel A - Lake Carlyle, Panel B

- Rend Lake, Panel C - Lake Shelbyville, N - number of observations. Average lake water level calculated based on observations of water levels over years.

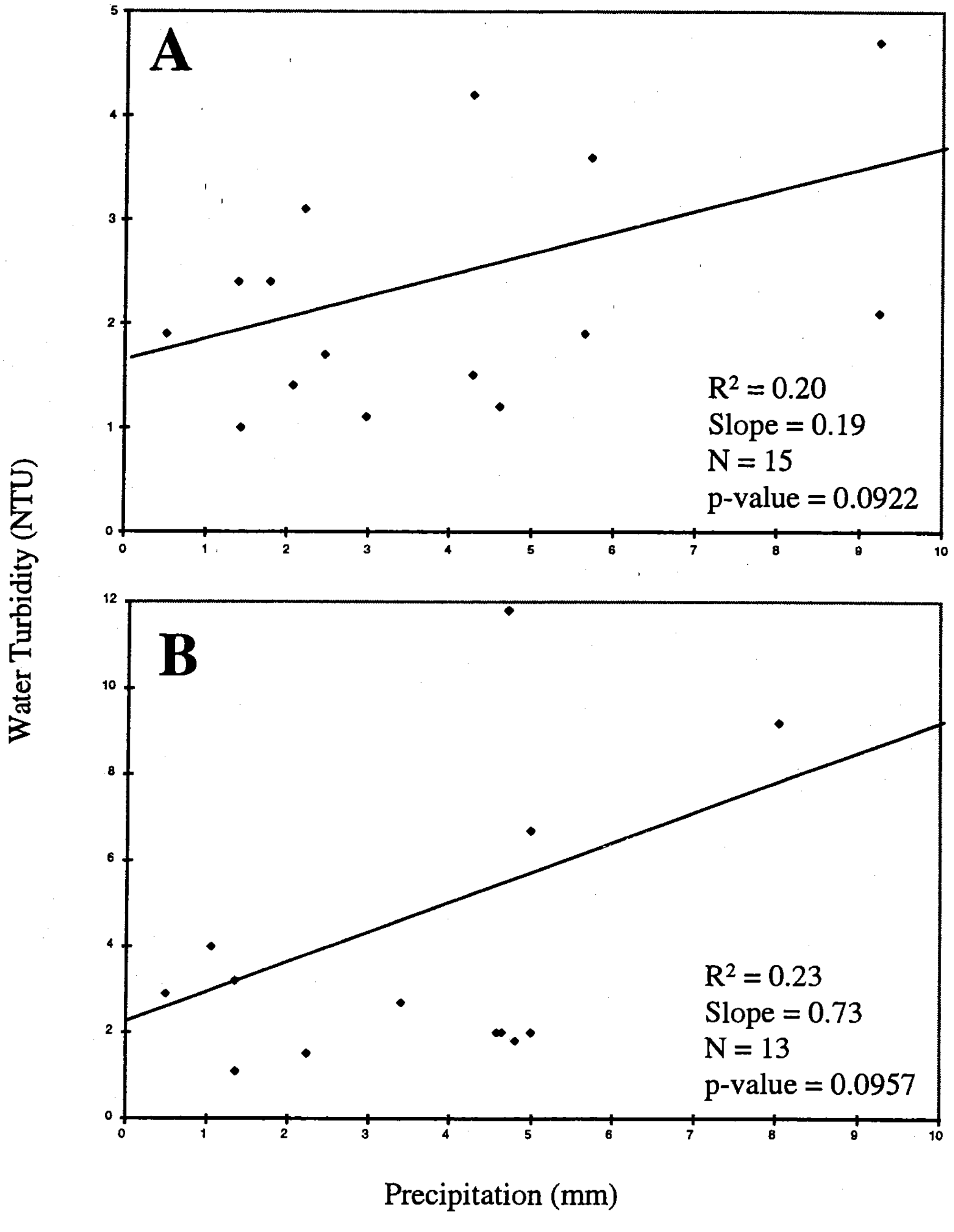

A
5
4
3
2
1
0
0
1
2
3
4
5
6
7
8
9
10
R² = 0.20
Slope = 0.19
N = 15
p-value = 0.0922
Water Turbidity (NTU)
B
12
10
8
6
4
2
0
0
1
2
3
4
5
6
7
8
9
10
R² = 0.23
Slope = 0.73
N = 13
p-value = 0.0957
Precipitation (mm)

Figure 5. Relationship between mean monthly water turbidity and monthly precipitation for two Illinois lakes. Panel A - Lake Carlton, Panel B - Shabbona Lake, N - number of observations.

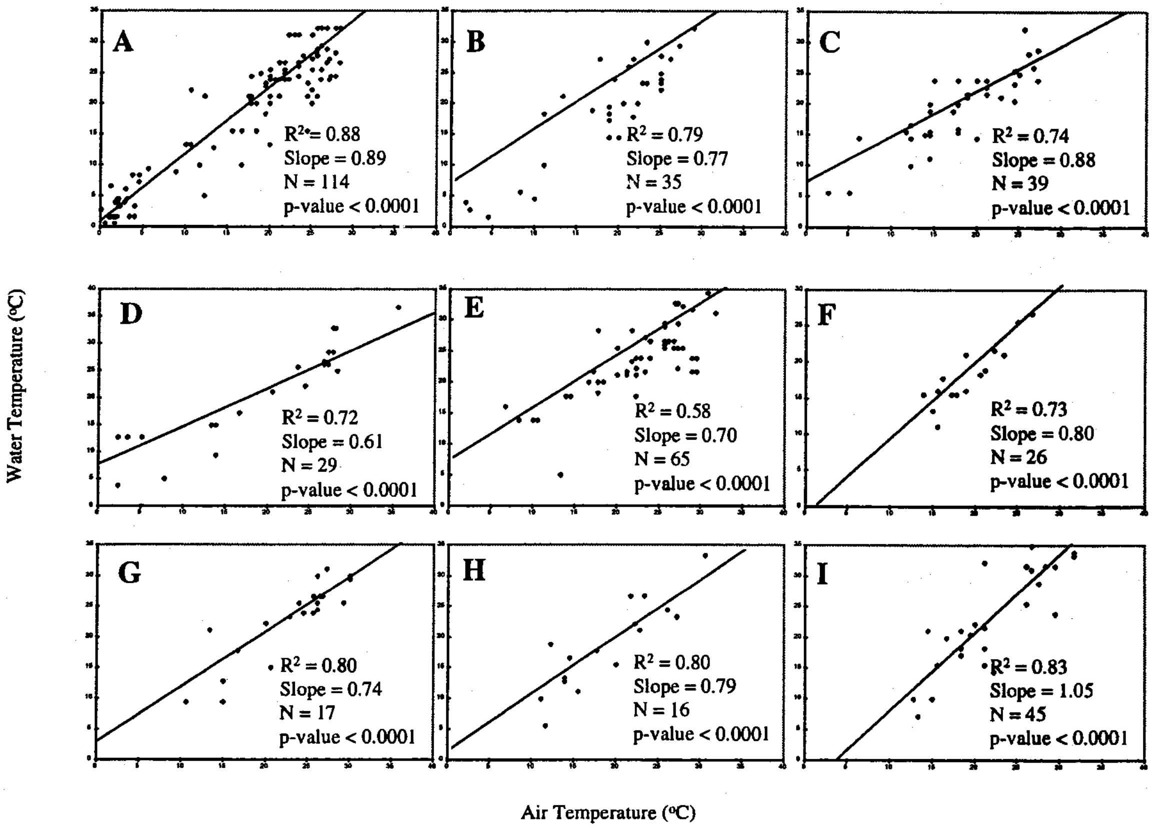
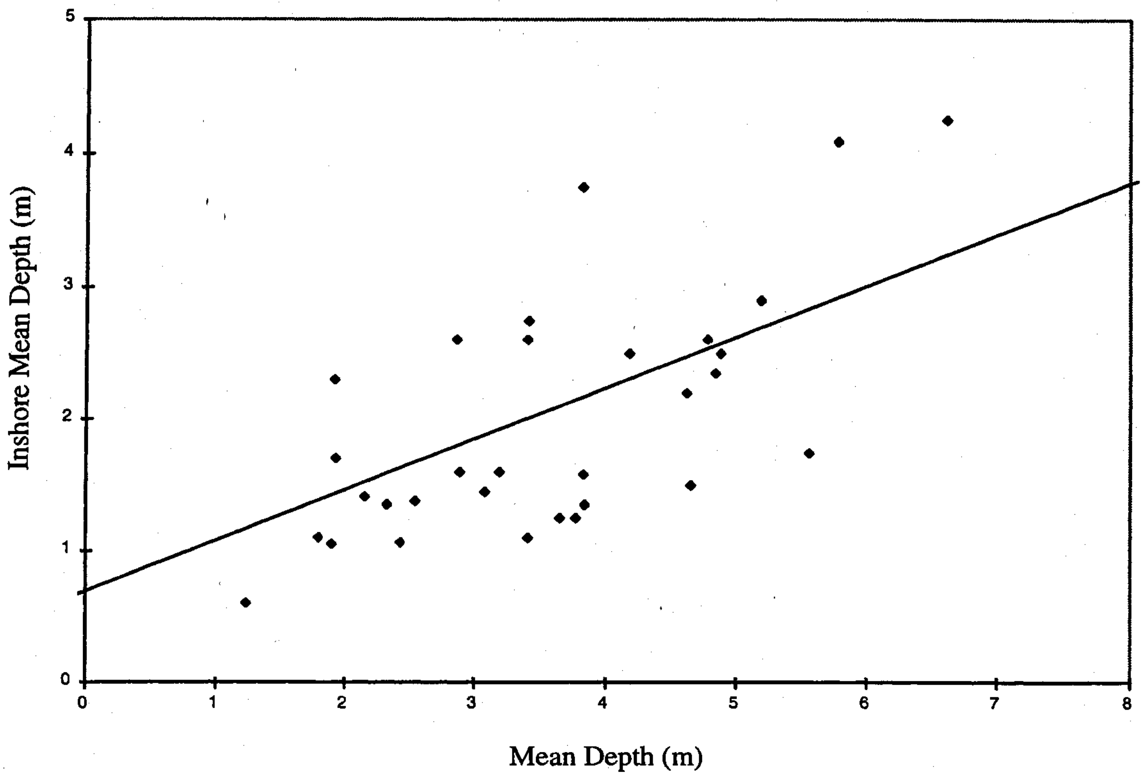


Figure 6. Relationship between mean monthly air and water temperature for nine Illinois lakes. Panel A - Lake Le-Aqua-Na, Panel B - Pierce Lake, Panel C - Defiance Lake, Panel D - Washington County Lake, Panel E - Red Hills, Panel F - Dolan State Lake, Panel G - Lake of the Woods, Panel H - Schuy-Rush Lake, Panel I - Anderson Lake, N - number of observations.



```
Response variable - Inshore mean depth
R squared = 0.44
29  degrees of freedom

Source      Sum of Squares      df      Mean Square      F-ratio
Regression           11.09       1            11.09         23.2
Residual             13.88      29             0.49

Variable      Coefficient      s.e. of Coeff      t-ratio      p-value
Constant             0.35               0.36         0.96       0.3469
Mean Depth           0.46               0.10         4.81      <0.0001
```

Figure 7. Relationship between inshore mean depth and mean depth for 31 lakes in Illinois. Inshore mean depth = mean depth calculated over a lake volume between the shore out to a distance of 15 m.

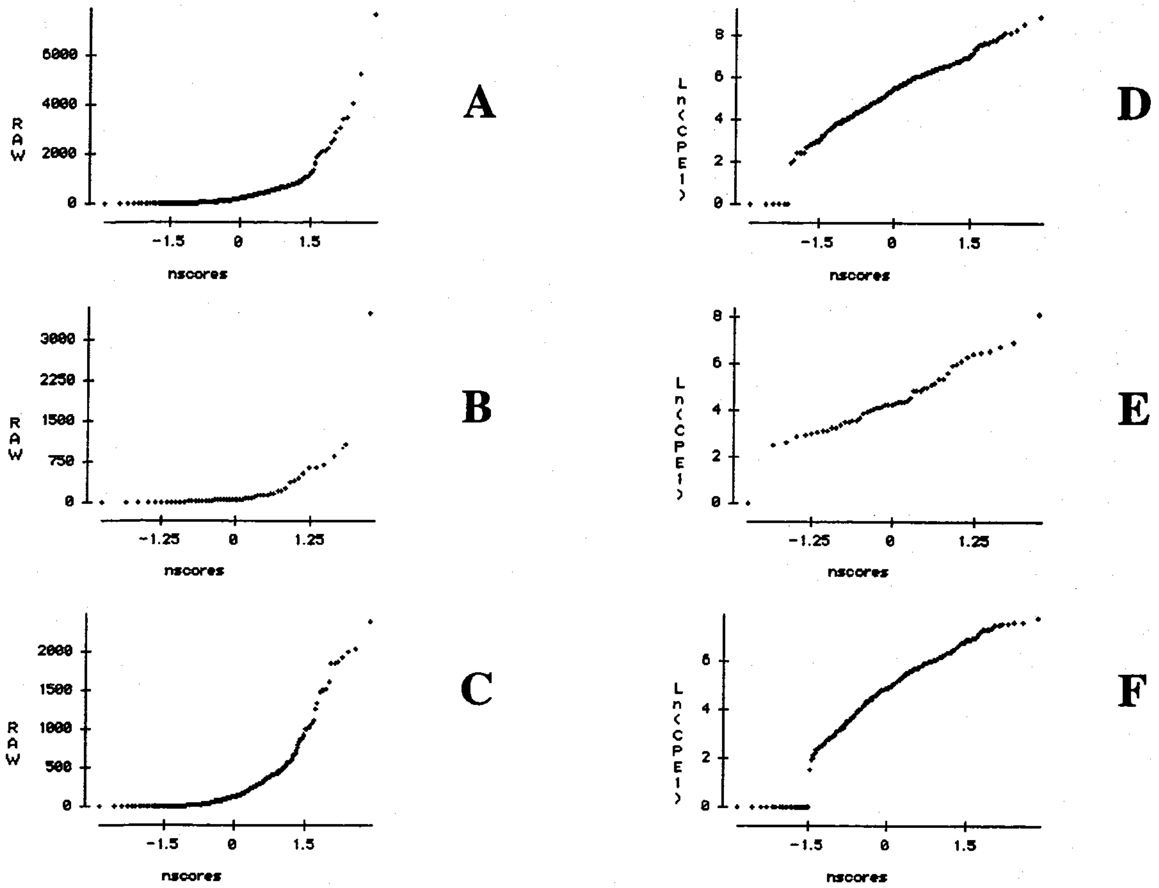


Figure 8. Normal probability plots of the response variables. Panel A - raw data for age-1 largemouth bass; Panel B - raw data for age-2 largemouth bass; Panel C - raw data for adult largemouth bass; Panel D - logarithm transformed data for age-1 largemouth bass; Panel E - logarithm transformed data for age-2 largemouth bass; Panel F - logarithm transformed data for adult largemouth bass.

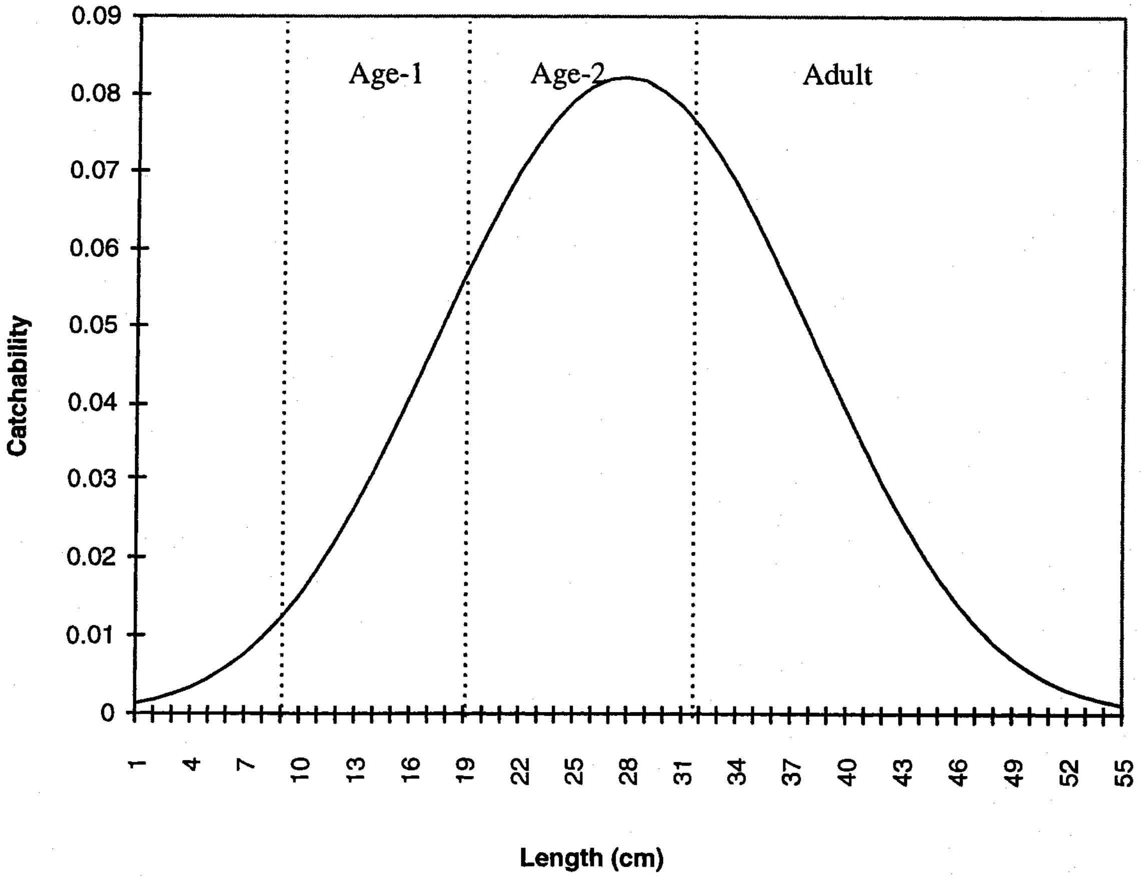


Figure 9. Electrofishing catchability curve for largemouth bass sampled in the lake inshore zone (from shore out to 15 meters) during the fall. Vertical dashed lines indicate age limits for the response variables based on state of Illinois average age at size.

Catchability = $\{1/\{1+\exp[-(-3.469)+(0.1837*\text{length})+(-0.003299*\text{length}^2)]\}\}^2$. Coefficients obtained from Bayley, personal communication.

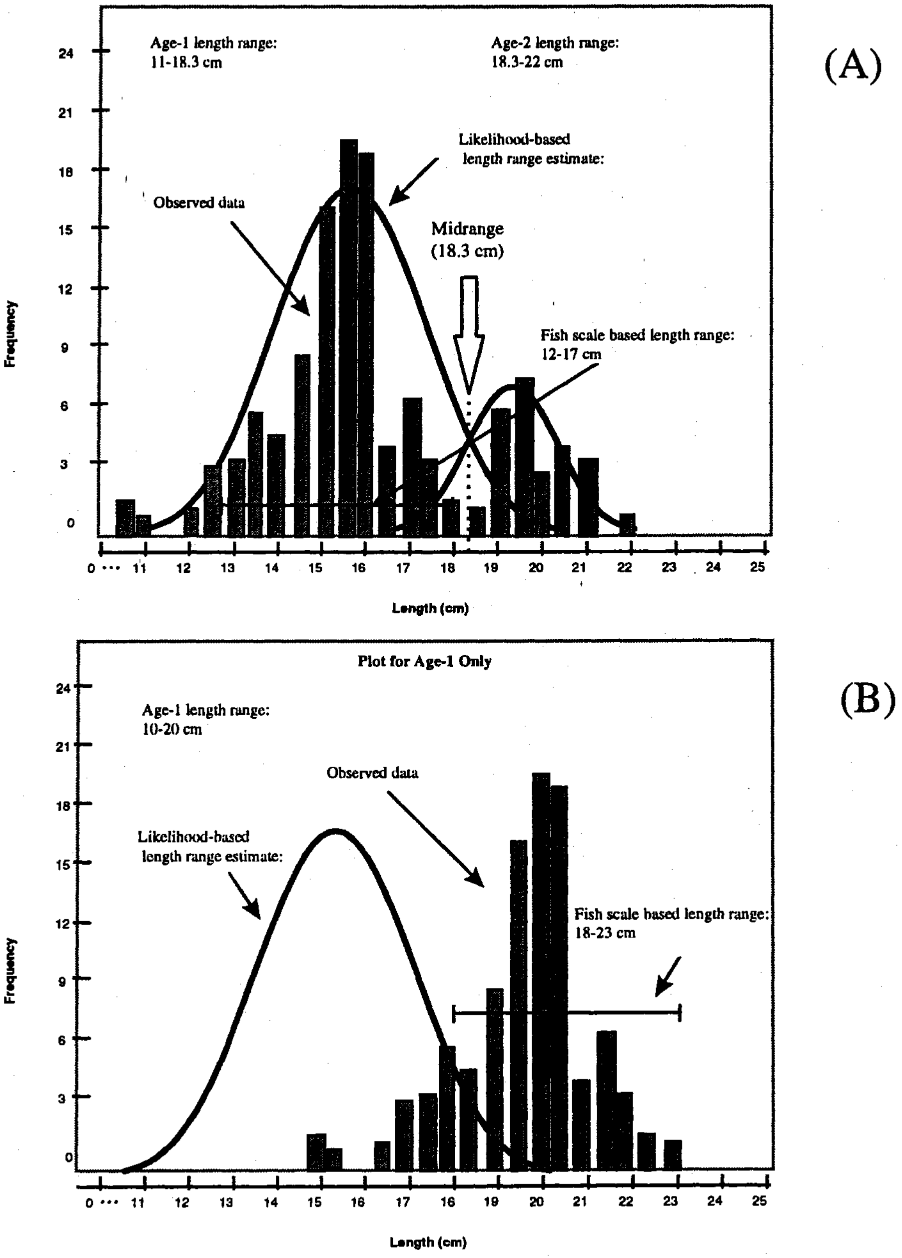


Figure 10. Age-class size range estimation for age-1 and age-2 largemouth bass based on a maximum likelihood model (Fournier 1990) for multiple length-frequency data analysis and on largemouth bass scale readings. Observed data are represented by the bars and are from Lake Le-Aqua-Na (Panel A - 1978; Panel B - 1979) for fall electrofishing. Curves represent estimates from the likelihood model. The horizontal

line represents scale-based length range. Panel A - Likelihood model matches with observed data. Panel B - Likelihood model underestimates length range based on observed scale readings.

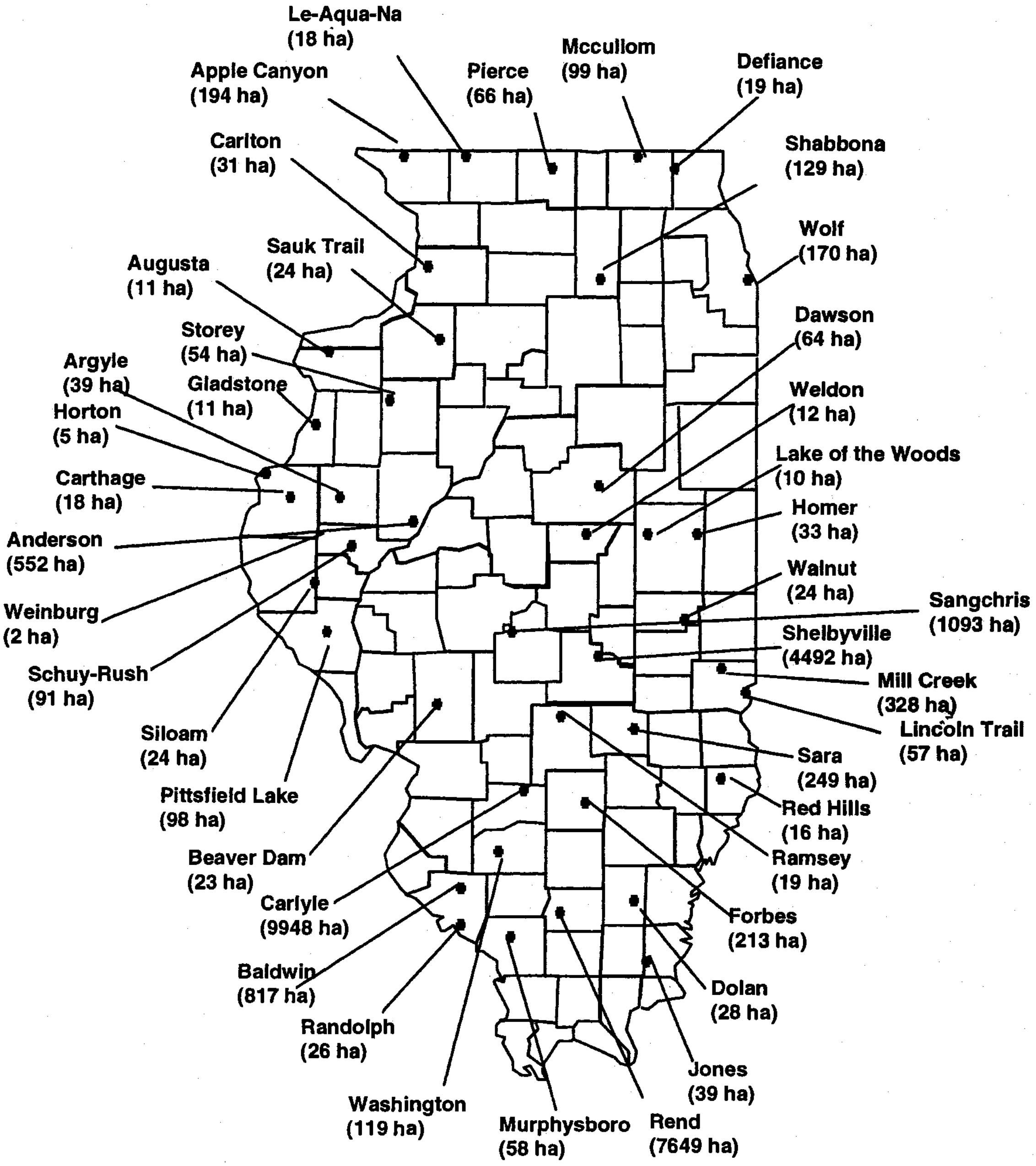

Le-Aqua-Na (18 ha)
Apple Canyon (194 ha)
Pierce (66 ha)
Mccullom (99 ha)
Defiance (19 ha)
Carlton (31 ha)
Shabbona (129 ha)
Wolf (170 ha)
Sauk Trail (24 ha)
Augusta (11 ha)
Dawson (64 ha)
Storey (54 ha)
Argyle (39 ha)
Gladstone (11 ha)
Weldon (12 ha)
Horton (5 ha)
Lake of the Woods (10 ha)
Carthage (18 ha)
Homer (33 ha)
Anderson (552 ha)
Walnut (24 ha)
Sangchris (1093 ha)
Weinburg (2 ha)
Shelbyville (4492 ha)
Schuy-Rush (91 ha)
Mill Creek (328 ha)
Lincoln Trail (57 ha)
Siloam (24 ha)
Sara (249 ha)
Pittsfield Lake (98 ha)
Red Hills (16 ha)
Beaver Dam (23 ha)
Ramsey (19 ha)
Carlyle (9948 ha)
Forbes (213 ha)
Baldwin (817 ha)
Dolan (28 ha)
Randolph (26 ha)
Jones (39 ha)
Washington (119 ha)
Murphysboro (58 ha)
Rend (7649 ha)

Figure 11. Lake names and surface area for the 42 lakes used to investigate environmental and anthropogenic effects on largemouth bass abundance.

2.6. List of References

Ager, L. 1989. Effects of an increase in length limit for largemouth bass in West Point Reservoir. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 43:172-181.

Aggus, L. and G. Elliot. 1975. Effects of cover and food on year-class strength of largemouth bass. Pages 317-322 in R. H. Stroud and H. Clepper, editors. Black bass biology and management, Sports Fishing Institute, Washington, DC.

Applegate, R. and J. Mullan. 1967. Food of young largemouth bass (*Micropterus salmoides*), in a new and old reservoir. Transactions of the American Fisheries Society 96:74-77.

Austen, D., J. Peterson, B. Newman, S. Sobaski, and P. Bayley. 1993. Compendium of 143 Illinois lakes: bathymetry, physico-chemical features, and habitats (Vols. I and II). Aquatic Ecology Technical Report 93/9 (1 and 2).

Avault, J. W. and G. C. Radonsky. 1968. Use of antimycin as a fish toxicant with emphasis on removing trash fish from catfish ponds. Proceedings of the Annual Conference of the Southeastern Association of Game and Fish Commissioners 21(1967):472-476.

Bayley, P. and D. Austen. 1987. Comparative analysis of fish populations in Illinois impoundments: gear efficiencies and standards for condition factors. Aquatic Biology Technical Report 87/14, Illinois Natural History, Champaign, IL.

Bayley, P. and D. Austen. 1989. Fisheries analysis system: data management and analysis for fisheries management and research. American Fisheries Society Symposium 6:199-205.

