Integrated Management of Macrophytes and Fisheries

University of Wisconsin- Madison, Center for Limnology

Final Report 1997

by

Brian R. Herwig[1]

and

Karen A. Wilson[1]

to the

Wisconsin Department of Natural Resources

Principal Investigator: Stephen R. Carpenter[1]

W.D.N.R. Project Coordinator: Paul Cunningham[2]

1. Center for Limnology, University of Wisconsin- Madison, 680 North Park Street, Madison, WI 53706

2. Wisconsin Department of Natural Resources, Bureau of Fisheries Management, 101 S. Webster Street, P.O. Box 7921, Madison, WI 53707-7921.

Acknowledgment of Funding

This research was funded by the Federal Aid to Sport Fishing Restoration Act administered through the Wisconsin Department of Natural Resources, project F-95-P; the National Science Foundation North Temperate Lakes Long-Term Ecological Research Program; the Andrew Mellon Foundation; the University of Wisconsin, Department of Zoology; and the University of Wisconsin, Center for Limnology.

CONTENTS

1. Abstract

North American lakes with heavy infestations of nuisance macrophytes (e.g.- Eurasian watermilfoil, *Myriophyllum spicatum*) are often associated with slow growing populations of bluegill (*Lepomis macrochirus*) and largemouth bass (*Micropterus salmoides*). Reducing macrophyte densities has often been suggested as one way of improving fish growth in such lakes. We conducted a series of planning and modeling exercises to optimize the design of a multi-lake study designed to test the effects of macrophyte harvesting on growth of bluegill and largemouth bass. From a large group of candidate lakes, we selected thirteen lakes in southern and central Wisconsin for study. These had slow growing bluegill populations and were dominated by watermilfoil and other fine-leafed macrophytes. In 1994, macrophytes were mechanically removed from approximately 20% of the littoral zone in four lakes selected for experimental manipulation. The other nine lakes served as unmanipulated controls. Macrophytes were removed in a series of deep channels spaced evenly around the lake with a macrophyte harvester retrofitted with a deep cutting bar to remove macrophytes at the plant-sediment interface at depths deeper than those reached with a commercial harvester.

We observed significant increases in the growth of some age classes of bluegill and largemouth bass in the harvested lakes in the first full year after manipulation. These increases in growth were observed despite rapid re-growth of macrophytes in the harvested lakes. Fewer than 25% of the channels were visible two years after the manipulation. Our results suggest that removing about 20% of the fine-leafed macrophytes, such as watermilfoil, from the littoral zone of heavily infested lakes may be a valuable tool for improving the growth rates of bluegill and largemouth bass.

2. Introduction

Dense beds of aquatic vegetation represent a major problem for the management of many inland lakes throughout Wisconsin. For example, high densities of macrophytes, especially those that grow at or near the surface, can severely reduce the aesthetic value of a lake, especially for swimming, angling and boating. In response to the concerns of lake users, lake managers routinely use chemical or mechanical techniques to remove macrophytes from the entire littoral zone. Unfortunately, strategies directed at removing nuisance vegetation may come at a cost to the fishery. Macrophytes play an important role in the ecology of many fishes, serving as a refuge for small fish, a substrate for spawning, and a habitat for valuable invertebrate prey. Completely removing macrophytes from the littoral zone may therefore have strong negative impacts on fishes. However, the relationship between macrophytes and fishes is complex, and high densities of macrophytes may also be detrimental to fish. In particular, numerous studies have found that fish feeding rates (and thus growth rates) decline at high plant densities. Therefore, it is theoretically possible to maintain macrophytes at a density that enhances both the aesthetic value and the quality of the fishery. The primary goal of the Littoral Zone Fisheries Project is to integrate plant and fish management to meet both of these goals.

The idea of improving fish growth through macrophyte management is not new. However, previous studies of fish-macrophyte interactions have given inconclusive or inconsistent results, and have provided little in the way of guidance for fish managers. One problem with many of these studies is that they were often conducted at small scales (e.g. enclosures or small ponds) which do not accurately reflect the spatial scale at which fish and macrophytes interact. Other studies were performed on whole lakes (or bays in lakes), but these were typically unreplicated and results were difficult to generalize. Our experiment attempts to overcome the problem of previous studies by conducting a replicated experiment at the scale of whole lakes.

The first step in assessing the potential for improving fish growth through macrophyte manipulations was to determine the amount of vegetation that must be removed to maximize fish growth. In 1992, an intensive modeling effort, led by Dr. Anett Trebitz (now with the Environmental Protection Agency, Duluth MN) predicted that the removal of approximately 20% of the vegetation provides optimal fish growth responses (Trebitz 1995). Central to this prediction is the fact that macrophytes must be removed in a series of channels. This strategy increases the amount of edge (i.e., the interface between open water and vegetation), which is an important zone of interaction in many lakes.

In 1993, an intensive lake survey was conducted to facilitate the selection of lakes for the experiment, and to collect pre-treatment data for those lakes to be chosen as study lakes (Fig.1). Lakes were initially chosen for the 1993 survey based on (WDNR) state data-bases and communications from lake managers. Lake selection criteria included: a history of Eurasian watermilfoil (*Myriophyllum spicatum*) infestation (or other aquatic plant problems), at least 25% of the surface area of the lake must be covered by dense beds of macrophytes, slow growing bluegill populations, small size (less than about 140 ha, for easy manipulation), closed basin (absence of stream connections to prevent mixing of fish populations between lakes), thermally stratified in summer, lakes where the occurrence of winterkills is unlikely (<1 in 10 years), and lakes must have no history of significant management actions that might confound the experiment. Lakes were initially chosen for the 1993 survey based on (WDNR) state data-bases and communications from lake managers. Final lake selections were based on bluegill growth (Fig. 2) and aquatic plant characteristics of each lake (Table 1). Because of the lack of small, closed-basin lakes that were completely dominated by *M. spicatum*, the study group was extended to include lakes with native milfoils and other fine-leafed macrophytes. In addition, treatment (cut) lakes had to have a well developed boat landing that could accommodate the harvesting equipment. Lake-user groups were consulted and public meetings held to solicit opinions about and garner support for the proposed cutting in candidate lakes.

