

**EFFECTS OF AQUATIC PLANT MANIPULATION ON ANGLING AND FISH
IN FISH LAKE, DANE COUNTY, WISCONSIN**

by

JEAN M. L. UNMUTH

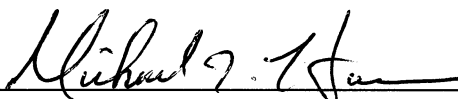
**A Thesis
submitted in partial fulfillment of the
requirements of the degree
MASTER OF SCIENCE**

College of Natural Resources

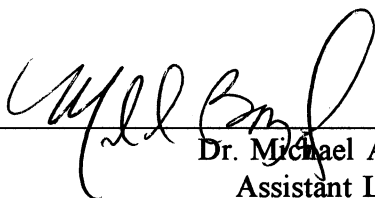
**UNIVERSITY OF WISCONSIN
Stevens Point, Wisconsin**

December 1998

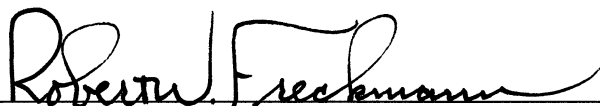
APPROVED BY THE GRADUATE COMMITTEE OF:



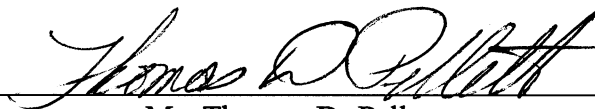
Dr. Michael J. Hansen, Committee Chairman
Associate Professor of Fisheries
College of Natural Resources



Dr. Michael A. Bozek
Assistant Leader
Wisconsin Cooperative Fishery Research Unit



Dr. Robert W. Freckmann
Professor of Biology
College of Letters and Science



Mr. Thomas D. Pellett
Aquatic Ecologist
Wisconsin Department of Natural Resources

ABSTRACT

Slow-growing centrarchid populations are a common management problem in heavily vegetated lakes. Typically, vegetation is managed to increase recreational opportunities, with little regard to the effects it may have on fish populations or associated angling catch rates. This thesis evaluates largemouth bass, bluegill, and angling responses to a plant reduction at a whole-lake scale, and provides guidance about the link between vegetation management and fish management.

A plant manipulation was initiated in 1994, using an experimental close-cut mechanical harvester as a fishery management tool to increase macrophyte bed edge habitat, and increase the growth of predator and prey fish populations. Measuring direct and indirect effects of the manipulation were important objectives, thus I compared largemouth bass and bluegill populations, and angling dynamics between pre- and post-treatment years.

A reduction in vegetation increased the growth and survival of largemouth bass. This led to increased recruitment of largemouth bass to larger size, thereby increasing the population size structure. Effects on the bluegill population were less consistent. Following macrophyte reduction, bluegill growth declined or remained similar as fish aged. Yet, increased bluegill survival led to improved population size structure. I conclude that increased survival of largemouth bass and bluegill was the result of a decline in natural mortality.

The plant manipulation increased angling opportunities, and was associated with increased angler pressure. I conclude that a decline in summer angling catch

rates of largemouth bass were caused by a combination of increased angler effort, increased availability of bluegill, and increased available cruising habitat for largemouth bass. Summer angling catch rates of bluegill also declined with increased angler pressure. Reduced vegetation was associated with sharp declines in natural mortality of fish that left more fish available for anglers, and coincided with much higher fishing mortality of bluegill. Anglers caught more large bluegill, and the increased fishing mortality after the plant manipulation did not appear to reduce bluegill population size structure.

This field research indicates that a reduction in plant biomass, and increase in vegetated edge habitat can significantly increase the growth, survival and size structure of largemouth bass and bluegill populations, and produce more angling opportunities.

ACKNOWLEDGEMENTS

My thesis is the product of many years of research on the Fish Lake Project. I could not have accomplished such a monumental task without the dedication of many of my comrades at the Wisconsin Department of Natural Resources. Tom Pellett, Dick Lillie and Rich Narf were primarily responsible for getting the Fish Lake Project off the ground. I spent countless days and nights with Dave Dreikosen, Dick Lillie, Dave Sloey, Terry Schenk, Bill Halverson and Gary Greene, squeezing fish and collecting invertebrates and plants. You truly were the A-Team! Paul Rasmussen offered his statistical knowledge, design of the creel survey and analysis of the data. Greg Quinn and Gerry Wegner assisted with the plant survey, and kept a watchful eye while I dove the weeds of Fish Lake. Christine Storlie, Ron Grasshoff, Dave Marshall, Paul Garrison, Randy Piette, and Keith Otis came to the rescue when we were short-staffed during sampling. I am most indebted to Mike Staggs for giving me the opportunity to pursue this degree. WDNR Fish Research was fortunate to have you as a Section Chief.

I owe thanks to the people from the University of Wisconsin - Center for Limnology for collaboration on the project. Dr. Steve Carpenter and Annett Trebitz developed the Fish Lake bioenergetics model, and Nate Nibbelink, Karen Wilson, Sarig Gafney, Melissa Weaver, and Tom Martin assisted in sampling.

Ken Kosciak and Joe Yaeger of Dane County Public Works designed and built the close-cut plant harvester to cut the channels in Fish Lake, and were extremely patient in following our time consuming cutting scheme.

The University of Wisconsin - Stevens Point is a wonderful place to do fisheries science. So many of my friends and colleagues at the College of Natural Resources contributed to my personal and professional development that I cannot mention them all, but just a few. Laura Jester gave me insight into the magical world of the "milfoil weevil", and was a lovely travel companion. Nancy Nate and I shared our common bond of personal experiences. Tim Lizotte, Justine Newby and Darrin Kron brought good humor to the classroom and on the volleyball court. Kevin Jorgenson and Pat Short guided me through those harrowing fish habitat assignments when I was at my wits end! Thank you all for pulling me away from my studies, and introducing me to the night life at Partners Pub, just when I needed it the most.

I owe my greatest thanks to my graduate committee: Dr. Michael Bozek, Dr. Robert Freckmann, Tom Pellett, and especially Dr. Michael Hansen, who reshaped my thinking about fisheries science and fish ecology, and set high scientific standards that I can strive for throughout the rest of my career.

Finally, I thank my husband, Mike Wipperfurth, my parents Pat and Lois, and my brothers Dan, Brian, Sean and Kelly for consoling me during my most difficult times as a graduate student, and for believing in me as an aspiring fisheries scientist.

TABLE OF CONTENTS

LIST OF FIGURES	VIII
INTRODUCTION	1
The Relation Between Fishes and Aquatic Vegetation	1
The Influence of Vegetation on Sport Fishing	2
Hypotheses and Objectives	4
CHAPTER I: LARGEMOUTH BASS AND BLUEGILL RESPONSES TO VEGETATION REDUCTION IN FISH LAKE, WISCONSIN	7
Introduction	8
Methods	10
Study Site	10
Fish Sampling	12
Statistical Analysis	13
Results	16
Largemouth Bass	16
Bluegill	18
Discussion	28
Management Implications	31
CHAPTER II: ANGLING RESPONSES TO VEGETATION REDUCTION IN FISH LAKE, WISCONSIN	33
Introduction	34
Methods	36
Study Site	36
Creel Survey	37
Mortality	39
Results	40
Discussion	54
Management Implications	57
SUMMARY AND CONCLUSIONS	59
APPENDIX A - ADDITIONAL TABLES	63
REFERENCES	68

LIST OF FIGURES

Figure 1. Fish Lake, Dane County, Wisconsin; hydrographic map.	11
Figure 2. Spring electrofishing abundance of largemouth bass in Fish Lake among pre-treatment (1992-1993) and post-treatment (1995-1996) years . .	17
Figure 3. Growth difference in length (cm) of four age classes of Fish Lake largemouth bass among pre-treatment (1992-1993) and post-treatment (1995-1996) years.	19
Figure 4. Growth difference in weight (g) of four age classes of Fish Lake largemouth bass among pre-treatment (1992-1993) and post-treatment (1995-1996) years.	20
Figure 5. Survival rate of four age classes of Fish Lake largemouth bass among pre-treatment (1992-1993) and post-treatment (1995-1996) years. . .	21
Figure 6. Length-frequency of Fish Lake Largemouth bass electrofished in spring among pre-treatment (1992-1994) and post-treatment (1995-1996) years.	22
Figure 7. Spring fyke net abundance of bluegill in Fish Lake among pre-treatment (1992-1993) and post-treatment (1995-1996) years.	24
Figure 8. Growth difference in length (cm) of three age classes of Fish Lake bluegill among pre-treatment (1992-1993) and post-treatment (1995-1996) years.	25
Figure 9. Survival rate of three age classes of Fish Lake bluegill among pre-treatment (1992-1993) and post-treatment (1995-1996) years.	26
Figure 10. Length-frequency of Fish Lake bluegill in spring fyke nets among pre-treatment (1992-1994) and post-treatment (1995-1996) years.	27
Figure 11. Angler effort hours among years on Fish Lake. Line at top of figure represents summer (white) and winter (shaded) seasons.	42
Figure 12. Summer shore angling trips among years on Fish Lake.	43
Figure 13. Summer boat angling trips among years on Fish Lake.	44

Figure 14. Angler catch rates of largemouth bass among years on Fish Lake. Line at top of figure represents summer (white) and winter (shaded) seasons.	45
Figure 15. Total catch of largemouth bass among years on Fish Lake. Line at top of figure represents summer (white) and winter (shaded) seasons. . . .	46
Figure 16. Total harvest of largemouth bass among years on Fish Lake. Line at top of figure represents summer (white) and winter (shaded) seasons. . .	47
Figure 17. Angler catch rates of bluegill among years on Fish Lake. Line at top of figure represents summer (white) and winter (shaded) seasons.	48
Figure 18. Total catch of bluegill among years on Fish Lake. Line at top of figure represents summer (white) and winter (shaded) seasons.	50
Figure 19. Total harvest of bluegill among years on Fish Lake. Line at top of figure represents summer (white) and winter (shaded) seasons.	51
Figure 20. Mortality rate of 4 age classes of largemouth bass and 3 age classes of bluegill in Fish Lake among pre-treatment (1992-1993) and post-treatment (1995-1996) years.	52
Figure 21. Length-frequency of Fish Lake bluegill harvested by anglers among pre-treatment (1992-1994) and post-treatment (1995-1996) years.	53

INTRODUCTION

Dense aquatic vegetation is a nuisance in lakes throughout the United States. Mechanical plant harvesting is a technique used to reduce vegetation and improve angling opportunities; as cover for prey species is reduced, predation rates and angler access increases. Largemouth bass *Micropterus salmoides* and bluegill *Lepomis macrochirus* are highly valued sportfish found throughout North America, and are the focus of fish management activities in many states. The complexity of aquatic vegetation mediates fish predator-prey relations, and is strongly linked to largemouth bass and bluegill population dynamics. Understanding the interactions among plants, fish and anglers is important to more effective management of aquatic systems.

The Relation Between Fishes and Aquatic Vegetation

Submersed aquatic plants can influence physical and chemical environments (Carpenter and Lodge 1986), and littoral zone fish productivity (Crowder and Cooper 1982, Wiley et al. 1984). Vegetation composition, structure and density influences fish abundance (Miranda and Pugh 1997, Trebitz et al. 1997), survival (Miranda and Pugh 1997), and growth (Crowder and Cooper 1979, Olson et al. 1998). The accessibility and architecture of vegetation may affect fish growth rates by altering their behavior and distribution (Savino et al. 1992). In small lakes and ponds bluegill are primary prey fish for largemouth bass (Swingle 1946), and population

dynamics of the two species are influenced by littoral zone structure (Crowder and Cooper 1979, Wiley et al. 1984).

As vegetation density increases, predators have difficulty capturing prey such that largemouth bass capture of bluegill declines to zero at ≥ 250 stems/m² (Savino and Stein 1982), and bluegill foraging efficiency is low (Crowder and Cooper 1982). Conversely, when cover is sparse fish may overexploit their prey (Heck and Crowder 1991). When plant bed edge was doubled in a small pond, largemouth bass capture rates increased significantly (Smith 1993), and at intermediate plant density bluegill foraged more efficiently and grew larger than fish held at low or high plant densities (Crowder and Cooper 1979). Additionally, plant bed edges, rather than the interior of the bed, hold a higher biomass, density, and diversity of attached invertebrates (Sloey et al. 1997). Therefore, density as well as the patchiness of macrophyte beds plays an important role in mediating prey availability, and influencing predator-prey interactions.

The Influence of Vegetation on Sport Fishing

Dense aquatic vegetation can reduce the effectiveness of angling (Colle et al. 1987). Yet, few studies have addressed the effects of reduced plants on angling pressure, success, or the interplay of fishing and natural mortality of largemouth bass and bluegill. Plant cover exceeding 80% in Orange Lake, Florida, led to an 85% reduction in fishing effort (Colle et al. 1987). Conversely, when plants were reduced from 2,438 gm⁻² to 211 gm⁻², shore angler effort doubled in Red Haw Lake, Iowa

(Mitzner 1978). Plant infestation is a problem, yet reduction as opposed to eradication provides benefits to sport fisheries. For example, the production of harvestable size largemouth bass was greatest when hydrilla *Hydrilla verticillata* coverage reached 10 to 20% (Moxely and Langford 1982).

The refuge provided by plants reduces the vulnerability of larger fish to angling (Maceina and Reeves 1996), but the evidence for vegetation's influence on fish catch is conflicting. Angler catch of largemouth bass was little influenced by plant cover (Colle et al 1987), while catch rates were positively correlated with increasing plant cover (Maceina and Reeves 1996, Wrenn et al. 1996). Although catch may improve, in terms of numbers of fish, the average size (biomass) of harvestable largemouth bass declines (Maceina and Reeves 1996, Wrenn et al. 1996). This implies that sportfish catch is greater as plant cover increases, but that it is dominated by smaller fish.

The evidence for the effects of vegetation on angler catches of bluegill is also conflicting. Long-term data from the Yahara Lakes, Dane County, Wisconsin, indicated that bluegill catches declined in years when plant biomass was low (Lathrop et al. 1992). Conversely, catch increased with an 85% reduction in macrophytes in Orange Lake, Florida (Colle et al. 1987). While vegetation can be managed to provide anglers with greater fishing opportunities, there is little research that documents the mortality of fish caused by angling, before and after a plant manipulation. Reduced vegetation may increase exploitation rates with serious consequences to the fishery.

Hypotheses and Objectives

This research was conducted during an intensive experimental macrophyte manipulation on Fish Lake, Dane County, Wisconsin that was initiated by the Wisconsin Department of Natural Resources (WDNR) in 1991. The goal was to evaluate the potential of selective, close-cut mechanical harvest of Eurasian watermilfoil *Myriophyllum spicatum* to improve fish growth and recruitment to larger size, and increase angler access to sport fishes.

Creating additional edge habitat should, theoretically, increase fish predator-prey encounters and thereby improve the structure of gamefish populations through increased availability of prey (Pellett 1997). Because a reduction in the abundance of small prey fish reduces their density and thus competition, this should increase prey fish foraging success, and improve prey fish growth rates.

My goals were to evaluate the response of largemouth bass and bluegill populations, and angler success to selective, close-cut mechanical plant harvesting. Fish Lake was chosen for the plant manipulation because largemouth bass and bluegill grew poorly at specific life history stages, and angler access to the fish was nearly impossible during peak plant growth. Largemouth bass below 250 mm were not effectively foraging on prey fish (Sloey et al. 1996), and though bluegill were abundant, only 10% reached 150 mm and fewer than 0.1% exceeded 200 mm (Pellett 1997). This suggested that small to intermediate size largemouth bass were not foraging efficiently, and may have been forced to compete with bluegill for

macroinvertebrate prey. Thus, dense vegetation may have inhibited predator-prey interactions, and thereby caused poor growth of fish at specific life history stages.

Lake use was made difficult by the dense contiguous ring of Eurasian watermilfoil inhabiting Fish Lake. At public meetings lake front property owners, anglers and boaters supported the need to reduce the vegetation.

This thesis consists of two chapters. In Chapter I, I quantify largemouth bass and bluegill population characteristics and size structure between pre- and post-treatment periods. I constructed two testable hypotheses that allow an objective evaluation of the effects of manipulating vegetation on fishes:

H1: largemouth bass abundance, survival and growth will

increase following the reduction of macrophytes in Fish Lake;

H2: bluegill abundance and survival will decrease, while

growth will increase following the reduction of macrophytes in Fish Lake.

In the case of H1, the null hypothesis (H0) states that no increase in largemouth bass abundance, survival and growth will occur. For H2, the null hypothesis states that no reduction in bluegill abundance and survival will occur, and no growth increase will occur. Note that H1 and H2 are one sided hypotheses; the manipulation is expected to result in a positive response (reject H0) or not (accept H0).