Bennett, G. 1948. The bass-bluegill combination in a small artificial lake. Illinois Natural History Bulletin 24(3):377-412.

Bennett, G. 1971. Management of artificial lakes and ponds. 2nd ed. Chapman and Hall, London, 375 pp.

Bettoli, P. W., M. Maceina, R. Noble, and R. Betsill. 1992. Piscivory in largemouth bass as a function of aquatic vegetation abundance. North American Journal of Fisheries Management 12:509-516.

Blosz, J. 1952. Propagation of largemouth bass and bluegill sunfish in federal hatcheries of the southeast. Progressive Fish-Culturist 14(2):61-66.

Boxrucker, J. 1986. Evaluation of supplemental stocking of largemouth bass (*Micropterus salmoides*) as a management tool in small impoundments. North American Journal of Fisheries Management 6(3):391-396

Brousseau, C. S. and E. R. Armstrong. 1987. The role of size limits in walleye management. Fisheries 12:2-5.

Buck, D. 1956. The effects of turbidity on fish and fishing. Transactions of the North American Wildlife Conference 21:249-261.

Buynak, G. L., L. E. Kornman, A. Surmont, and B. Mitchell. 1991. Evaluation of a smallmouth bass stocking program in a Kentucky reservoir. North American Journal of Fisheries Management 11:293-297.

Carlander, K. 1977. Handbook of freshwater fishery biology. Volume 2, The Iowa State University Press, Ames, Iowa, 431 pp.

Chatterjee, S. and B. Price. 1991. Regression analysis by example. Wiley, New York.

Cofer, L. 1993. Evaluation of a trophy bass length limit on Lake Fuqua, Oklahoma. Proceeding of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 47:702-710.

Cohen J. and P. Cohen 1983. Applied multiple regression/correlation analysis for the behavioral sciences. Lawrence Erlbaum, Hillsdale, New Jersey.

Cole, G. 1994. Textbook of limnology. Waveland Press, Prospect Heights, IL, USA, 412 pp.

Conrow, R. A. V. Zale, and R. W. Gregory. 1990. Distributions and abundances of early life stages of fishes in a Florida lake dominated by aquatic macrophytes. Transactions of the American Fisheries Society 119:521-528.

Coutant, C. 1975. Responses of bass to natural and artificial temperature regimes. Pages 272-285 In R. H. Stroud and H. Clepper, editors. Black bass biology and management, Sports Fishing Institute, Washington, DC.

Cross, F. 1967. Handbook of the fishes of Kansas. Museum of the Natural History of the University Kansas, Lawrence, KS, 357 pp.
Davis, H. 1930. Some principles of bass culture. Transactions of the American Fisheries Society 60:48-52.

Davis, R. 1979. The use of antimycin to reduce stunted sunfish populations in hardwater lakes. Minnesota Department of Natural Resources, Section of Fisheries, Investigational Report 363.

Dean, W., D. Terre, W. Dolman, and T. Schlagenhaft. 1991. Largemouth bass population structure changes and harvest under a slot length limit. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 45:261-269.

Eder, S. 1984. Effectiveness of an imposed slot length limit of 12.0-14.9 inches on largemouth bass. North American Journal of Fisheries Management 4:469-478.

Eiper, A. 1975. Environmental influences on the mortality of bass embryos and larvae. Pages 295-305 In R. H. Stroud and H. Clepper, editors. Black bass biology and management, Sports Fishing Institute, Washington, DC.

Farabee, G. B. 1974. Effects of a 12-inch length limit on largemouth bass and bluegill populations in two northeast Missouri lakes. Pages 95-99 In J. L. Funk, editor. Symposium on overharvest and management of largemouth bass in small impoundments. American Fisheries Society, North Central Division, Special Publication 3, Bethesda, Maryland.

Fielder, D. 1992. Evaluation of stocking walleye fry and fingerlings and factors affecting their success in lower Lake Oahe, South Dakota. North American Journal of Fisheries Management 12:336-345.

Fields, R., S. Lowe, C. Kaminski, G. Whitt, and D. Philipp. 1987. Critical and chronic thermal maxima of northern and Florida largemouth bass and their reciprocal F-1 and F-2 hybrids. Transactions of the American Fisheries Society 116(6):856-863.

Filipek, S. and M. Gibson. 1986. Evaluation of supplemental stocking of fingerling largemouth bass in lake Coronado, Arkansas. Page 313 in G. Hall and M. Van Den Avyle, editors. Reservoir Fisheries Management. American fisheries society, Bethesda, MD, USA, 327 pp.

Fisher, W. and A. Zale. 1991. Effects of water level fluctuations on abundance of young-of-the-year largemouth bass in a hydropower reservoir. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 45:422-431.

Fournier, D., J. Sibert, J. Majkowski, and J. Hampton. 1990. MULTIFAN, a likelihood-based method for estimating growth parameters and age composition from multiple length frequency data sets illustrated using data for southern bluefin tuna (*Thunnun maccoyii*). Canadian Journal of Fisheries and Aquatic Sciences 47(2):301-317.

Goeman, T. J. and P. D. Spencer. 1992. Fish community responses to manipulation of northern pike and yellow perch densities in a Minnesota centrarchic lake. Minnesota Department of Natural Resources, Section of Fisheries, Investigational Report 416.

Goodyear, C. and S. Christensen. 1984. On the ability to detect the influence of spawning stock on recruitment. North American Journal of Fisheries Management 4:186-193.

Green, R. H. 1987. Statistical and mathematical aspects: distinction between natural and induced variation. Pages 335-354 in V. B. Vouk, G. C. Butler, A. C. Upton, D. V. Parke, and S. L. Asher, editors. Methods for assessing mixtures of chemicals. Wiley, Chichester, UK.

Greenbank., J. 1945. Limnological conditions in ice-covered lakes, especially as related to winterkill of fish. Ecological Monographs 15:343-392.

Guenther, P. and W. Hubert. 1991. Factors influencing dissolved oxygen concentrations during winter in small Wyoming reservoirs. Great Basin Naturalist 51(3):282-285.

Guest, W. 1982. Survival of adult Florida and northern largemouth bass subjected to cold temperature regimes. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 36:332-339.

Gulland, J. 1965. Survival of the youngest stages of fish, and its relation to year-class strength. International Commission of the Northwest Atlantic Fisheries, Special Publication 6:363-371.

Gutreuter, S. and R. Anderson. 1985. Importance of body size to the recruitment process in largemouth bass populations. Transactions of the American Fisheries Society 114:317-327.

Hall, D. and T. Ehlinger. 1989. Perturbation, planktivory, and pelagic community structure: the consequence of winterkill in a small lake. Canadian Journal of Fisheries and Aquatic Sciences 46:2203-2209.

Heidinger, R. 1975. Life history and the biology of largemouth bass. Pages 11-20 in R. H. Stroud and H. Clepper, editors. Black bass biology and management, Sports Fishing Institute, Washington, DC.

Hill, 1980. Manipulation of bass-bluegill populations by summer drawdown. Iowa Conservation Commission, Project No. F-90-R, Des Moines, IA.

Howick, G., F. Denoyelles, S. Dewey, L. Mason, and D. Baker. 1993. The feasibility of stocking largemouth bass in 0.04-ha mesocosms used for pesticide research. Environmental Toxicology and Chemistry 12(10):1883-1893.

Jackson, S. W., Jr. 1966. Summary of lake management activities on Lakes Eucha and Spavinaw, Oklahoma 1951-1964. Proceedings of the Annual Conference of the Southeastern Association of Game and Fish Commissioners 19(1965):315-343.

Jenkins, R. M. 1970. Reservoir fish management. Pages 173-182 in N. Benson, editor. A century of fisheries in North America. American Fisheries Society, Special Publication No. 7, Washington, DC.

Johnson, D. L. and R. O. Anderson. 1974. Evaluation of a 12-inch length limit on largemouth bass in Philips lake, 1966-1973. Pages 106-113 In J. L. Funk, editor. Symposium on overharvest and management of largemouth bass in small impoundments. American Fisheries Society, North Central Division, Special Publication 3, Bethesda, Maryland.

Johnson, F. H. and T. C. Osborne. 1977. Experimental management of a small reclaimed lake in northern Minnesota for walley (*Stizostedion vitreum*). Minnesota Department of Natural Resources, Section of Fisheries, Investigational Report 349.

Johnson, M. 1965. Limnology of Ontario ponds in relation to winterkill of largemouth bass. The Progressive Fish-Culturist 27(4):193-198.

Johnson, M. and W. Charlton. 1960. Some effects of temperature on the metabolism and activity of the largemouth bass, *Micropterus salmoides*. The Progressive Fish-Culturist 22(4):155-163.

Keith, W. 1975. Management by water level manipulation. pp. 489-497 In Black bass biology and management, R. H. Strout and H. Clepper, ed. Sports Fishing Institute, Washington, DC.

Keith, W. E. 1968. Turbidity control and fish population renovation on Blue Mountain Lake, Arkansas. Proceedings of the Annual Conference of the Southeastern Association of Game and Fish Commissioners 21(1967):495-505.

Kramer, R. and L. Smith. 1960. First-year growth of largemouth bass, *Micropterus salmoides* (Lacepede), and some related ecological factors. Transactions of the American Fisheries Society 89(2):222-233.

Kramer, R. and L. Smith. 1962. Formation of year classes in largemouth bass. Transactions of the American Fisheries Society 91(1):29-41.

Krumholz, L. 1952. Management of Indiana ponds for fishing. Journal of Wildlife Management 16:254-257.

Kurzawski, K. and P. Durocher. 1993. Effects of a slot length limit on largemouth bass in a newly opened Texas reservoir. Proceeding of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 47:711-719.

Langbein, W. and S. Schumm. 1958. Yield of sediment relation to mean annual precipitation. Transactions of the American Geophysical Union 39(6):1076-1084.

Lantz, K. E., J. T. Davis, J. S. Hughes, and H. E. Schafer, Jr. 1967. Water level fluctuation - its effects on vegetation control and fish population management. Proceedings of the Annual Conference of the Southeastern Association of Game and Fish Commissioners 18(1964):483-494.

Lawson, C. and W. Davies. 1977. Effects of bass stocking and rates of fishing on largemouth bass population. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 31:493-497.

Lemons, D. and L. Crawshaw. 1985. Behavioral and metabolic adjustments to low temperatures in the largemouth bass (*Micropterus salmoides*). Physiological Zoologist 58(2):175-180.

Lennon, R. E., J. B. Hunn, R. A. Schnick, and R. M. Buress. 1970. Reclamation of ponds, lakes, and streams with fish toxicants: a review. FAO (Food and Agriculture Organization of the United Nations) Fisheries Technical Paper 100.

Martin, C. 1995. Evaluation of slot length limits for largemouth bass in two Delaware ponds. North American Journal of Fisheries Management 15:713-719.

Mathias, J. and J. Barica. 1980. Factors controlling oxygen depletion in ice-covered lakes, Canada. Canadian Journal of Fisheries and Aquatic Sciences 37(2):185-194.

McAllister, M. and R. Peterman. 1992. Experimental design in the management of fisheries: a review. North American Journal of Fisheries Management 12:1-18.

McCauley, R. and D. Kilgour. 1990. Effect of air temperature on growth of largemouth bass in North America. Transactions of the American Fisheries Society 119:276-281.

Meals, K. and L. Miranda. 1991. Variability in abundance of age-0 centrarchids among littoral habitats of flood control reservoirs in Mississippi. North American Journal of Fisheries Management 11:298-304.

Mertz, G. and R. Myers. 1995. Estimating the predictability of recruitment. Fishery Bulletin 93:657-665.

Mikol, G. Effect of mechanical control of aquatic vegetation on biomass, regrowth rates, and juvenile fish populations at Saratoga Lake, New York. Proceedings of the Third Annual Conference of Lake and Reservoir Management. United States Environmental Protection Agency.

Miller, R. 1975. Comparative behavior of centrarchid basses. Pages 85-94 in R. H. Stroud and H. Clepper, editors. Black bass biology and management, Sports Fishing Institute, Washington, DC.

Miller, S. and T. Storck. 1984. Temporal spawning distribution of largemouth bass and young-of-the-year growth determined from daily otolith rings. Transactions of the American Fisheries Society 113:571-578.

Ming, A. and W. McDonald. 1975. Effects of length limits on an overharvested largemouth bass population. Pages 416-424 in R. H. Stroud and H. Clepper, editors. Black bass biology and management, Sports Fishing Institute, Washington, DC.

Miranda, L. and L. Pugh. 1997. Relation between vegetation coverage and abundance, size and diet of juvenile largemouth bass during winter. North American Journal of Fisheries Management 17:601-610.

Miranda, L. and W. Hubbard. 1994. Length-dependent winter survival and lipid composition of largemouth bass in Bay Springs Reservoir, Mississippi. Transactions of the American Fisheries Society 123:80-87.

Miranda, L., W. Shelton, and T. Bryce. 1984. Effects of water level manipulation on abundance, mortality, and growth of young-of-the-year largemouth bass in West Point reservoir, Alabama-Georgia. North American Journal of Fisheries Management 4:314-320.

Mittelbach, 1988. Competition among refuging sunfishes and effects of fish density on littoral zone invertebrates. Ecology 69:614-623.

Moore, W. 1942. Field studies of the oxygen requirements of certain fresh-water fishes. Ecology 23(3):319-329.

Moss, D. and D. Scott. 1961. Dissolved oxygen requirements of three species of fish. Transactions of the American Fisheries Society 90(4):377-393.

Moyle, P. and J. Cech. 1982. Fishes: an introduction to ichthyology. Prentice Hall, Englewood Cliffs, New Jersey, 559 pp.

Müller, H. 1957. Untersuchungen der Sauerstoffverhältnisse unter eis. Zeitschrift zur Fischerei 6:316-322.

Nickum, J. G. 1970. Limnology of winterkill lakes in South Dakota. Pages 19-25 in E. Schneberger, editor. A symposium on the management of Midwestern winterkill lakes, Winnipeg, Manitoba, Canada. Special Publication of the North Central Division of the American Fisheries Society, 75 pp.

Novinger, G. D. 1987. Evaluation of a 15.0-inch minimum length limit on largemouth bass and spotted bass catches at Table Rock Lake, Missouri. North American Journal of Fisheries Management 7:260-272.

Olson, M. 1998. Ontogenetic niche shifts in largemouth bass: variability and consequences of first-year growth. Ecology 77(1):179-190.

Paller, M. 1997. Recovery of a reservoir fish community from drawdown related impacts. North American Journal of Fisheries Management 17:726-733.

Paragamian, V. L. 1982. Catch rates and harvest results under a 14-inch minimum length limit for largemouth bass in a new Iowa impoundment. North American Journal of Fisheries Management 2:224-231.

Pasch, R. 1975. Some relationships between food habits and growth of largemouth bass in Lake Blackshear, Georgia. Proceeding of the Annual conference of the Southeastern Association of Game and Fish Commissioners 28:307-321.

Paulin, L. 1960. Snow removal heads off winterkill. Wisconsin Conservation Bulletin 25:24-25.

Pedhazur, E. 1982. Multiple regression in behavioral research. Holt, Rinehart, and Winston, New York.

Peterman, R., M. Bradford, N. Lo, and R. Methot. 1988. Contribution of early life stages to interannual variability in recruitment of northern anchovy (*Engraulis mordax*). Canadian Journal of Fisheries and Aquatic Sciences 45:8-16.

Phillipi, T. 1993. Multiple regression: herbivory. Pages 183-210 In S. Scheiner and J. Gurevitch, editors. Design and analysis of ecological experiments. Chapman and Hall, New York, 445 pp.

Pierce, C., J. Frey, and H. Yawn. 1965. An evaluation of fishery management techniques utilizing winter drawdowns. Proceedings of the Annual Conference of the Southeastern Association of Game and Fish Commissioners 17(1963):347-363.

Rice, J., J. Breck, S. Bartell, and J. Kitchell. 1983. Evaluating the constraints of temperature, activity and consumption on growth of largemouth bass. Environmental Biology of Fishes 9(3/4):263-275.

Ricker, W. 1949. Effects of removal of fins upon the growth and survival of spiny-rayed fishes. Journal of Wildlife Management 13:29-40.

Ricker, W. 1949. Effects of removal of fins upon the growth and survival of spiny-rayed fishes. Journal of Wildlife Management 13:29-40.

Ricker, W. 1954. Stock and recruitment. Journal of the Fisheries Research Board of Canada 11(5):559-623.

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

Ricklefs, R. 1990. Ecology. W. H. Freeman, New York, 1020 pp.

Robinson, D. 1961. Stream and lake survey: stream reclamation. West Virginia division of Game and Fish, Federal aid in fish restoration, Project F-10-R-2, Job 4, Charleston.

Rose, G. and W. Leggett. 1989. Predicting variability catch-per-effort in Atlantic cod, *Gadus morhua*, trap and gill net fisheries. Journal of Fish Biology 35(Supplement A)155-161.

Roseberry, 1950. Fishery management of Clayton lake, an impoundment on the New river in Virginia. Transactions of the American Fisheries Society 80:194-209.

Saila, S. 1952. Some results of farm pond management in New York. Journal of Wildlife Management 16(3):279-282

Savino, J. F. and R. A. Stein. 1982. Predator-prey interaction between largemouth bass and bluegills as influenced by simulated, submersed vegetation. Transactions of the American Fisheries Society 111:255-266.

Scott, T. M. 1968. Spotted gar predation on bluegill and selected forage species. Proceedings of the Annual Conference of the Southeastern Association of Game and Fish Commissioners 21(1967):357-360.

Shirley, K. and A. Andrews. 1977. Growth, production, and mortality of largemouth bass during the first year of life in Lake Carl Blackwell, Oklahoma. Transactions of the American Fisheries Society 106(6):591-595.

Stevens, J. 1992. Applied multivariate statistics for the social sciences. Lawrence Erlbaum Associates, Hillsdale, New Jersey, 629 pp.

Storms, K., J. Foltz, and E. Wilde. 1986. Upper thermal tolerance of early life stages of South Carolina and Florida largemouth bass. Proceeding of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 40:57-64.

Strange, R., C. Berry, and C. Schreck. 1995. Aquatic plant control and reservoir fisheries. Pages 513-521 In R. H. Stroud and H. Clepper, editors. Black bass biology and management. Sports Fishing Institute, Washington, DC.

Summers, G. 1988. Largemouth bass population changes following implementation of a slot length limit. Proceeding of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 42:209-217.

Swingle, H. 1949. Some recent developments in pond management. Transactions of the North American Wildlife Conference 14:295-312.

Swingle, H. S. 1950. Experiments with various rates of stocking bluegills, *Lepomis macrochirus*, and largemouth bass, *Micropterus salmoides* in ponds. Transactions of the American Fisheries Society 80:218-230.

Toneys, M. and D. Coble. 1979. Size-related first winter mortality of freshwater fishes. Transactions of the American Fisheries Society 108:415-419.

Warnick, D. C. 1977. Commercial fishing of rough fish control in South Dakota, some views and apparent values. South Dakota Department of Game, Fish, and Parks, Bulletin 7, Pierre, SD.

Weisberg, S. Applied linear regression. 1985. Wiley, New York, 324 pp.
Werner, E., D. Hall, D. Laughlin, D. Wagner, L. Wilsmann, and F. Funk. 1977. Habitat partitioning in a habitat fish community. Journal of the Fisheries Research of the Board of Canada 34:360-370.

Werner, E., D. Hall, D. Laughlin, D. Wagner, L. Wilsmann, and F. Funk. 1977. Habitat partitioning in a habitat fish community. Journal of the Fisheries Research of the Board of Canada 34:360-370.

Wiley, M., Gorden, R., Waite S., and T. Powless. 1984. The relationship between aquatic macrophytes and sport fish production in Illinois ponds: a simple model. North American Journal of Fisheries Management 4:111-119.

Wynne, M., A. Little, and K. Nelson. 1993. Evaluation of a protected slot regulation for largemouth bass on Lake Sutton, North Carolina. Proceeding of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 47:686-694.

Wynne, M., A. Little, and K. Nelson. 1993. Evaluation of a protected slot regulation for largemouth bass on Lake Sutton, North Carolina. Proceeding of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 47:686-694.

Zar, J. 1996. Biostatistical analisys. Prentice Hall, Upper Saddle River, New Jersey, 662 pp.

Zweiacker, P., R. Summerfelt, and J. Johnson. 1973. Largemouth bass growth in relation to annual variations in mean pool elevations in Carl Blackwell, Oklahoma. Proceedings of the Southeastern Association of Fish and Game Commissioners 26(1972):530-540.

CHAPTER 3: METHODS AND RESULTS FOR EVALUATING LAKE PRODUCTIVITY FOR LARGEMOUTH BASS AND MANAGEMENT PRACTICES ON AGE-1 LARGEMOUTH BASS

3.1. Lake Productivity for Largemouth Bass

3.1.1. Analytical Procedure

Lake-specific management practices may be justified if differences in lake abundance for largemouth bass (Section 2.2.1.4) can be explained by factors constant through time (such as lake morphology). Similarly, more attention by managers may be devoted to lakes with low productivity when management is aimed at largemouth bass. The effects of lake abiotic characteristics on largemouth bass abundance were, therefore, investigated to determine the effects of lakes on productivity.

The 28 lakes listed in Table 7 were used with growing-degree-days, percent of lake volume in the euphotic zone, lake conductivity, shoreline habitat type, and lake inshore mean depth as predictors (Section 2.2.1.4; Figure 12). Not all lakes available for this dissertation (Table 3) were used because data for some or all predictors were not present in some lakes. The response variable was calculated separately for each lake by averaging the number of largemouth bass caught per hour in fall electrofishing samplings. Fish numbers were corrected for catchability (Section 2.3.1). The response variable was logarithm transformed estimated abundance of largemouth bass of ages one and older caught per hour of fall electrofishing. Age-zero largemouth bass were excluded due to fish being frequently ignored or overlooked by sampling personnel. Each lake yielded one response variable. To avoid confounding with management practices, only years with none of the management practices used herein (Section 2.2.2) were used to derive the response variable.

An average growing-degree-day observation from 1945 to 1996 (the period of available climatic data) was calculated (Section 2.4.1) for each lake in Table 7 because there was only one observation for the response variable at each lake. Artificially heated lakes may have a growing season independent of variations in growing-degree-days. Those lakes have been shown to enhance growth rates of largemouth bass compared to naturally heated lakes (Galloway and Kilambi 1988; Perry and Tranquilli

1984; Sule 1981). Because high temperatures may increase survival through winter months (Toneys and Coble 1979; Gutreuter and Anderson 1985; Miranda and Hubbard 1994), lakes used for electricity power plant cooling were excluded.

The maximum depth of macrophyte colonization was used as a proxy for estimating the percent of lake volume in the euphotic zone. The euphotic zone volume was obtained by first estimating the maximum depth for macrophyte colonization according to Chambers and Kalff (1985). Maximum depth for macrophyte colonization was calculated according to the following formula (Chambers and Kalff 1985):

$z_c = [1.33*\log(D)+1.4]^2$, where

z_c = maximum depth of macrophyte colonization (meters)
D = Secchi disk depth (meters)

Percent of lake volume in the stratum from the surface to the maximum depth of macrophyte colonization was calculated based on plots of lake depth on the abscissa versus lake volume enclosed in the area between the shoreline and that depth in the ordinate. A separate plot was used for each lake. Plots for lakes were obtained from Austen (personal communication). Figure 13 shows an example of estimation of percent of lake volume in the euphotic zone for Lake Carlton.

Lake inshore habitat type, conductivity, and inshore mean depth were obtained from Austen et al. (1993). Inshore habitat type was calculated based on woody cover rating in the water along the shoreline. Cover ratings were of 0 (no hard cover), 1 (between 1-33% hardcover), 2 (between 34-66% hardcover), and 3 (above 66% hardcover). The percentage of shoreline covering habitat of each rating was used to estimate the effects of inshore habitat type. The predictor for inshore habitat type was obtained by multiplying the hard cover rating by the percent of shoreline covering habitat of that rating to obtain a predictor weighted for hard cover along the shoreline.

The range of the values of the response variable and the predictors used are summarized in Table 6.

3.1.2. Results

No trend in the residuals nor any relationship of the predictors with the response variable were detected. The statistical power of the test was 0.157 (Table 8). The ranges of the predictors were of 2694-3984 (growing-degree-day), 125-547 (conductivity), 0-2.8 (hard cover), 0.6-4.3 (inshore mean depth), and 0.01-0.95 (percent lake in the euphotic zone; Table 8).

3.2. Effects of Management Practices on Age-1 Largemouth Bass.

3.2.1. Analytical Procedures

This section describes the analyses of the effects of largemouth bass stocking, lake rehabilitation, water level manipulation, aquatic vegetation control, and chemical fish removal on the age-1 response variable (Section 2.2.2; Figure 12). Each of the anthropogenic predictors was analyzed separately because the same combination of treatments rarely occurred in the same year at a lake. The source database was filtered to extract those lakes which had received the treatment (anthropogenic predictor) of interest. As a result, some lakes were excluded from analyses of certain anthropogenic predictors. Data from confounding years were discarded. Confounding years were those years when management practices other than the one being analyzed had detectable effects on the response variable and coincided with the practice being investigated.

Not all possible treatment lags were tested for each anthropogenic predictor. A lag 0 (Section 2.5.3) was used for fish removal and aquatic vegetation control to address the effects of management practices during the year the practice was conducted. A lag -1 was used for fish removal, aquatic vegetation control, largemouth bass stocking, water level manipulation, and lake rehabilitation to address the effects of management practices one year after the practice was conducted. A lag -2 was used only for lake rehabilitation to address the effects of management practices two years after the practice was conducted.

In addition to the environmental predictors (Section 2.2.1), a predictor representing a lake effect was used. This predictor was of logarithm transformed absolute abundance of largemouth bass of ages one and older caught per hour of fall electrofishing samples during years when no anthropogenic predictors were implemented (response variable for the lake productivity model, Section 2.2.1.4). The lake-effect predictor was derived to investigate possible differences in treatment response among lakes. No confounding between the lake effect predictor and potential treatment effects was present because only control observations were used to derive the predictor. Except for lake rehabilitation, observations for the environmental predictors were of the year the management practice was conducted (lag 0). For rehabilitation practices observations for the environmental predictors were of one year following the practice because largemouth bass was stocked during those years (observations for the environmental predictors coincided with the year the fish population was initiated). Spatial trends in the results were identified by inspecting the results of analyses for the anthropogenic predictor superimposed on a figure of the state of Illinois. Spatial trends were only investigated when the lake effect was significant.

The analytical procedure on the lag 0, lag -1, and lag -2 delays incorporating all lakes which received the treatment of interest was as discussed in Section 2.5.

3.2.2. Results

The values of regression slopes from dichotomous predictors represent changes from control years (coded as zero) to treatment years (coded as one). The values reported are of logarithm of fish abundance. The intercept value represents the predicted value for control years and the slope represents the predicted value for treatment years. The slope, therefore, represents the change of fish abundance after treatment. An example: if the intercept is five and the slope one, the total change (increase) following treatment years is of 255 fish per hour ($e^6 - e^5 = 403 - 148$; where e = 2.718).

3.2.2.1. Stocking

No detectable effects of largemouth bass stocking were found nor any trend in the residuals observed. The statistical power of the test was larger than 0.99 (Table 9, items 4 and 5).

3.2.2.2. Lake Rehabilitation

The precipitation compound variable was significant (slope = -11.15; p = 0.0035) when analyzed in conjunction with lake rehabilitation lag -1 only. Significance was found for rehabilitation practices for both, lag -1 and lag -2 treatments. Slopes of -1.48 (p = 0.0009) for the lag -1 and of 1.97 (p < 0.0001) for the lag -2 in the regression models (r-square = 0.17, power > 0.99 for both, the lag -1 and lag -2 treatments) were observed (Tables 10 and 11, item 4). No trends in the residuals were found for either treatment lags (Tables 10 and 11, item 5). Three lakes with negative slopes out of 12 for the lag -1 and two with positive slopes out of 13 for the lag -2 delay treatments were found significant after lake-specific regression analysis (Tables 10 and 11, item 6). No geographical patterns in the regression slopes following treatments were observed for either treatment lag (Figures 14 and 15).

3.2.2.3. Water Level Manipulation

No detectable effects of lake water level manipulation were found nor any trend in the residuals observed. The statistical power of the test was larger than 0.99 (Table 12, items 4 and 5).

3.2.2.4. Aquatic Vegetation Treatments

Significance was found for aquatic vegetation lag 0 treatment only. A slope of 0.55 (p = 0.0019) in the regression model (r-square = 0.07) was observed. The statistical power of the test for the lag 0 treatment was larger than 0.99 and for the lag -1 treatment was of 0.548 (Tables 12 and 13, item 4 and 5). No trends in the residuals were found for either treatment lag (Tables 13 and 14, item 5). Lake-specific regression analysis showed two lakes out of 20 with significant positive slopes (Table 13, item 6). No geographical patterns in the regression slopes following aquatic vegetation lag 0 treatments were observed (Figure 16).

3.2.2.6. Fish Removal

No detectable effects of fish removal practices were found nor any trend in the residuals observed. The statistical power of the test for both treatment lags was larger than 0.99 (Table 15 and 16, items 4 and 5).

LAKE (DISTRICT)	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91
LAKE LE-AQUA-NA (1)																											
PIERCE LAKE (1)							*		*																		
SHABBONA LAKE (1)												*	*	*													
SAUK TRAIL (2)								*		*																	
ARGYLE LAKE (4)			*								*																
DEFIANCE LAKE (7)						*		*		*		*	*	*	*	*											
MCCULLOM LAKE (7)		*		*				*								*											
LAKE OF THE WOODS (8)					*		*		*		*	*	*	*	*												
WOLF LAKE (9)	*		*	*	*		*	*			*	*			*	*											
SILOAM SPRINGS (10)			*	*	*	*	*	*			*		*				*	*	*	*	*						
WALNUT POINT LAKE (12)			*	*		*					*	*	*	*													
DAWSON LAKE (13)								*			*			*	*		*	*	*								
LINCOLN TRAIL LAKE (14)						*				*			*					*	*								
MILL CREEK LAKE (14)																	*	*	*	*	*						
AUGUSTA LAKE (15)	*		*	*	*	*		*							*			*	*				*	*		*	
CARTHAGE LAKE (15)		*				*												*					*	*	*	*	
HORTON LAKE (15)								*		*	*	*	*	*		*	*	*		*	*	*	*	*	*	*	
PITTSFIELD LAKE (15)			*		*					*	*	*	*			*	*	*	*	*	*	*	*	*	*	*	

RED HILLS (15)	*																	*		*	*	*					
SCHUY-RUSH LAKE (15)													*	*		*	*	*	*	*	*	*	*	*	*	*	
DOLAN STATE LAKE (16)														*													
BEAVER DAM LAKE (18)								*	*	*	*																
RANDOLPH COUNTY LAKE (21)		*		**	*				*	*		*				*											
WASHINGTON COUNTY LAKE (21)		*	*	**				*		*			*	*	*	*	*	*									
FORBES LAKE (22)									*							*	*	*	*								
LAKE SARA (22)			*				*		*				*						*	*							
RAMSEY LAKE (22)	*											*					*										
LAKE MURPHYSBORO (25)										*	*	*		*					*			*					

Table 7. List of 28 lakes by district used in the static model investigating largemouth bass productivity (absolute number of age-1 and older fish caught per hour of electrofishing sampling during years when no anthropogenic predictors were implemented) as a function of lake abiotic characterisitcs. Asterisks denote years with available information.

1. Key:

DEG - Average growing-degree-days (°C)
CON - Average conductivity (mohs)
HAB - Shoreline habitat type
IMN - Inshore mean depth (meters)
EUP - Percent of lake volume in euphotic zone.

2. Model tested:

Average Ln(age-1 and older largemouth bass) = DEG + CON + HAB + IMN + EUP + all first order interactions + error.

3. Summary statistics for the response variable and predictors:

Variable	Mean	StdDev	Min	Max	Skewness	Kurtosis
Response	3.33	0.31	2.58	4.10	-0.06	0.37
DEG	3422.43	368.11	2694.05	3983.98	-0.52	-0.57
CON	326.57	110.88	125.00	547.00	0.48	-0.57
HAB	1.05	0.54	0.04	2.81	1.25	2.76
IMN	2.05	0.93	0.60	4.25	0.80	0.01
EUP	0.39	0.26	0.01	0.95	0.45	-0.69

4. Results:

Response variable: Average Ln(age-1 and older largemouth bass) based on fall electrofishing sampling.

R squared = 0.09
22 degrees of freedom
Power = 0.157

Source	*Sum of Squares*	*df*	*Mean Square*	*F-ratio*
Regression	0.23	5	0.05	0.407
Residual	2.44	22	0.11	

Variable	*Coefficient*	*s.e. of Coeff*	*t-ratio*	*p-value*
Constant	3.44	1.01	3.42	0.0025
DEG	<0.01	<0.01	-0.27	0.7922
CON	<0.01	<0.01	0.19	0.8497
HAB	<0.15	0.13	1.12	0.2729
IMN	-0.04	0.08	-0.54	0.5943
EUP	<0.01	0.27	0.01	0.9907

Table 8. Results for the static model for largemouth bass index of abundance for 28 lakes (absolute number of age-1 and older fish caught per hour of electrofishing sampling during years when no anthropogenic

predictors were implemented) as a function of lake abiotic characteristics (Section 3.1.2). (Continued).

5. Residual plot:

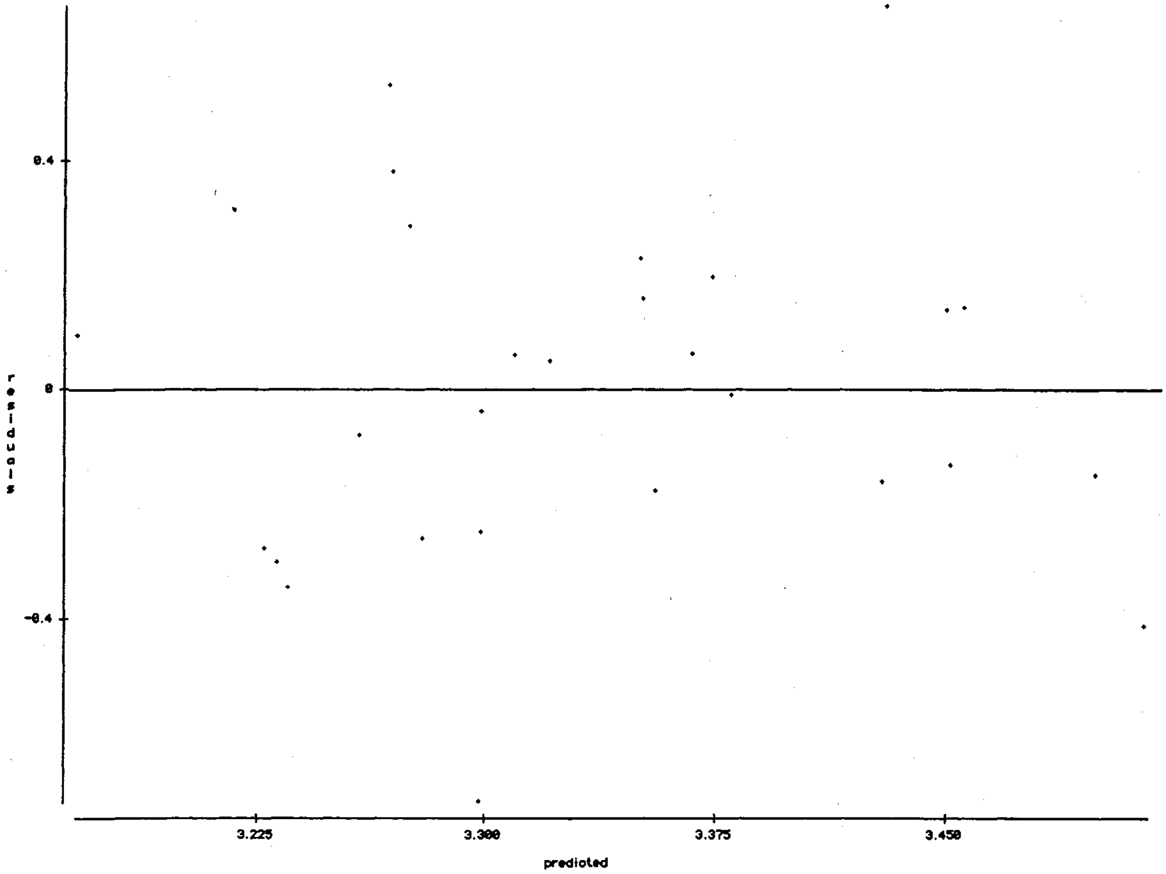


Table 8. (Concluded).

1. Key:

ACP - Average Ln(age-1 and older largemouth bass)
PPT - [(precipitation*watershed area)*(1+percent uncovered land)]/(lake volume*volume development index)
GDD - Growing-degree-days (°C)
CDD - Cooling degree days (°C)
SND - Snow depth (millimeters)
STO - Predictor for largemouth bass stocking (fish/hectare)

2. Model tested:

Ln(Age-1) = ACP + PPT + GDD + CDD + SND + STO + first order interactions + error

3. Summary statistics for the response variable and predictors:

Variable	Mean	StdDev	Min	Max	Skewness	Kurtosis
Response	4.94	1.59	0.00	8.78	-0.61	1.00
ACP	3.18	0.46	2.46	4.40	0.39	-0.09
PPT	0.04	0.05	<0.01	0.25	1.95	3.78
GDD	3462.67	440.85	1994.01	4468.04	-0.55	0.05
CDD	638.39	336.22	76.98	1750.00	0.79	0.45
SND	44.19	55.93	0.85	439.34	3.39	15.93
STO	20.47	92.38	0.00	1110.42	7.38	69.42

4. Results for the anthropogenic and significant environmental predictors:

R squared = 0.20
307 degrees of freedom
Power > 0.99

Source	*Sum of Squares*	*df*	*Mean Square*	*F-ratio*
Regression	157.01	2	78.51	38.4
Residual	627.03	307	2.04	

Variable	*Coefficient*	*s.e. of Coeff*	*t-ratio*	*p-value*
Constant	0.60	0.52	1.15	0.2513
ACP	1.23	0.15	8.31	<0.0001
STO	<0.01	<0.01	1.57	0.1171

Table 9. Results for largemouth bass stocking following multiple regression analysis on the Ln(Age-1) response variable (Section 3.2.2.1). (Continued).

5. Residual plot:

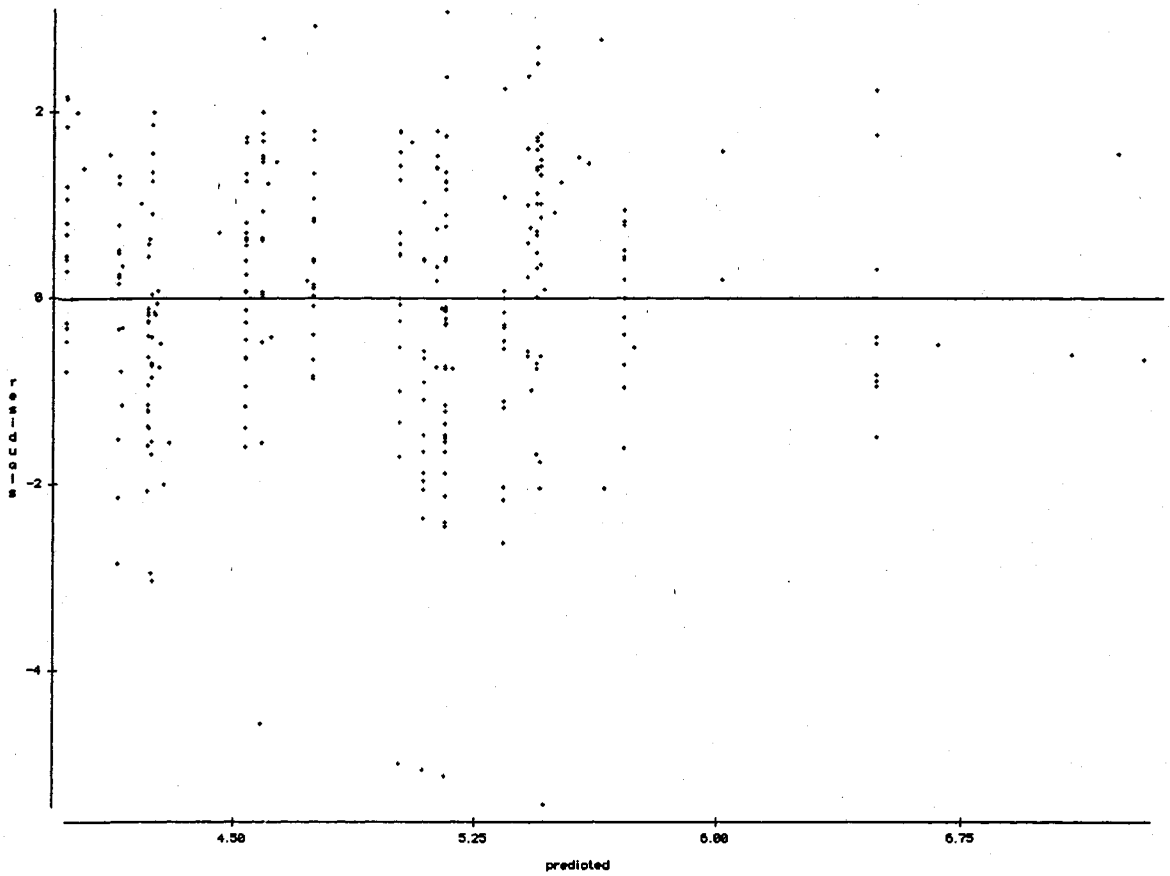


Table 9. (Concluded).

1. Key:

ACP - Average Ln(age-1 and older largemouth bass)
PPT - [(precipitation*watershed area)*(1+percent uncovered land)]/(lake volume*volume development index)
GDD - Growing-degree-days (°C)
CDD - Cooling degree days (°C)
SND - Snow depth (millimeters)
REH - Predictor for lake rehabilitation (dichotomous)

2. Model tested:

Ln(Age-1) = ACP + PPT + GDD + CDD + SND + REH + first order interactions + error

3. Summary statistics for the response variable and predictors:

Variable	Mean	StdDev	Min	Max	Skewness	Kurtosis
Response	5.53	1.71	0.00	8.95	-0.99	1.78
ACP	3.48	0.33	3.02	4.10	0.33	-0.60
PPT	0.04	0.03	<0.01	0.23	2.18	7.78
GDD	3372.17	422.48	2205.98	4411.00	0.06	-0.45
CDD	615.60	308.83	91.00	1827.03	0.93	1.13
SND	41.57	44.23	1.27	265.89	2.35	6.36
REH	0.08	0.27	0.00	1.00	3.11	7.66

4. Results for the anthropogenic and significant environmental predictors:

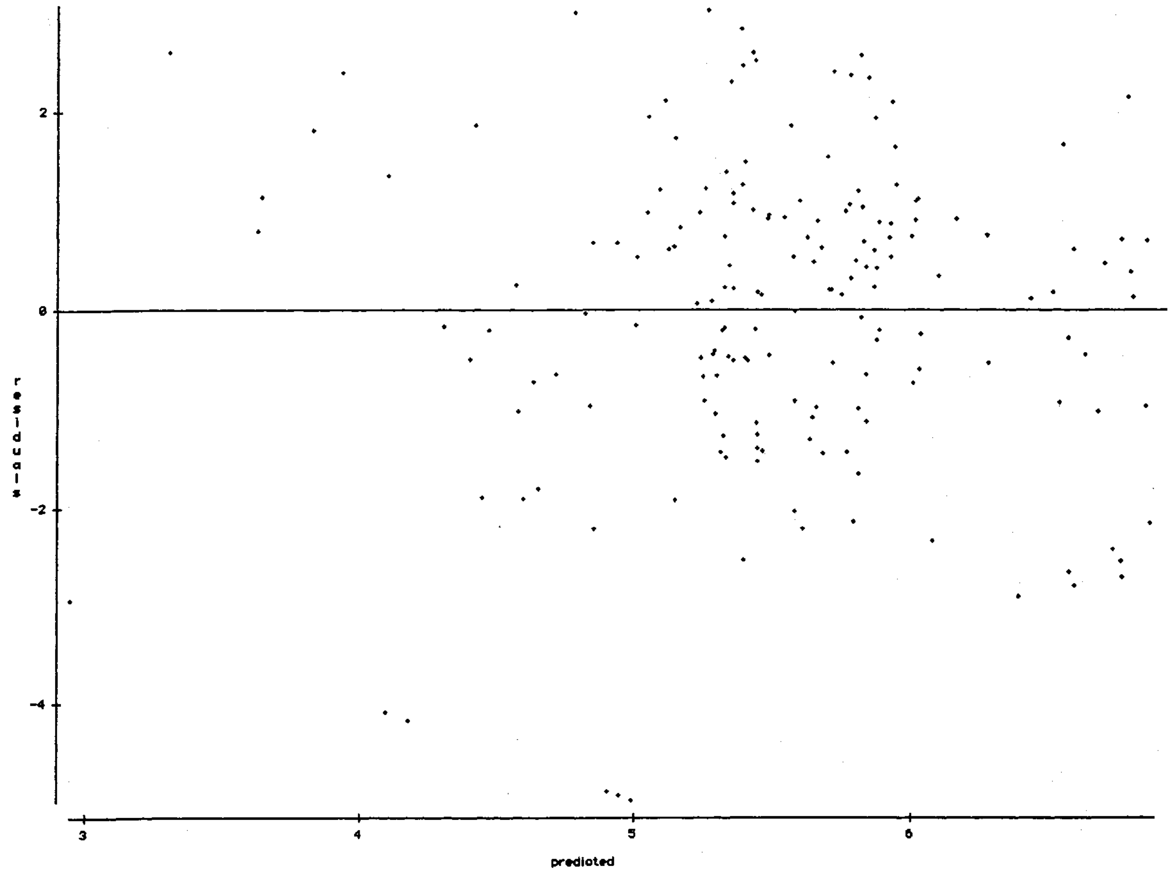
R squared = 0.17
172 degrees of freedom
Power > 0.99

Source	***Sum of Squares***	***df***	***Mean Square***	***F-ratio***
Regression	**86.80**	**3**	**28.93**	**11.7**
Residual	**424.28**	**172**	**2.47**	

Variable	***Coefficient***	***s.e. of Coeff***	***t-ratio***	***p-value***
Constant	**0.89**	**1.24**	**0.72**	**0.4739**
ACP	**1.48**	**0.36**	**4.15**	**<0.0001**
PPT	**-11.15**	**3.77**	**-2.96**	**0.0035**
REH	**-1.48**	**0.44**	**-3.37**	**0.0009**

Table 10. Results for lake rehabilitation (Lag -1 treatment) following regression analyses on the Ln(Age-1) response variable (Section 3.2.2.2). (Continued).

5. Residual plot:



6. Lake-specific results (Ln(Age-1) = intercept + REH + error):

LAKE	N	R-SQUARE	INTERCEPT	SLOPE	SLOPE P-VALUE	POWER (0.1)
SAUK TRAIL	10	0.61	6.11	-3.98	0.0080	0.91
LAKE STOREY	9	0.49	6.56	-3.89	0.0357	0.74
DAWSON LAKE	17	0.34	6.33	-2.91	0.0132	0.83
LAKE LE-AQUA-NA	14	0.12	5.28	-2.33	0.2248	0.35
GLADSTONE LAKE	14	0.17	5.78	-1.88	0.1449	0.45
RED HILLS	13	0.10	5.66	-1.52	0.2960	0.29
RAMSEY LAKE	9	0.03	6.04	-0.59	0.6434	0.13
ARGYLE LAKE	23	<0.01	6.37	-0.09	0.9419	0.13
WASHINGTON COUNTY LAKE	21	0.01	5.27	0.37	0.7263	0.13
HORTON LAKE	18	0.01	5.81	0.68	0.6651	0.13
WALNUT POINT LAKE	14	0.03	5.35	0.98	0.5799	0.16
CARTHAGE LAKE	14	0.02	3.39	1.04	0.6496	0.14

Table 10. (Concluded).

1. Key:

ACP - Average Ln(age-1 and older largemouth bass)
PPT - [(precipitation*watershed area)*(1+percent uncovered land)]/(lake volume*volume development index)
GDD - Growing-degree-days (°C)
CDD - Cooling degree days (°C)
SND - Snow depth (millimeters)
REH - Predictor for lake rehabilitation (dichotomous)

2. Model tested:

Ln(Age-1) = ACP + PPT + GDD + CDD + SND + REH + first order interactions + error

3. Summary statistics for the response variable and predictors:

Variable	Mean	StdDev	Min	Max	Skewness	Kurtosis
Response	5.41	1.88	0.00	8.95	-0.94	1.30
ACP	3.44	0.33	3.02	4.10	0.56	-0.52
PPT	0.03	0.03	<0.01	0.23	2.18	8.00
GDD	3312.74	487.32	1994.01	4411.00	-0.17	-0.46
CDD	670.52	353.27	91.00	1819.00	0.81	0.37
SND	45.15	47.72	1.93	312.35	2.37	7.09
REH	0.08	0.27	0.00	1.00	3.21	8.30

4. Results for the anthropogenic and significant environmental predictors:

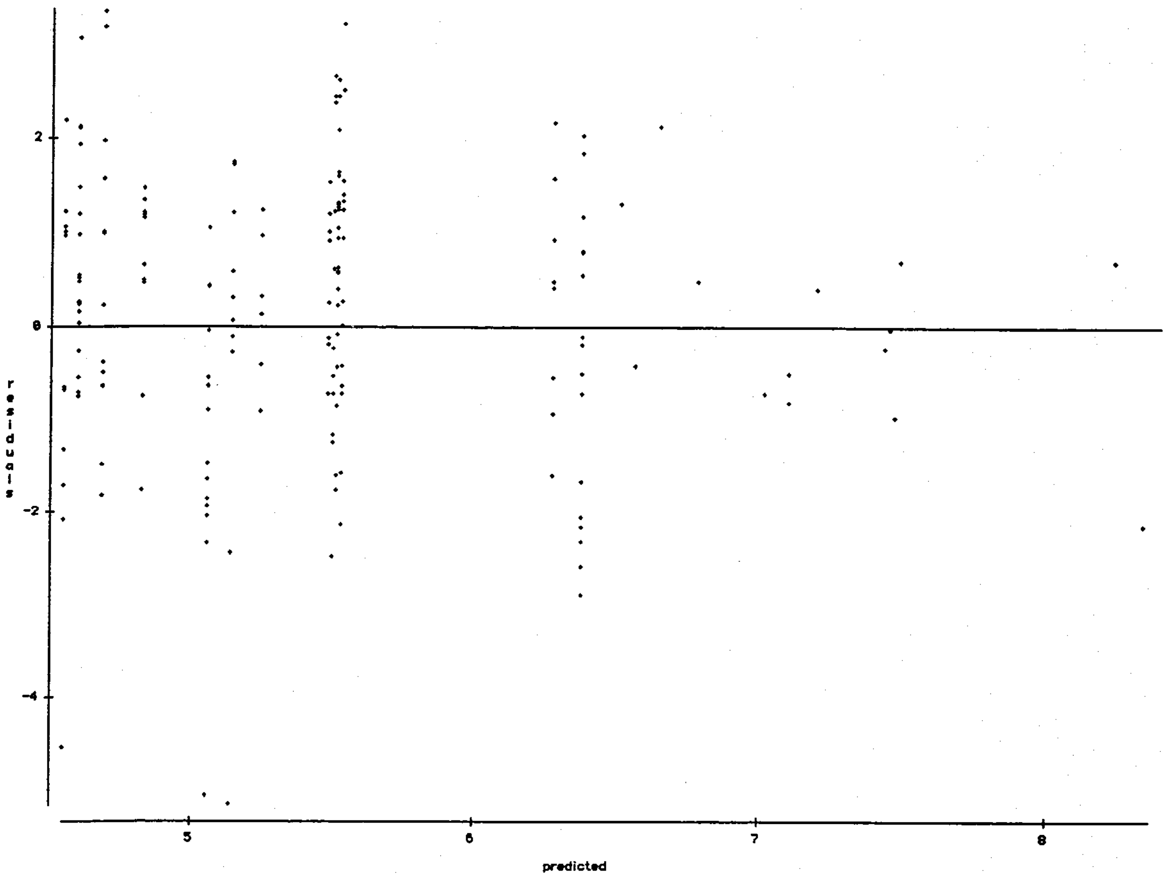
R squared = 0.17
182 degrees of freedom
Power > 0.99

Source	*Sum of Squares*	*df*	*Mean Square*	*F-ratio*
Regression	**109.11**	**2**	**54.56**	**18.5**
Residual	**538.13**	**182**	**2.96**	

Variable	*Coefficient*	*s.e. of Coeff*	*t-ratio*	*p-value*
Constant	**-0.57**	**1.32**	**-0.43**	**0.6675**
ACP	**1.69**	**0.38**	**4.44**	**<0.0001**
REH	**1.97**	**0.48**	**4.11**	**<0.0001**

Table 11. Results for lake rehabilitation (Lag -2 treatment) following regression analyses on the Ln(Age-1) response variable (Section 3.2.2.2). (Continued).

5. Residual plot:



6. Lake-specific results (Ln(Age-1) = intercept + REH + error):

LAKE	N	R-SQUARE	INTERCEPT	SLOPE	SLOPE P-VALUE	POWER (0.1)
ARGYLE LAKE	22	0.00	6.24	0.28	0.8188	0.13
HORTON LAKE	17	0.00	5.89	0.31	0.8539	0.12
WASHINGTON COUNTY LAKE	21	0.04	5.25	0.90	0.4106	0.23
SAUK TRAIL	10	0.23	5.84	1.39	0.1558	0.43
LAKE LE-AQUA-NA	12	0.09	4.92	1.55	0.3411	0.25
RED HILLS	12	0.08	5.77	1.67	0.3748	0.24
LAKE MURPHYSBORO	11	0.25	5.37	1.91	0.1137	0.50
RAMSEY LAKE	8	0.49	5.58	2.03	0.0524	0.68
DAWSON LAKE	16	0.12	6.09	2.12	0.1851	0.38
LAKE STOREY	9	0.30	6.60	2.35	0.1249	0.49
MCCULLOM LAKE	19	0.12	3.02	3.30	0.1517	0.44
WALNUT POINT LAKE	14	0.26	5.22	3.56	0.0599	0.62
CARTHAGE LAKE	14	0.21	3.51	4.32	0.1038	0.53

Table 11. (Concluded).

1. Key:

ACP - Average Ln(age-1 and older largemouth bass)
PPT - [(precipitation*watershed area)*(1+percent uncovered land)]/(lake volume*volume development index)
GDD - Growing-degree-days (°C)
CDD - Cooling degree days (°C)
SND - Snow depth (millimeters)
WLM - Predictor for water level manipulation (centimeters)

2. Model tested:

Ln(Age-1) = ACP + PPT + GDD + CDD + SND + WLM + first order interactions + error

3. Summary statistics for the response variable and predictors:

Variable	Mean	StdDev	Min	Max	Skewness	Kurtosis
Response	5.19	1.63	0.00	8.83	-1.02	1.68
ACP	3.38	0.36	2.66	4.44	0.66	0.89
PPT	0.06	0.17	<0.01	1.79	6.85	51.98
GDD	3454.88	465.26	1994.01	4671.04	-0.23	0.05
CDD	630.93	332.97	32.00	1827.03	0.80	0.48
SND	40.21	47.67	1.17	370.96	2.86	11.03
WLM	20.75	65.07	0.00	457.2	3.99	16.56

4. Results for the anthropogenic and significant environmental predictors:

R squared = 0.14
407 degrees of freedom

Source	*Sum of Squares*	*df*	*Mean Square*	*F-ratio*
Regression	154.65	3	51.55	22.5
Residual	931.92	407	2.29	

Variable	*Coefficient*	*s.e. of Coeff*	*t-ratio*	*p-value*
Constant	-0.91	0.79	-1.15	0.2509
ACP	1.81	0.24	7.65	<0.0001
PPT	-1.03	0.496	-2.08	0.0378
WLM	<0.01	<0.01	1.60	0.1098

Table 12. Results for lake water level manipulation (Lag -1 treatment) following multiple regression analysis on the Ln(Age-1) response variable (Section 3.2.2.3). (Continued).

5. Residual plot:

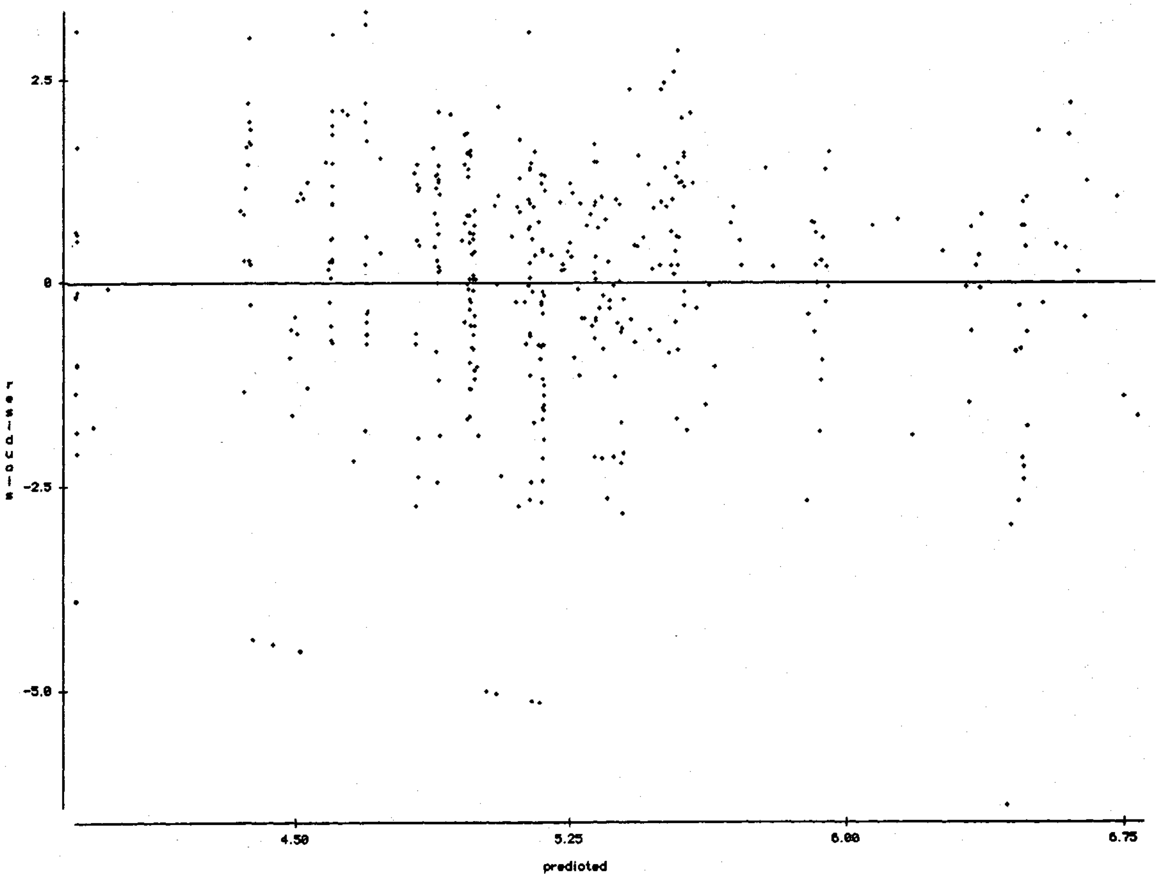


Table 12. (Concluded).