In Chapter II, I quantify angling responses to changes in vegetation density and associated largemouth bass and bluegill populations. I constructed three testable hypotheses to objectively evaluate the responses for largemouth bass and bluegill fisheries:

H3: angler pressure (effort) to the fishery will

increase following the reduction of macrophytes in Fish Lake;

H4: angler catch rates and fishing mortality for

largemouth bass will not show a significant change following the reduction of macrophytes in Fish Lake;

H5: angler catch rates and fishing mortality for

bluegill will increase following the reduction of macrophytes in Fish Lake.

The plant reduction is expected to result in a significant increase (reject H0) in angler effort (H3), and in angler catch rates and fishing mortality of bluegill (H5). No change (accept H0) is expected in angler catch rates and fishing mortality of largemouth bass (H4).

CHAPTER I: LARGEMOUTH BASS AND BLUEGILL RESPONSES TO VEGETATION REDUCTION IN FISH LAKE, WISCONSIN

Abstract.— To optimize the growth of fish, 262 close-cut channels were made at the sediment-water interface through dense beds of Eurasian watermilfoil *Myriophyllum spicatum*, in Fish Lake, Dane County, Wisconsin. Largemouth bass *Micropterus salmoides* and bluegill *Lepomis macrochirus* abundance, growth, survival, and population size structure were compared between pre- and post-treatment years to determine if reduced vegetation improved fish populations. Cutting the channels created 36,200 linear m of vegetated edge habitat and reduced total plant biomass by 18%. Plant biomass was further reduced when a partial dieback of the vegetation occurred in some post-treatment years. A reduction in plant biomass led to significant changes in largemouth bass and bluegill population characteristics. Growth in length and weight increased for some ages of largemouth bass, but declined for some age classes of bluegill. Largemouth bass and bluegill survival was poor in pre-treatment years, and improved significantly in post-treatment years, which increased the recruitment of fish to larger size. Increased survival of fish at intermediate ages contributed to a significant improvement in population size structure, while fish abundance remained relatively similar. These results indicate that a reduction in total Eurasian watermilfoil biomass can effectively improve centrarchid populations in lakes.

Introduction

Vegetative habitat can effect largemouth bass and bluegill abundance, survival, and growth. Centrarchid abundance and density increases in dense vegetation (Kilgore et al. 1989), yet, the majority of fish in dense plant stands are juveniles (Keast 1983) avoiding predation (Gocietas and Colgan 1987). Predation avoidance leads to increased survival of young Centrarchids (Smith and Orth 1990), greater competitive interactions, density-dependent reductions in growth (Osenberg et al. 1987, Nibbelink and Carpenter 1998), and stunting in the population (Colle and Shireman 1980, Engel 1987).

Reductions in plant biomass are associated with declines in Centrarchid abundance (Colle et al. 1987, Bettoli 1987, Lathrop et al. 1992) and density (Bettoli 1993). When vegetation was reduced in Lake Conroe, Texas, bluegill abundance decreased by 69% and largemouth bass density significantly declined, while fish biomass remained constant (Bettoli 1987, Bettoli 1993). This suggests that fish growth improves as fish abundance or density declines.

Although plant density is positively related to the growth of young sunfishes (Werner and Hall 1977), the relationship is parabolic, so that at intermediate levels of plant density, food availability and foraging efficiency increases and fish growth is optimized (Trebitz 1995). Bluegill consumed more prey and grew better at intermediate vegetation density than fish held at either high or low plant densities in Michigan ponds (Crowder and Cooper 1982). Intermediate-aged bluegill grew better

when 20% of the biomass of Eurasian watermilfoil *Myriophyllum spicatum* was removed from several Wisconsin lakes (Olson et al. 1998). Reduced vegetation improves young largemouth bass growth (Engel 1985, Cross et al. 1992, Hoyer and Canfield 1996, Miranda et al. 1996). However, a comparison of cut (treatment) to uncut (control) lakes dominated by Eurasian watermilfoil showed that improved growth rates for largemouth bass were not statistically significant (Carpenter et al. 1998, Olson et al. 1998). While other research has documented changes in one or two parameters of fish populations, after a plant manipulation, few studies attempt to describe the changes in fish abundance, growth, survival and population size structure when close-cut channels are used to increase vegetated edge habitat and reduce total plant biomass.

My objectives in this chapter were to determine if largemouth bass and bluegill abundance, growth, survival and population size structure changed from pre- to post-plant reduction years. Because the vegetation was reduced in August of 1994, I compared fish population parameters between pre-treatment (1992-93) and post-treatment (1995-96) years, and discuss the implications of reduced Eurasian watermilfoil on largemouth bass and bluegill population dynamics.

Methods

Study Site

Fish Lake, Dane County, Wisconsin is a 101 ha seepage lake located 50 km northwest of Madison, Wisconsin (Figure 1). It has a maximum depth of 19.5 m and a mean depth of 6.6 m. Secchi measurements ranged from 1.5 to 3.5 m during the summer months (Marshall et al. 1996), and the lake is characterized as mesotrophic-eutrophic. Two culverts connect Fish Lake to 30 ha Mud Lake (Marx Pond), which has a maximum depth of 2.3 m. Fish Lake has a diverse fish fauna, with largemouth bass and bluegill the dominant predator and prey fishes (Appendix A, Table 1). At the start of the study the littoral zone was dominated by a dense stand of Eurasian watermilfoil, which formed a contiguous ring around the lake's perimeter at depths ranging from 1.5 m to 4.5 m (Lillie 1996). Eurasian watermilfoil comprised 90% of the total plant biomass and covered approximately 40% of the total lake bottom (Budd et al. 1995, Lillie 1996). Estimated average plant biomass within milfoil stands varied among years and was $283 \pm 13 \text{ gm}^{-2}$ in the year of the plant manipulation (Appendix A, Table 2) (Lillie 1996). Coontail *Ceratophyllum demersum* formed a dense band at the deep water edge of the milfoil bed, and a mixture of native species grew in shallow water, inshore from the milfoil bed (Appendix A, Table 3) (Lillie and Nichols 1997). Based on bioenergetics modelling, selective removal of 20-40% of the biomass of vegetation in Fish Lake was shown to optimize the growth of bluegill and largemouth bass populations (Trebitz 1995, Trebitz and Nibbelink 1996). After 2 years of collecting baseline data, 262 channels were cut in a radial pattern

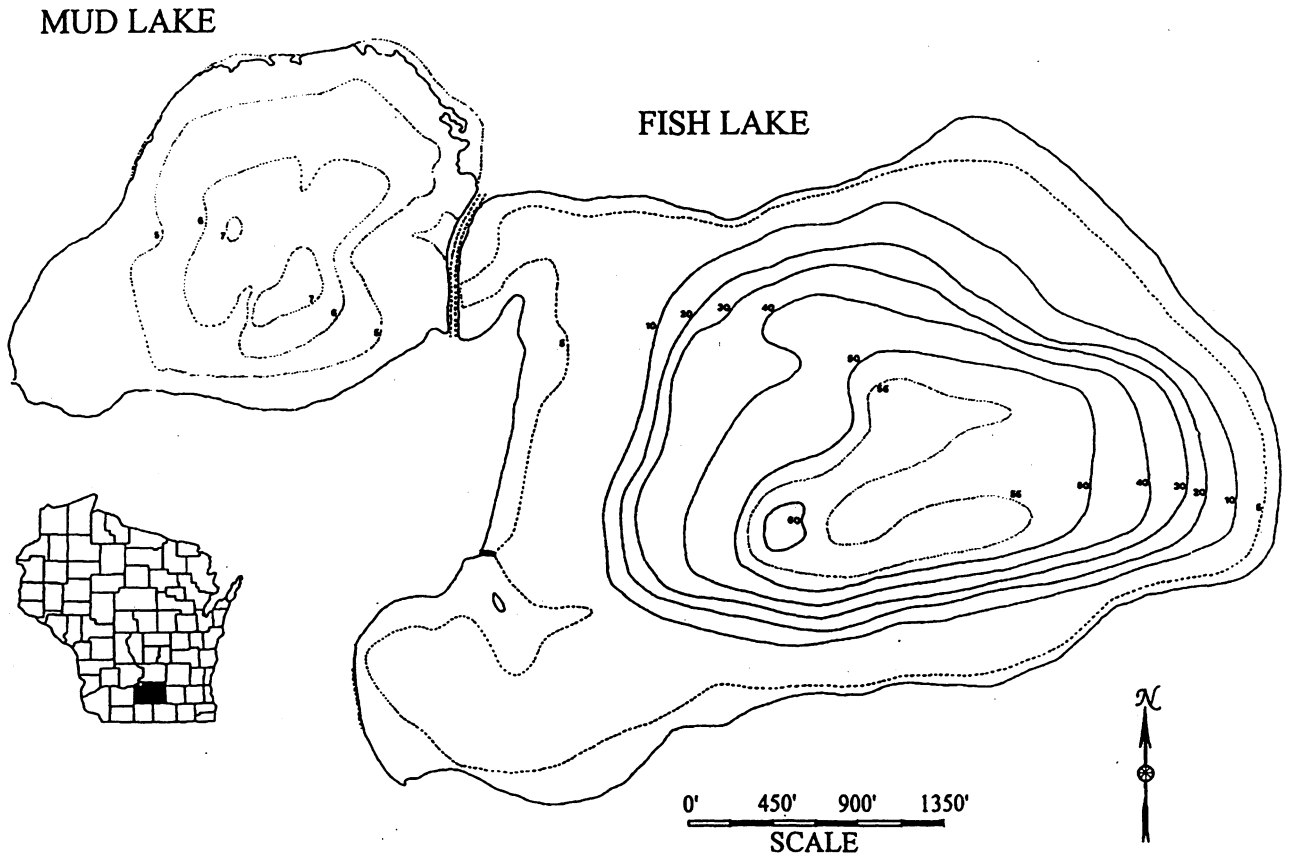


Figure 1. Fish Lake, Dane County, Wisconsin; hydrographic map.

through the Eurasian watermilfoil beds, near the sediment-water interface using a standard cutter that was modified to cut in depths as great as 6 m (Unmuth et al. 1997). Harvesting removed 18% of the total plant biomass, and created 36,200 m of vegetated edge habitat (Unmuth et al., in press). Plant biomass was further reduced by a weevil infestation during 2 of the 5 years of the study (Appendix A, Table 2).

Fish Sampling

Fyke nets and electrofishing were used to collect bluegill and largemouth bass during 3 months in spring, 1992 through 1996. Ten standard fyke nets were fished daily from March, after ice-out, through mid-May, and again during June. As spring progressed, and more fish moved into the shallows, the number of fyke nets was reduced to reflect the amount of fish that the crew could process each day. We electrofished daily for a 2 week period from middle to the end of May, and shocked 2 to 3 laps of the entire shoreline. A standard Wisconsin Department of Natural Resources electrofishing boat was used, and depending on water conditions, amperage ranged from 9 to 11, volts from 180 to 350, and pulse rate from 53 to 60. Fish captured were measured (mm, TL), and a subsample weighed (g). We took scale samples from at least 10 fish of each species per 10 mm size class to determine growth rates. Largemouth bass greater than 100 mm, and bluegill over 80 mm were marked by removal of a fin for population estimation, except in 1994, the year of the plant manipulation. In addition, largemouth bass ≥ 250 mm were tagged with numbered T-bar tags.

Statistical Analysis

Largemouth bass and bluegill abundance were estimated each year to gauge changes that may have resulted from cutting the vegetation. Data for estimations were collected over a 3 to 7 week period each year. Fish abundance was estimated for each year using the modified Schnabel method:

$$N = \frac{\sum (C_t M_t)}{R+1}$$

Where C_t is the number of fish caught at time t , M_t is the number of marked fish at large at time t , and R is the total number of recaptured fish (Ricker 1975). Variance was calculated using the formulae:

$$V\left(\frac{1}{N}\right) = \frac{R}{\sum (C_t M_t)^2}$$

Where $V(1/N)$ is the variance of the inverse of the abundance estimate, and other terms are as previously defined (Ricker 1975). The 95% confidence intervals were estimated for abundance in each year.

To determine if cutting vegetation affected a change in the rate of fish growth, estimates of growth were compared between pre- and post-treatment years for largemouth bass ages 2-5 and bluegill ages 4-6. Mean length at age for bluegill and largemouth bass were taken directly from aged fish scales collected in the spring. The absolute increase in mean length (cm) for specific year classes was described using the growth equation:

$$G = l_2 - l_1$$

Where G is the incremental increase or decrease in growth, l_1 is the mean length of fish in a specific year class (for example at age 2) and l_2 is the mean length of fish in that same cohort the following year, (age 3) (Ricker 1975). The same equation was used to estimate incremental change in weight (g) of largemouth bass by substituting weight for length in the previous equation. Differences in growth in weight were not calculated for bluegill because weights were not collected for several age classes during the spring of the first year of this study. Variance was calculated using the equation:

$$S^2 = \frac{\sum (x_i - \bar{x}_i)^2}{n_i - 1}$$

Where S^2 is the length or weight variance of a sample of fish of a specific age, x is the length or weight of each fish of age i , \bar{x} is the mean length or weight of all fish of age i , and n is the sample size of fish of age i (Ricker 1975). The 95% confidence intervals were constructed for growth differences.

Estimates of the annual survival rates for largemouth bass and bluegill were compared between pre- and post-treatment years for largemouth bass ages 2-5 and bluegill ages 4-6, to assess the effects of reduced vegetation on fish survival in Fish Lake. The catchability (q) of fish collected during surveys can differ between years because plant bed density affects gear efficiency, and may mask true mortality of fishes. This was taken into account before estimating mortality using the equation:

$$q_t = \frac{C_t}{f_t N_t}$$

Where q_t is the catchability or the fraction of the population taken by 1 unit of fishing effort in year t , C_t is the total catch of fish in year t , f_t is the total fishing effort in year t , and N_t is the estimated number in the population in year t (Ricker 1975). The catchability (q_t) was then averaged across years (\bar{q}) and used to standardize the catch for each age class by the rearranged equation:

$$C_t = \frac{N_t}{q_t \bar{q}}$$

Where C_t is the catch by age in year t , N_t is the estimated number of fish in the population at a specific age in year t , q_t is the catchability of fish in the gear for a given year t , and \bar{q} is the average catchability among years (Ricker 1975). Survival rates for largemouth bass and bluegill were then estimated for fish at specific age classes using the equation:

$$S = \frac{n_{t+1}}{n_t}$$

Where S is the rate of survival, n_t is the estimated number of fish of a given age in the first year, and n_{t+1} is the estimated number of fish of a given age in the year immediately following (Ricker 1975). Survival was calculated for largemouth bass ages 2 to 5, and for bluegill ages 4 to 6. The 95% confidence intervals for survival rates were estimated using the equation:

$$CI = \hat{p} \pm Z\sqrt{\hat{p}\hat{q}n}$$

Where CI is the confidence interval estimate, \hat{p} is the number of fish caught in a specific age cohort in a given year divided by the number of fish of that same cohort caught in the previous year, Z is the standard score at $\alpha = .05$, \hat{q} is $1-\hat{p}$, and n is the number of fish caught in a specific age cohort in a given year. Hypothesis tests for the differences between proportions of two independent samples were made to determine if survival was greater after the plant reduction.

To assess whether the plant reduction may have improved fish population size structure, length distributions were compared for largemouth bass ranging from 100 to 500 mm in length (ages 2-8) and for bluegill between 80 and 210 mm (ages 2-8). Length distributions were combined for pre-treatment (1992-1994) and post-treatment (1995-1996) years, and compared using the Kolmogorov-Smirnov test for differences in distributions (Sokal and Rohlf 1981).

Results

Largemouth Bass

Abundance of largemouth bass did not change significantly from pre- to post-treatment years. The mean number of fish ranged from 1,405 to 2,012 or 14 to 20 fish/ha (Figure 2).