1. Key:

ACP - Average Ln(age-1 and older largemouth bass)
PPT - [(precipitation*watershed area)*(1+percent uncovered land)]/(lake volume*volume development index)
GDD - Growing-degree-days (°C)
CDD - Cooling degree days (°C)
SND - Snow depth (millimeters)
VEG - Predictor for aquatic vegetation control (dichotomous)

2. Model tested:

Ln(Age-1) = ACP + PPT + GDD + CDD + SND + VEG + first order interactions + error

3. Summary statistics for the response variable and predictors:

Variable	Mean	StdDev	Min	Max	Skewness	Kurtosis
Response	5.62	1.55	0.00	8.83	-0.84	1.66
ACP	3.49	0.37	2.93	4.44	1.23	1.36
PPT	0.08	0.22	<0.01	1.79	5.08	27.98
GDD	3480.48	370.42	2524.02	4671.04	0.08	0.23
CDD	592.59	336.02	32.00	1756.01	1.03	0.95
SND	37.08	47.22	1.68	439.34	4.23	26.16
VEG	0.41	0.49	0.00	1.00	0.37	-1.86

4. Results for the anthropogenic and significant environmental predictors:

R squared = 0.07
295 degrees of freedom
Power > 0.99

Source	*Sum of Squares*	*df*	*Mean Square*	*F-ratio*
Regression	51.20	2	25.60	11.4
Residual	659.98	295	2.24	

Variable	*Coefficient*	*s.e. of Coeff*	*t-ratio*	*p-value*
Constant	2.38	0.90	2.65	0.0085
ACP	0.77	0.23	3.37	0.0008
VEG	0.55	0.18	3.13	0.0019

Table 13. Results for aquatic vegetation control (Lag 0 treatment) following regression analyses on the Ln(Age-1) response variable (Section 3.2.2.4). (Continued).

5. Residual plot:

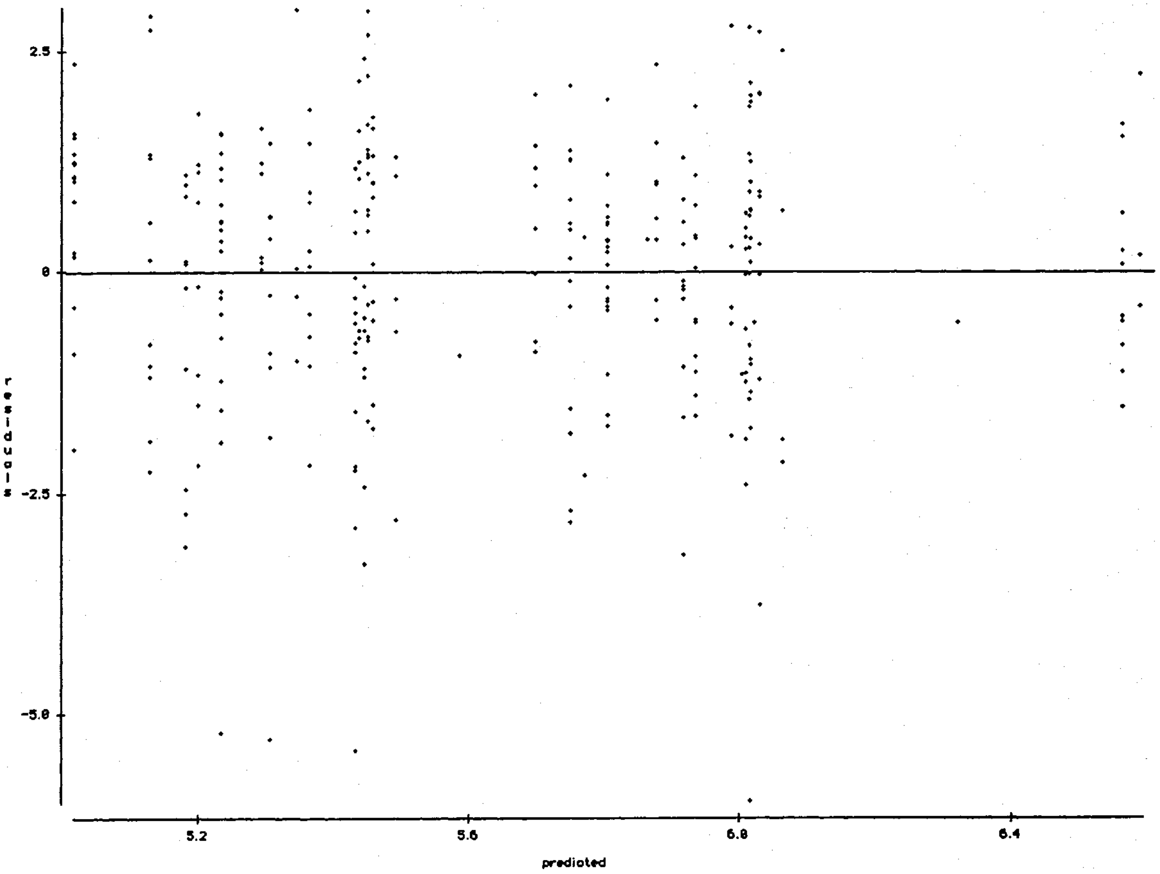


Table 13. (Continued).

6. Lake-specific results (Ln(Age-1) = intercept + VEG + error):

LAKE	N	R-SQUARE	INTERCEPT	SLOPE	SLOPE P-VALUE	POWER (0.1)
RANDOLPH COUNTY LAKE	16	0.06	5.71	-1.07	0.3668	0.24
ARGYLE LAKE	16	0.03	6.31	-0.87	0.5349	0.17
SAUK TRAIL	16	0.11	6.22	-0.76	0.2098	0.36
LAKE STOREY	7	0.03	6.32	-0.56	0.7074	0.12
JONES STATE LAKE	10	0.01	5.19	-0.37	0.7683	0.11
RAMSEY LAKE	15	0.00	5.78	-0.20	0.8107	0.10
LINCOLN TRAIL LAKE	22	0.00	5.78	-0.02	0.9725	0.11
SHABBONA LAKE	7	0.02	6.01	0.23	0.7761	0.12
WELDON SPRINGS	22	0.02	5.45	0.35	0.4874	0.17
AUGUSTA LAKE	16	0.00	4.46	0.40	0.8238	0.10
LAKE CARLTON	15	0.04	6.03	0.49	0.5043	0.19
LAKE MURPHYSBORO	18	0.04	4.55	0.61	0.4364	0.21
BEAVER DAM LAKE	9	0.03	5.22	0.64	0.6345	0.13
DAWSON LAKE	20	0.05	5.78	0.68	0.3582	0.25
WALNUT POINT LAKE	19	0.10	5.29	0.96	0.1902	0.38
WEINBURG - KING LAKE #1	13	0.06	5.96	1.30	0.4030	0.21
SILOAM SPRINGS	18	0.10	4.88	1.39	0.1988	0.37
DOLAN STATE LAKE	9	0.15	4.13	1.59	0.3014	0.28
RED HILLS	21	0.29	4.58	1.83	0.0122	0.84
LAKE LE-AQUA-NA	9	0.44	4.16	3.00	0.0508	0.68

Table 13. (Concluded).

1. Key:

ACP - Average Ln(age-1 and older largemouth bass)
PPT - [(precipitation*watershed area)*(1+percent uncovered land)]/(lake volume*volume development index)
GDD - Growing-degree-days (°C)
CDD - Cooling degree days (°C)
SND - Snow depth (millimeters)
VEG - Predictor for aquatic vegetation control (dichotomous)

2. Model tested:

Ln(Age-1) = ACP + PPT + GDD + CDD + SND + VEG + first order interactions + error

3. Summary statistics for the response variable and predictors:

Variable	Mean	StdDev	Min	Max	Skewness	Kurtosis
Response	5.62	1.48	0.00	8.83	-0.85	1.78
ACP	3.50	0.37	2.93	4.44	1.23	1.30
PPT	0.08	0.22	<0.01	1.79	5.10	28.21
GDD	3476.43	361.43	2524.02	4515.00	0.15	0.25
CDD	587.20	343.13	32.00	1756.01	1.05	0.86
SND	37.93	52.19	1.17	439.34	3.91	20.28
VEG	0.41	0.49	0.00	1.00	0.38	-1.85

4. Results for the anthropogenic and significant environmental predictors:

R squared = 0.03
295 degrees of freedom
Power = 0.768

Source	*Sum of Squares*	*df*	*Mean Square*	*F-ratio*
Regression	**19.80**	**2**	**9.90**	**4.64**
Residual	**629.06**	**295**	**2.13**	

Variable	*Coefficient*	*s.e. of Coeff*	*t-ratio*	*p-value*
Constant	**3.33**	**0.81**	**4.14**	**<0.0001**
ACP	**0.63**	**0.23**	**2.75**	**0.0063**
VEG	**0.20**	**0.17**	**1.16**	**0.2452**

Table 14. Results for aquatic vegetation control (Lag -1 treatment) following multiple regression analysis on the Ln(Age-1) response variable (Section 3.2.2.4). (Continued).

5. Residual plot:

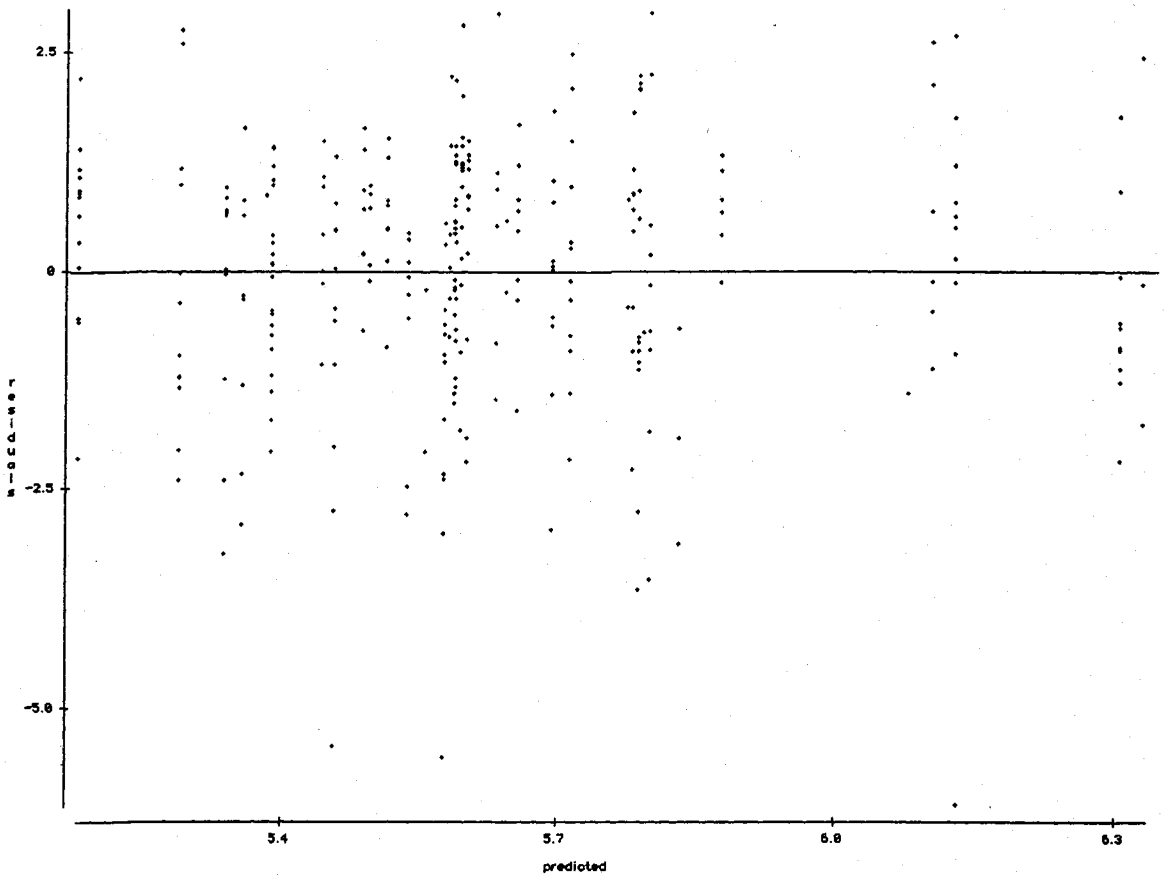


Table 14. (Concluded).

1. Key:

ACP - Average Ln(age-1 and older largemouth bass)
PPT - [(precipitation*watershed area)*(1+percent uncovered land)]/(lake volume*volume development index)
GDD - Growing-degree-days (°C)
CDD - Cooling degree days (°C)
SND - Snow depth (millimeters)
REM - Predictor for fish removal (dichotomous)

2. Model tested:

Ln(Age-1) = ACP + PPT + GDD + CDD + SND + REM + first order interactions + error

3. Summary statistics for the response variable and predictors:

Variable	Mean	StdDev	Min	Max	Skewness	Kurtosis
Response	5.21	1.43	0.00	8.41	-0.73	1.40
ACP	3.28	0.30	2.58	4.04	-0.15	0.08
PPT	0.04	0.07	<0.01	0.48	3.58	13.73
GDD	3412.27	467.85	1994.01	4671.04	-0.03	0.00
CDD	594.80	352.02	32.00	1762.98	1.06	0.76
SND	40.29	49.59	1.32	370.96	3.24	14.71
REM	0.20	0.40	0.00	1.00	1.49	0.22

4. Results for the anthropogenic and significant environmental predictors:

R squared = 0.09
323 degrees of freedom
Power > 0.99

Source	*Sum of Squares*	*df*	*Mean Square*	*F-ratio*
Regression	58.71	2	29.36	15.9
Residual	595.99	323	1.85	

Variable	*Coefficient*	*s.e. of Coeff*	*t-ratio*	*p-value*
Constant	1.33	0.70	1.90	0.0577
ACP	1.03	0.18	5.59	<0.0001
REM	0.13	0.19	0.70	0.4837

Table 15. Results for fish removal practices (Lag 0 treatment) following multiple regression analysis on the Ln(Age-1) response variable (Section 3.2.2.5). (Continued).

5. Residual plot:

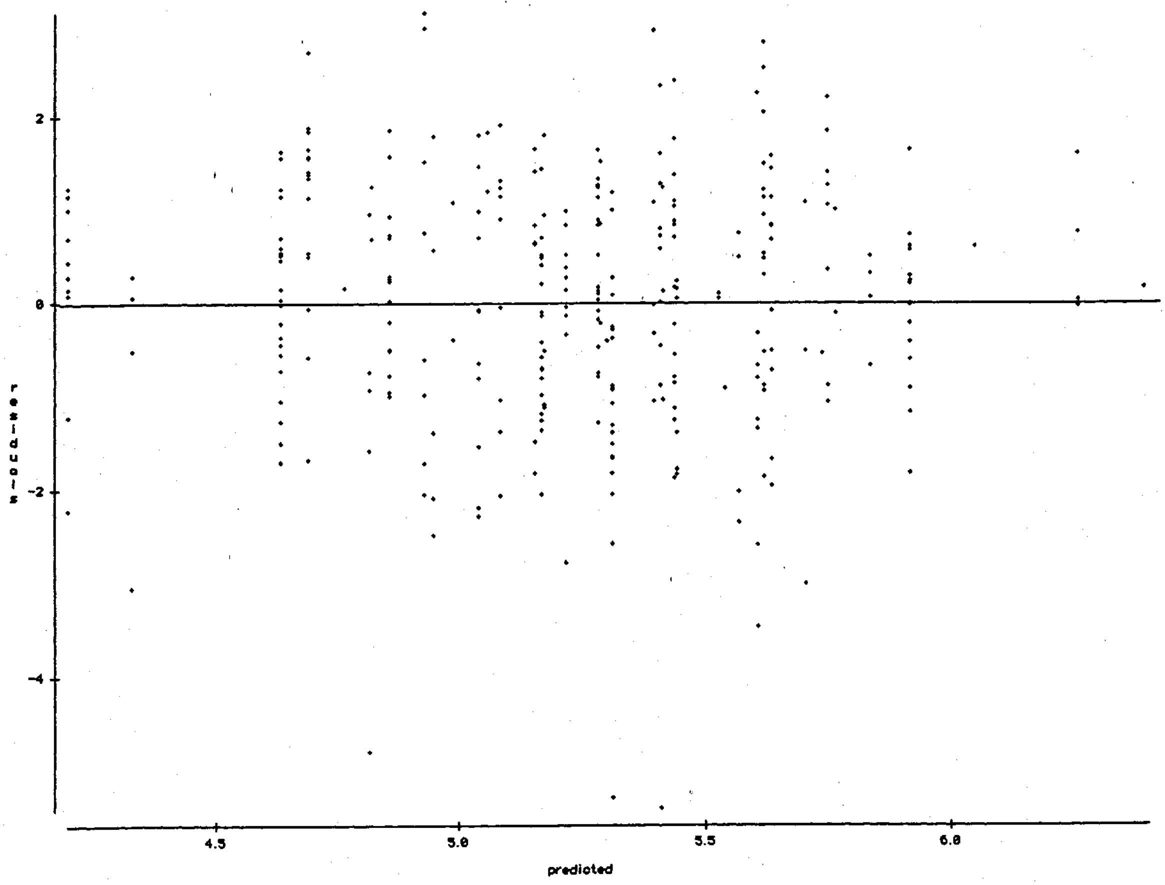


Table 15. (Concluded).

1. Key:

ACP - Average Ln(age-1 and older largemouth bass)
PPT - [(precipitation*watershed area)*(1+percent uncovered land)]/(lake volume*volume development index)
GDD - Growing-degree-days (°C)
CDD - Cooling degree days (°C)
SND - Snow depth (millimeters)
REM - Predictor for fish removal (dichotomous)

2. Model tested:

Ln(Age-1) = ACP + PPT + GDD + CDD + SND + REM + first order interactions + error

3. Summary statistics for the response variable and predictors:

Variable	Mean	StdDev	Min	Max	Skewness	Kurtosis
Response	5.21	1.44	0.00	8.57	-0.91	1.72
ACP	3.28	0.31	2.58	4.04	-0.11	-0.01
PPT	0.04	0.07	<0.01	0.48	3.52	13.21
GDD	3421.26	481.49	1994.01	4671.04	-0.05	-0.09
CDD	607.96	355.74	43.99	1762.98	1.03	0.70
SND	41.23	51.72	1.32	370.96	3.11	13.28
REM	0.20	0.40	0.00	1.00	1.50	0.26

4. Results for the anthropogenic and significant environmental predictors:

R squared = 0.13
323 degrees of freedom
Power > 0.99

Source	*Sum of Squares*	*df*	*Mean Square*	*F-ratio*
Regression	88.69	2	44.35	24.5
Residual	585.65	323	1.81	

Variable	*Coefficient*	*s.e. of Coeff*	*t-ratio*	*p-value*
Constant	-0.36	0.80	-0.45	0.6561
ACP	1.69	0.24	6.95	<0.0001
REM	0.14	0.19	0.74	0.4576

Table 16. Results for fish removal practices (Lag -1 treatment) following regression analyses on the Ln(Age-1) response variable (Section 3.2.2.5). (Continued).

5. Residual plot:

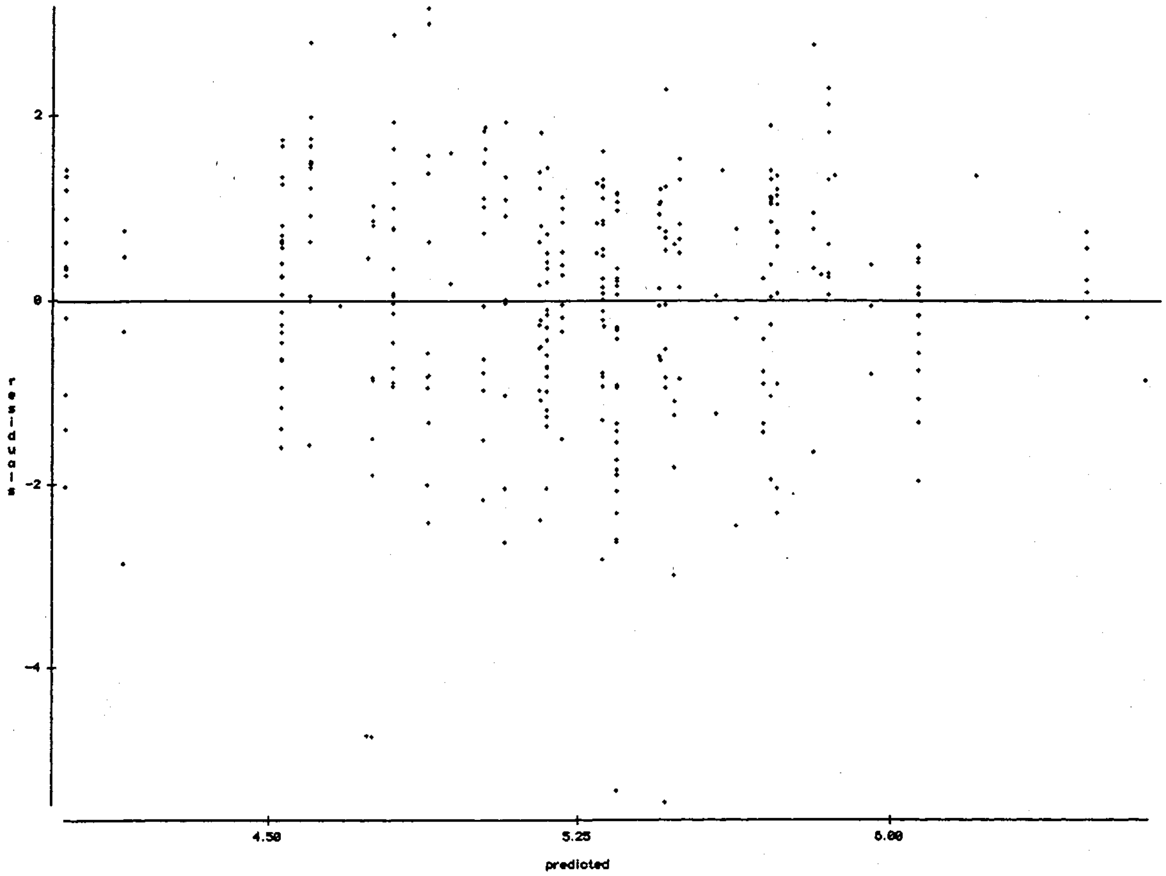


Table 16. (Concluded).

Predictors

Response Variables

Model for Lake Productivity Index of Largemouth Bass

Growing Degree Days (+)	Conductivity (+)	Euphotic Zone Volume (+/-)	Shoreline Habitat Type (+/-)	Inshore Mean Depth (+/-)		⇨	Productivity

Model for the Anthropogenic Predictors

Lake Effect (+/-)	Precipitation `Variable` (+/-)	Growing Degree Days (+)	Cooling Degree Days (-)	Snow Depth (-)	Stocking (+)	⇨	Age-1 Largemouth Bass
Lake Effect (+/-)	Precipitation `Variable` (+/-)	Growing Degree Days (+)	Cooling Degree Days (-)	Snow Depth (-)	Rehabilitation (-)	⇨	Age-1 Largemouth Bass
Lake Effect (+/-)	Precipitation `Variable` (+/-)	Growing Degree Days (+)	Cooling Degree Days (-)	Snow Depth (-)	Water Level Manipulation (+/-)	⇨	Age-1 Largemouth Bass
Lake Effect (+/-)	Precipitation `Variable` (+/-)	Growing Degree Days (+)	Cooling Degree Days (-)	Snow Depth (-)	Aquatic Vegetation (+/-)	⇨	Age-1 Largemouth Bass
Lake Effect (+/-)	Precipitation `Variable` (+/-)	Growing Degree Days (+)	Cooling Degree Days (-)	Snow Depth (-)	Chemical Fish Removal (+/-)	⇨	Age-1 Largemouth Bass

Model for Largemouth Bass Recruitment at Age-2

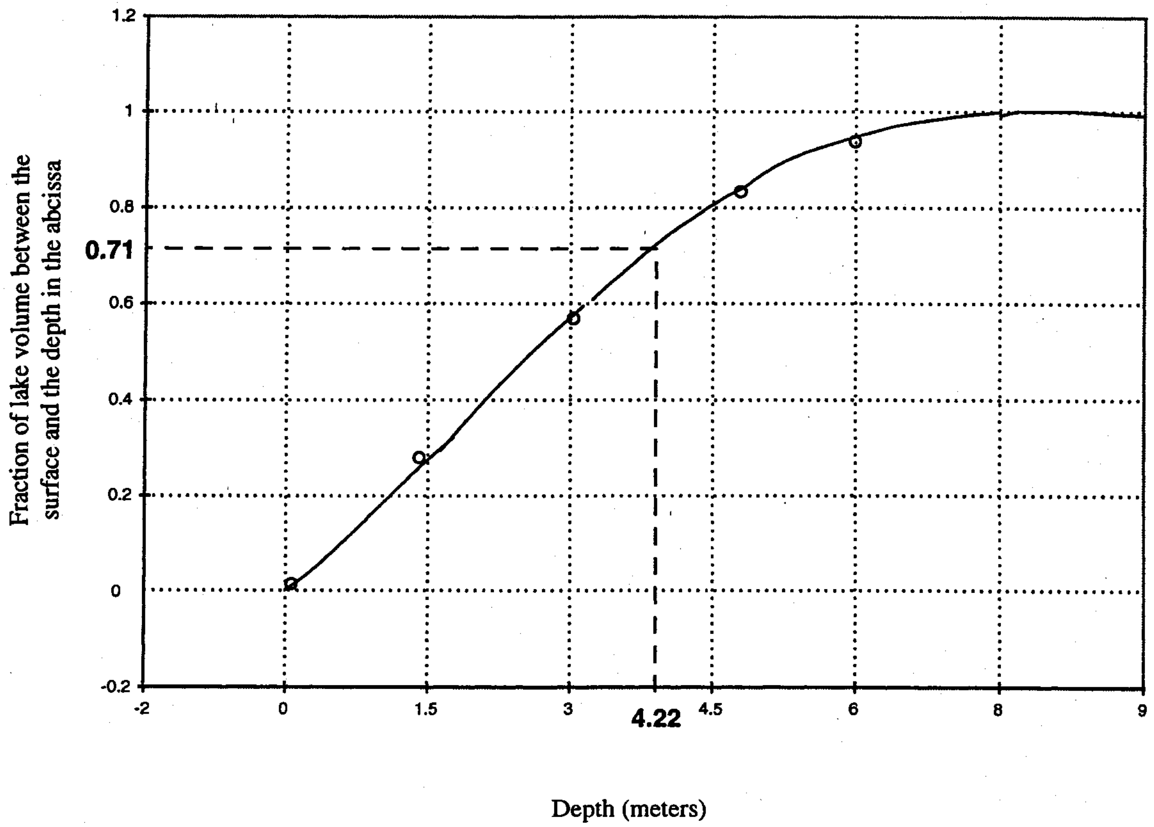
Lake Effect (+/-)	Precipitation `Variable` (+/-)	Growing Degree Days (+)	Cooling Degree Days (-)	Snow Depth (-)	Age-1 Largemouth Bass (+)	⇨	Age-2 Largemouth Bass

Model for the Changes in Regulations on Adult Lagemouth Bass

Lake Effect (+/-)	Precipitation `Variable` (+/-)	Growing Degree Days (+)	Cooling Degree Days (-)	Snow Depth (-)	Change to 350 mm (+/-)	⇨	Adult Largemouth Bass
Lake Effect (+/-)	Precipitation `Variable` (+/-)	Growing Degree Days (+)	Cooling Degree Days (-)	Snow Depth (-)	Change to 375 mm (+/-)	⇨	Adult Largemouth Bass
Lake Effect (+/-)	Precipitation `Variable` (+/-)	Growing Degree Days (+)	Cooling Degree Days (-)	Snow Depth (-)	Change to 300-375 mm (+/-)	⇨	Adult Largemouth Bass

Precipitation Variable - [(precipitation*watershed area)*(1+percent uncovered land)]/(lake volume*volume development index)

Figure 12. Schematic representation of the predictors and response variables tested with general linear models. Productivity = absolute number of age-1 and older fish caught per hour of electrofishing sampling during years when no anthropogenic predictors were implemented. Signs indicate the hypothesized direction of the effect on the response variable.



Average secchi depth: 1.636 m

$Z_c = [1.33*\mathrm{Ln}(1.636)+1.4]^2$ (maximum depth of aquatic vegetation colonization)

$Z_c = 4.22$ m

Proportion of lake in the euphotic zone = 0.71

Figure 13. An example of plot relating depth and lake volume in the euphotic zone between the surface and that depth. Data for Lake Carlton.

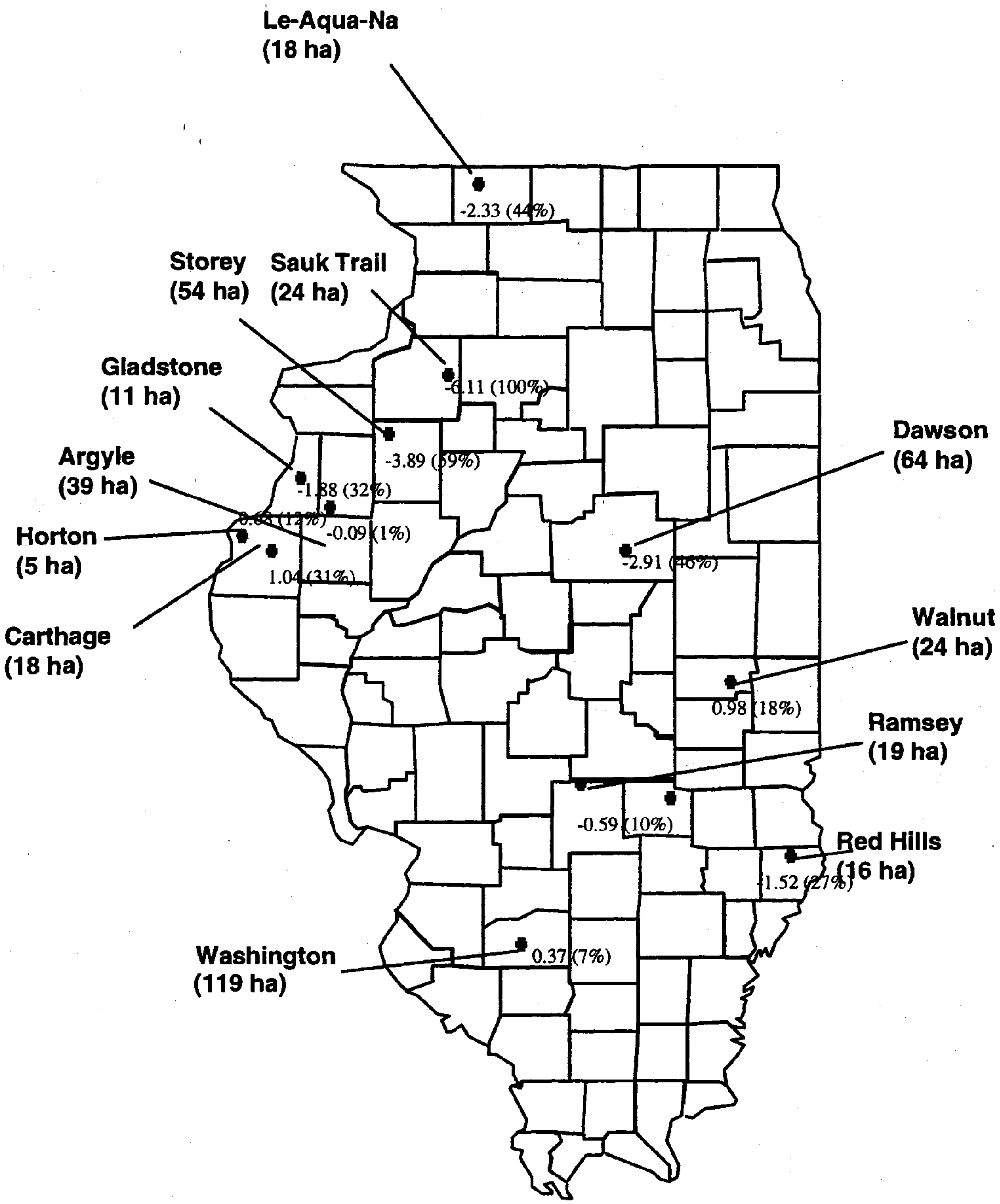

Le-Aqua-Na
(18 ha)
-2.33 (44%)
Storey
(54 ha)
Sauk Trail
(24 ha)
-6.11 (100%)
Gladstone
(11 ha)
-3.89 (59%)
Argyle
(39 ha)
-1.88 (32%)
0.68 (12%)
-0.09 (1%)
Horton
(5 ha)
1.04 (31%)
Carthage
(18 ha)
Dawson
(64 ha)
-2.91 (46%)
Walnut
(24 ha)
0.98 (18%)
Ramsey
(19 ha)
-0.59 (10%)
Red Hills
(16 ha)
1.52 (27%)
Washington
(119 ha)
0.37 (7%)

Figure 14. Lake-specific regression slopes and percent increase after treatment of the Ln(Age-1) response variable after rehabilitation practices (lag -1 treatments). Signs indicate direction of changes.

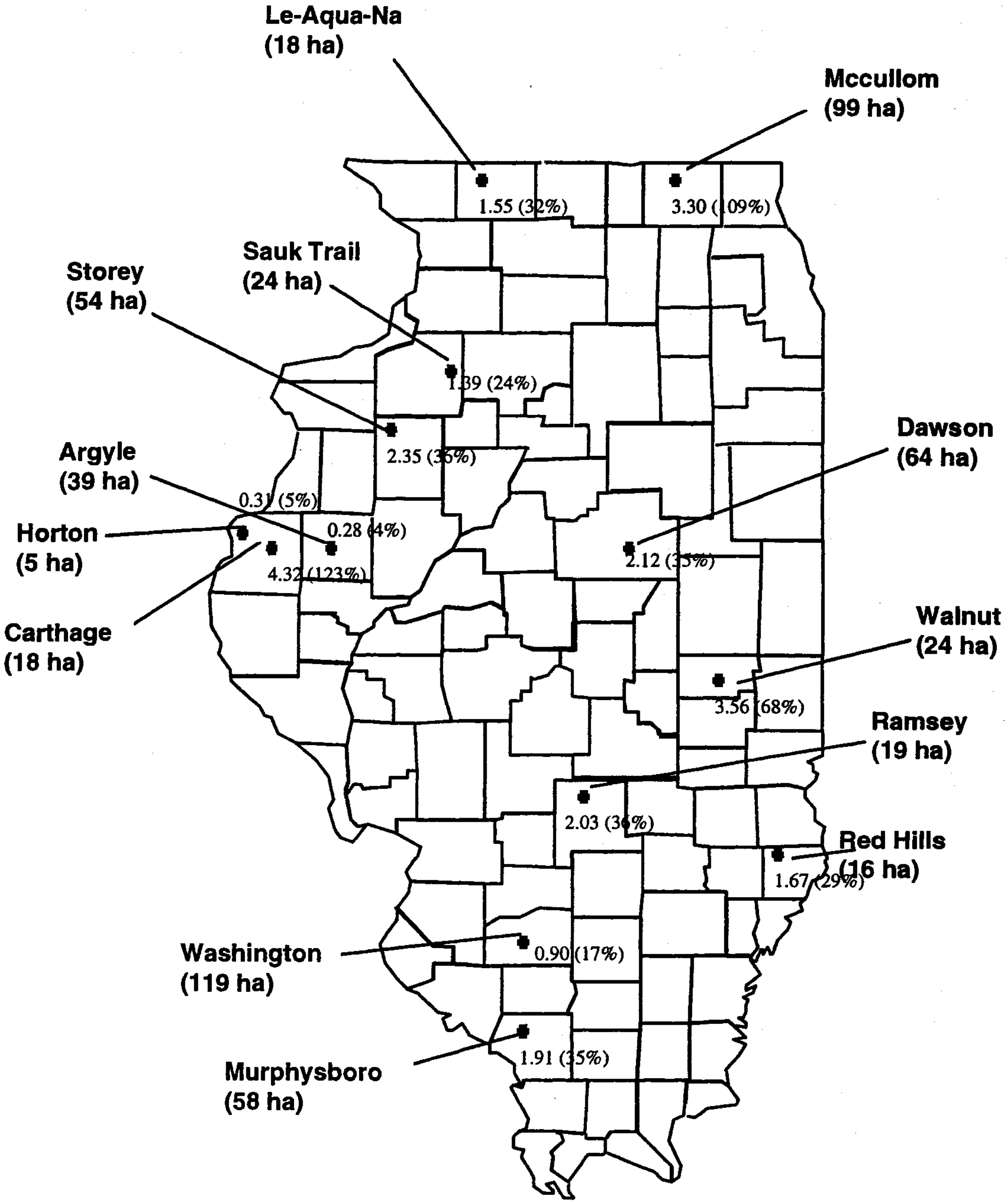

Le-Aqua-Na
(18 ha)
Mccullom
(99 ha)
1.55 (32%)
3.30 (109%)
Sauk Trail
(24 ha)
Storey
(54 ha)
1.39 (24%)
Dawson
(64 ha)
Argyle
(39 ha)
2.35 (36%)
0.31 (5%)
Horton
(5 ha)
0.28 (4%)
4.32 (123%)
2.12 (35%)
Carthage
(18 ha)
Walnut
(24 ha)
3.56 (68%)
Ramsey
(19 ha)
2.03 (36%)
Red Hills
(16 ha)
1.67 (29%)
Washington
(119 ha)
0.90 (17%)
Murphysboro
(58 ha)
1.91 (35%)

Figure 15. Lake-specific regression slopes and percent increase after treatment of the Ln(Age-1) response variable after rehabilitation practices (lag -2 treatments). Signs indicate direction of changes (all positive).

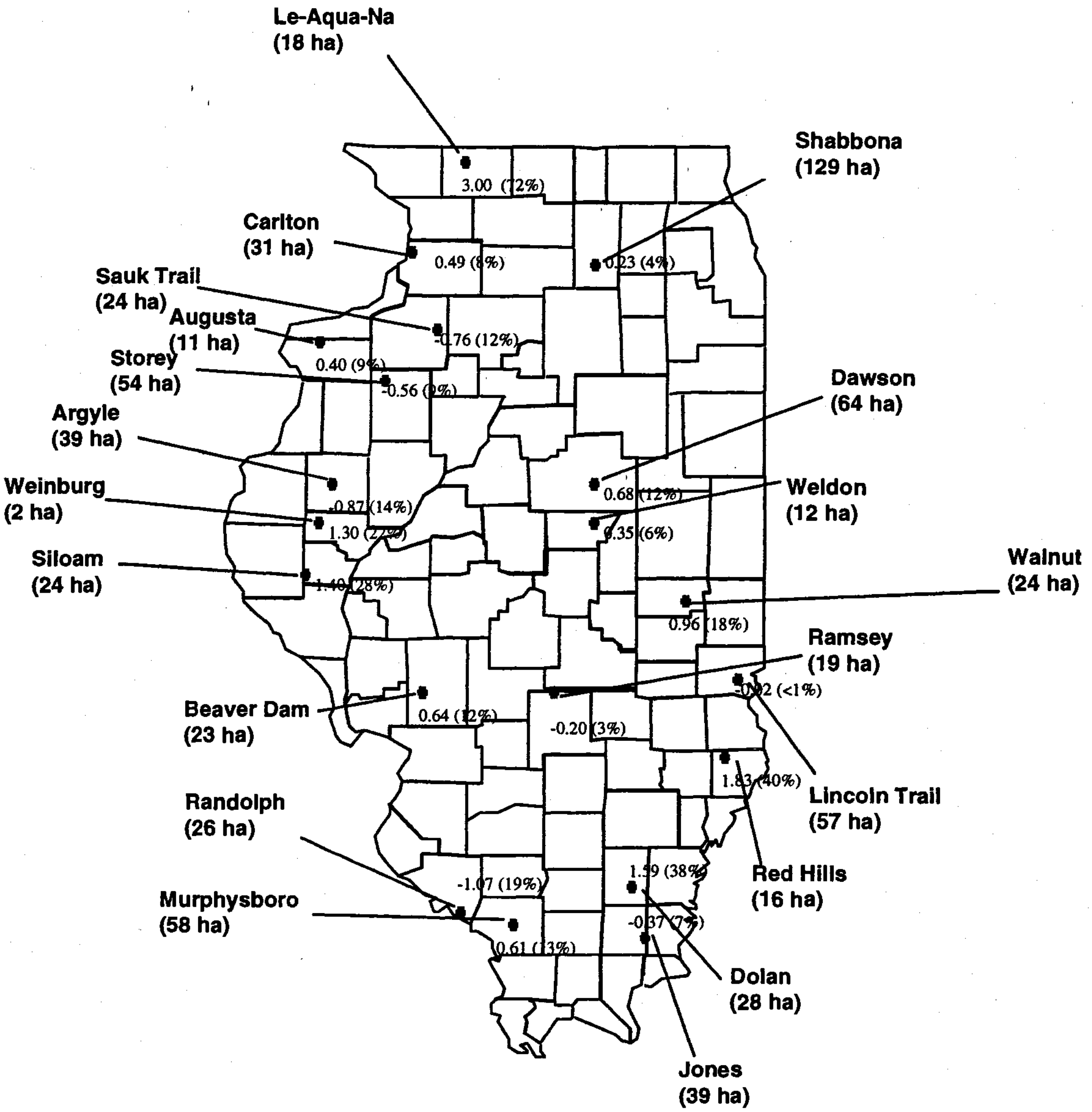

Le-Aqua-Na
(18 ha)
3.00 (72%)
Shabbona
(129 ha)
0.23 (4%)
Carlton
(31 ha)
0.49 (8%)
Sauk Trail
(24 ha)
-0.76 (12%)
Augusta
(11 ha)
0.40 (9%)
Storey
(54 ha)
-0.56 (9%)
Argyle
(39 ha)
-0.87 (14%)
Weinburg
(2 ha)
1.30 (27%)
Siloam
(24 ha)
1.40 (28%)
Dawson
(64 ha)
0.68 (12%)
Weldon
(12 ha)
0.35 (6%)
Walnut
(24 ha)
0.96 (18%)
Ramsey
(19 ha)
-0.20 (3%)
-0.02 (<1%)
Beaver Dam
(23 ha)
0.64 (12%)
Lincoln Trail
(57 ha)
1.83 (40%)
Randolph
(26 ha)
-1.07 (19%)
Red Hills
(16 ha)
1.59 (38%)
Murphysboro
(58 ha)
0.61 (13%)
-0.37 (7%)
Dolan
(28 ha)
Jones
(39 ha)

Figure 16. Lake-specific regression slopes and percent increase after treatment of the Ln(Age-1) response variable after aquatic vegetation controls (lag 0 treatments). Signs indicate direction of changes.

3.3. List of References

Austen, D., J. Peterson, B. Newman, S. Sobaski, and P. Bayley. 1993. Compendium of 143 Illinois lakes: bathymetry, physico-chemical features, and habitats (Vols. I and II). Aquatic Ecology Technical Report 93/9 (1 and 2).

Chambers, P and J. Klaff. 1985. Depth distribution and biomass of submersed aquatic macrophyte communities in relation to Secchi depth. Canadian Journal of Aquatic Sciences 42:710-709.

Galloway, M. and R. Kilamby. 1988. Thermal enrichment of a reservoir and the effects on annulus formation and growth of largemouth bass, *Micropterus salmoides*. Journal of fish Biology 32:533-543.

Gutreuter, S. and R. Anderson. 1985. Importance of body size to the recruitment process in largemouth bass populations. Transactions of the American Fisheries Society 114:317-327.

Miranda, L. and W. Hubbard. 1994. Length-dependent winter survival and lipid composition of largemouth bass in Bay Springs Reservoir, Mississippi. Transactions of the American Fisheries Society 123:80-87.

Perry, L. and J. Tranquilli. 1984. Age and growth of largemouth bass in a thermally altered reservoir, as determined by otoliths. North American Journal of Fisheries Management 4:321-330.

Sule, M. 1981. First-year growth and feeding of largemouth bass in a heated reservoir. *In* R. Larimore and J. Tranquilli (editors) The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32: 520-535.

Toneys, M. and D. Coble. 1979. Size-related first winter mortality of freshwater fishes. Transactions of the American Fisheries Society 108:415-419.

CHAPTER 4: METHODS AND RESULTS FOR EVALUATING RECRUITMENT AT AGE-2 LARGEMOUTH BASS AND CHANGES IN LENGTH LIMITS ON ADULT LARGEMOUTH BASS

4.1. Recruitment at Age-2 as a Function of Environmental Factors

4.1.1. Analytical Procedures

The lake-effect and environmental predictors (Section 3.2.1), and the analytical procedures described in Section 2.5 (general linear models) were used to investigate effects on the age-2 response variable (Section 2.3). Age-1 largemouth bass was used as an additional predictor to estimate the effect of age-1 abundance on recruitment at age-2. The age-1 predictor was the same as the age-1 response variable (Section 2.3; Figure 12). Recruitment was assessed using control years to avoid confounding of potential biological or environmental effects with management practices. The environmental predictors were lagged by one year with respect to the response variable to correspond to the period between age-1 and age-2.

The effects on natural mortality of the environmental variables used for investigating recruitment were also investigated. The logarithm of the ratio between the abundance of age-2 and age-1 fish was used as the response variable expressing mortality between the age-1 and age-2 period (Hilborn and Walters 1992). Because fishing mortality of age-2 and younger fish is minimum (Miller 1984; Summers 1990; Gabelhouse 1994; Howells et al. 1995; Martin 1995), if existent, the response variable represents natural mortality. The age-1 predictor was not used when investigating mortality.

4.1.2. Results

The abundance of age-2 was significantly correlated with the abundance of age-1. A slope in the regression model (r-square = 0.44; power = 0.996) of 0.35 ($p = 0.0004$) was observed. No relationship between any environmental predictor and age-2 fish abundance (Table 17, item 4.1) nor any trend in the residuals (Table 17, item 5.1) were detected. Similarly, natural mortality was not dependent on any of the environmental variables tested (Table 17, item 4.2) nor any trend in the residuals were detected (Table 17, item 5.2). Natural mortality was, however, density-dependent (Table 17, item 4.2).

4.2. Effects of Changes in Length Limits

All anthropogenic predictors were dichotomous, coded as zero or one. The intercept value represents the predicted value for control years and the slope represents the predicted value for treatment years. The slope, therefore, represents the change of fish abundance after treatment (Section 3.2.2).

4.2.1. Analytical Procedures

Changes in fish length limits were investigated using the adult-fish response variable. Each of the length limit predictor was analyzed separately. The source database was filtered in the same manner and confounding years treated as described in Section 3.2.1. Only lake rehabilitation was used as a confounding treatment on the response variable because it involves a total lake renovation, which may also affect adult size fish. The same predictors referred to in Section 3.2.1 (environmental predictors and the predictor for lake-effect) and analytical procedures described in Section 2.5 (general linear models) were used (Figure 12). Lag 0 treatments were used for all changes in length limit because harvest potentially produces an immediate effect on adult fish abundance. Spatial trends in the results were identified as described in Section 3.2.1.

The number of years needed to detect an effect on the response variable following changes in fish length limits was estimated for length limit treatments only because length limits are in effect during a sequence of years. Lakes where length limit changes occurred consisted of a pre- (300 mm length limit in effect) and post- (when any other length limit described in Section 2.2.2.4 was in effect) treatment. A regression of years since size limit change versus the adult response variable was conducted separately for each lake. Regression analyses were conducted for a lake with all pre-treatment years and the post-treatment years starting with the most recent observation after imposition of the size limit being analyzed. Post-treatment observations were added chronologically until all post-treatment data were incorporated. After each addition of post-treatment observations, a new regression was calculated and the slope with its significance value recorded. The resulting trend in significance values was an indication of the length in time needed for detection of effects, if any, of changes in length limit. An alpha level of significance of 0.1 was chosen due to the low number of observations associated with each lake (Section 2.5.4.2). Similarly, only significant predictors from the multiple-lake model were considered to allow for enough degrees of freedom.

4.2.2. Results

4.2.2.1. Change to a 350 mm Minimum Length

A slope of 0.59 ($p < 0.0002$) in the regression model (r-square = 0.057; power = 0.989) was observed (Table 18, item 4). No trends in the residuals were found (Table 18, item 5). Nine lakes with a positive slope and one with a negative slope out of eighteen were found significant after lake-specific regression analysis (Table 18, item 6). No geographical patterns in the regression slopes following treatments were observed (Figure 17). The time period necessary to detect an effect following treatment ranged from zero to six years (Table 19).

4.2.2.2. Change to a 375 mm Minimum Length

Significance was found for changes to a 375 mm minimum length limit. A slope of 0.99 ($p = 0.0005$) in the regression model (r-square = 0.114; power = 0.888) was observed (Table 20, item 4). No trends in the residuals were found (Table 20, item 5). Two lakes with a positive slope out of seven (all positive) were found significant after lake-specific regression analysis (Table 20, item 6). No geographical patterns in the regression slopes following treatments were observed (Figure 18). The time period necessary to detect and effect following treatment ranged from zero to four years (Table 21).

4.2.2.3. Change to a 300 to 375 mm Exclusive Slot Length

Significance was found for changes to a 300 to 375 mm slot length limit. A slope of 1.49 ($p < 0.0001$) in the regression model (r-square = 0.38; power > 0.99) was observed (Table 22, item 4). No trends in the residuals were found (Table 22, item 5). Four out of six lakes (all positive) had significant positive slopes after lake-specific regression analysis (Table 22, item 6). No geographical patterns in the regression

slopes following treatments were observed (Figure 19). The time period necessary to detect and effect following treatment ranged from three to ten years (Table 23).

1. Key:

PPT - [(precipitation*watershed area)*(1+percent uncovered land)]/(lake volume*volume development index)
GDD - Growing-degree-days (°C)
CDD - Cooling degree days (°C)
SND - Snow depth (millimeters)

2. Models tested:

Model 1: Ln(Age-2) = Ln(Age-1) + PPT + GDD + CDD + SND + first order interactions + error

Model 2: Ln(Age-2 / Age-1) = PPT + GDD + CDD + SND + first order interactions + error

3. Summary statistics for response variables and predictors:

Variable	Mean	StdDev	Min	Max	Skewness	Kurtosis
Ln(AGE 2/AGE 1)	0.12	1.01	-3.98	2.77	-0.91	4.07
Ln(AGE 2)	4.45	1.11	0.00	6.68	-1.13	3.14
Ln(AGE 1)	4.47	1.40	0.00	8.16	-0.01	1.03
PPT	0.04	0.06	<0.01	0.35	3.32	13.18
GDD	3457.90	489.16	2286.97	4339.03	-0.64	-0.14
CDD	552.79	378.24	43.99	1750.00	1.52	2.26
SND	36.65	80.03	1.42	439.34	4.01	15.80

4. Results:

4.1. Model 1:

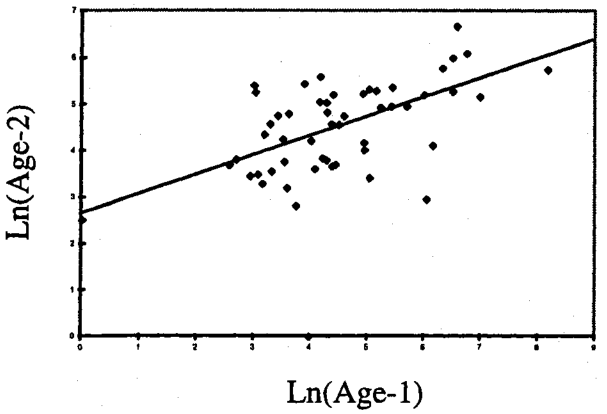
R squared = 0.39
52 degrees of freedom
Power = 0.996

Source	*Sum of Squares*	*df*	*Mean Square*	*F-ratio*
Regression	28.97	6	4.83	5.61
Residual	44.77	52	0.86	

Variable	*Coefficient*	*s.e. of Coeff*	*t-ratio*	*p-value*
Constant	1.21	2.18	0.56	0.5818
Ln(AGE 1)	0.34	0.09	4.00	0.0002
ACP	0.31	0.36	0.89	0.3789
PPT	-3.26	2.17	-1.50	0.1395
GDD	<0.01	<0.01	0.89	0.3784
CDD	<0.01	<0.01	-0.79	0.4350
SND	<0.01	<0.01	-0.52	0.6074

Table 17. Results for recruitment at age 2 and natural mortality of largemouth bass as a function of environmental variables (Section 4.1.2). (Continued).

Scatter plot of Ln(age-2) versus Ln(age-1):



4.2. Model 2:

R squared = 0.15
53 degrees of freedom
Power = 0.568

Source	*Sum of Squares*	*df*	*Mean Square*	*F-ratio*
Regression	11.75	5	2.35	1.84
Residual	67.52	53	1.27	

Variable	*Coefficient*	*s.e. of Coeff*	*t-ratio*	*p-value*
Constant	-3.21	2.64	-1.22	0.2288
ACP	0.07	0.41	0.18	0.8618
PPT	0.52	2.63	0.20	0.8452
GDD	<0.01	<0.01	1.94	0.0579
CDD	<0.01	<0.01	-0.20	0.8401
SND	<0.01	<0.01	0.33	0.7465

Results without non-significant predictors:

R squared = 0.25

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	18.46	1	18.46	19
Residual	55.28	57	0.97	

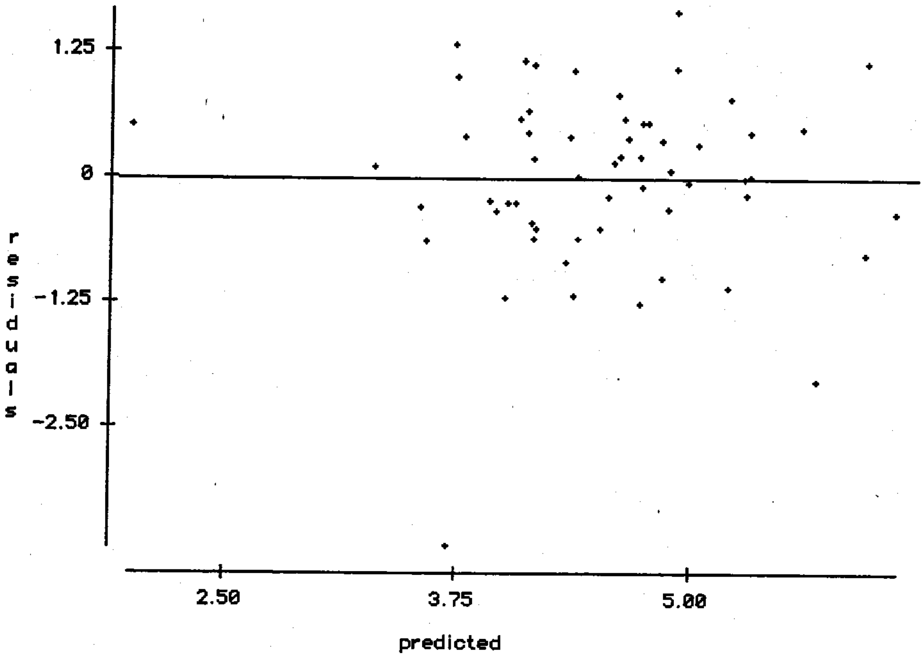
Variable	Coefficient	s.e. of Coeff	t-ratio	p-value
Constant	2.80	0.42	6.68	<0.0001
Ln(AGE 1)	0.37	0.08	4.36	<0.0001

Natural Mortality (Ln(age-2/age-1)) = 2.80 - 0.63*Ln(age-1)

Table 17. (Continued).

5. Residual plots:

5.1 Model 1:



5.2. Model 2:

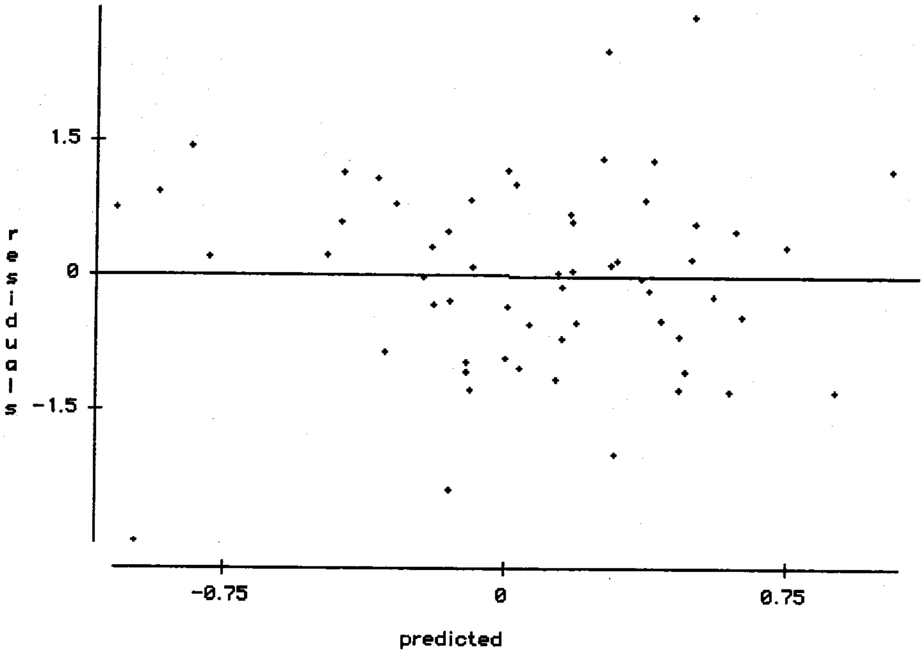


Table 17. (Concluded).