Growth (cm) of ages 2 and 3 largemouth bass increased in post-treatment years, but no change occurred in ages 4 and 5. Fish of ages 2 and 3 grew slower in

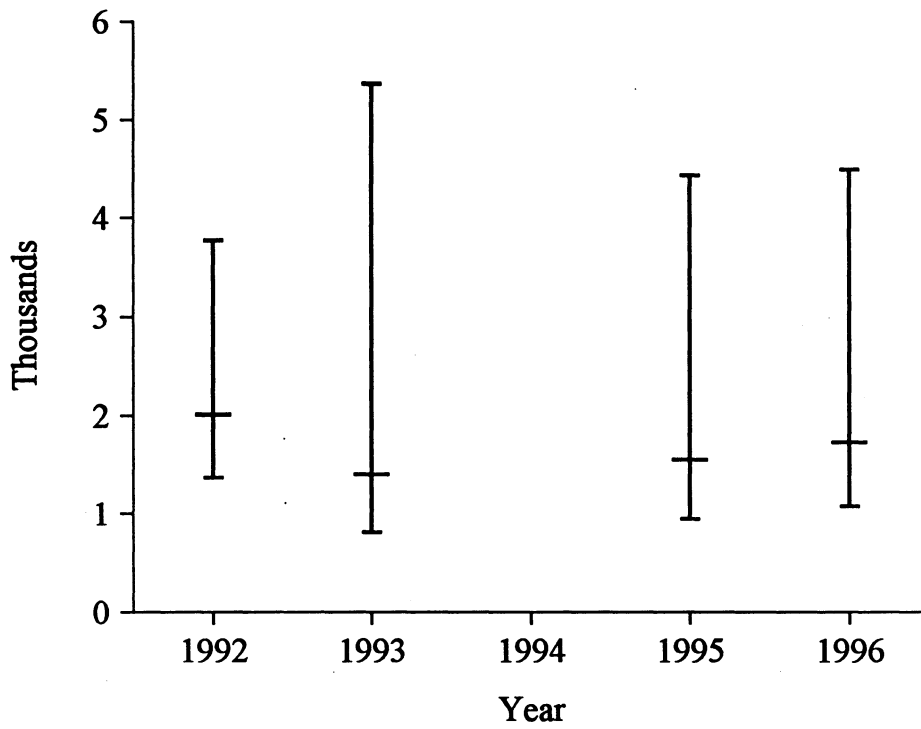


Figure 2. Spring electrofishing abundance of largemouth bass in Fish Lake among pre-treatment (1992-1993) and post-treatment (1995-1996) years.

length than fish of ages 4 and 5 in pre-treatment years, but their growth in length increased significantly in post-treatment years such that growth was similar among ages 2-5 (Figure 3).

Young fish also put on more weight (g) concurrent with increased length in post-treatment years. Age 2 fish nearly doubled their weight, while age 3 fish more than tripled their weight (Figure 3). Weight of age 4 fish remained stable, and weight declined for age 5 fish among pre- and post-treatment years (Figure 4).

Survival of largemouth bass improved significantly for most year classes after the plant manipulation. Less than 20% of the fish survived between pre-treatment years, and improvements were at least five fold for 3 of the 4 age classes between post-treatment years (Figure 5).

The population size structure of largemouth bass greater than 100 mm in length increased after the plant manipulation as indicated by the Kolmogorov-Smirnov test ($D = 0.314$; $N_1 = 883$; $N_2 = 364$; $P < 0.01$). Small fish ranging in length from 150 to 230 mm (2-4 years old) predominated in pre-treatment years, whereas fish from 170-280 mm total length (3-6 years old) predominated in post-treatment years (Figure 6).

Bluegill

Abundance of bluegill remained relatively stable among years, with the exception of one year prior to cutting, when the population nearly doubled.

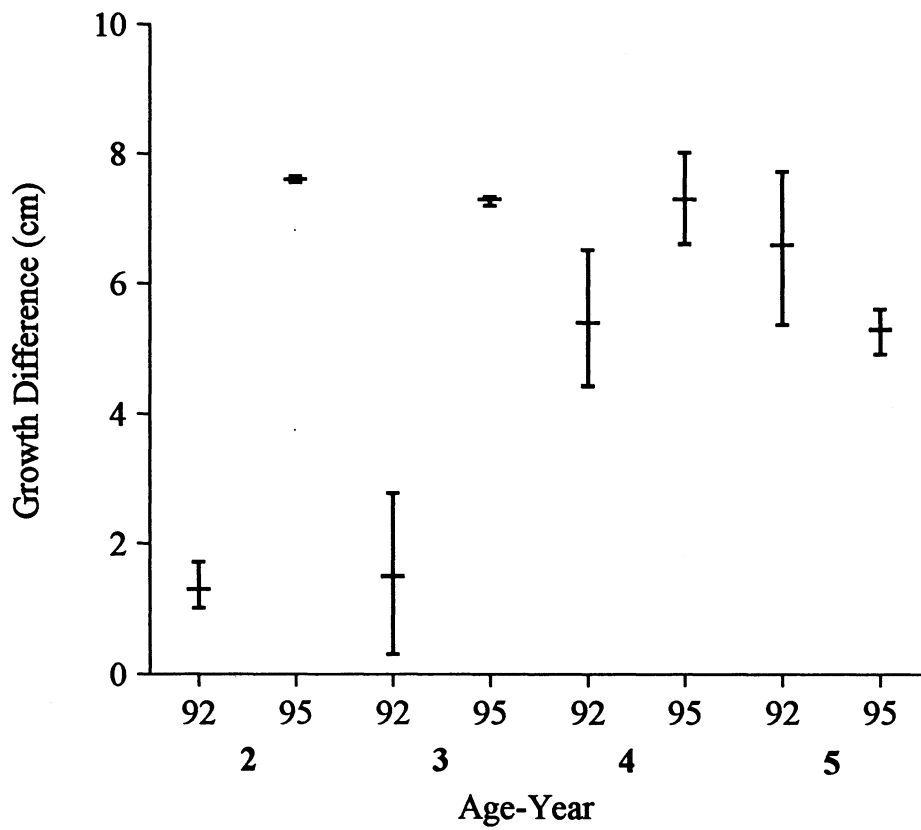


Figure 3. Growth difference in length (cm) of four age classes of Fish Lake largemouth bass among pre-treatment (1992-1993) and post-treatment (1995-1996) years.

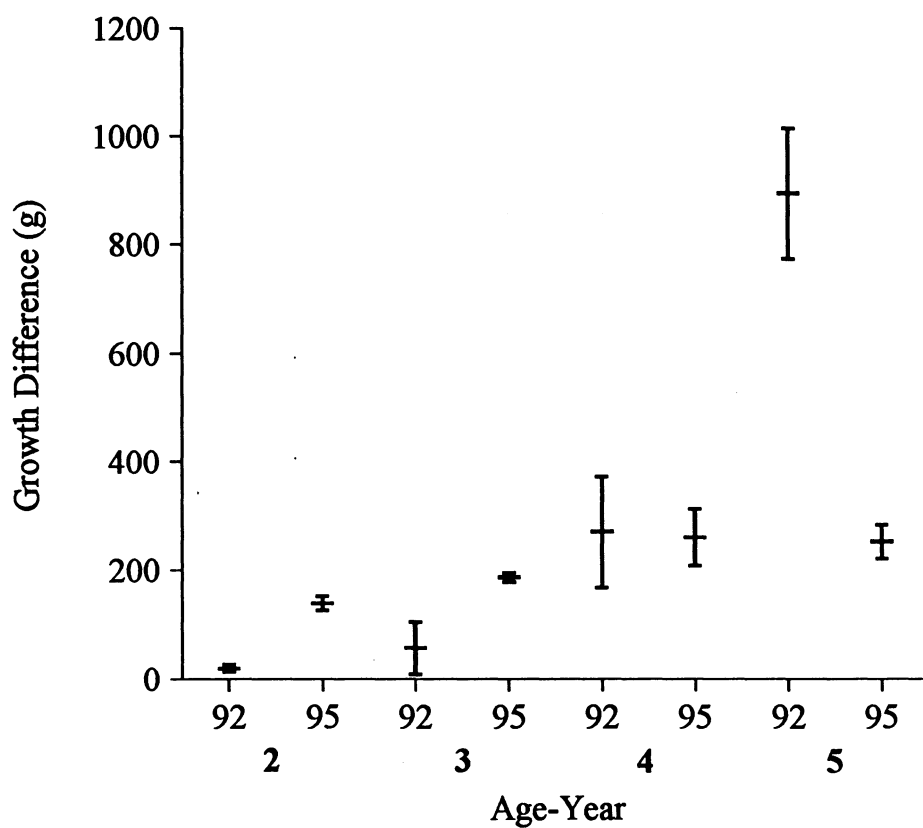


Figure 4. Growth difference in weight (g) of four age classes of Fish Lake largemouth bass among pre-treatment (1992-1993) and post-treatment (1995-1996) years.

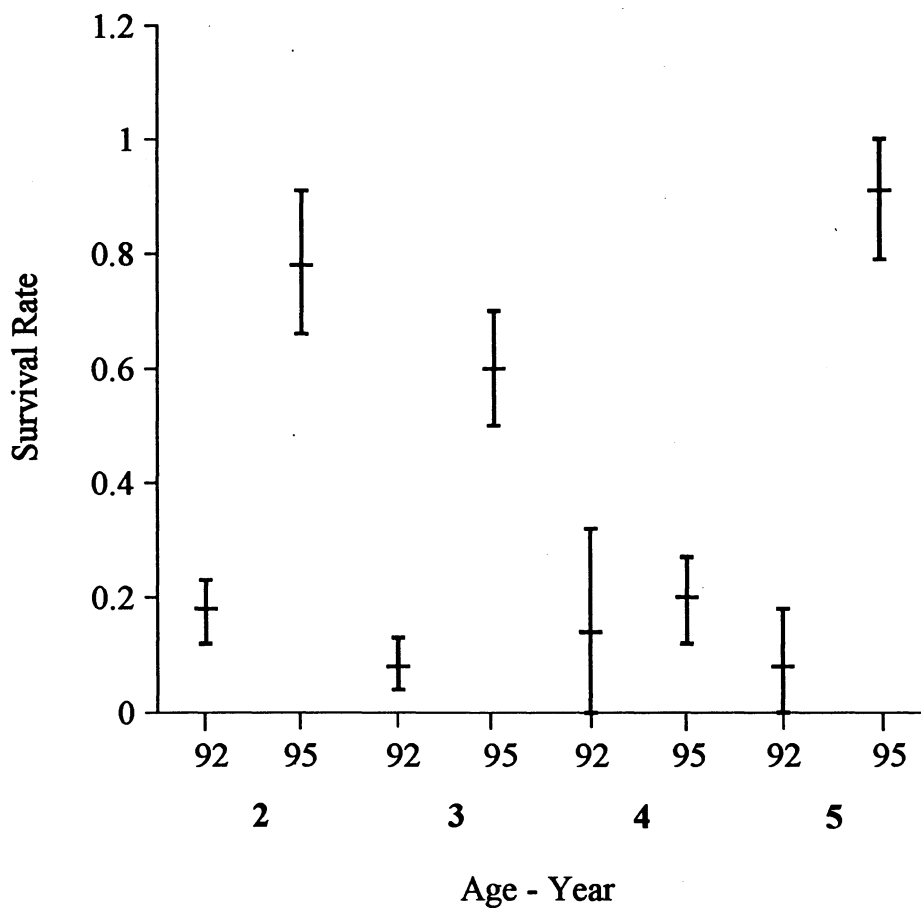


Figure 5. Survival rate of four age classes of Fish Lake largemouth bass among pre-treatment (1992-1993) and post-treatment (1995-1996) years.

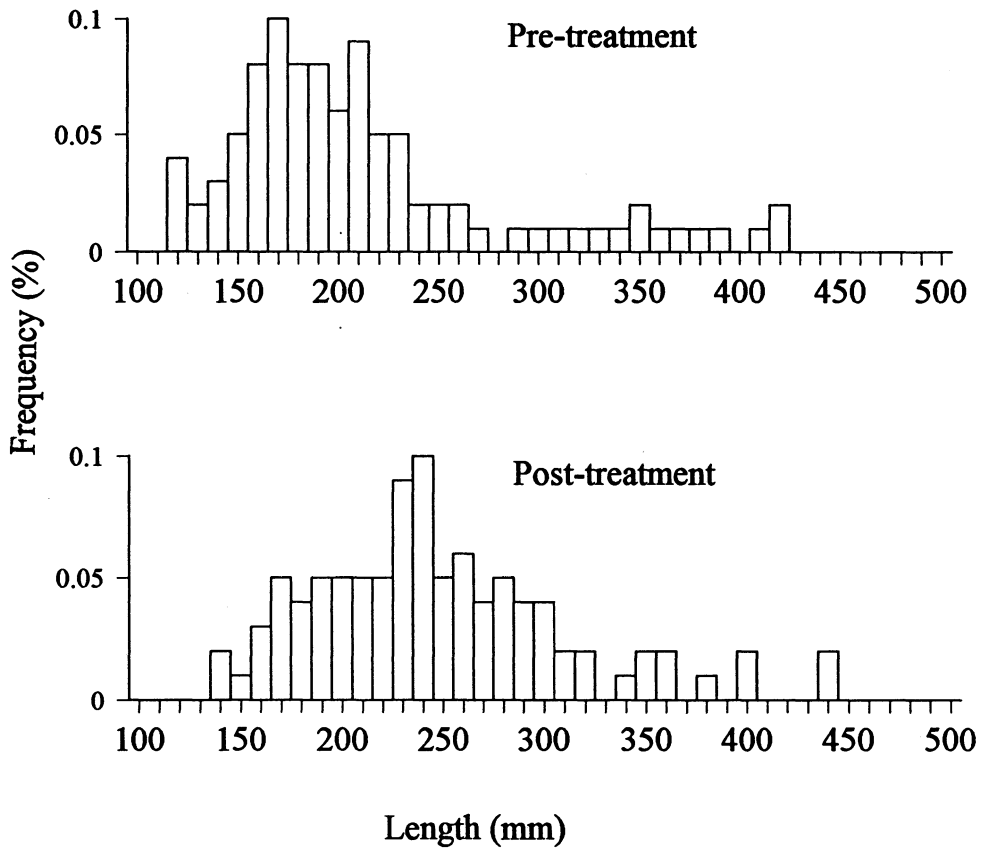


Figure 6. Length-frequency of Fish Lake Largemouth bass electrofished in spring among pre-treatment (1992-1994) and post-treatment (1995-1996) years.

The mean number of bluegill ranged from 76,707 to 141,785 or 759 to 1,404 fish/ha (Figure 7).

Growth (length) of bluegill declined for age classes 4-6 after the plant manipulation. Bluegill grew faster during pre-treatment years, when their length increased by at least 3.0 cm in each age class than in post-treatment years, when their length increased 1.0-2.0 cm in each age class (Figure 8).

Survival of bluegill improved for age classes 4-6 in post-treatment years. Less than 35% of the bluegill in each age class survived between pre-treatment years, whereas at least 50% of bluegill survived in each age class between post-treatment years (Figure 9).

The population size structure of bluegill greater than 80 mm in was significantly different after the plant manipulation as indicated by the Kolmogorov-Smirnov test ($D = 0.347$; $N_1 = 27196$; $N_2 = 23494$; $P < 0.01$). Bluegill 120-160 mm total length (3- 6 years old), predominated in pre-treatment years, and the size distribution was skewed towards smaller fish. In post-treatment years, bluegill 140-180 mm total length (ages 4-7) predominated (Figure 10), and the size distribution was less skewed.

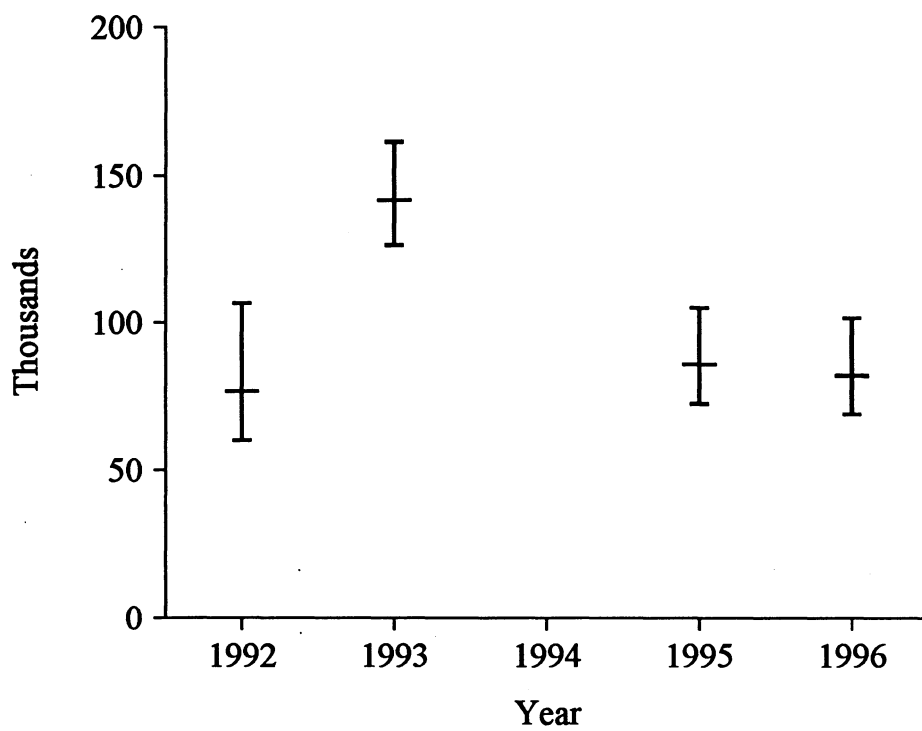


Figure 7. Spring fyke net abundance of bluegill in Fish Lake among pre-treatment (1992-1993) and post-treatment (1995-1996) years.