1. Key:

ACP - Average Ln(age-1 and older largemouth bass)
PPT - [(precipitation*watershed area)*(1+percent uncovered land)]/(lake volume*volume development index)
GDD - Growing-degree-days (°C)
CDD - Cooling degree days (°C)
SND - Snow depth (millimeters)
L35 - Length limit change to 350 mm (dichotomous)

2. Model tested:

Ln(Adult) = ACP + PPT + GDD + CDD + SND + L35 + first order interactions + error

3. Summary statistics for the response variable and predictors:

Variable	Mean	StdDev	Min	Max	Skewness	Kurtosis
Response	5.06	1.49	0.00	8.04	-1.17	2.25
ACP	3.20	0.43	2.46	4.40	0.83	1.53
PPT	0.06	0.08	<0.01	0.48	2.43	7.18
GDD	3473.15	527.25	1994.01	4671.04	-0.20	-0.63
CDD	655.75	384.95	76.98	1827.03	0.91	0.31
SND	42.65	54.85	1.32	439.34	3.51	16.93
L35	0.38	0.48	0.00	1.00	0.51	-1.74

4. Results for the anthropogenic and significant environmental predictors:

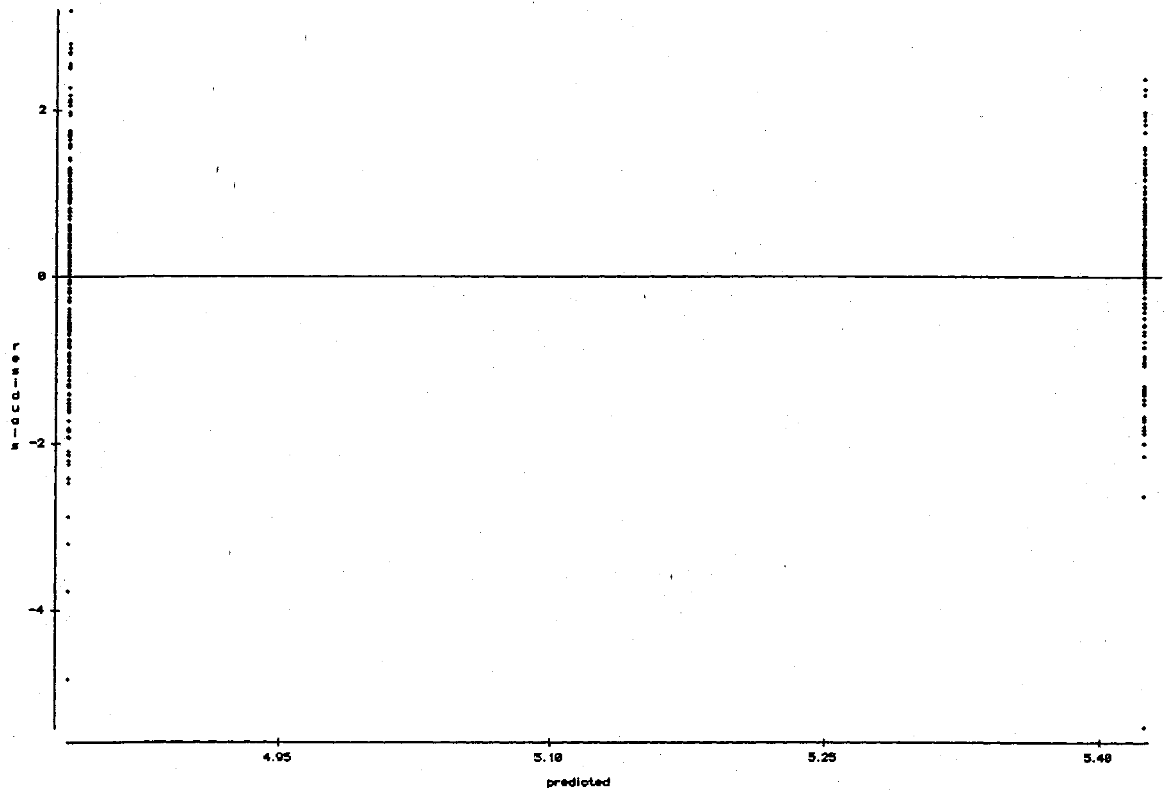
R squared = 0.04
360 degrees of freedom

Source	*Sum of Squares*	*df*	*Mean Square*	*F-ratio*
Regression	29.68	1	29.68	13.8
Residual	772.75	360	2.15	

Variable	*Coefficient*	*s.e. of Coeff*	*t-ratio*	*p-value*
Constant	4.83	0.10	49.6	<0.0001
L35	0.59	0.16	3.72	0.0002

Table 18. Results for a change to 350 mm minimum length limit for largemouth bass following regression analyses on the Ln(Adult) response variable (Section 4.2.2.1). (Continued).

5. Residual plot:



6. Lake-specific results (Log(Adult) = intercept + L35 + error):

LAKE	N	R-SQUARE	INTERCEPT	SLOPE	SLOPE P-VALUE	POWER (0.1)
LAKE CARLTON	22	0.33	3.65	2.00	0.0053	0.90
JONES STATE LAKE	26	0.25	3.74	1.92	0.0095	0.85
LAKE SHELBYVILLE	19	0.33	4.23	1.36	0.0100	0.86
DOLAN STATE LAKE	25	0.19	5.37	1.56	0.0302	0.73
WASHINGTON COUNTY LAKE	23	0.19	6.12	1.27	0.0355	0.69
CARLYLE LAKE	24	0.18	5.40	0.61	0.0403	0.69
LAKE LE-AQUA-NA	25	0.16	4.25	1.38	0.0472	0.65
RANDOLPH COUNTY LAKE	20	0.18	4.58	-1.20	0.0591	0.61
FORBES LAKE	6	0.55	4.89	2.01	0.0896	0.60
SAUK TRAIL	29	0.10	5.59	0.54	0.0993	0.52
PIERCE LAKE	17	0.12	3.38	0.97	0.1806	0.40
REND LAKE	11	0.19	5.80	0.70	0.1863	0.40
HOMER LAKE	11	0.17	4.62	0.87	0.2095	0.37
WALNUT POINT LAKE	23	0.07	4.35	0.91	0.2293	0.34
DEFIANCE LAKE	22	0.06	4.94	-0.84	0.2660	0.30
SHABBONA LAKE	11	0.10	5.28	0.70	0.3367	0.25

RAMSEY LAKE	22	0.04	5.53	-0.71	0.3901	0.23
WOLF LAKE	26	0.01	4.22	0.34	0.6342	0.14

Table 18. (Concluded).

LAKE	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
CARLYLE LAKE										0.58	0.51	0.40	0.50	0.56	0.57		0.61	
										0.4462	0.3380	0.3649	0.1965	0.1073	0.0754		0.0403	
DEFIANCE LAKE							-0.35	0.41	-0.01	0.20	0.27	-0.60	-1.22	-1.09	-1.10	-1.13	-0.92	-0.84
							0.7707	0.6422	0.9919	0.7597	0.6384	0.4846	0.2064	0.2259	0.1940	0.1600	0.2413	0.2660
DOLAN STATE LAKE												|		1.54	1.45		1.56	
														0.2029	0.0947		0.0302	
FORBES LAKE												1.28			2.01			
												0.3525			0.0896			
HOMER LAKE							|		1.03		0.89	0.93		0.87				
									0.4719		0.3742	0.2518		0.2095				
JONES STATE LAKE												2.21	1.96	1.85		1.92		
												0.1194	0.0541	0.0276		0.0095		
LAKE CARLTON		-0.21	1.38	1.75	1.77	1.87	1.79	1.64	1.60	1.59	1.56	1.63	1.61	1.77	1.84	1.93	2.00	
		0.9254	0.4423	0.2421	0.1683	0.1047	0.0854	0.0882	0.0741	0.0581	0.0489	0.0332	0.0271	0.0181	0.0121	0.0080	0.0053	
LAKE LE-AQUA-NA							1.91	1.45	1.52	1.41	1.51	1.57		1.63	1.36		1.38	
							0.3363	0.3011	0.1878	0.1593	0.0941	0.0577		0.0350	0.0656		0.0472	
LAKE SHELBYVILLE				1.19	1.27	1.13	1.12	1.11	1.14	1.16	1.09		1.15	1.25	1.30		1.36	
				0.4967	0.3017	0.2571	0.1891	0.1453	0.1002	0.0703	0.0680		0.0440	0.0258	0.0163		0.0100	
PIERCE LAKE		0.57	0.79	1.02	1.04	1.04	1.16		0.51	0.71	0.83		0.82	0.85		0.97		
		0.4431	0.1553	0.0482	0.0211	0.0098	0.0044		0.5516	0.3996	0.3060		0.2855	0.2422		0.1806		
RAMSEY LAKE										-1.16	-1.48	-0.91	-0.47	-1.48	-1.20	-0.95	-0.71	
										0.5005	0.2315	0.3749	0.6009	0.1456	0.1985	0.2791	0.3901	
RANDOLPH COUNTY LAKE							-0.53	-1.15	-1.20									

						0.6073	0.1338	0.0591								
REND LAKE									|	0.35		0.58		0.58		0.70
										0.7344		0.4322		0.3307		0.1863
SAUK TRAIL	1.68	1.53	1.36	1.20	1.09	0.93	0.80	0.74	0.72	0.67	0.47	0.43	0.45	0.43		0.54
	0.0888	0.0321	0.0209	0.0201	0.0186	0.0301	0.0446	0.0493	0.0420	0.0472	0.1854	0.2038	0.1742	0.1718		0.0993
SHABBONA LAKE						0.09		0.21	0.58			0.53	0.68		0.70	
						0.9612		0.8706	0.5845			0.5507	0.4031		0.3367	
WALNUT POINT LAKE						|		-0.45	-0.60	-0.51	0.11	0.55	0.87	0.92	0.84	0.91
								0.8296	0.6818	0.6662	0.9187	0.5772	0.3492	0.2844	0.2932	0.2293
WASHINGTON COUNTY LAKE									1.69		1.47	1.41		1.27		
									0.1544		0.0831	0.0432		0.0356		
WOLF LAKE											0.71	0.45	0.23	0.02	0.13	0.34
											0.6772	0.7112	0.8156	0.9776	0.8644	0.6342

Table 19. Number of years required to detect an effect on the Ln(Adult) response variable of a change from a 300 mm to a 350 mm minimum length limit. Entries in the first line of a lake are slopes of lake-specific regressions. Entries in the second line are the probability value of the slope. Bold face slopes are when significance ($p < 0.1$) was first detected. Bars indicate the year when the length-limit change was first implemented for lakes where the first regression entry is not the year of regulation implementation (Section 4.2.2.1).

1. Key:

ACP - Average Ln(age-1 and older largemouth bass)
PPT - [(precipitation*watershed area)*(1+percent uncovered land)]/(lake volume*volume development index)
GDD - Growing-degree-days (°C)
CDD - Cooling degree days (°C)
SND - Snow depth (millimeters)
L37 - Length limit change to 375 mm (dichotomous)

2. Model tested:

Ln(Adult) = ACP + PPT + GDD + CDD + SND + L37 + first order interactions + error

3. Summary statistics for the response variable and predictors:

Variable	Mean	StdDev	Min	Max	Skewness	Kurtosis
Response	5.50	1.38	0.00	8.00	-1.30	2.87
ACP	3.40	0.26	2.95	3.80	-0.14	-0.98
PPT	0.03	0.22	<0.01	0.12	1.46	1.89
GDD	3403.75	449.95	1994.01	4175.03	-0.84	0.49
CDD	561.84	362.36	32.00	1750.00	1.00	0.39
SND	39.41	50.87	1.17	370.96	3.27	15.35
L37	0.26	0.44	0.00	1.00	1.08	-0.84

4. Results for the anthropogenic and significant environmental predictors:

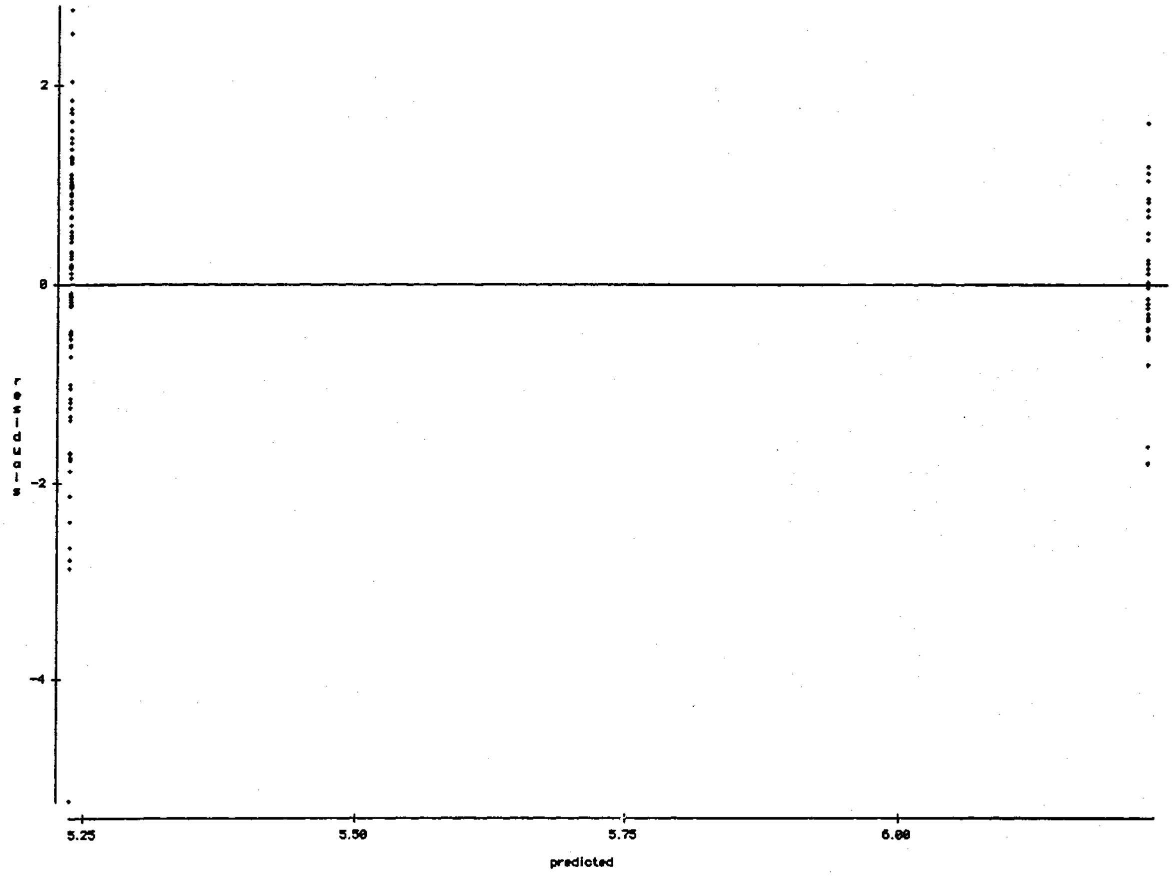
R squared = 0.10
116 degrees of freedom
Power = 0.888

Source	*Sum of Squares*	*df*	*Mean Square*	*F-ratio*
Regression	22.48	1	22.48	12.9
Residual	201.50	116	1.74	

Variable	*Coefficient*	*s.e. of Coeff*	*t-ratio*	*p-value*
Constant	5.24	0.14	37.1	<0.0001
L37	0.99	0.28	3.6	0.0005

Table 20. Multiple-lake and lake-specific results for a change to 375 mm minimum length limit for largemouth bass following regression analyses on the Ln(Adult) response variable (Section 4.2.2.2). (Continued).

5. Residual plot:



6. Lake-specific results (Log(Adult) = intercept + L37 + error):

LAKE	N	R-SQUARE	INTERCEPT	SLOPE	SLOPE P-VALUE	POWER (0.1)
MCCULLOM LAKE	20	0.26	3.62	1.96	0.0229	0.77
LAKE OF THE WOODS	17	0.28	4.70	1.58	0.0306	0.74
BEAVER DAM LAKE	6	0.49	5.43	1.07	0.1214	0.53
RED HILLS	26	0.09	5.57	1.19	0.1473	0.45
WELDON SPRINGS	11	0.21	5.75	0.60	0.1535	0.43
LAKE SARA	14	0.16	6.12	0.64	0.1619	0.43
LAKE MURPHYSBORO	24	0.00	5.63	0.15	0.7465	0.1

						1

Table 20. (Concluded).

LAKE	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
BEAVER DAM LAKE							1.63		1.07									
							0.0830		0.1214									
LAKE MURPHYSBORO														0.82	0.62	0.08	0.15	
														0.3541	0.3238	0.8872	0.7465	
LAKE OF THE WOODS							1.40	1.73	2.05	1.79	1.64	1.57		1.58				
							0.4431	0.1890	0.0657	0.0636	0.0578	0.0465		0.0306				
LAKE SARA											0.28	0.71			0.88	0.60	0.64	
											0.7631	0.2933			0.1226	0.2395	0.1619	
MCCULLOM LAKE												2.06	1.44	1.92	1.64	1.93	1.96	
												0.2892	0.2946	0.1002	0.1048	0.0401	0.0229	
RED HILLS													2.28	1.85		1.19		
													0.0996	0.0619		0.1473		
WELDON SPRINGS							0.46			0.49			0.35			0.60		
							0.5246			0.3381			0.4055			0.1535		

Table 21. Number of years required to detect an effect on the Ln(Adult) response variable of a change from a 300 mm to a 375 mm minimum length limit. Entries in the first line of a lake are slopes of lake-specific regressions. Entries in the second line are the probability value of the slope. Bold face slopes are when significance ($p < 0.1$) was first detected (Section 4.2.2.2).

1. **Key:**

ACP - Average Ln(age-1 and older largemouth bass)
PPT - [(precipitation*watershed area)*(1+percent uncovered land)]/(lake volume*volume development index)
GDD - Growing-degree-days (°C)
CDD - Cooling degree days (°C)
SND - Snow depth (millimeters)
LSL - Length limit change to a 300-375 mm slot limit (dichotomous)

2. **Model tested:**

Ln(Adult) = ACP + PPT + GDD + CDD + SND + LSL + first order interactions + error

3. **Summary statistics for the response variable and predictors:**

Variable	Mean	StdDev	Min	Max	Skewness	Kurtosis
Response	4.63	1.65	0.00	7.59	-0.91	0.91
ACP	3.54	0.19	3.26	4.04	0.90	1.51
PPT	0.03	0.02	<0.01	0.08	1.08	0.78
GDD	3349.76	325.69	2623.97	4494.02	0.54	0.33
CDD	613.46	261.15	79.97	1520.02	0.81	1.24
SND	40.74	41.27	1.42	265.89	2.75	9.41
LSL	0.31	0.46	0.00	1.00	0.84	-1.29

4. **Results for the anthropogenic and significant environmental predictors:**

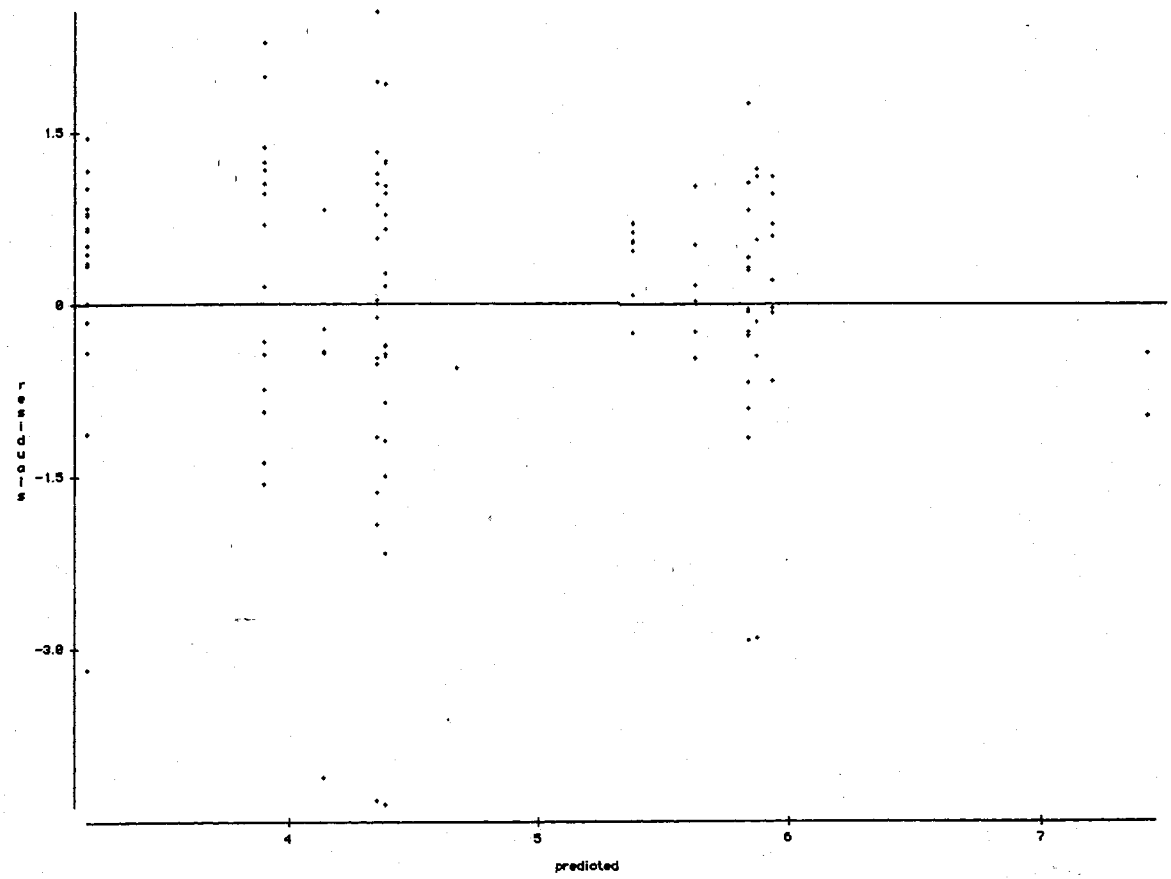
R squared = 0.38
118 degrees of freedom
Power > 0.99

Source	*Sum of Squares*	*df*	*Mean Square*	*F-ratio*
Regression	125.62	2	62.81	36.8
Residual	201.48	118	1.71	

Variable	*Coefficient*	*s.e. of Coeff*	*t-ratio*	*p-value*
Constant	-8.31	2.18	-3.81	0.0002
ACP	3.53	0.62	5.72	<0.0001
LSL	1.49	0.26	5.74	<0.0001

Table 22. Results for a change to a 300-375 mm slot length limit for largemouth bass following regression analyses on the Ln(Adult) response variable (Section 4.2.2.3). (Continued).

5. Residual plot:



6. Lake-specific results (Ln(Adult) = intercept + LSL + error):

LAKE	N	R-SQUARE	INTERCEPT	SLOPE	SLOPE P-VALUE	POWER (0.1)
GLADSTONE LAKE	24	0.35	4.32	1.49	0.0023	0.94
MILL CREEK LAKE	11	0.52	3.27	2.52	0.0120	0.86
ARGYLE LAKE	30	0.20	4.31	1.41	0.0132	0.82
DAWSON LAKE	24	0.18	4.20	1.57	0.0376	0.69
LAKE STOREY	10	0.10	6.29	0.44	0.3672	0.24
SILOAM SPRINGS	22	0.02	3.14	0.99	0.5062	0.17

Table 22. (Concluded).

LAKE	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
ARGYLE LAKE				0.36	0.92	1.04	1.09	1.24	1.14	0.78	0.78	0.90	0.96	1.04			1.17	1.26	1.41
				0.8385	0.4658	0.3152	0.2240	0.1268	0.1252	0.2784	0.2409	0.1596	0.1170	0.0761			0.0428	0.0256	0.0132
DAWSON LAKE										1.52	1.38	1.87	1.96	2.13		1.57			
										0.3370	0.2215	0.0519	0.0206	0.0063		0.0376			
GLADSTONE LAKE							1.60	1.69	1.40	1.33	1.42	1.46	1.48			1.49			
							0.2100	0.0677	0.0657	0.0438	0.0184	0.0085	0.0043			0.0023			
LAKE STOREY												0.71				0.44			
												0.3051				0.3672			
MILL CREEK LAKE												1.88	2.13	2.26	2.22	2.35	2.52		
												0.4179	0.1962	0.0954	0.0560	0.0265	0.0120		
SILOAM SPRINGS													0.99						
													0.5062						

Table 23. Number of years required to detect an effect on the Ln(Adult) response variable of a change from a 300 mm minimum length limit to a 300-375 mm slot limit. Entries in the first line of a lake are slopes of lake-specific regressions. Entries in the second line are the probability value of the slope. Bold face slopes are when significance ($p < 0.1$) was first detected. Bars indicate the year when the length-limit change was first implemented for lakes where the first regression entry is not the year of regulation implementation (Section 4.2.2.3).

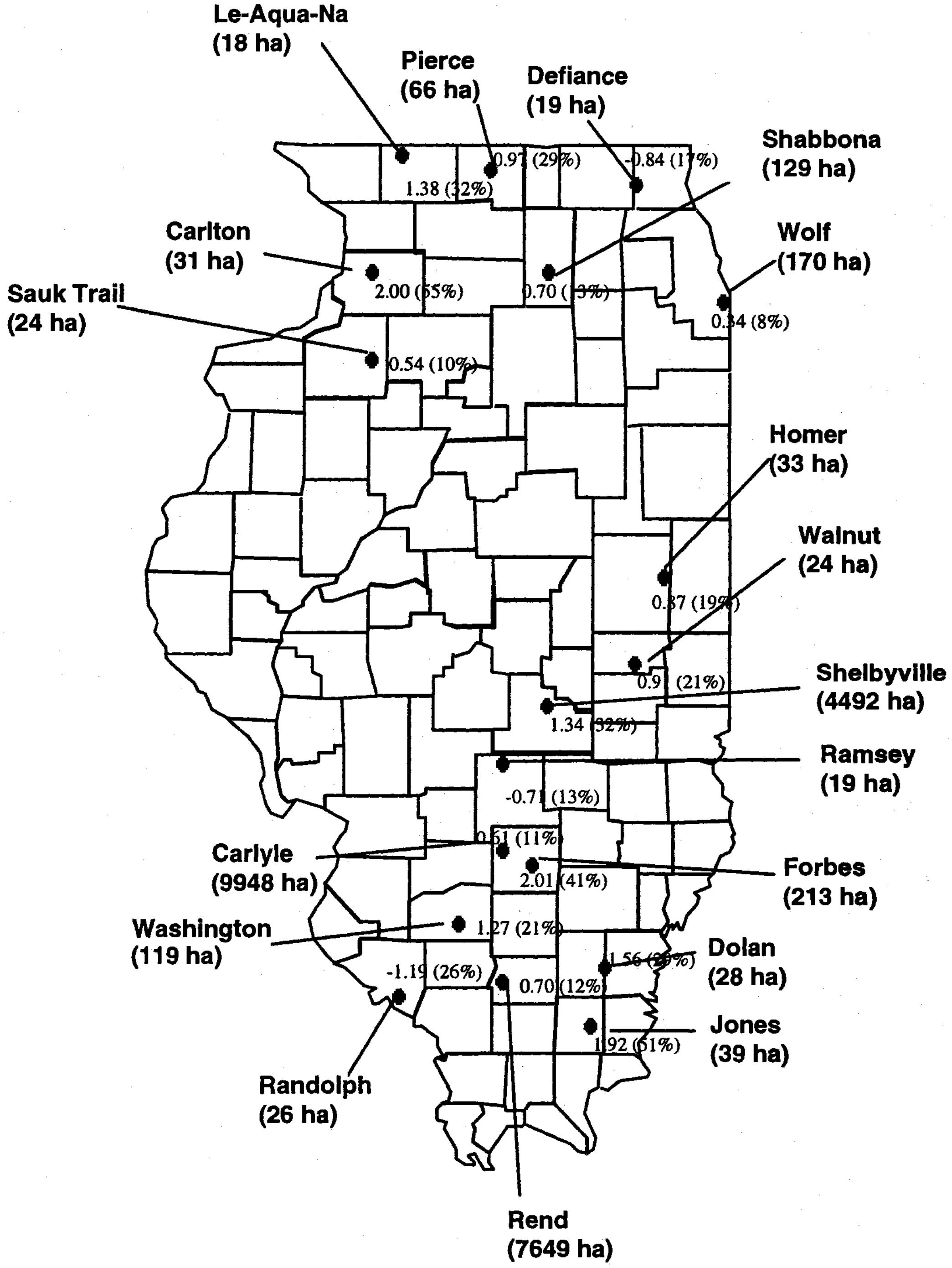

Le-Aqua-Na (18 ha)
1.38 (32%)
Pierce (66 ha)
0.97 (29%)
Defiance (19 ha)
-0.84 (17%)
Shabbona (129 ha)
0.70 (13%)
Carlton (31 ha)
2.00 (55%)
Wolf (170 ha)
0.34 (8%)
Sauk Trail (24 ha)
0.54 (10%)
Homer (33 ha)
0.87 (19%)
Walnut (24 ha)
0.91 (21%)
Shelbyville (4492 ha)
1.34 (32%)
Ramsey (19 ha)
-0.71 (13%)
Carlyle (9948 ha)
0.61 (11%)
Forbes (213 ha)
2.01 (41%)
Washington (119 ha)
1.27 (21%)
Dolan (28 ha)
1.56 (29%)
Randolph (26 ha)
-1.19 (26%)
Rend (7649 ha)
0.70 (12%)
Jones (39 ha)
1.92 (61%)

Figure 17. Lake-specific regression slopes and percent increase after treatment of the Ln(Adult) response variable after changes from a 300 mm to a 350 mm minimum length limit. Signs indicate direction of changes.

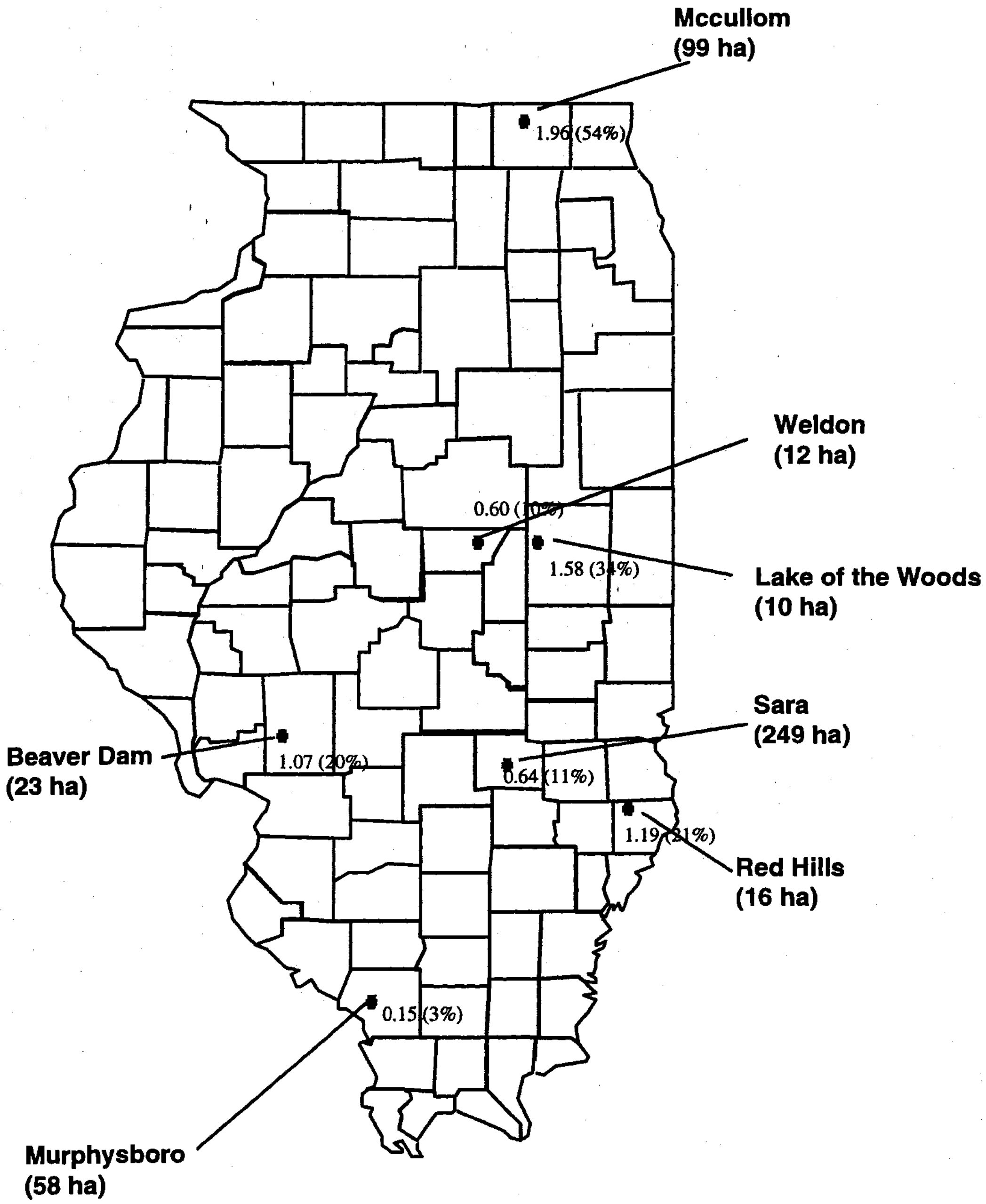

Mccullom
(99 ha)
1.96 (54%)
Weldon
(12 ha)
0.60 (10%)
1.58 (34%)
Lake of the Woods
(10 ha)
Sara
(249 ha)
Beaver Dam
(23 ha)
1.07 (20%)
0.64 (11%)
1.19 (21%)
Red Hills
(16 ha)
0.15 (3%)
Murphysboro
(58 ha)

Figure 18. Lake-specific regression slopes and percent increase after treatment of the Ln(Adult) response variable after changes from a 300 mm to a 375 mm minimum length limit. Signs indicate direction of changes.

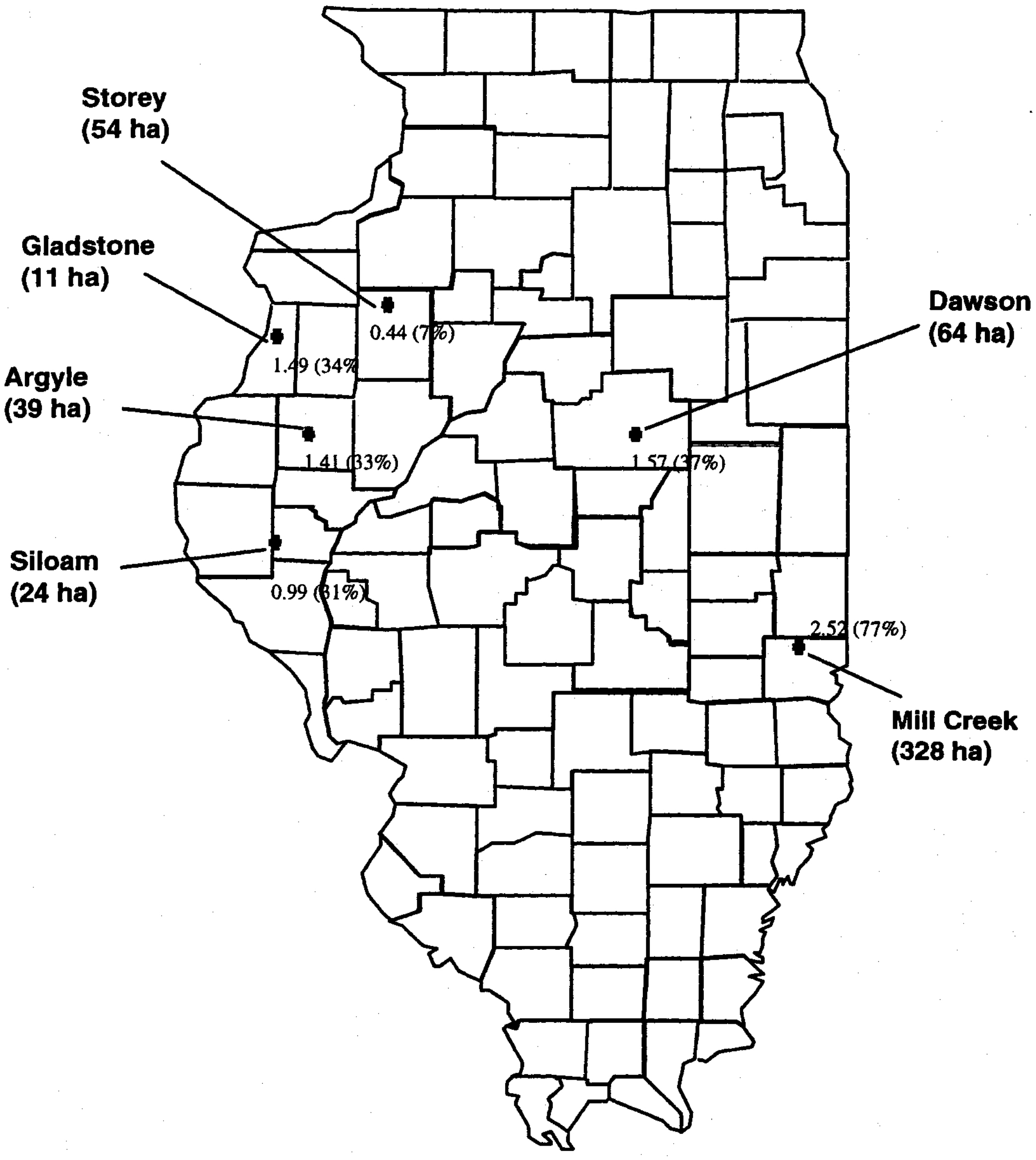

Storey
(54 ha)
Gladstone
(11 ha)
Argyle
(39 ha)
Siloam
(24 ha)
Dawson
(64 ha)
Mill Creek
(328 ha)
0.44 (7%)
1.49 (34%
1.41 (33%)
0.99 (31%)
1.57 (37%)
2.52 (77%)

Figure 19. Lake-specific regression slopes and percent increase after treatment of the Ln(Adult) response variable after changes from a 300 mm minimum length to a 300-375 mm slot limit. Signs indicate direction of changes.

4.3. List of References

Gabelhouse, D. 1984. A length-categorization system to assess fish stocks. North American Journal of Fisheries Management 4:273-285.

Hilborn, R., and C. Walters. 1992. Quantitative fisheries stock assessment. Chapman and Hall, New York, 570pp.

Howells, R., R. Betsill, and J. Prentice. 1995. Age estimation and length back-calculation for known-age largemouth bass. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 49:167-177.

Martin, C. 1995. Evaluation of slot length limits for largemouth bass in two Delaware ponds. North American Journal of Fisheries Management 15:713-719.

Miller, S. 1984. Age and growth of largemouth bass in Lake Shelbyville, Illinois. Transactions of Illinois Academy of Sciences 77:249-260.

Summers, G. 1988. Largemouth bass population changes following implementation of a slot length limit. Proceeding of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 42:209-217.

CHAPTER 5: DISCUSSION

This chapter includes the discussion of the effects of the environmental and anthropogenic predictors on the response variables tested in Chapters 3 and 4 (Figure 20), and the recommendations for future research for sport fisheries management.

5.1. Environmental Effects

There was little evidence of an effect on largemouth bass abundance of the environmental factors tested. The null results are an indication of either untested environmental factors playing a role in determining largemouth bass abundance or the absence of a single or few important factors operating at all times as major determinants of fish population fluctuations in abundance.

5.1.1. Precipitation

There was supporting evidence in this work that increases in precipitation resulted in increases of water level and turbidity, but no supporting evidence that those factors affected largemouth bass abundance. The compound variable including precipitation did not explain changes in the response variable. The potential effects of soil type, land use practices, and the duration of water level changes were probably too small to be detected with the data in this work. In many analyses the predictor incorporating precipitation was not representative of the total possible values after lake selection for the anthropogenic predictors. This might have affected the results because the effects of extreme values for the predictor could not be estimated.

High precipitation events are usually preceded or followed by strong winds (Coles 1970), which may increase water turbidity in lakes. A low nesting success and low egg survival has been associated with high turbidity and strong wind erosion (Kramer and Smith 1962; Cross 1967; Eipper 1975). Nest success and egg survival, however, may not translate into an increase in young fish abundance. The potential effects of lake turbidity due to precipitation events will be long term (>1 year) only if there is a cascading effect from nest success, to egg, to young fish, and finally to age-1 abundance. Even though most of the results herein suggest no long term effects of precipitation on fish, short term effects on young fish should not be ruled out (Werner et al. 1977; Martin et al. 1981; Jackson et al. 1982).

5.1.2. Growing-degree-days

The expected effect of growing-degree-days was of an increase in survival of largemouth bass with an increase in temperature experienced by fish. This was not observed after any analyses. The results suggest that growing-degree-days either does not affect growth or that differences in growth among young largemouth bass due to total temperature experienced are too small to influence survival (therefore abundance) to an extent to be detected by electrofishing samples.

Studies addressing the effects of temperature on fish abundance are more common than studies on the effects of growing-degree-days, possibly because the effects of growing season are not as immediately apparent as extremes in temperature. Studies of the effects of growing-degree-days and temperature on fish are usually short term (Hall and Ehlinger 1989; Fox and Keast 1990, 1991) or done on few systems (lakes or streams) (Moore 1942; Larimore et al. 1959; Johnson 1965; Hall and Ehlinger 1989). Long term studies within multiple systems are rare (Casselman and Harvey 1975). Causation is more difficult to defend in one-system studies and short term effects may be misleading. Studies limited to a year are, therefore, not conclusive. Studies with at least two years, preferably done in more than one system, may start to give some insight into temperature-related effects on fish.

Beamesderfer and North (1995) in a large-scale study of some environmental factors on growth and mortality rates of largemouth bass found air temperature, latitude, and growing-degree-days to correlate with fish mortality rates. Average regional values for the environmental predictors were used, making it impossible to attribute the correlations to fluctuations in weather. Fahy (1980) reported length of growing season to be most important in determining growth of sea trout during the first year. Growth in later years was less susceptible to changes in length of growing season, suggesting a short-term, non-persisting effect. The effects of growing-degree-days on fish may go undetected in long term studies due probably to density-dependent compensatory mechanisms operating on fish populations.

Temperature may also influence feeding behavior of fish. Shift to a piscivorous diet of largemouth bass has been correlated with growth (Summerfelt 1975; Coutant and Angelis 1983; Olson 1996) and growth with survival through the first winter (Eipper 1975; Coutant and Angelis 1983; Gutreuter and Anderson 1985). Olson (1996) observed average temperature in the summer to positively influence shift to piscivory of largemouth bass. Cooler temperatures throughout summer months produced a delay in spawning and a decrease in growth. The shift to piscivory was strongly related to size of largemouth bass. Smaller fish persisted on a diet consisting of macrobenthic organisms, which was the attributed cause of the observed slow growth (Olson 1996).

Physiological and feeding responses to temperature may be more complex and subtle than electrofishing data can detect. Investigating the effects of temperature or temperature experienced on a single species may further add to the difficulties because potential effects may be closely linked to or even masked by the availability and quality of prey (Olson 1996).

5.1.3. Cooling Degree Days and Snow Depth

No decreases in largemouth bass abundance were observed following cold years or years with high snow cover. Results for cooling degree days and snow depth suggest little or no effect on largemouth bass overwinter mortality. The power of tests involving cooling degree days and snow cover amount was high, lending further support to the above conclusion.

The adaptation of largemouth bass to winter conditions may have accounted for a lack of effect of snow depth. Largemouth bass oxygen requirements decrease with a decrease in water temperature due to a lowering in metabolism. A reduction of metabolism may reduce largemouth bass overwinter mortality, which may have accounted for the results. Mortality of fish due to low dissolved oxygen have mostly been reported for small, shallow (<1 m) eutrophic lakes, with rich vegetative cover (Cooper and Washburn 1949; Casselman and Harvey 1975; Magnuson et al. 1985). Lakes in Illinois, although eutrophic, are usually deeper, possibly making areas with oxygen too low for fish survival rare. An exception is Timber Lake, a small lake (12 hectares) in central Illinois that has suffered complete largemouth bass mortality (Bayley, personal communication). Laboratory experiments suggest largemouth bass to be adapted to the low temperature regimes prevalent during winter months in Illinois lakes (Guest 1982; Coutant 1975). Direct effects of low temperature on largemouth bass populations are, therefore, probably negligible, if at all present.

5.1.4. Lake Largemouth Bass Index of Abundance

The majority of the results in this dissertation were indicative of differences in largemouth bass abundance among lakes. Growing-degree-days, percent of lake volume in the euphotic zone, lake conductivity, shoreline habitat type, and lake inshore mean depth, however, did not explain those differences and the importance of abiotic factors determining largemouth bass productivity in Illinois lakes remains unanswered, but nontheless is shown here to be secondary to several management effects.

Studies have had inconsistent success detecting environmental effects on lake productivity (Prepas 1983; Kerr and Ryder 1988; Downing et al 1990; Downing and Plante 1993). A primary example of a model relating abiotic factors to fish yield in lakes is the morphoedaphic index (Ryder 1965, 1982; Ryder et al. 1974). The model has been applied with good success to a variety of lakes possibly because estimates of yield of a combination of many species were made. If year to year fluctuations of the abundance of aggregate species tend to fluctuate less than that of single species (Kerr and Ryder 1988), the use of indices for single species will yield poorer predictions. Predicting a single species such as largemouth bass, therefore, is more difficult with abiotic factors alone.

Another factor potentially influencing the poor predictive ability observed herein is the narrow spatial range of lakes compared to that of lakes in most other studies on fish production. Oglesby (1977) found phytoplankton standing crop (range of 12 - 3986 $gC/m^2/year$) to correlate with fish yield (range of 0.0033 - 16.1 $gC/m^2/year$) in 19 lakes located from the equator to north temperate latitudes. Downing and Plante (1993) in a study of factors affecting production of fish in 38 lakes worldwide found air temperature (mean annual temperature range between -9 and 25

°C) and lake trophic status (measured as algal production and total phosphorous; 0.7 - 881 gC/m^2 and 3 - 9850 mg/L range, respectively) to correlate with fish production. Downing et al. (1990) found fish production to correlate with phytoplankton production and total phosphorous in 20 lakes worldwide. Similarly, Schlesinger and Regier (1982) have observed mean annual air temperature to explain over 70% of maximum sustainable yield of commercial species from 123 natural lakes between 62°N and 15°S, again suggesting spatial scale to largely determine potential for detecting high effects. Temperature and factors related to primary production seem to be more strongly correlated with lake productivity. The largest distance between lakes in this dissertation was less than 400 kilometers with small differences in elevation, which is negligible compared to lakes situated on different hemispheres and continents. The range of the predictor for growing-degree-days was probably too narrow to detect any trend in productivity for largemouth bass. Additionally, surrogate variables were used to address primary production (such as percent of area in the euphotic zone and conductivity), which might have lowered the predictive power of the static model tested here.

Other abiotic factors have been observed to be correlated with fish productivity in lakes, such as total dissolved solids (Ryder 1965; Matuzek 1978), total phosphorous (Downing et al. 1990), and particle size (Sheldon et al. 1972). Similarly, several biotic factors influencing lake productivity have been explored by other researchers. Bottom fauna (Matuzek 1978), phytoplankton (Oglesby 1977; Jones and Hoyer 1982; Downing et al. 1990), zooplankton (Mills and Schiavone 1982), and macrobenthos (Hanson and Leggett 1982) have been observed to correlate with fish productivity. These variables may aid in explaining variation in largemouth bass productivity from Illinois lakes. Most of those variables, however, are expensive to collect on a regular basis. If differences in productivity are constant and recognized, management for largemouth bass may still be tailored according to those differences.

The results from the static model for lake productivity do not necessarily support uniform management protocols, such as statewide regulations. The differences among lakes exist, but were not explained. The observed differences in largemouth bass abundance or any other target species for management may be used for devising lake-specific management, if persistent from year to year.

5.1.5. Recruitment at Age-2 Largemouth Bass

Age-2 largemouth bass abundance only correlated with age-1 fish. The correlation coefficient was low, but the slope not negligible, was highly significant, and had high statistical power. These are encouraging results, given the high variability common in the data used for this dissertation. The results indicated that fisheries managers may be able to use the abundance of age-1 largemouth bass to estimate the strength of year-class entering harvestable ages. The results addressing mortality are evidence that natural mortality is density dependent, at least between the age-1 and age-2 period and that prediction of year-class strength from estimates of age-1 fish is promising.

Fisheries scientist have traditionally attempted to relate young fish abundance to year-class strength of harvestable fish (Gulland 1965; Goodyear and Christensen 1984; Peterman et al. 1988; Myers and Cadigan 1993; Mertz and Meyers 1995), which has been recognized to be largely unsuccessful (Goodyear and Christensen 1984; Bradford 1992; Mertz and Meyers 1995). Some successful cases where correlations were found were not repeated with new data obtained at later times (Saville 1959; Baranekova 1960), suggesting some correlations to be spurious or confounded with untested factors.

This work differed from most other works in that age-1 fish abundance was used in predicting recruitment at age-2. Most other investigators attempted to explain recruitment using age-0 fish as explanatory variables. The success in detecting a relationships between age-1 and age-2 largemouth bass may have stemmed from the fact that age-1 fish fluctuations are less sensitive to biotic and abiotic factors than age-0 fish. Another possibility for the detection is that the relationship becomes increasingly linear when older fish are used. The mechanisms operating between age-0 and age-1 fish may be more complex than current models describe. There may be a critical time during the first year which determines recruitment to older ages (Hjort 1926; Ricker 1954; DeAngelis et al. 1993). Age-0 fish populations would appear to fluctuate erratically due to the critical period, whereas age-2 and older fish abundance would fluctuate with respect to the abundance in the previous year in a more linear fashion. Age-1 fish, therefore, may provide a means to predict year-class strength of fish recruiting to harvestable sizes and provide an additional alternative for devising management plans, such as defining what numbers of fish are allowed to be harvested.

5.1.6. Conclusions

Environmental effects on fish are usually detected in small, shallow lakes or streams (Larimore et al. 1959; Tonn and Paszkowski 1986; Crivelli and Britton 1987; Fox and Keast 1990, 1991). Shallow waters tend to offer little regufia under extreme environmental conditions and are more readily affected by changes in weather, making severe drought, high temperatures, and extreme winter conditions immediately apparent. When fish populations increase (due to more habitat or prey) as a response to decrease due to a stressing factor in the past, however, the effects of the stressing factor on fish will disappear at a later time (Larimore 1959 et al.; Serns 1982; Davaine and Beal 1992).

Larimore et al. (1959) in a study of the effects of temperature on fish in Smith's Branch, Illinois, during the years of 1951-54 reported high mortalities during 1953, a year with exceptionally high temperatures. However, the original species assemblage was reestablished after 1954, suggesting the observed declines in fish to be of short duration. A strong immediate effect on young fish may not be persistent for longer than a season, making the temperature-related effects of little impact on long term (>1 year) fish abundance. Non-persisting effects of temperature on fish abundance have been reported for sea trout (*Salmo trutta*) populations in the Kereguelen Islands. A correlation between temperature and fish population density was not presistent (Davaine and Beal 1992). Similarly, Serns (1982) found summer water temperature to be correlated with only young smallmouth bass abundance and not persistent.

The results should be taken with caution due also to the fact that some environmental variables tested were indirectly related to lake water conditions. The compound variable incorporating precipitation, land use practice, watershed area, and lake vloume was to represent a combination of duration of water level change, and input of solids and water to lakes. Precipitation, however, was not a direct measure of water level change. Either the correlation between water level and precipitation did not hold for lakes other than the three shown in Figure 4 (Carlyle Lake, Lake Shelbyville, and Rend Lake) or the effects as postulated in Section 2.1.1.1 are of short duration, if existent. Ideally, environmental variables measured from within each lake should be chosen. The fact that climatic information was used as a surrogate for lake conditions might have inflated residual variance to an extent as to prevent the detection of the predictors analyzed. The use of environmental data more closely linked to the lakes of study would make results more believable, if not more informative. Similarly, if biological factors were considered, the effects of abiotic variables might have become more clear. Considering biological factors may separate the variability due to competition and predation to an extent to enable detection of environmental effects on fish abundance.

Even though there is no evidence for an effect on fish abundance of the environmental variables tested, that is not to say that data on environmental variables are of secondary need. Environmental variables may be useful for aspects not related to fish abundance, such as estimation of catchability for sampling gears because catchability is a function of environmental factors (Simpson 1978; Bayley and Austen 1987; Reynolds 1996). Estimates of population sizes may be compared across systems when corrections for catchability are made. Similarly, more accurate catchability estimates may be obtained when based on yearly observations, instead of lake averages, of some abiotic factors. More accurate correction factors for catchability may increase the sensitivity of electrofishing sampling data, which may lead to more detecting power of the effects of environmental factors.

5.2. Anthropogenic Effects

5.2.1. Largemouth Bass Stocking

The survival of stocked largemouth bass may be a function of environmental factors prevailing during stocking and during the first winter following stocking events. Largemouth bass is a naturally reproducing species in Illinois. Stocking is done with the intention to increase the number of largemouth bass or to maintain a pre-existing population size in a lake. Stocked largemouth bass is usually of young fish. As suggested elsewhere, mortality of stocked largemouth bass is

Page 173 missing from the bound original may never be validated and the use of public fund supporting stocking questioned.

5.2.2. Lake Rehabilitation

Lake rehabilitation is the most extreme management practice done in Illinois. A substantial and many times complete drop of water level, followed by chemical or physical fish removal may leave few, if any, survivors. When the water comes to normal pool levels, an intensive stocking is done to restart fish populations. Due to the extreme results and the sometimes intensive cost and labor of this practice, it is not often done.

As would be expected, lake rehabilitation produced the highest effects on fish abundance compared to the other management practices tested. An increase in fish abundance following a water level reduction has also been reported elsewhere (Hill 1980; Pierce et al. 1965). Compared to control years, age-1 largemouth bass abundance declined the year after rehabilitation events, because mostly stocked young fish might have been present, and increased two years after the event, possibly because of higher survivors of fish. These results are suggestive of a decline of largemouth bass, possibly of all sizes, during the practice of lake rehabilitation, followed by an increase in young fish due to stocking in the next year, which then translated to a higher number of age-1 largemouth bass two years after lake rehabilitation events. Lake-specific analyses for the lag -2 model showed all lakes responding to treatment in the direction expected, lending credence to the results.

The results of the lake-specific regression slopes for both lag -1 and lag -2 treatments indicated differences among lakes in response to treatments. Some lakes in the lag -1 treatments showed presence of age-1 largemouth bass (evidenced by a positive slope), possibly due eradication not being complete. Lakes where a complete eradication was not effected did not show any different pattern of response after the lag -2 treatment, suggesting that partial fish kills are as effective for restarting largemouth bass populations.

5.2.3. Water Level Manipulation

The change in the water level of a lake is primarily done to increase crowding of fish, which helps the elimination of excess of certain fish through predation, temperature, and oxygen stresses. This practice is more commonly done during the summer, but fall manipulations are also observed.

The absence of effects on largemouth bass suggest that water level manipulation practices as done in Illinois are ineffective for managing largemouth bass population abundance. Presence of effects on fish after water level manipulation have more commonly been reported to be after over six months (Pierce et al. 1965; Lantz et al. 1967; Hill 1980; Paller 1997). Man-made water level changes are of short duration (few weeks) in Illinois, which may explain its weak effects on fish.

A no-effect situation was observed possibly because water level changes are often done during late summer and early fall in Illinois. When water levels are dropped with the purpose of increasing predation on excessive young fish, it may be more effective when done during spawning periods (Shields 1957). A combination of low and high water levels may even produce better results. A year of low levels followed by a year of flooding may enhance growth and survival of fish (Aggus and Elliott 1975). As it is done now in Illinois, water level manipulations do not produce any detectable change in age-1 largemouth bass numbers, and, when done for managing fish, should be reconsidered as to its timing and duration.

5.2.4. Aquatic Vegetation Control

The positive effects of aquatic vegetation control observed from the lag 0 model are largely due to a few lakes with a high increase in electrofishing catches after reductions in aquatic vegetation along the shoreline. One quarter of the lakes was in the opposite direction as detected significant in the regression model incorporating all lakes. Electrofishing catchability has been reported to be an inverse function of vegetative cover (Bayley and Austen 1987). Change in catchability, therefore, is one possible cause of the observed increase in age-1 fish during years when aquatic vegetation controls were implemented. If aquatic vegetation is reduced, fish are more easily noticed during sampling procedures, which may have accounted for the observed increase in age-1 fish.

The main reason for controlling aquatic vegetation in Illinois lakes is to improve lake recreational use by creating access lanes, opening fishing areas, and freeing shoreline for swimming. This practice is not intended to have effects on fish. The results, however, indicate a possible effect of vegetation manipulations on age-1 largemouth bass and possibly on angling.

5.2.5. Fish Removal

Effects from fish removal are commonly detected on fish growth or abundance only when intensively done (Keith 1967; Beckman 1950; Jackson 1966) and are many times done in conjunction with different techniques (Keith 1967). The effects of partial, less intense fish removals as examined in this dissertation are not reported.

Fish removal in Illinois is done mainly to control excess of young sunfish, especially bluegill and is mostly done with rotenone or antimycin. Fish poisoning is not aimed at adult fish and may not affect them (as suggested herein). The benefits (control of excessive young fish) were not tested in this dissertation because no data were available pertaining to the pre- and post-treatment quantity of young fish. Regular estimates of young fish done before and after treatment may provide information as to the short-term efficacy of fish removal practices in reducing young fish abundance.