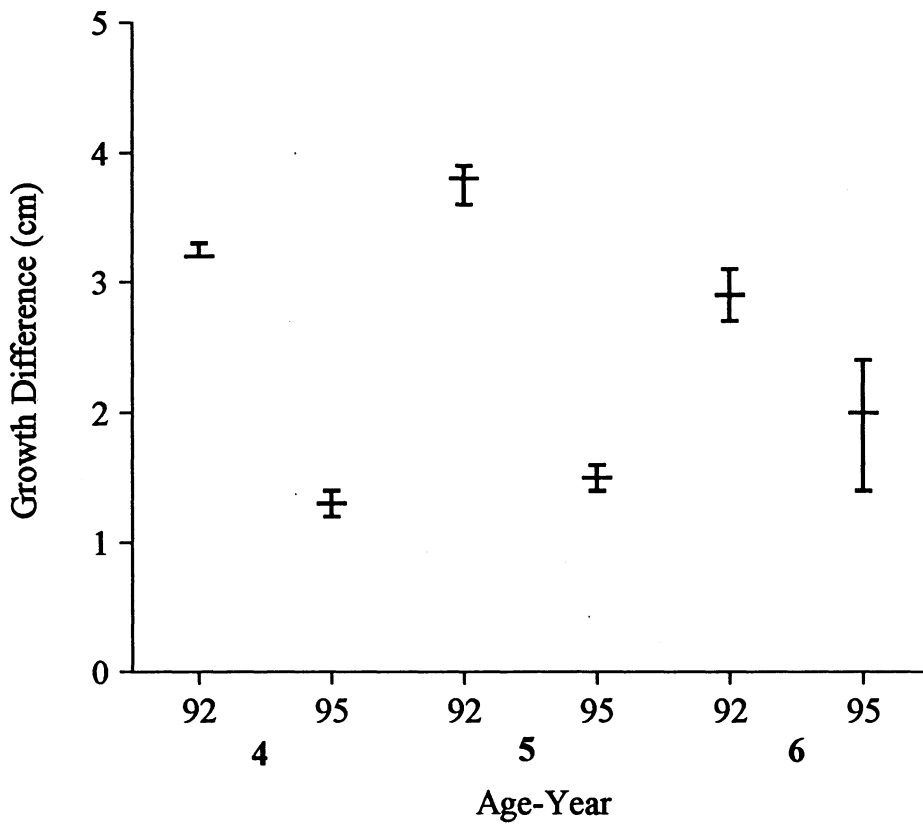


Figure 8. Growth difference in length (cm) of three age classes of Fish Lake bluegill among pre-treatment (1992-1993) and post-treatment (1995-1996) years.

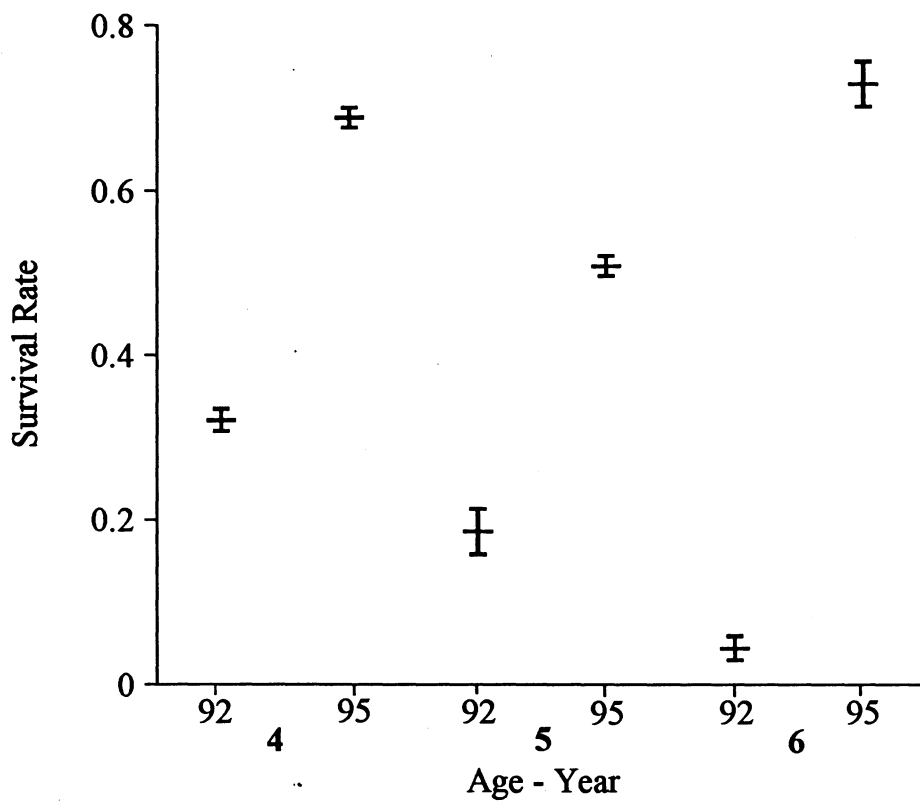


Figure 9. Survival rate of three age classes of Fish Lake bluegill among pre-treatment (1992-1993) and post-treatment (1995-1996) years.

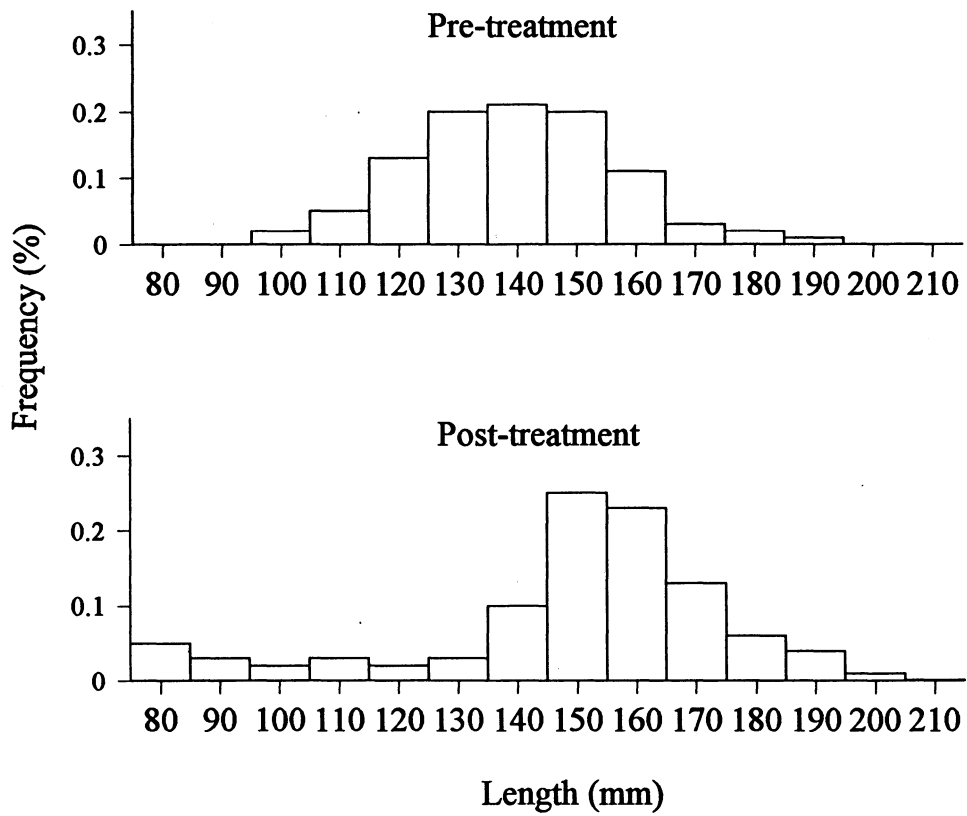


Figure 10. Length-frequency of Fish Lake bluegill in spring fyke nets among pre-treatment (1992-1994) and post-treatment (1995-1996) years.

Discussion

My results indicate that a reduction in total plant biomass did not alter the total abundance of largemouth bass or bluegill. Keast (1983) found a significant reduction in bluegill nesting sites in dense stands of Eurasian watermilfoil. Apparently, dense vegetation in Fish Lake did not limit the available spawning habitat because fish abundance did not increase significantly after the treatment. Cutting the plants in a channel configuration may have increased largemouth bass access to bluegill, yet the ratio of bluegill to largemouth bass in Fish Lake was high. Bluegill were likely so numerous that any additional predation did not cause a noticeable reduction in their abundance. Because errors in estimating fish abundance are quite large (evidenced by the wide confidence intervals surrounding the Schnabel estimates), the probability of detecting a change in fish population size is low for pre- to post-manipulation experiments (Carpenter et al. 1998).

A reduction in total plant biomass in Fish Lake did increase growth of largemouth bass, however growth of bluegill decreased. In pre-treatment years, dense vegetation may have limited growth rates of young largemouth bass. In healthy populations, centrarchids commonly experience rapid growth at early life stages, and slower growth at older ages (Ricker 1975). In Fish lake, the opposite was true; young fish grew slower than older fish, which suggests food limited the growth of young fish. After the plant reduction, growth rates increased for largemouth bass of ages 2 and 3. Other studies have also documented improved growth of young fish when

vegetation declined or was reduced (Engel 1985, Cross et al. 1992, Hoyer and Canfield 1996, Miranda et al. 1996). Growth increases for Fish Lake largemouth bass were slightly higher than for other Wisconsin populations. Historical age and growth information taken from the Yahara chain of lakes, located within 50 km of Fish Lake, showed that age 2 largemouth bass grew at rates as high as 6.0 cm/year (Engel 1985); post-manipulation growth increased 7.6 cm for age 2 fish in Fish Lake. However, mean lengths of largemouth bass from Fish Lake were still within the range of mean lengths found in 300 waters in Wisconsin and neighboring states (Engel 1987).

A factor primarily responsible for increased growth of largemouth bass was the earlier ontogenetic shift to piscivory after the plant manipulation. Diets of Fish Lake largemouth bass in pre-treatment years showed that only fish longer than 250 mm in length were effective predators of bluegill and pumpkinseed (Sloey and Schenck 1997), whereas largemouth bass below 200 mm in length consumed mainly insects, and a few cyprinids and percids (Storlie et al. 1995). Yet, the relative abundance of fish as prey in the diets of largemouth bass shorter than 200 mm increased from 8% to 62%, between pre- and post-treatment years, and was comprised almost entirely of centrarchids (unpublished data, Wisconsin Department of Natural Resources). Creating channels in plant beds may therefore have increased interactions between centrarchid predators and prey in Fish Lake. In contrast, growth did not increase for largemouth bass of intermediate ages because most of these fish were primarily piscivorous before the plant manipulation (Storlie et al. 1995).

A reduction in vegetation indirectly increased the survival of intermediate-age bluegill in post-treatment years. Increased plant bed edge, and reduced vegetation density led to higher capture rates of small bluegill by largemouth bass (Savino and Stein 1982, Smith 1995). Largemouth bass in Fish Lake may have switched to a diet of young, small bluegill, thus relieving predation pressure on larger fish of intermediate ages.

The decline in growth that bluegill experienced after the plant manipulation may have resulted from a reduction in bluegill prey availability, increased competition for prey, or a combination of both. Bluegill > 150 mm typically forage in edges and open water (Trebitz et al. 1997) for zooplankton prey. The biomass of prey in the diets of Fish Lake bluegill > 130 mm (> age 3) prior to the plant manipulation was made up of 98% zooplankton (Sloey and Schenck 1997), when intermediate age bluegill grew faster. In the year of the plant manipulation, bluegill > 130 mm were much more general in their food habits, and zooplankton made up only 53% of the total biomass of prey items (Sloey and Schenck 1997). This suggests a decline in zooplankton abundance or that zooplankton resources were shared among greater numbers of bluegills. When plant bed edge was increased, and bluegill were risk neutral in their foraging, growth increases were shared more evenly among all size classes (Trebitz et al. 1997), which suggests fish competed for prey items. My results indicate bluegill older than age 4 survived better in post-treatment years. This would result in increased competition for zooplankton prey, and thus slower growth of intermediate-age bluegill.

A reduction in vegetation in Fish Lake improved the survival of both centrarchid species, which increased recruitment to larger size. Largemouth bass were directly affected by the change in habitat because the channels likely allowed them to spread out into formerly unoccupied areas of Fish lake. Smith (1995) showed that largemouth bass remained widely separated in experimental enclosures when plant bed edge habitat was doubled. Yet, when vegetation was left untouched, fish were much more concentrated (Smith 1993). Thus, increasing the available habitat in Fish Lake may have led to a decline in density-dependent mortality of largemouth bass.

The population size structure of largemouth bass and bluegill was positively influenced by a reduction in plants. Increased survival of fish at intermediate ages contributed to a marked improvement in population size structure. Similarly, recruitment of largemouth bass to harvestable size was significantly correlated with plant cover of up to 26% in 30 Texas reservoirs (Durocher et al. 1984). Initially 40% of Fish Lake was covered with dense Eurasian watermilfoil, and when plant biomass was reduced, centrarchid recruitment increased.

Management Implications

Close-cut mechanical harvest of vegetated littoral zone habitat is a useful fishery management tool. A reduction in Eurasian watermilfoil biomass can significantly improve centrarchid growth, survival and population size structure. In Fish Lake, effects on largemouth bass were greatest, especially for young fish that grew faster and survived better. Reduced plant biomass led to increased fish predator-

prey interactions, giving young largemouth bass greater opportunity to eat young bluegill, thereby reducing bass predation on intermediate age bluegill and enhancing their survival. However, bluegill growth declined, either through increased competition for zooplankton prey or a decline in zooplankton abundance. A reduction in vegetation did not change the total abundance of fish, but increased survival of young and intermediate-age largemouth bass and intermediate-age bluegill which suggests that abundance of these age groups increased. Recruitment of fish to larger size increased, as evidenced by increased centrarchid population size structure. Improvements were greatest for largemouth bass, while less consistent beneficial effects were evident for bluegill.

In hindsight, it would be valuable to evaluate fish population dynamics over all age classes, from pre- to post-plant treatment. We did not do so because sampling was ineffective in catching some size (age) segments of each population, especially very young and old fish. Collecting fish is difficult in dense vegetation, and it was necessary to use data collected in the same season, using similar gear in order to make comparisons across years. I recommend that future vegetation manipulation experiments include documentation of changes in fish abundance, as well as changes in growth and survival for each age class in the population. This would provide a better understanding of fish predator-prey relationships, necessary for more effective management of the fisheries in densely vegetated lakes.

CHAPTER II: ANGLING RESPONSES TO VEGETATION REDUCTION IN FISH LAKE, WISCONSIN

Abstract.— To improve angling opportunities, 262 close-cut channels were made through dense beds of Eurasian watermilfoil *Myriophyllum spicatum* in Fish Lake, Dane County, Wisconsin. Angling effort, catch rates, total catch and harvest, and fishing and natural mortality of largemouth bass *Micropterus salmoides* and bluegill *Lepomis macrochirus* were compared between pre- and post-treatment years to determine if reduced vegetation improved fishing. Cutting the channels created 36,200 linear m of vegetated edge habitat and reduced total plant biomass by 18%. Plant biomass was further reduced when a partial dieback of the vegetation occurred in some post-treatment years. A reduction in vegetation led to significant increases in angling effort during the winter months but not during summer. Summer catch rates of largemouth bass and bluegill generally declined, whereas winter catch rates did not change. Total catch of largemouth bass and bluegill remained similar among years, and while total harvest of largemouth bass declined to near zero, total harvest of bluegill did not change. Natural mortality of largemouth bass and bluegill declined, while fishing mortality increased for bluegill, but declined for largemouth bass. The size distribution of bluegill harvested by anglers increased, but anglers did not reduce the size of fish in the population. A reduction in total plant biomass in lakes dominated by Eurasian watermilfoil can lead to increased angling opportunities, while angler catch rates of largemouth bass and bluegill can decline.

Introduction

Dense aquatic vegetation reduces angling access to a fishery. When *Hydrilla verticillata* invaded Orange Lake, Florida, angling effort declined by 85%, and was associated with a loss in revenue (Colle et al. 1987). Controlling aquatic plants substantially increases the fishable shoreline of impoundments (Berry et al. 1974), and shore angler effort doubled when vegetation biomass was substantially reduced (Mitzner 1978).

The refuge provided by dense aquatic plants reduces the vulnerability of larger fish to angling (Maceina and Reeves 1996), and although catch in numbers of fish may improve, the average weight (biomass) of harvestable largemouth bass *Micropterus salmoides* may decline (Maceina and Reeves 1996, Wrenn et al 1996). Catch rates were positively correlated with increasing plant cover in reservoirs dominated by Eurasian watermilfoil *Myriophyllum spicatum*, but may have been influenced by strong recruitment of fish (Maceina and Reeves 1996, Wrenn et al. 1996). However, Colle et al. (1987) reported that catch of largemouth bass and bluegill during spring were little influenced by an 80% increase in hydrilla. Sportfish catch may therefore increase with increasing plant cover, but catch may be dominated by smaller fish, which reduces the quality of a fishery. The evidence for the effects of reduced vegetation on angler catch of fish is conflicting. Long-term data from the Yahara Lakes, Dane County, Wisconsin, indicated that bluegill catches declined in

years when plant biomass was low (Lathrop et al. 1992). Conversely, catch increased when plant biomass was reduced (Mitzner 1978).

Plant infestation is a problem for sport fish production. Often, plant control measures are employed to reduce plants to below nuisance levels. In well managed fisheries, vegetation should be controlled, not eradicated (Swingle 1966, Strange et al. 1975), because the net effect of eradication can be detrimental to Centrarchids and other fish in some way (Houser 1963, Judd and Taub 1973). The production of harvestable size largemouth bass was greatest when hydrilla coverage was 10 to 20% (Moxely and Langford 1982).

While vegetation can be managed to provide anglers with greater fishing opportunities, there is little research that documents angling pressure, success, or the interplay of fishing and natural mortality of largemouth bass and bluegill, before and after a plant manipulation. To assess changes in angling that may have resulted from increased access to the fishery, a creel survey was implemented to estimate angler effort, total catch and harvest, and catch rates on Fish Lake, Wisconsin. My objectives in this chapter were to determine if fishing effort, angling success of largemouth bass and bluegill, and fishing and natural mortality changed as a result of a plant manipulation.

Methods

Study Site

Fish Lake, Dane County, Wisconsin is a 101 ha seepage lake located 50 km northwest of Madison, Wisconsin (Figure 1). It has a maximum depth of 19.5 m and a mean depth of 6.6 m. Secchi measurements ranged from 1.5 to 3.5 m during the summer months (Marshall et al. 1996), and the lake is characterized as mesotrophic-eutrophic. Two culverts connect Fish Lake to 30 ha Mud Lake (Marx Pond), which has a maximum depth of 2.3 m. Fish Lake has a diverse fish fauna, with largemouth bass and bluegill the dominant predator and prey fishes (Appendix A, Table 1). Dense vegetation became a nuisance for anglers by the late 1970s, and by the mid-1980s limited angler access to the fishery. By 1992, the littoral zone was dominated by a dense stand of Eurasian watermilfoil, which formed a contiguous ring around the lake's perimeter at depths ranging from 1.5 m to 4.5 m (Lillie 1996). Eurasian watermilfoil comprised 90% of the total plant biomass and covered approximately 40% of the total lake bottom (Budd et al. 1995, Lillie 1996). Estimated average plant biomass within milfoil stands varied among years and was $283 \pm 13 \text{ gm}^{-2}$ in the year of the plant manipulation (Appendix A, Table 2) (Lillie 1996). Coontail *Ceratophyllum demersum* formed a dense band at the deep water edge of the milfoil bed, and a mixture of native species grew in shallow water, inshore from the milfoil bed (Appendix A, Table 3) (Lillie and Nichols 1997).

Based on bioenergetics modelling, selective removal of 20-40% of the biomass of vegetation in Fish Lake in a was believed to optimize the production of bluegill and

largemouth bass populations (Trebitz 1995, Trebitz and Nibbelink 1996). After two years of collecting baseline data, 262 channels were cut in a radial pattern through the Eurasian watermilfoil beds, near the sediment-water interface using a standard cutter that was modified to cut in depths as great as 6 m (Unmuth et al. 1997). Close-cut harvesting removed 18% of the total plant biomass, and 36,200 m of vegetated edge habitat (Unmuth et al., in press). Plant biomass was further reduced by a weevil infestation during 2 of the 5 years of the study (Appendix A, Table 2).

Creel Survey

Sport fishery effort and catch rates on Fish Lake were surveyed year-round using a 20 h per week roving-access creel survey design (Pollock et al. 1994, Newman et al. 1997). The survey occurred primarily during daylight hours, and three non-overlapping sample shifts (early, mid-day, late) were stratified by month and day type (weekday and weekend). Shift length was defined as fishing day length divided by 3, and thus varied among time periods. All weekend and three randomly selected weekdays were sampled in summer (May - November) 1992-1996 and in winter (January - April) 1992-1995. The number of boat, shore, and ice-angling parties were counted, and anglers were interviewed upon completing their trips. All access points were visited four times during a shift.

Effort in angling hours was estimated from cumulative counts during the summer and instantaneous counts during the winter. Methods of Robson and Jones (1989) were used to convert cumulative counts to summer angler hours within each

stratum. Instantaneous counts were converted to winter angler hours by multiplying by fishing day length, and the estimated angler hours for each day were computed as the average of these values (Newman et al. 1997). Effort in angler hours for each month-day stratum was computed as the average of the daily estimates multiplied by the total number of days in the stratum (Newman et al. 1997). Variance estimates were calculated using formulas for two-stage surveys (Cochran 1977). Approximate 95% confidence intervals for estimated effort were calculated using the mean \pm 1.96 SE.

Largemouth bass and bluegill catch rates were estimated from completed trip interviews, using the mean of ratios estimator:

$$R = \frac{\sum \frac{y_i}{x_i}}{n}$$

Where R is the per angler estimator of catch rate, x_i is the trip length (h) of the i^{th} angler, y_i is the catch by the i^{th} angler or party, and n is the number of anglers or parties interviewed (Jones et al. 1995). To compare angling success before and after the plant manipulation, variance of the catch rates was calculated as the variance of a ratio (Cochran 1977, Rasmussen et al. 1998), and the square root of the variance was used to estimate SE. Confidence intervals were constructed using \pm 1.96 SE.

Estimated total catch and harvest in summer were calculated as the mean catch per hour from completed trip interviews, multiplied by the estimated number of angling hours. Total catch and harvest in winter were estimated by calculating the

mean catch or harvest per party from the completed trip interviews multiplied by the estimated number of angling trips.

To determine the effects of the plant manipulation on angling, I compared total hours of angler effort, total catch, total harvest and catch rates of largemouth bass and bluegill, for summer and winter among years. Because the vegetation was manipulated in August of 1994, and the majority of angling in summer occurred before August, summer effort and catch comparisons were made between pre-treatment years (1992-1994) and post-treatment years (1995-1996); winter effort and catch rates were compared between pre-treatment years (1992-1993) and post-treatment years (1994-1995).

Length frequencies of bluegill harvested by anglers in summer and winter were compiled from length data recorded from anglers completing their trip. Length distributions were combined for pre-treatment (1992-1994) and post-treatment (1995-1996) years, and compared using the Kolmogorov-Smirnov test for differences in distributions (Sokal and Rohlf 1981).

Mortality

Yearly exploitation rates for each species were calculated from the total number of marked fish harvested from the creel survey divided by the number of fish marked from population sampling. Techniques for estimating largemouth bass and bluegill abundance and survival were previously described (Chapter I). Total instantaneous mortality (Z), and annual mortality rate (A), were estimated by the equations:

$$Z = -\log_e S$$

$$A = 1 - S$$

Where S is the annual survival rate (Chapter I). Instantaneous rates of fishing mortality for bluegill (ages 4 to 6), and largemouth bass (ages 2 to 5) were estimated by the equation:

$$F = \frac{uZ}{A}$$

Where F is the instantaneous rate of fishing mortality, u is the rate of exploitation, and A is the annual mortality rate (Ricker 1975). Estimates of natural mortality were made by subtracting instantaneous fishing mortality (F) from instantaneous total mortality (Z). Rates were compared for bluegill and largemouth bass among pre-treatment (1992-1993) and post-treatment years (1995-1996), to show how total mortality was affected by a reduction in plants, and portions of mortality that resulted from angling and natural causes.

Results

Angling effort on Fish Lake was higher during summer than winter months prior to treatment, but was similar among seasons after treatment. A significant rise in winter angler effort occurred in post-treatment years, when pressure nearly doubled (Figure 11). In contrast, summer effort increased significantly in 1993, before the

vegetation was reduced, and remained steady through all post-treatment years (Figure 11). Shore angling was more popular than boat angling during the summer. The number of shore anglers visiting the lake was similar among pre- and post-treatment years, with a peak in 1993, just prior to the plant manipulation (Figure 12). The number of boat angling trips was similar among all years (Figure 13).

Catch rates of largemouth bass were less than one fish per hour in both summer and winter for all years, yet were highest in pre-treatment years, declined to a low point in the first post-treatment year, and increased to pre-treatment levels in the last post-treatment year (Figure 14). The highest catch rate occurred in summer 1992, synonymous with the peak in fish abundance (Chapter I). Catch rates of largemouth bass were lower in winter than summer, and remained relatively similar among pre- and post-treatment years, with a peak occurring just prior to the plant manipulation (Figure 14). Total catches of largemouth bass during the summer were highest in pre-treatment years, declined to a low point in the first post-treatment year, and increased to pre-treatment levels in the last post-treatment year (Figure 15), while total harvest in summer declined to near zero after the plant manipulation (Figure 16). Total catch and harvest of largemouth bass during the winter months was low, and similar among pre- and post-treatment years (Figures 15 & 16).

Catch rates of bluegill were less than 5 fish per hour in both summer and winter for all years. Catch rates peaked in pre-treatment years, synonymous with a peak in fish abundance (Chapter 1), and declined thereafter in both summer and winter (Figure 17).

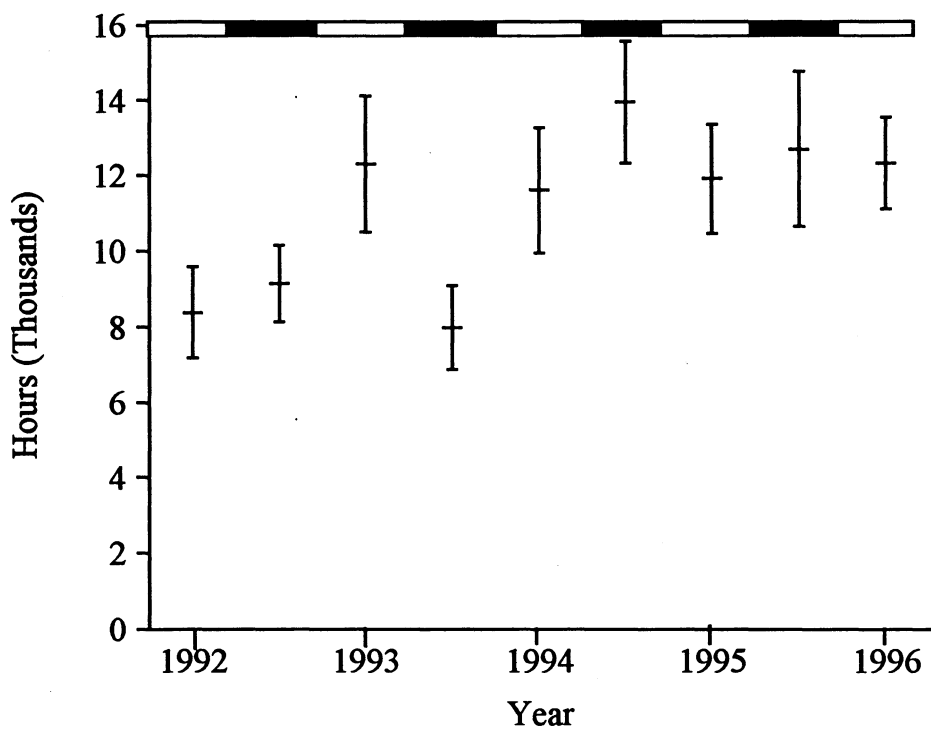


Figure 11. Angler effort hours among years on Fish Lake. Line at top of figure represents summer (white) and winter (shaded) seasons.

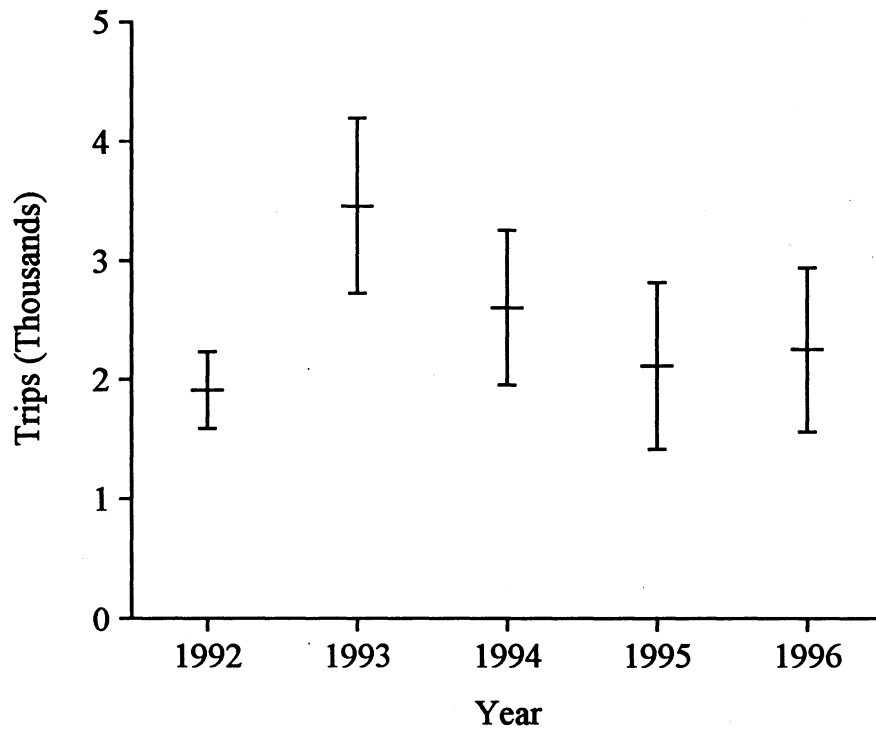


Figure 12. Summer shore angling trips among years on Fish Lake.

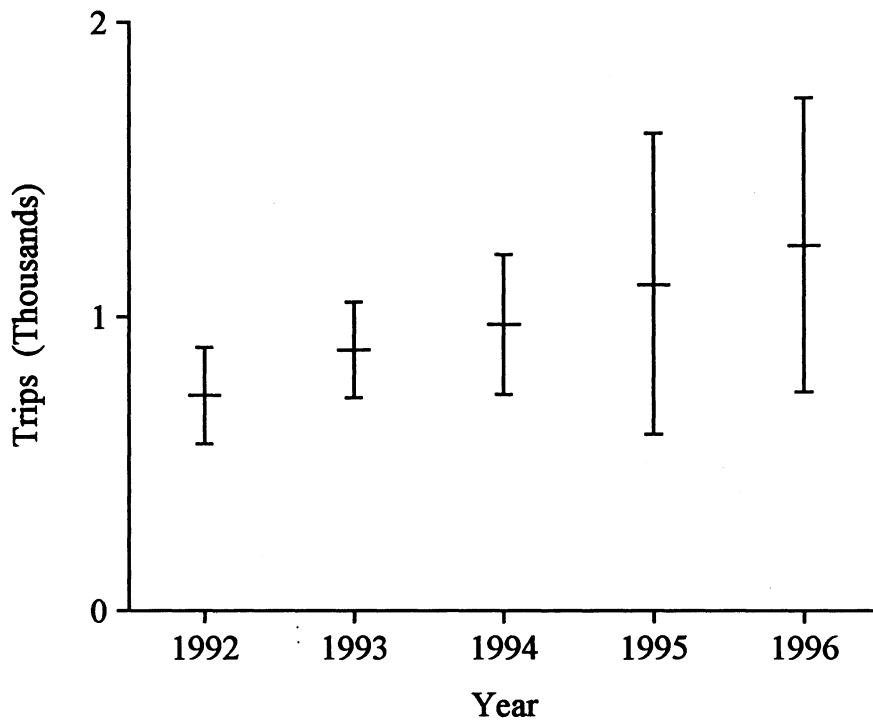


Figure 13. Summer boat angling trips among years on Fish Lake.