5.2.6. Changes in Largemouth Bass Length Limits

Implementations of fishing regulations are done in Illinois primarily to improve angling. Lakes with persisting excessive numbers of small fish are strong candidates for becoming subject to regulations. Regulations are press events, in that they tend to persist over longer time periods compared to other management actions. The effects of regulations, therefore, tend to yield stronger results than the more common one-time or occasional management events.

More restrictive fishing regulations as to the allowable minimum size of harvestable fish increased fish abundance as shown by the relationship

between fish catch-per-effort and regulation type (almost twice an increase for a change to a 350 mm minimum length compared to an increase of almost three times and over four times for a change to a 375 mm minimum length and to a 300-375 mm exclusive slot length limit, respectively). The results are in agreement with other studies (Eder 1984; Hoff 1995; Wilde 1997). The results of regressions analyses incorporating all lakes were in agreement with the statistically significant results from lake-specific analyses. Fishing regulations are one of the most used management tools in the US fisheries sector and are becoming increasingly important (Johnson and Martinez 1995; Mather et al. 1995). Effects in agreement with the expectations of fisheries managers and the low cost of regulation implementations should keep this practice a preferred choice for managers.

The effects of length limits are closely dependent on fishing pressure. Paragamian (1982) reported a depression in largemouth bass abundance due to high fishing pressure following implementation of a 350 mm length limit. An increase in the numbers of catchable fish, as suggested by this work, is evidence of fishing pressure not being too high to depress fish of harvestable sizes. The observed increases in fish abundance following length limit changes might not have happened under a more intense fishing pressure regime following the regulation (or, conversely, under very low fishing intensity). Current Illinois regulations aiming to control fishing pressure are based on fish quotas for individual anglers. Instead, fish quotas for lakes need to be implemented to limit potential overfishing and a consequent reversal of the benefits following size limits. Fishing pressure was not able to be included in this analyses due to only few lakes presenting such data, but should be considered an important factor determining the benefits of fishing regulations, especially with the increasing efficiency of anglers (Noble and Jones 1993).

The number of years necessary to detect the effects of changes in length limit greatly varied among lakes. The low number of observations within lakes and the high background variation in adult largemouth bass abundance was probably the cause of the variable results. In some occasions, the significance observed in one year was not retained at later years, again suggesting that fluctuations in adult fish are high compared to the observed increase in the abundance at individual lakes.

Within-lake unexplained fluctuations of abundance in adult fish may be reduced if data for fishing pressure is incorporated.

5.2.7. Conclusions

Results from the anthropogenic component are support for some management practices having an effect on largemouth bass abundance. Stronger effects for extreme practices (lake rehabilitations) and practices with effects over multiple years (changes in length limits) were associated with the highest effects. The results support the fact that managers have control over fish populations and, as such, striving to optimize management using the methods tested here is justified. Lake-specific results, although not always in close agreement with the results of regressions incorporating all lakes, suggest the outcome of management practices to be lake dependent. In summary, the outcome of some management practices are of a strong enough effect to be detected by electrofishing data from field samplings and in agree with expectation from theory.

It is disappointing to realize that spatially and temporally broad scale data such as those used herein only detects major effects on fish. It raises the question of whether the quality of our data collection is poor or intrinsic variations in fish are too sensitive to even minor factors or too difficult to track with current methods. Combining data from different sources may help explaining some of the variation of fish abundance. A combination of electrofishing with other sampling gears and with creel data may increase the sensitivity of the data available to managers and researchers such that the effects may be established for those management practices for which no detectable effects were found in this analysis.

5.3. General Discussion

The results of this work are most useful for fishery management in situations where quality fishing is strongly associated with the size and quantity of fish caught, as in the sport fishery. The results might not be as useful when total catch is more important, as it is in commercial fishing. Commercial and sport fishery differ in that management objectives in the former are well established. The objectives in commercial fishery management are to maximize profit from catch on a sustainable basis. Sport fishery management has as its prime objective the more elusive concept of angler satisfaction, which includes, but is not limited to, quantity and size of fish caught (not necessarily kept). Angler satisfaction is the objective in sport fishery management because fishery agencies rely on license sales as part of their budget. Fishery agencies have to compete with alternative recreation opportunities, which makes knowledge of anglers' preferences necessary to incorporate into management plans. The results herein focused on an increase of available catch to anglers and should, therefore, not be used in situations where angler satisfaction involves different aspects related to fishing.

The question often asked by managers, scientists, and the general public is whether people have any control over exploited natural resources. The question often leads to whether managers should intensify their efforts overall, concentrate on more effective tools, or steward natural systems with minimal intervention. If managers are to direct their efforts to more effective tools, the question becomes what those tools should be. The answer for these questions is certainly system and time dependent, which adds to the difficulty in trying to resolve man's role in modifying natural systems to reflect our perception of high quality.

A related problem in sport fisheries management is that of resource allocation. The question of what management practices to prioritize and devote more attention and resources to was started to be addressed in this dissertation. Harvest regulations, recruitment issues, and sport fish stocking are major priorities in the fisheries management sector in the United States (Mather et al. 1995). The results of this dissertation are encouraging because fishing size limits produced strong and desirable effects on harvestable fish, suggesting that resource allocation should be directed to regulation related practices. Length and bag limits may be currently the most promising management tools available. Research on the effects of stocking and water level manipulations mimicking floodplain systems, however, should not be discarded, due to the benefits of flooded areas for many fish (Bayley 1995). Largemouth bass is one of the major species produced by Illinois hatcheries. Hatcheries benefit from approximately 35% of the annual budget of the IDNR (IDNR 1996). If stocking of largemouth bass is conducted only in association with lake rehabilitation, more resources can be directed to potentially more effective practices for improving fishing (such as fish sampling).

The results of this work point to a few management practices having detectable effects, despite the high variability inherent in fisheries data for fish number estimators, suggesting these practices to be of a strong effect. Environmental factors produced weaker results compared to anthropogenic factors, suggesting weather to be less important than management practices in accounting for fluctuations in fish abundance. This, however, should not be generalized. Illinois lakes are small systems compared to systems like the oceans, seas, and the great lakes. Illinois lakes being small and shallow, should be expected to be much more prone to human perturbations than larger water bodies. In large water bodies, environmental factors may play a bigger role in determining the characteristics of the biota.

The effects of management practices have traditionally been evaluated by considering short-term data from one or few lakes only (Viosca 1945; Krumholz 1950; Swingle 1950; Martin et al. 1981). The high annual variation of fish abundance estimates from electrofishing samples suggest that statistical power from results of studies relying on only a few years of observation from one or few lakes is low and should be interpreted with caution. For more robust results, more attention should be paid to existing large data sets. Due to the nature of data collection, large scale data sets in fisheries rarely follow statistical designs, which makes analyses difficult. These data sets, however, may provide important information after an initial data filtering and exploration phase. Considering lakes as replicates (only possible when large-scale data are available) by averaging within lake observations is an alternative approach for averaging out unexplained extreme observations and controlling for possible effects of autocorrelation.

The potential benefits of analyzing large data sets for inland fisheries management may be extended to regions outside Illinois. Similar data sets for other areas exist, and, even if their quality is marginal, might still be worth analyzing. Such data may provide not only a better understanding of biological systems, but also facilitate the development of management designs which more readily and reliably lend themselves to quantitative analyses addressing fisheries related questions.

Although the locations of fish sampling stations did not change, fisheries managers selected prime areas for fish sampling to maximize the catch. The biased selection of sampling locations might have yielded estimates of annual fluctuations in fish abundance which were not representative of the entire population in each of the sampled lakes. Fishery managers' selection of sampling locations, therefore, may have contributed to the infrequency of statistically significant effects of treatments. Fish populations in habitats of marginal quality are likely to be more sensitive to treatment effects, especially those which induce stress. By choosing areas with higher fish abundance, managers may be selectively sampling higher quality habitats, potentially biasing results of management interventions and environmental factors on fish.

Not only sampling protocols, but also management designs are of importance in determining anthropogenic and environmental effects on fish populations. The procedure of management practices still does not follow a design that promptly lends itself to inter-lake comparative analyses. Experimental management techniques (Walters 1986; Walters et al. 1988; McAllister and Peterman 1992), whereby control and treatment lakes are used, may prove useful in overcoming this problem. The benefits of understanding the effects of management practices by using different intensities of the same practice could outweigh short-term costs which might be borne at control lakes, where managers would have to refrain from implementing any management practice or allowing any fish harvest.

Incorporating experimental designs in the structure of fisheries management practices is not the only potential improvement. Other species of fish sharing food, habitat, and also predators may influence largemouth bass abundance (Hackney 1975; Jenkins 1975). Unexplained fluctuations in largemouth bass abundance were common in the data used. Absolute values for fish abundance, incorporating many species, may yield data sets more sensitive to detect the effects of management practices with marginal impacts on fish. The catchability of the various fish sampling gears is, therefore, of concern especially when information on fish community structure is required. Single-species management can tolerate differential catchability in sampling gear because information on relative abundance suffices, so long as catchability stays constant with time in the same system. When comparisons across systems are desired or multispecies management is the goal, however, absolute values for fish abundance are preferred. Gear calibration factors may circumvent this problem. Routine sampling of fish with different gears before lake rehabilitation practices produce more accurate lake-specific calibration factors for sampling devices (Bayley and Austen 1987), which in turn can be used for estimating accurate species abundance and compositions.

In summary, this work suggests that the anthropogenic component in Illinois fisheries management more strongly determines fish abundance in inland lakes. This places a stronger responsibility on fisheries agencies, fisheries managers, and the public in general for the optimal functioning of lakes and other interrelated systems. Optimal functioning is dependent not only on angler's expectations, but also on the intrinsic characteristic of each lake. It is understandable that management is ultimately aimed to satisfy anglers, however, considering angler's preference as the primary variable for devising management plans may lead to unwanted consequences, such as declines in fish abundance after unlimited fishing pressure.

5.4. Recommendations

Rehabilitation practices and fishing regulations are shown to have effects strong enough to be detected despite the high year-to-year fluctuations characteristics of the data set analyzed. Rehabilitation practices are labor-intensive, expensive, and not done on a regular basis. Conversely, fishing regulations are easier to implement, not as disturbing, and, if complied with, potentially beneficial to angling quality. Fishing regulations in Illinois are size and bag limits. Bag limits were not investigated, but are closely associated with the potential success of any regulation. Bag limits are presently angler-specific, whereby anglers are allowed a maximum number of fish to be harvested. Under this scenario, the effects of regulations may vary if the number of anglers varies. Bag limits should be lake-specific for the effects of regulations to persist despite anglers fish harvest experience or numbers.

More emphasis on regulations and monitoring at the expense of stocking and chemical removals is advised. Aquatic vegetation treatments and water level manipulations are potentially beneficial if alternative measures are taken. The timing of water level manipulations in combination with aquatic vegetation practices might prove beneficial to establishing strong fish year-classes. Additionally, for determining sampling effort, multiple electrofishing sampling during a short interval (weeks) may estimate the extent to which variations in catches reflect variations in fish abundance or catchability. If variation in catches is due to variations in fish abundance, sampling effort should increase or at least remain as frequent as once a year. If catchability is mostly the culprit for the observed variability, a combination of gears such as gill nets and electrofishing used concurrently may minimize the problem.

5.5. Future Research

Management practices at inland Illinois lakes through the 1980s have unfortunately resulted in a data set with problems (Section 2.3.3). Despite the problems, some management practices were sufficiently strong for detection of an effect. Future fisheries management will hopefully operate under protocols more closely mimicking experimental management. It is probably unrealistic to expect designs as rigorous as those implemented in purely experimental settings, because imposing necessary restrictions on management, such as prohibiting all interventions and fishing at a control lake even for a short period of time, is probably still not well accepted by managers and the public. Not using control lakes, but still using management practices of varying, but consistent, intensities among lakes for several years may offer an intermediate and feasible step towards refining the results obtained in this dissertation.

Some management practices appeared to affect fish abundance only marginally. Further investigation of these practices might prove valuable. Controlled experiments should be conducted on stocking effects, particularly related to differential mortality between stocked and naturally breeding fish. Similarly, promising management practices such as vegetation controls and water level manipulations (the latter addressing issues related to timing and duration) should be investigated. Controlling the density of vegetation and manipulating water levels may prove to be an inexpensive management tool for manipulating habitat and food supply.

The data used in this dissertation indicated high year-to-year variation in the abundance of largemouth bass. This phenomenon is common in fisheries data (Miller 1975). Power analyses indicated that analyses based on single lakes are suspicious. Multiple lakes are, however, not always available, making it necessary to determine the reason for fish fluctuations, if the statistical power is to be increased in studies based on single or few lakes (with many occasions considering only a few years) using sampling protocols similar as the one used herein. Among the possible reasons are high variations in catchability, or high sensitivity of young and maybe adult fish to minor abiotic or biotic factors, causing high variations in fishing mortality. It may be difficult to predict year-class strength if the variation observed in the data is mostly due to mortality. Variations in fish catchability of gears used in samplings may, however, be estimated. If variation in catchability is a major factor in the observed fish fluctuation, data sets may become less variable in the future if habitat-specific catchability estimates are determined.

The reason for the unexplained year-to-year variation in fish abundance may be the most immediate issue needed to be addressed for determining the amount of sampling effort necessary to detect the effects of management. Large differences in catches may occur if largemouth bass possess an escape response to electrofishing. Multiple samplings within a season separated by a few days may also indicate the extent to which the observed fluctuations in fish are due to catchability. Assuming that mortality is minimum during the multiple sampling period, estimates of the variation of catchability may be established. If done on a regular basis, multiple samplings combined with regular sampling before and after lake rehabilitation events may provide good estimates of catchability for fish. Catchability is not the only factor needed to determine the reason of fish fluctuations over time, but is a central one, potentially cleaning data sets from excessive unexplained fluctuations of fish.

This page is intentionally blank.

direction of the effects on the response variable (o = no effect detected), black boxes indicate an effect ($p <= 0.05$).

5.6. List of References

Aggus, L. and G. Elliot. 1975. Effects of cover and food on year-class strength of largemouth bass. Pages 317-322 *in* R. H. Stroud and H. Clepper, editors. Black bass biology and management, Sports Fishing Institute, Washington, DC.

Baranekova, A. 1960. The results of survey of young cod and haddock in the Barents Sea during the period 1946-1959. Soviet fisheries Investigation of the North European seas. Moscow, VNIRO and PINRO p. 267-278.

Bayley, P. 1995. Understanding large river-floodplain ecosystems. Bioscience 45:153-158.

Bayley, P. and D. Austen. 1987. Comparative analysis of fish populations in Illinois impoundments: gear efficiencies and standards for condition factors. Aquatic Biology Technical Report 87/14, Illinois Natural History, Champaign, IL.

Beamersderfer, R. and J. North. 1995. Growth, natural mortality, and predicted responses to fishing for largemouth bass and smallmouth bass populations in North America. North American Journal of Fisheries Management 15:688-704.

Beckman, W. 1941. Further studies on the increased growth rate of the rock bass *Ambloplites rupestris* following reduction of density in the population. Transactions of the American Fisheries Society 70:143-148.

Blosz, J. 1952. Propagation of largemouth bass and bluegill sunfish in federal hatcheries of the southeast. Progressive Fish-Culturist 14(2):61-66.

Boxrucker, J. 1986. Evaluation of supplemental stocking of largemouth bass (*Micropterus salmoides*) as a management tool in small impoundments. North American Journal of Fisheries Management 6(3):391-396

Bradford, M. 1992. Precision of recruitment predictions from early life stages of marine fishes. Fishery Bulletin 90:439-453.

Casselman, J. and H. Harvey. 1975. Selective fish mortality resulting from low winter oxygen. Verhandlungen zur Internazionale Vereinigung für Limnologie 19:2418-2429.

Casselman, J. and H. Harvey. 1975. Selective fish mortality resulting from low winter oxygen. Verhandlungen zur Internazionale Vereinigung für Limnologie 19:2418-2429.

Clady, M. 1981. Survival and shifts in food of young-of-year *Micropterus* penned at high densities in an Oklahoma pond. Proceedings of the Oklahoma Academy of Science 61:15-22.

Coles, J. 1970. Introduction to meteorology. Wiley, New York, 388 pp.

Cooper, G. and G. Washburn. 1949. Relation of dissolved oxygen to winter mortality of fish in Michigan lakes. Transactions of the American Fisheries Society 76:23-33.

Coutant, C. 1975. Responses to bass to natural and artificial temperature regimes. Pages 272-285 *in* R. H. Stroud and H. Clepper, editors. Black bass biology and management, Sports Fishing Institute, Washington, DC.

Coutant, C. and D. Angelis. 1983. Comparative temperature-dependent growth rates of largemouth bass and smallmouth bass fry. Transactions of the American Fisheries Society 112:416-423.

Crivelli, A. and R. Britton 1987. Life history adaptations of *Gasterosteus aculeatus* in a Mediterranean wetland. Environmental Biology of Fishes 18(2):109-126.

Cross, F. 1967. Handbook of the fishes of Kansas. Museum of the Natural History of the University Kansas, Lawrence, KS, 357 pp.

Davaine, P. and E. Beall. 1992. Relationships between temperature, population density, and growth in a seatrout population (*Salmo trutta*) of the Kereguelen Islands. ICES Journal of Marine Sciences 49:445-451.

DeAngelis, D., B. Shuter, M. Ridgway, and M. Scheffer. 1993. Modeling growth and survival in an age-0 fish cohort. Transactions of the American Fisheries Society 122:927-941.

Downing, J. and C. Plante. 1993. Production of fish population in lakes. Canadian Journal of Fisheries and Aquatic Sciences 50:110-120.

Downing, J., C. Plante, and S. Lalonde. 1990. Fish production correlated with primary productivity, not the morphoedaphic index. Canadian Journal of Fisheries and Aquatic Sciences 47:1929-1936.

Eder, S. 1984. Effectiveness of an imposed slot length limit of 12.0-14.9 inches on largemouth bass. North American Journal of Fisheries Management 4:469-478.

Eiper, A. 1975. Environmental influences on the mortality of bass embryos and larvae. Pages 295-305 In R. H. Stroud and H. Clepper, editors. Black bass biology and management, Sports Fishing Institute, Washington, DC.

Fahy, E. 1980. Growing season as a factor in sea trout production. Journal of Fish Biology 17:541-546.

Filipek, S. and M. Gibson. 1986. Evaluation of supplemental stocking of fingerling largemouth bass in lake Coronado, Arkansas. Page 313 in G. Hall and M. Van Den Avyle, editors. Reservoir Fisheries Management. American fisheries society, Bethesda, MD, USA, 327 pp.

Fox, M and A. Keast. 1990. Effect of winterkill on population structure, body size, and prey consumption patterns of pumpkinseed in isolated beaver ponds. Canadian Journal of Zoology 68(12):2489-2498.

Fox, M and A. Keast. 1991. Effect of overwinter mortality on reproductive life history characteristics of pumkinseed (*Lepomis gibbosus*) populations. Canadian Journal of Fisheries and Aquatic Sciences 48:1792-1799.

Goodyear, C. and S. Christensen. 1984. On the ability to detect the influence of spawning stock on recruitment. North American Journal of Fisheries Management 4:186-193.

Guest, W. 1982. Survival of adult Florida and northern largemouth bass subjected to cold temperature regimes. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 36:332-339.

Gulland, J. 1965. Survival of the youngest stages of fish, and its relation to year-class strength. International Commission of the Northwest Atlantic Fisheries, Special Publication 6:363-371.

Gutreuter, S. and R. Anderson. 1985. Importance of body size to the recruitment process in largemouth bass populations. Transactions of the American Fisheries Society 114:317-327.

Hackney, P. 1975. Bass population in ponds and community lakes Pages 131-139 in R. H. Stroud and H. Clepper, editors. Black bass biology and management, Sports Fishing Institute, Washington, DC.

Hall, D. and T. Ehlinger. 1989. Perturbation, planktivory, and pelagic community structure: the consequence of winterkill in a small lake. Canadian Journal of Fisheries and Aquatic Sciences 46:2203-2209.

Hanson, J. and W. Leggett. 1982. Empirical prediction of fish biomass and yield. Canadian Journal of Fisheries and Aquatic Sciences 39:257-263.

Hill, 1980. Manipulation of bass-bluegill populations by summer drawdown. Iowa Conservation Commission, Project No. F-90-R, Des Moines, IA.

Hjort, J. 1926. Fluctuations in year classes of important food fishes. Journal du Conseil International Exploration de le Mer 1:5-38.

Hoff, M. H. 1995. Comparisons of the effects of 10-inch, 8-inch, and no minimum length limit on the smallmouth bass population and fishery in Nebish lake, Wisconsin. Transactions of the American Fisheries Society 15:95-102.

Illinois Department of Natural Resources. 1996. Annual report 1996. Division of Fisheries.

Jackson, D., R. Kilambi, and P. Polechla, Jr. 1982. Impact of drought on lake Elmdale largemouth bass. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 36:272-279.

Jackson, S. W., Jr. 1966. Summary of lake management activities on Lakes Eucha and Spavinaw, Oklahoma 1951-1964. Proceedings of the Annual Conference of the Southeastern Association of Game and Fish Commissioners 19(1965):315-343.

Jenkins, R. 1975. Black bass crops and species associations in reservoirs. Pages 114-124 in R. H. Stroud and H. Clepper, editors. Black bass biology and management, Sports Fishing Institute, Washington, DC.

Johnson, B. and P. Martinez. 1995. Selecting harvesting regulations for recreational fisheries: opportunities for research/management cooperation. Fisheries 20(10):22-29.

Johnson, M. 1965. Limnology of Ontario ponds in relation to winterkill of largemouth bass. The Progressive Fish-Culturist 27(4):193-198.

Jones, J. and M. Hoyer. 1982. Sportfish harvest predicted by summer chlorophyll-a concentration in Midwestern lakes and reservoirs. Transactions of the American Fisheries Society 111:176-179.

Keith, W. E. 1968. Turbidity control and fish population renovation on Blue Mountain Lake, Arkansas. Proceedings of the Annual Conference of the Southeastern Association of Game and Fish Commissioners 21(1967):495-505.

Kerr, S. and R. Ryder. 1988. The applicability of fish yield indices in freshwater and marine ecosystems. Limnology and Oceanography 33(4, part 2):973-981.

Kramer, R. and L. Smith. 1962. Formation of year classes in largemouth bass. Transactions of the American Fisheries Society 91(1):29-41.

Krumholz, L. 1950. Further observations on the use of hybrid sunfish in stocking small ponds. Transactions of the American Fisheries Society 79:112-123.

Lantz, K. E., J. T. Davis, J. S. Hughes, and H. E. Schafer, Jr. 1967. Water level fluctuation - its effects on vegetation control and fish population management. Proceedings of the Annual Conference of the Southeastern Association of Game and Fish Commissioners 18(1964):483-494.

Larimore, R. W., W. F. Childers, and C. Heckrotte. 1959. Destruction and reestablishment of stream fish and invertebrates affected by drought. Transactions of the American Fisheries Society 88:261-285.

Magnuson, J., L. Beckel, K. Mills, and S. Brandt. 1985. Surviving winter hypoxia: Behavioral adaptations of fishes in a northern Wisconsin winterkill lake. Environmental Biology of Fishes 14(4):241-250.

Martin, D., L. Mengel, J. Novotny, and C. Walburn. 1981. Spring and summer water levels in a Missouri river reservoir: effects on age-0 fish and zooplankton. Transactions of the American Fisheries Society 110:370-381.

Mather, M., D. Parrish, R. Stein, and R. Muth. 1995. Management issues and their relative priority within state fisheries agencies. Fisheries 20(10):14-21.

Matuzek, J. 1978. Empirical predictions of fish yield of large North American lakes. Transactions of the American Fisheries Society 107(3):385-394.

McAllister, M. and R. Peterman. 1992. Experimental design in the management of fisheries: a review. North American Journal of Fisheries Management 12:1-18.

Mertz, G. and R. Myers. 1995. Estimating the predictability of recruitment. Fishery Bulletin 93:657-665.

Miller, R. 1975. Comparative behavior of centrarchid basses. Pages 85-94 in R. H. Stroud and H. Clepper, editors. Black bass biology and management, Sports Fishing Institute, Washington, DC.

Mills, E. and A. Schiavone. 1982. Evaluation of fish communities through assessment of zooplankton populations and measures of lake productivity. North American Journal of Fisheries Management 2:14-27.

Mitzner, L. 1992. Evaluation of walleye fingerling and fry stocking in Rathbun lake, Iowa. North American Journal of Fisheries Management 12-321-328.

Moore, W. 1942. Field studies of the oxygen requirements of certain fresh-water fishes. Ecology 23(3):319-329.

Noble, R. and T. Jones. 1993. Managing fisheries with regulations. Pages 383-402 in C. Kohler and W. Hubert, editors. Inland fisheries Management in North America. American Fisheries Society, Bethesda, MD.

Oglesby, R. 1977. Relationships of fish yield to lake phytoplankton standing crop, production, and morphoedaphic factors. Journal of the Fisheries Research Board of Canada 34:2271-2279.

Olson, M. 1998. Ontogenetic niche shifts in largemouth bass: variability and consequences of first-year growth. Ecology 77(1):179-190.

Paller, M. 1997. Recovery of a reservoir fish community from drawdown related impacts. North American Journal of Fisheries Management 17:726-733.

Paragamian, V. L. 1982. Catch rates and harvest results under a 14-inch minimum length limit for largemouth bass in a new Iowa impoundment. North American Journal of Fisheries Management 2:224-231.

Peterman, R., M. Bradford, N. Lo, and R. Methot. 1988. Contribution of early life stages to interannual variability in recruitment of northern anchovy (*Engraulis mordax*). Canadian Journal of Fisheries and Aquatic Sciences 45:8-16.

Pierce, C., J. Frey, and H. Yawn. 1965. An evaluation of fishery management techniques utilizing winter drawdowns. Proceedings of the Annual Conference of the Southeastern Association of Game and Fish Commissioners 17(1963):347-363.

Prepas, E. 1983. Total dissolved solids as a predictor of lake biomass and productivity. Canadian Journal of Fisheries and Aquatic Sciences 40:92-95.

Reynolds, J. B. 1996. Electrofishing. Pages 221-253 in B. Murphy and D. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland, 732 pp.

Ricker, W. 1954. Stock and recruitment. Journal of the Fisheries Research Board of Canada 11(5):559-623.

Roseberry, 1950. Fishery management of Clayton lake, an impoundment on the New river in Virginia. Transactions of the American Fisheries Society 80:194-209.

Ryder, R. A. 1965. A method for estimating the potential fish production of north-temperate lakes. Transactions of the American Fisheries Society 96:214-218.

Ryder, R. A. 1982. The morphoedaphic index - use, abuse, and fundamental concepts. Transactions of the American Fisheries Society 111:154-164.

Ryder, R. A., S. Kerr, K. Loftus, and H. Regier. 1974. The morphoedaphic index, a fish yield estimator. Review and evaluation. Journal of the Fisheries Research Board of Canada 31:663-688.

Santucci, V. and D. Wahl. 1993. Factors influencing survival and growth of stocked walleye (*Stizostedion vitreum*) in a centrarchid-dominated impoundment. Canadian Journal of Fisheries and Aquatic Sciences 50:1548-1548.

Saville, A. 1956. Eggs and larvae of haddock (*Melanogrammus aeglefinus*) at Faroe. Marine Research of Scotland, Number 4.

Schlesinger, D. and H. Regier. 1982. Climatic and morphoedaphic indices of fish yields from natural lakes. Transactions of the American Fisheries Society 111:141-150.

Serns, S. 1982. Relation of temperature and population density to first-year recruitment and growth of smallmouth bass in a Wisconsin lake. Transactions of the American Fisheries Society 111:570-574.

Shields, 1957. Experimental control of carp reproduction through water drawdowns in Fort Randall reservoir, South Dakota. Transactions of the American Fisheries Society 87:23-33.

Simpson, 1978. Evaluation of electrofishing efficiency for largemouth bass and bluegill populations. MS thesis. University of Columbia, MO.

Summerfelt, R. 1975. Relation between weather and year-class strength of largemouth bass. Pages 166-174 *in* R. H. Stroud and H. Clepper, editors. Black bass biology and management, Sports Fishing Institute, Washington, DC.

Swingle, H. S. 1950. Experiments with various rates of stocking bluegills, *Lepomis macrochirus*, and largemouth bass, *Micropterus salmoides* in ponds. Transactions of the American Fisheries Society 80:218-230.

Tonn, W. M. and C. A. Paszkowski. 1986. Size-limited predation, winterkill, and organization of *Umbra-Perca* fish assemblages. Canadian Journal of Fisheries and Aquatic Sciences 43:194-202.

Viosca, P. 1945. Critical analysis of practices in the management of warmwater fish with a view to greater food production. Transaction of the American Fisheries Society 73:274-283

Walters, C. 1986. Adaptive management of renewable resources. Macmillan, New York, 374 pp.

Werner, E., D. Hall, D. Laughlin, D. Wagner, L. Wilsmann, and F. Funk. 1977. Habitat partitioning in a habitat fish community. Journal of the Fisheries Research of the Board of Canada 34:360-370.

Wilde, G. 1997. Largemouth bass fishery responses to length limits. Fisheries 22(6)14-23.