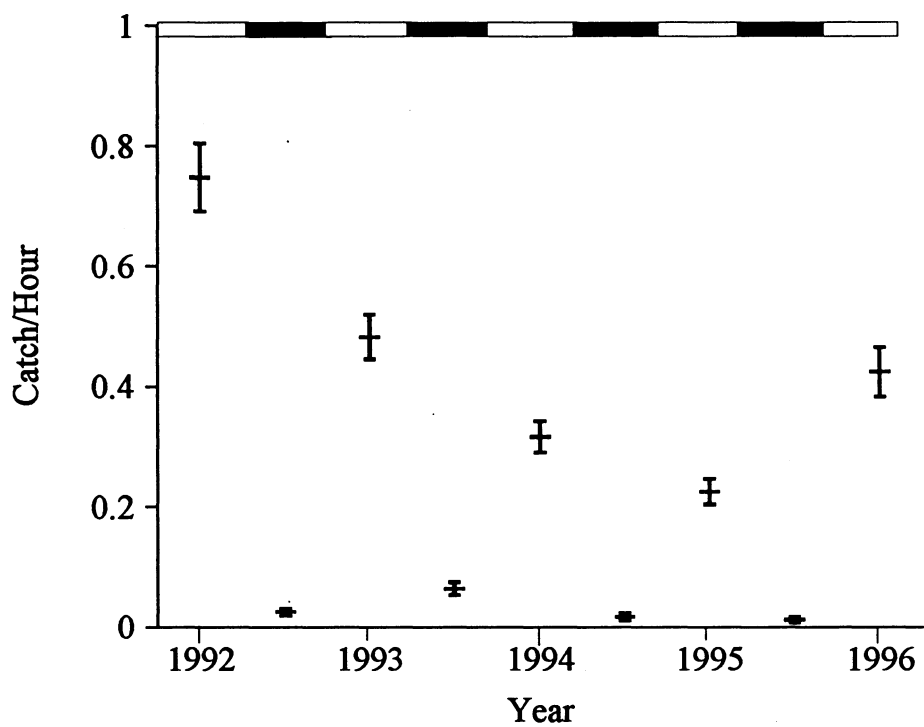


Figure 14. Angler catch rates of largemouth bass among years on Fish Lake. Line at top of figure represents summer (white) and winter (shaded) seasons.

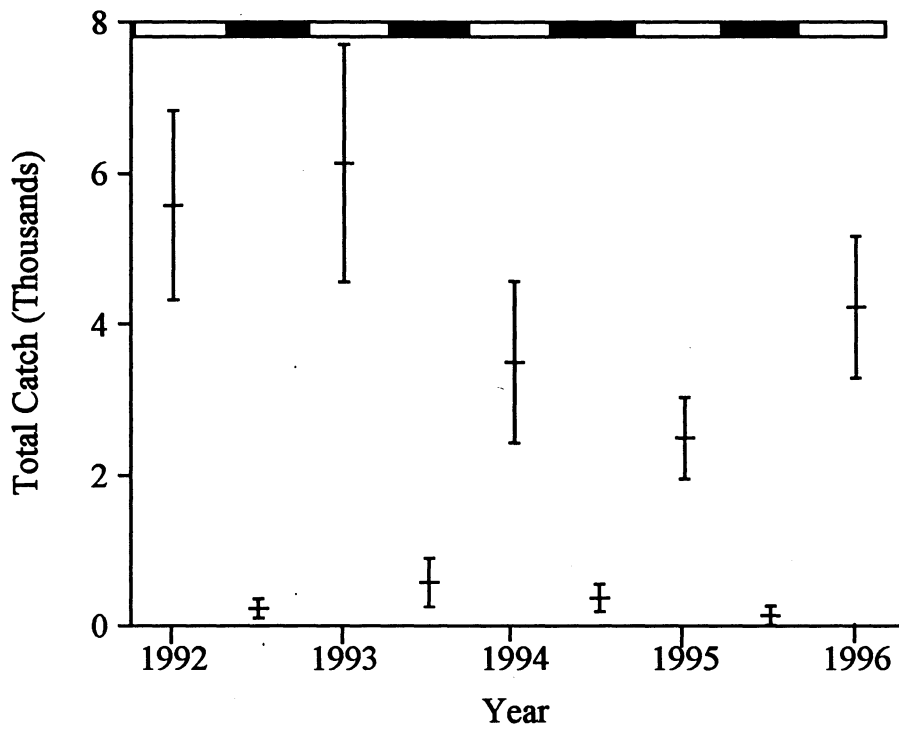
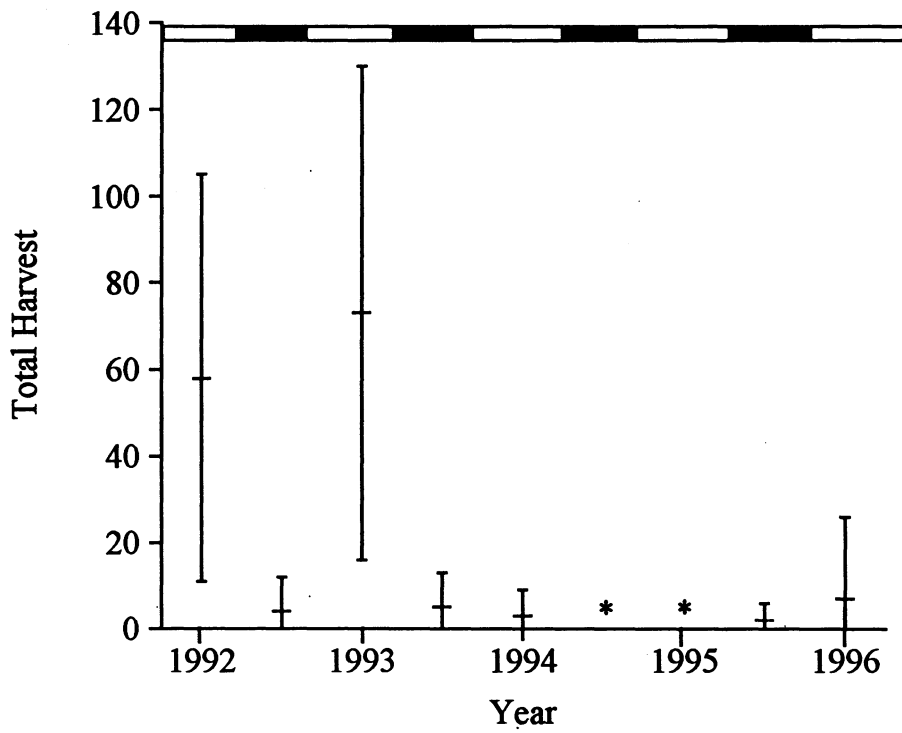


Figure 15. Total catch of largemouth bass among years on Fish Lake. Line at top of figure represents summer (white) and winter (shaded) seasons.



*Harvest of zero

Figure 16. Total harvest of largemouth bass among years on Fish Lake. Line at top of figure represents summer (white) and winter (shaded) seasons.

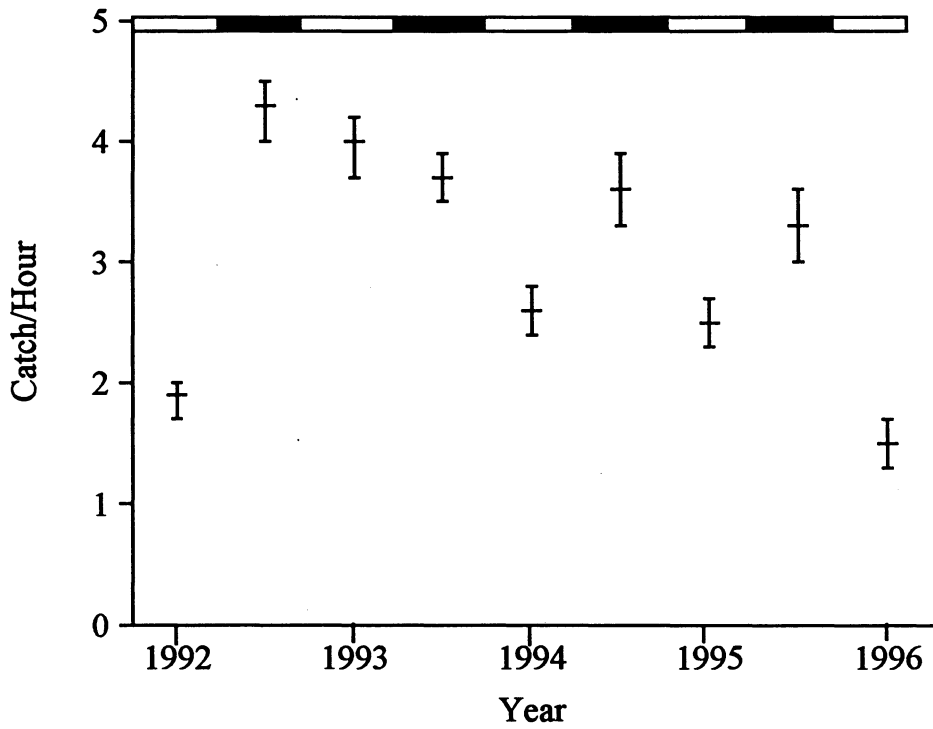


Figure 17. Angler catch rates of bluegill among years on Fish Lake. Line at top of figure represents summer (white) and winter (shaded) seasons.

Total catch and harvest of bluegill during the summer months peaked before the plant manipulation, and declined thereafter (Figures 18 & 19). Total catch and harvest of bluegill during the winter months remained similar among pre- and post-treatment years (Figures 18 & 19).

Instantaneous total mortality of largemouth bass declined following the plant manipulation mainly from a decline in natural mortality. Natural mortality decreased 80-96% for three of four age classes of largemouth bass (Figure 20). Fishing mortality was minimal before the plant manipulation and nearly zero after the plant manipulation (Figure 20).

Although angling mortality of bluegill increased, following the plant manipulation, the instantaneous total mortality declined because fewer fish died of natural causes (Figure 20). Natural mortality decreased 60-91% for three age classes of bluegill in post-treatment years. Angling strongly influenced bluegill mortality after the plant manipulation, when fishing mortality more than doubled, accounting for most of the total mortality of 4 to 6 year old fish (Figure 20).

The size structure of bluegill harvested by anglers increased after the plant manipulation as indicated by the Kolmogorov-Smirnov test ($D = 0.144$; $N_1 = 6668$; $N_2 = 17170$; $P < 0.01$). The majority of bluegill kept ranged in length from 150-170 mm in pre- and post-treatment years, but the harvest of fish ranging in size from 180 to 200 mm increased in post-treatment years (Figure 21).

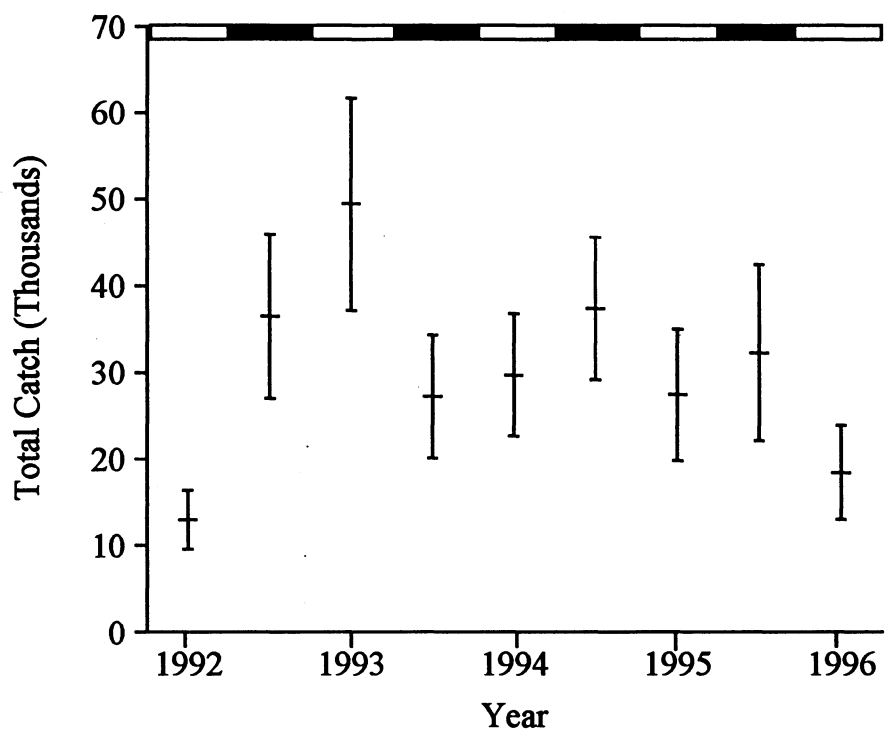


Figure 18. Total catch of bluegill among years on Fish Lake. Line at top of figure represents summer (white) and winter (shaded) seasons.

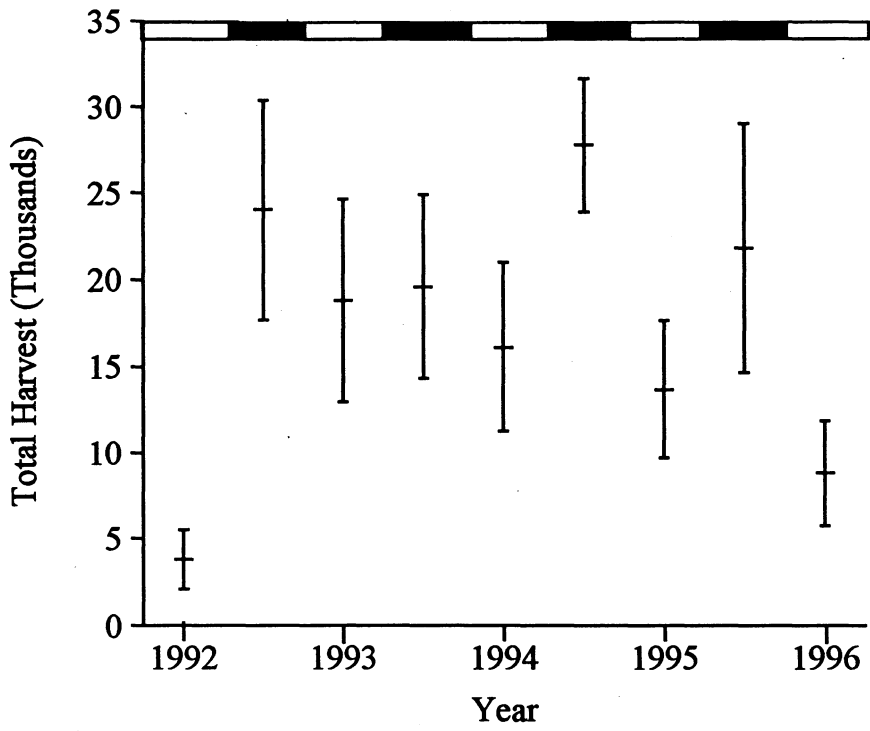


Figure 19. Total harvest of bluegill among years on Fish Lake. Line at top of figure represents summer (white) and winter (shaded) seasons.

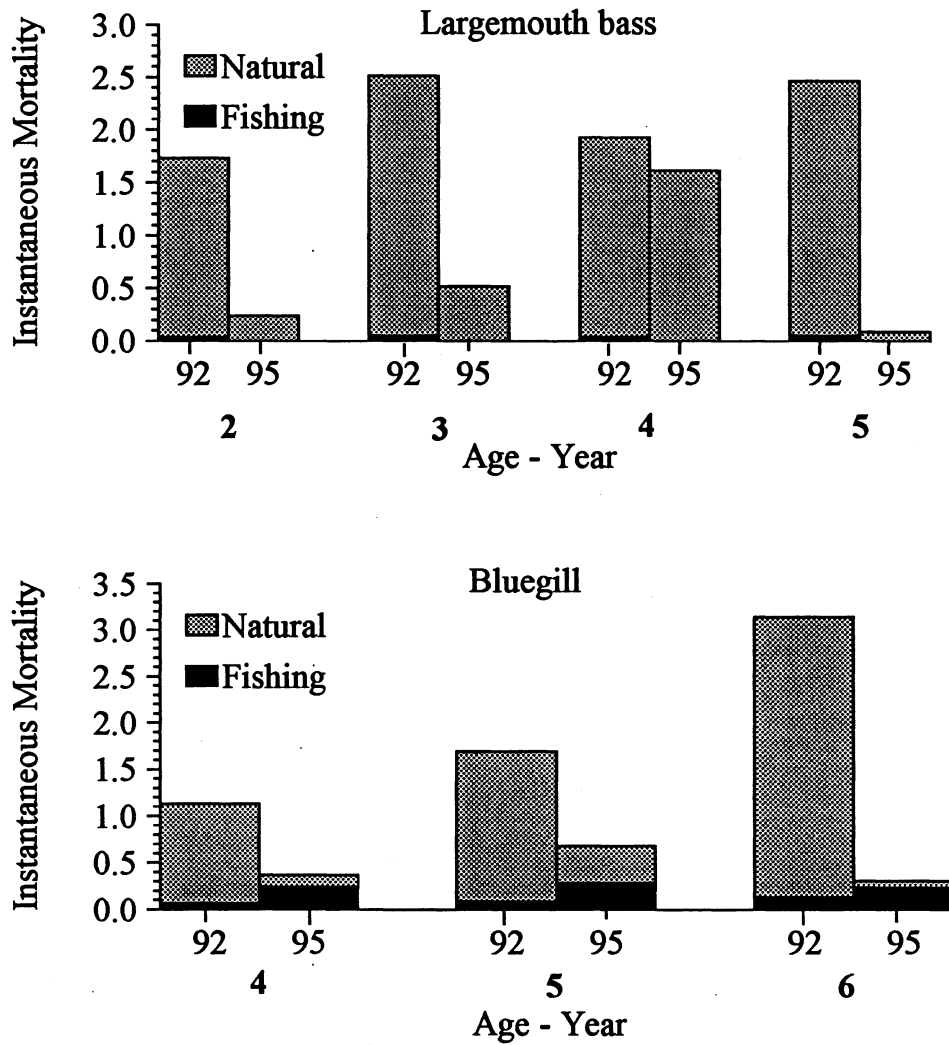


Figure 20. Mortality rate of 4 age classes of largemouth bass and 3 age classes of bluegill in Fish Lake among pre-treatment (1992-1993) and post-treatment (1995-1996) years.

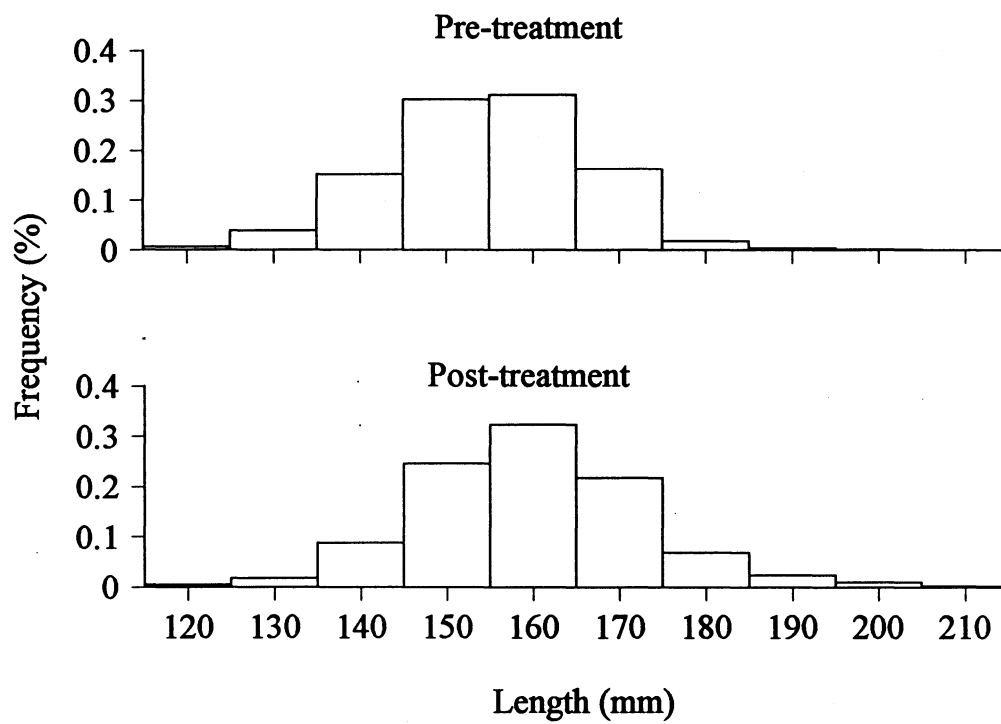


Figure 21. Length-frequency of Fish Lake bluegill harvested by anglers among pre-treatment (1992-1994) and post-treatment (1995-1996) years.

Discussion

A reduction in plant biomass resulted in significantly higher winter angling effort, while summer effort remained similar among years. Angling catch rates, total catch and harvest of largemouth bass and bluegill showed no improvement after the plant manipulation.

Increased angling effort in the winter months suggests that a reduction in vegetated habitat may have influenced anglers more during winter than summer. Churchill (1957) found that winter anglers are primarily local people familiar with a given lake. On Fish Lake, winter anglers fished mainly over the beds of Eurasian watermilfoil, and avoided the pelagia and inshore areas of the lake, described by winter anglers as "the dead zone". Winter anglers primarily targeted bluegill, and having unlimited access to the lake, concentrated their efforts within the area of habitat that was manipulated. Most summer anglers also targeted bluegill, and fished from shore amongst beds of vegetation dominated by native plant species intermixed with Eurasian watermilfoil. During the plant manipulation, we avoided cutting inshore areas so that native vegetation was left intact. The habitat where shore anglers concentrated their fishing was therefore not manipulated, and anglers may have had little motivation to respond to habitat changes made further out in the lake. In addition, shore angling access is limited because more than 90% of the shoreline is privately owned, and drastic increases in summer angling effort immediately following the plant manipulation may not have occurred because of limited shoreline access.

Boat anglers primarily targeted largemouth bass, and the number of boat angling trips gradually increased across years, yet did not rise dramatically after the plants were manipulated. Similarly, when vegetation was reduced by half in Red Haw Lake, Iowa, boat angling increased only slightly (Mitzner 1978). Cutting channels may not have attracted significantly more boat anglers to the fishery because motors have been prohibited on Fish Lake since the 1970s, and because the length limit (457 mm) and daily bag limit (1 per day) for largemouth bass may have been too restrictive. Restrictive regulations may be perceived as a disadvantage by some anglers, and cause them to leave the fishery, while other anglers may respond by increasing their effort though they harvest few fish (Carpenter et al. 1994). Collectively, this could produce little net change in angler effort (Carpenter et al. 1994).

Several key factors that influence catch rates are stock density (Beard et al. 1997), prey abundance (Johnson and Carpenter 1994), angler effort (Carpenter et al. 1994), and vegetation density (Bettoli et al. 1993). Angler catch rates will tend towards low levels as angler populations rise (Carpenter et al. 1994), and catch rates declined following eradication of vegetation in Lake Conroe, Texas (Bettoli et al. 1993). This was the case for Fish Lake anglers targeting largemouth bass, because angler effort increased across years, while catch rates declined in summer. Largemouth bass were targeted mainly by boat anglers, and the increasing number of boat angling trips resulted in more effort expended for catching similar numbers of fish. This reduced angler catch rates and total catch between pre-treatment and post-

treatment years. Two other factors that likely contributed to the reduction in summer angler success for largemouth bass included an expansion in the distribution of fish throughout the lake when vegetated habitat was reduced, and increased predation of largemouth bass on prey fish. The additional 36,000 m of plant bed edge we created gave largemouth bass, a cruising predator, the ability to spread into formerly unoccupied areas of the lake, and more effectively forage for prey fish. It is well known that the availability of prey resources can cause angling catchability of predators to vary (Lux and Smith 1960, Kempinger et al. 1975). Thus a combination of higher angler effort, and more elusive fish gave anglers little chance to catch more largemouth bass during the summer after the channels were cut.

The decline in angling mortality of largemouth bass after the plant manipulation cannot be attributed to the reduction in vegetation. The higher minimum length limit (457 mm), and lower daily bag limit (1 per day) instituted for largemouth bass during the year of the manipulation likely reduced angler mortality of harvestable size fish. Institution of a higher minimum length limit and lower daily bag limit greatly reduced the harvest of northern pike on Lake Mendota (Johnson 1993). In addition, length frequency information taken from Fish Lake spring electrofishing sampling indicated that few largemouth bass greater than 457 mm were available for harvest (Chapter I) in any year of the study. Too few fish were kept to determine length frequency trends in harvested fish, yet without the restrictive length and daily bag limits, greater angler effort might have reduced the number of harvestable size fish.

Angler catch rates of bluegill showed no improvement after a reduction in vegetation. Angling for bluegill was best during the winter months, and higher winter angling pressure in post-treatment years may have resulted in reduced angler catch rates, while total catch and harvest remained similar. Angling catch rates declined steadily with an increase in annual angler effort on Escanaba Lake (Churchill 1957), and catch rate was inversely related to angler effort on Lake Mendota (Johnson and Carpenter 1994). Catch rates also declined when vegetation was eradicated in Red Haw Lake (Mitzner 1978). Similarly, catch rates of Fish Lake bluegill declined when the catch was spread among greater numbers of anglers after the vegetation was reduced. Natural mortality of bluegill was substantially reduced after the plant manipulation which resulted in more large fish available for anglers to harvest. Anglers harvested a greater number of larger bluegill, thus the quality of the bluegill fishery improved.

Management Implications

Providing more angling opportunities is often a primary goal when managing vegetated habitat. A reduction in the vegetation in Fish Lake was associated with improved winter angling effort only. Cutting channels in a 2- m-wide swath may have done little to alter the perception of access by summer boat anglers, since anglers complained of the difficulty in finding channels, and many channels were hard to distinguish from the lake's surface because vegetation at the channel edges arched over the channel (D. Sloey and D. Lillie, Personal Observation). Harvesting channels in

swaths wider than 2 m, closer inshore, may have attracted additional summer anglers.

Close-cut mechanical plant harvesting may improve a bluegill fishery through dramatic declines in natural mortality, increased sport fishing mortality, and a greater percentage of large bluegill harvested. However, declining catch rates and increased harvest of larger bluegill should be a concern when managing vegetation where fish regulations are liberal.

To understand the dynamics of sport fisheries when vegetation is reduced, a more complex and longer-term investigation than the one presented here will be needed. Few studies have attempted to thoroughly investigate angling responses to habitat manipulation. What is needed, but rarely attempted, is a large-scale approach to determine the responses of anglers to plant management. This would involve quantifying angler effort, catch and harvest, and fishing and natural mortality of dominant fish species across a broad range of lakes; an expensive and time consuming proposition. Yet, future research needs to emphasize angler response to plant manipulations on a regional scale, incorporating angler information across a range of lakes, and providing a clearer understanding of how anglers may affect a fishery in response to vegetation manipulation.

SUMMARY AND CONCLUSIONS

A reduction in Eurasian watermilfoil biomass can benefit Centrarchid populations and the fishery. While the total abundance of largemouth bass and bluegill in Fish Lake did not change, predator-prey interactions appeared to increase, thereby increasing the production of several age classes of fish.

When vegetation was dense in Fish Lake, young largemouth bass were ineffective predators, grew slowly, and had poor survival. After the plant reduction, predator-prey interactions increased because young largemouth bass gained more access to small bluegill prey. As a consequence, growth and survival of largemouth bass improved. Largemouth bass of intermediate ages were effective predators in dense vegetation, and grew better than younger largemouth bass. After the vegetation was reduced, however, largemouth bass of intermediate age grew no better than before. However, the poor survival, and high natural mortality of intermediate age largemouth bass in years of dense plant growth suggests that density-dependent mortality occurred, and a reduction in vegetation biomass reduced this effect, resulting in reduced natural mortality.

Bluegill grew better in dense vegetation, and the plant removal resulted in poorer growth for fish of intermediate ages. The decline in bluegill growth and change in food habits suggests that food web dynamics changed for bluegill, either through changing abundance or availability of zooplankton resources, or by increased competition between bluegill for zooplankton prey. The much higher survival of

bluegill that occurred after the plant manipulation may have led to increased competition for zooplankton prey. My results also suggest that reduced bluegill growth may have been caused by increased fishing mortality that affected the mean size of fish at age. The percentage of larger bluegill that anglers harvested from Fish Lake was greatest in post-treatment years, and the size that anglers harvested related to the age of fish whose growth changed. The larger fish of a year class are often most vulnerable to anglers (Ricker 1975), and larger fish are frequently harvested in a greater proportion than they exist in the population (Beard et al. 1992). Cropping off the larger fish reduces the mean length of fish remaining in the lake, and this would be exhibited through a decline in apparent growth of bluegill. Ricker (1980) attributed a decline in the abundance of salmon of larger average size to increased fishing effort.

Dense vegetation clearly limited the survival of bluegill. High natural mortality of intermediate-age bluegill suggests that predation by largemouth bass may have exerted an important force of mortality on this segment of the bluegill population. The improved survival rate, and much lower natural mortality rate of bluegill that occurred after the plants were cut, suggests that predation pressure on intermediate-age bluegill was reduced when largemouth bass had greater access to younger bluegill.

The population size structure of largemouth bass and bluegill were skewed towards smaller fish when vegetation was dense. Poor survival resulted in low recruitment of fish to greater length. Reducing vegetation improved fish recruitment and led to improved fish population size structure.

The reduction in plant biomass increased angling opportunities and resulted in significantly greater angler effort. However, angling catch rates of largemouth bass declined as effort increased. Yet, increased effort was just one of many factors that likely contributed to the decline in catch rates. The additional 36,000 m of plant bed edge habitat allowed largemouth bass, a cruising predator, to distribute more evenly throughout the lake and to forage more effectively for prey fish. Angling catch rates declined with increased availability of largemouth bass habitat and prey resources.

Angling catch rates of bluegill also declined after the plant reduction and was inversely related to the increase in angling effort. Yet, fishing mortality of bluegill more than doubled. Although improved survival of bluegill should have prompted increases in angling catch rates, increased annual angling effort likely negated the possibility of improved catch rates.

Examining the top predator and prey species at a whole-lake scale is only the first step. It is widely accepted that management actions that manipulate fish populations will produce indirect effects that affect the food webs of entire ecosystems (Kitchell 1992, Carpenter and Kitchell 1993). To refine this approach it is necessary to evaluate fish population dynamics over all age classes of fish, from pre- to post-plant manipulation. In addition, fish populations should be examined at the ecosystem scale to give broader scope to the efficacy of mechanical plant harvesting.

Sport anglers also produce strong indirect effects because they can dramatically alter keystone species, yet are not restricted to the bounds of a given water body (Johnson 1993). Thus, the need to evaluate angler response to plant manipulations at a

larger spatial scale than that of an individual fishery is necessary because anglers can switch to other waters as alternate fisheries improve. Broad-scale studies require more financial commitment, but may improve our understanding of habitat manipulation, making them more cost-effective in the long term.

APPENDIX A - ADDITIONAL TABLES

Appendix Table 1. Taxonomic list of fish species collected during the period 1992-1996 in Fish Lake, Dane County, Wisconsin.

Common Name	Scientific Name
Trouts	Salmonidae
Cisco	<i>Coregonus artedi</i>
Pikes	Esocidae
Northern Pike	<i>Esox lucius</i>
Carps and Minnows	Cyprinidae
Common carp	<i>Cyprinus carpio</i>
Golden shiner	<i>Notemigonus crysoleucas</i>
Blackchin shiner	<i>Notropis heterodon</i>
Blacknose shiner	<i>Notropis heterolepis</i>
Suckers	Catostomidae
White sucker	<i>Catostomus commersoni</i>
Bullhead Catfishes	Ictaluridae
Black bullhead	<i>Ameiurus melas</i>
Yellow bullhead	<i>Ameiurus natalis</i>
Brown bullhead	<i>Ameiurus nebulosus</i>
Killifishes	Cyprinodontidae
Banded killifish	<i>Fundulus diaphanus</i>
Sunfishes	Centrarchidae
Green sunfish	<i>Lepomis cyanellus</i>
Pumpkinseed	<i>Lepomis gibbosus</i>
Bluegill	<i>Lepomis macrochirus</i>
Smallmouth bass	<i>Micropterus dolomieu</i>
Largemouth bass	<i>Micropterus salmoides</i>
Black crappie	<i>Pomoxis nigromaculatus</i>
Perches	Percidae

Iowa darter

Etheostoma exile

Johnny darter

Etheostoma nigrum

Yellow perch

Perca flavescens

Sauger

Stizostedium canadense

Walleye

Stizostedium vitreum

Appendix Table 2. Estimated average dry weight of plant biomass among years within Eurasian watermilfoil stands in Fish Lake, Dane County, Wisconsin.

Year	Total Biomass (gm ⁻²)	SE
1992	406	12
1993	538	19
1994	283	13
1995	289	16
1996	466	15

Appendix Table 3. Taxonomic list of floating leafed and submersed macrophytes collected during the period 1991-1994 in Fish Lake, Dane County, Wisconsin.

Common Name	Scientific Name
Water marigold	<i>Bidens beckii</i> Torr.
Water shield	<i>Brasenia schreberi</i> Gmel.
Coontail	<i>Ceratophyllum demersum</i> L.
Stonewort or Muskgrass	<i>Chara</i> spp.
Spike rush	<i>Eleocharis acicularis</i> (L.) R.&S.
Waterweed	<i>Elodea canadensis</i> Michx.
Eurasian watermilfoil	<i>Myriophyllum spicatum</i> L.
Bushy pondweed	<i>Najas flexilis</i> (Willd.)Rostk.&Schmidt
Yellow water lily	<i>Nuphar variegata</i> Durand
White water lily	<i>Nymphaea odorata</i> Ait.
Smartweed	<i>Polygonum natans</i> Eat.
Large-leaf pondweed	<i>Potamogeton amplifolius</i> Tuckerm.
Curly-leaf pondweed	<i>Potamogeton crispus</i> L.
Variable-leaf pondweed	<i>Potamogeton gramineus</i> L.
Floating-leaf pondweed	<i>Potamogeton natans</i> L.
Sago pondweed	<i>Potamogeton pectinatus</i> L.
Clasping-leaf pondweed	<i>Potamogeton richardsonii</i> (Benn.)Rydb.

REFERENCES

- Annett, C., J. Hunt, and E. D. Dibble. 1996. The compleat bass: Habitat use patterns for all stages of the life cycle of largemouth bass. *American Fisheries Society Symposium* 16:306-314.
- Beard et al. 1992. Managing panfish in Wisconsin: a recommendation to the natural resources board. Wisconsin Department of Natural Resources, Bureau of Fisheries Management report.
- Beard, T. D. Jr., M. T. Drake, J. E. Breck, and N. A. Nate. Effects of simulated angling regulations on stunting in bluegill populations. *North American Journal of Fisheries Management* 17:525-532.
- Bettoli, P. W. 1987. The restructuring of a forage fish community following large-scale aquatic vegetation control. Doctoral dissertation, Texas A&M University, College Station..
- Bettoli, P. W., M. J. Maciena, R. L. Noble, and R. K. Betsill. 1993. Response of a reservoir fish community to aquatic vegetation removal. *North American Journal of Fish Management* 13:110-124.
- Berry, C., C. Schreck, R. Strange, S. van Horn, and R. Corning. 1974. Aerial photographic monitoring of an aquatic macrophyte community following herbicide application. *Journal of Science* 25:60.
- Borawa, J. C., J. H. Kerby, M. T. Huish, and A. W. Mullis. 1978. Currituck Sound fish populations before and after infestation by Eurasian water-milfoil. *Proceedings Annual Conference for the Southeast Association of Fish and Wildlife Agencies* 32:520-528.
- Budd, J., R. A. Lillie, and P. Rasmussen. 1995. Morphological characteristics of the aquatic macrophyte, *Myriophyllum spicatum* L., in Fish Lake, Wisconsin. *Journal of Freshwater Ecology* 10:19-31.
- Carlander, K. D. 1982. Standard intercepts for calculating lengths from scale measurements for some centrarchid and percid fishes. *Transactions of the American Fisheries Society* 111:332-336.

- Carpenter, S. R., and J. F. Kitchell. 1993. The trophic cascade in lakes. Cambridge University Press, Cambridge, Great Britian.
- Carpenter, S. R., and D. M. Lodge. 1986. Effects of submersed macrophytes on ecosystem processes. *Aquatic Botany* 26:341-370.
- Carpenter, S. R., A. Munoz-Del-Rio, S. Newman, P. W. Rasmussen, and B. M. Johnson. 1994. Interactions of anglers and walleyes in Escanaba Lake, Wisconsin. *Ecological Applications* 4:822-832.
- Carpenter, S. R., M. Olson, P. Cunningham, S. Gafny, N. Nibbelink, T. Pellett, C. Storlie, A. Trebitz, and K. Wilson. 1998. Macrophyte structure and growth of bluegill (*Lepomis macrochirus*): design of a multilake experiment. Pages 217-226 in E. Jeppesen, Ma. Sondergaard, Mo. Sondergaard, and K. Christoffersen, editors. *The Structuring Role of Submerged Macrophytes in Lakes*. Springer Verlag, Berlin.
- Churchill, W. 1957. Conclusions from a ten-year creel census on a lake with no angling restrictions. *Journal of Wildlife Management* 21:182-188.
- Colle, D. E., J. V. Shireman. 1980. Coefficients of condition for largemouth bass, bluegill, and redear sunfish in hydrilla-infested lakes. *Transactions of the American Fisheries Society* 109:521-531.
- Colle, D. E., J. V. Shireman, W. T. Haller, J. C. Joyce and D. E. Canfield Jr. 1987. Influence of hydrilla on harvestable sport fish populations, angler use, and angler expenditures at Orange Lake, Florida. *North American Journal of Fish Management* 7:410-417.
- Cochran, W. G. 1977. *Sampling Techniques*, 2cnd edition. Wiley, New York.
- Cross, T. K., M. C. McInerny, and R. A. Davis. 1992. Macrophyte removal to enhance bluegill, largemouth bass and northern pike populations. Minnesota Department of Natural Resources Investigational Report 415, St. Paul.
- Crowder, L. B., and W. E. Cooper. 1979. Structural complexity and fish-prey interactions in ponds: A point of view. Pages 2-10 in D. L. Johnson and R. A. Stein, (editors). *Response of fish to habitat structure in standing water*. North Central Division American Fisheries Society Special Publication 6.

- Crowder, L. B., and W. E. Cooper. 1982. Habitat structural complexity and the interaction between bluegills and their prey. *Ecology* 63:1802-1813.
- Durocher, P. P., W. C. Provine, and J. E. Kraai. 1984. Relationship between abundance of largemouth bass and submerged vegetation in Texas reservoirs. *North American Journal of Fish Management* 4:84-88.
- Engel, S. 1985. Aquatic community interactions of submerged macrophytes. Wisconsin Department of Natural Resources Technical Bulletin No. 156.
- Engel, S. 1987. The impact of submerged macrophytes on largemouth bass and bluegills. *Lake and Reservoir Management* 3:227-224.
- Gocietas, V., and P. Colgan. 1987. Selection between densities of artificial vegetation by young bluegills avoiding predation. *Transactions of the American Fisheries Society* 116:40-49.
- Heck, K. L. Jr., and L. B. Crowder. 1991. Habitat structure and predator-prey interactions in vegetated aquatic systems. Pages 281-299 in S. S. Bell, E. D. McCoy, and H. R. Mushinsky, (editors). *Habitat Structure and the Physical Arrangement of Objects in Space*. Chapman and Hall, New York.
- Houser, A. 1963. Loss of weight of sunfish following aquatic vegetation control using the herbicide silvex. *Proceedings of Oklahoma Academy of Science* 43: 232-237.
- Hoyer, M. V., and D. E. Canfield, Jr. 1996. Largemouth bass abundance and aquatic vegetation in Florida Lakes: An empirical analysis. *Journal of Aquatic Plant Management* 34:23-32.
- Johnson, B. M. 1993. Toward a holistic recreational fisheries management: fish-angler-management interactions in Lake Mendota, Wisconsin. Doctoral dissertation. University of Wisconsin, Madison.
- Johnson, B. M., and S. R. Carpenter. 1994. Functional and numerical responses: a framework for fish-angler interactions? *Ecological Applications* 4:808-821.
- Johnson, B. M., and M. D. Staggs. 1992. The Fishery. Pages 353-375 in J. F. Kitchell, editor. *Food Web Management: A Case Study of Lake Mendota, Wisconsin*. Springer Verlag, Berlin.

- Jones, C. M., D. S. Robson, H. D. Lakkis, and J. Kressel. 1995. Properties of catch rates used in analysis of angler surveys. *Transactions of the American Fisheries Society* 124:911-928.
- Judd, J. and S. Taub. 1973. The effects of the ecological changes on Buckeye Lake, Ohio with emphasis on largemouth bass and aquatic vascular plants. Ohio Biological Survey, Biological Notes No. 6. 51 pp.
- Keast, A. 1983. The introduced aquatic macrophyte, *Myriophyllum spicatum*, as habitat for fish and their invertebrate prey. *Canadian Journal of Zoology* 62:1289-1303.
- Kempinger, J. J., W. S. Churchill, G. R. Priegel, and L. M. Christenson. 1975. Estimate of abundance, harvest and exploitation of the fish population of Escanaba Lake, Wisconsin, 1946-69. Wisconsin Department of Natural Resources, Technical Bulletin 84, Madison.
- Kilgore, K. J., R. P. Morgan, and N. B. Rybicki. 1989. Distribution and abundance of fishes associated with submersed aquatic plants in the Potomac River. *North American Journal of Fisheries Management* 9:101-111.
- Kitchell, J. F. 1992. Food web management: a case study of Lake Mendota. Springer Verlag, New York.
- Lathrop, R. C., S. B. Nehls, C. L. Brynildson, and K. R. Plass. 1992. The fishery of the Yahara Lakes. Wisconsin Department of Natural Resources, Technical Bulletin No. 181, Madison.
- Lillie, R. A. 1996. A quantitative survey of the floating-leafed and submersed macrophytes of Fish Lake, Dane County, Wisconsin. *Transactions of the Wisconsin Academy of Sciences, Arts, and Letters* 84:111-125
- Lillie, R. A. and S. A. Nichols. 1997. A taxonomic inventory of aquatic macrophytes found in Fish Lake. Pages 17-19 *in* T. D. Pellett, editor. Pretreatment results of the Fish Lake project, fishery and aquatic community responses to mechanical harvesting of aquatic macrophytes: Evaluating edge effect. Wisconsin Department of Natural Resources, Research Report Publ-RS-924-96, Madison.

- Lux, F. E. and L. L. Smith, Jr. 1960. Some factors influencing seasonal changes in angler catch in a Minnesota lake. *Transactions of the American Fisheries Society* 89:67-79.
- Maceina, M. J., and W. C. Reeves. 1996. Relations between submersed macrophyte abundance and largemouth bass tournament success on two Tennessee River impoundments. *Journal of Aquatic Plant Management* 34:33-38.
- Marshall, D. 1990. Managing deep water stands of Eurasian watermilfoil to improve fish habitat and boating access. Wisconsin Department on Natural Resources Unpublished Report.
- Miranda, L. E., K. B. Hodges, and L. L. Pugh. 1996. Aquatic vegetation influences on growth and recruitment of Age-0 largemouth bass in Aliceville Lake, Mississippi Cooperative Fish and Wildlife Research Unit, Completion Report, Mississippi State University.
- Miranda, L. E., and L. L. Pugh. 1997. Relationship between vegetation coverage and abundance, size and diet of juvenile largemouth bass during winter. *North American Journal of Fisheries Management* 17:601-610.
- Mitzner, L. 1978. Evaluation of biological control of nuisance aquatic vegetation by grass carp. *Transactions of the American Fisheries Society* 107:135-145.
- Moxely, D. J., and F. H. Langford. 1982. Beneficial effects of hydrilla on two eutrophic lakes in Central Florida. *Proceedings Annual Conference for the Southeast Association of Fish and Wildlife Agencies* 36:280-286.
- Newman, S. P., P. W. Rasmussen, and L. M. Andrews. 1997. Comparison of a stratified, instantaneous count creel survey with a complete mandatory creel census on Escanaba Lake, Wisconsin. *North American Journal of Fisheries Management* 17:321-330.
- Nibbelink, N. P., and S. R. Carpenter. 1998. Interlake variation in growth and size structure of bluegill (*Lepomis macrochirus*): inverse analysis of an individual-based model. *Canadian Journal of Fisheries and Aquatic Science* 55:387-396.

- Olson, M. H., S. R. Carpenter, P. Cunningham, S. Gafny, B. R. Herwig, N. P. Nibbelink, T. Pellett, C. Storlie, A. S. Trebitz, and K. A. Wilson. 1998. Managing macrophytes to improve fish growth: A multi-lake experiment. *Fisheries* 23(2):6-12.
- Osenberg, C. W., E. E. Werner, G. G. Mittelbach, and D. J. Hall. 1987. Growth patterns in bluegill (*Lepomis macrochirus*) and pumpkinseed (*Lepomis gibbosus*) sunfish: Environmental variation and the importance of ontogenetic niche shifts. *Canadian Journal of Fisheries and Aquatic Sciences* 45:17-26.
- Pellett, T. D. 1997. Pretreatment results of the Fish Lake project, fishery and aquatic community responses to mechanical harvesting of aquatic macrophytes: Evaluating edge effect. Wisconsin Department of Natural Resources, Research Report Publ-RS-924-97, Madison.
- Pollock, K. H., C. M. Jones, and T. L. Brown. 1994. Angler survey methods and their applications in fisheries management. American Fisheries Society Special Publication 25, Bethesda, Maryland.
- Rasmussen, P. W., M. D. Staggs, T. D. Beard Jr., and S. P. Newman. 1998. Bias and confidence interval coverage of creel survey estimators evaluated by simulation. *Transactions of the American Fisheries Society* 127:469-480.
- Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Bulletin 191. Fisheries Research Board of Canada.
- Ricker, W. E. 1980. Causes of the decrease in age and size of Chinook Salmon (*Oncorhynchus Tshawytscha*). Canadian Technical Report of Fisheries and Aquatic Sciences. No. 944.
- Robson, D. S., and C. M. Jones. 1989. The theoretical basis of an access site angler survey design. *Biometrics* 45:83-98.
- 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* 111:255-265.
- Savino, J. F., and R. A. Stein. 1989. Behavioural interactions between fish predators and their prey: effects of plant density. *Animal Behavior* 37:311-321.

- Savino, J. F., E. A. Marschall, and R. A. Stein. 1992. Bluegill growth as modified by plant density: an exploration of underlying mechanisms. *Oecologia* 89:153-160.
- Sloey, D., and T. Schenck. 1997. Fish diet analysis: Fish Lake (1992-1994). Pages 69-81 in T. D. Pellett, editor. Pretreatment results of the Fish Lake project, fishery and aquatic community responses to mechanical harvesting of aquatic macrophytes: Evaluating edge effect. Wisconsin Department of Natural Resources, Research Report Publ-RS-924-96, Madison.
- Sloey, D., T. Schenck, and R. Narf. 1997. Distribution of aquatic invertebrates within a dense bed of Eurasian milfoil (*Myriophyllum spicatum* L.). *Journal of Freshwater Ecology* 12:303-313.
- Smith, K. D. 1993. Vegetation-open water interface and the predator-prey interaction between largemouth bass and bluegills. Doctoral dissertation, University of Michigan, Ann Arbor.
- Smith, K. D. 1995. Vegetation-open water interface and the predatory-prey interaction between largemouth bass and bluegills: a field experiment. Michigan Department of Natural Resources, Research Report 2000, Lansing.
- Smith, S. M., and D. J. Orth. 1990. Distributions of largemouth bass in relation to submerged aquatic vegetation in Flat Top Lake, West Virginia. *Proceedings Annual Conference of the Southeast Association of Fish and Wildlife Agencies* 44:36-44.
- Sokal, R. R., and F. J. Rohlf. 1981. *Biometry*, 2nd edition, Freeman, San Francisco.
- Storlie, C. H., T. D. Pellett, D. J. Sloey, and J. M. L. Unmuth. 1995. Some macrophyte, invertebrate, fish associations in a *Myriophyllum spicatum* lake: Will increasing the "edge" change anything? Pages 263-272 in *Proceedings of the 29th Annual Meeting, Aquatic Plant Control Research Program*. Miscellaneous paper A-95-3, U. S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi.

- Strange, R. J., C. R. Berry, and C. B. Schreck. 1975. Aquatic plant control and reservoir fisheries. Pages 513-521 *in* R. H. Stroud and H. Clepper, editors. Black Bass Biology and Management. Sport Fishing Institute, Washington, D.C.
- Swingle, H., S. 1946. Experiments with combinations of largemouth black bass, bluegills, and minnows in ponds. Transactions of American Fisheries Society 76:46-62.
- Trebitz, A. S. 1995. Predicting bluegill and largemouth bass response to harvest of aquatic vegetation. Doctoral dissertation. University of Wisconsin, Madison.
- Trebitz, A. S., and N. Nibbelink. 1996. Effect of pattern of vegetation removal on growth of bluegill: a simple model. Canadian Journal of Fisheries and Aquatic Science 53:1844-1851.
- Trebitz, A., S. Carpenter, P. Cunningham, B. Johnson, R. Lillie, D. Marshall, T. Martin, R. Narf, T. Pellett, S. Stewart, C. Storlie, and J. Unmuth. 1997. A model of bluegill-largemouth bass interactions in relation to aquatic vegetation and its management. Ecological Modelling 94:139-156.
- Unmuth, J. M. L., R. A. Lillie and C. H. Storlie. 1997. The harvest - August 1994: an assessment. Pages 97-100 *in* T. D. Pellett, editor. Pretreatment results of the Fish Lake project, fishery and aquatic community responses to mechanical harvesting of aquatic macrophytes: Evaluating edge effect. Wisconsin Department of Natural Resources, Research Report Publ-RS-924-96, Madison.
- Unmuth, J. M. L., D. J. Sloey, and R. A. Lillie. 1998. An evaluation of close-cut mechanical harvesting of Eurasian watermilfoil. Journal of Aquatic Plant Management. In press.
- Werner, E. E., and D. J. Hall. 1977. Density and competition among sunfish: Some alternatives. Science 195:94-95.
- Werner, E. E., and D. J. Hall. 1988. Ontogenetic habitat shifts in bluegill: the foraging rate-predation risk trade-off. Ecology 69:1352-1366.

- Wiley, M. J., R. W. Gorden, S. W. Waite, 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.
- Wrenn, W. B., D. R. Lowery, M. J. Maceina, and W. C. Reeves. 1996. Relationships between largemouth bass and aquatic plants in Guntersville Reservoir, Alabama. *American Fisheries Society Symposium* 16:382-393.