A few lakes in the study were not part of the original, or the final study group. Carsten's Lake was sampled in 1993 and 1994, but dropped from the study because of a partial winterkill that occurred in the winter of 1993-1994. Gibbs Lake was included in the study in 1994 because of the high dominance of *M. spicatum* in the lake, and harvested in 1995, one year after the other cut lakes. Gibbs Lake was not included in the final analyses because we did not have a full year of post-manipulation data by the termination of the project. Finally, Harpt and White Mound lakes were sampled throughout the project, despite having better over-all growth rates of bluegill than the rest of the study lakes. These two lakes served as reference lakes for many individual projects over the years and have been included (in terms of the change in growth over years) as control lakes in one version of the fish growth analysis.

The statistical power to detect effects in a multi-lake experiment depends on the Inter-lake variance of the response variable, the number of lakes in the study, and the expected magnitude of the response. To optimize the study design, we first conducted a modeling exercise with 1993 data to determine the effects of sample size (number of lakes) on our ability to detect changes in various fish variates due to our manipulations (Carpenter et al. 1995). We considered four possible response variables for bluegill: length-at-age, parameters of growth curves (length or mass versus age), length-specific growth rates (hereafter referred to as growth), and population sizes. After some initial trials, we focused our efforts on a replicated, one-way

ANOVA-type study design in which changes in response variates (post-treatment minus pre-treatment) were measured in both the cut and control lakes, and compared using t-tests. We tested lake sample sizes of 3, 5 or 10 lakes per group (cut or control). This power analysis revealed that growth responses gave the greatest probability of response to the treatment and that five treatment lakes would provide enough power to confidently detect treatment effects. Consequently, the final study design was based on a five-sample design with growth as the response variable.

3. Summary of Methods

In general, we maintained the same methods used in the 1993 intensive survey in the following years. In 1994, we continued collection of pre-treatment data in the spring, and in mid- to late summer, we mechanically harvested macrophytes from a set of four lakes (Gibbs Lake was cut in 1995). Nine lakes were chosen as unmanipulated controls for purposes of comparison. In 1995 and 1996 field seasons we collected data necessary for determining fish growth responses to the manipulation. An overview of the project is presented below, and data available for each lake are summarized in Table 2.

A. Fish Sampling:

Sampling protocol remained similar throughout the project (1993, 1994, 1995, 1996). To examine fish growth responses to macrophyte harvesting, we measured total fish length and live mass and collected scale samples (for age determination) from bluegill and largemouth bass. Fish were collected by electroshocking with boat mounted electroshocking gear (beginning just after sunset) for 30 minutes in lakes < 40 ha, and for two 30 minute runs in lakes >40 ha. Fish were collected after they were shocked by two people dip netting from the bow of the boat. The first 30 minute run in each lake was designed to collect all species and sizes of fish (except carp). We electroshocked for additional time to fill out fish size classes for scales and lengths. After each electroshocking run, we identified and recorded total lengths of all fish captured. Depending on the year, we took weights and scales from 10-15 bluegill in each 10 mm size class. Fish scales were removed from behind the left or right pectoral fin of each fish weighed. Shocking transects were generally begun next to the boat launch, but did not necessarily cover the same areas in the lake each year. Electroshocking transects ran parallel to shore at depths less than 2 m. Electroshocking was done with DC pulse and the amperage was maintained between 9-12 amps. To quantify environmental conditions in each lake, temperature profiles and zooplankton samples were collected prior to fish sampling, just before sunset.

Fish were sampled in the spring for all years of the study. Data collected in the spring was used to determine annual growth rates for the entire previous growing season (summer) for comparison with previous years. Additional samples were taken throughout the summer in 1994 on a subset of lakes. All lakes were sampled in the fall of 1995 to determine growth for an initial estimate of growth change in response to the macrophyte harvesting. However, 1996 and 1994 spring data were used for the final growth analyses (corresponding to the 1995 and 1993 growing seasons), giving one year before cutting, and one year after cutting.

B. Macrophyte Sampling:

Macrophytes were sampled in mid summer (July 10-27) in 1993, 1994 and 1995. In each lake, plant community composition and relative abundance were quantified using a rake method (Deppe and Lathrop 1992). In 1993, four transects were made in each of the major compass headings, unless that lake was greater than 40 acres, in which an additional four transects were added between the first four transects (Fig. 3). Each transect began at the shore, and extended perpendicular into the lake. At one meter depth intervals, four casts of the rake were made (one off each corner of the boat), and plant species and abundance determined for each rake-full retrieved. In 1993, field workers continued sampling progressive depths until a depth was reached at which no macrophytes were found. In 1994 and 1995, field workers sampled until five meters, unless they reached a lesser depth at which no plants were found. In 1994 and 1995, eight transects were sampled on all lakes except Wingra and Fish; 12 transects were used to quantify the macrophytes on these larger lakes. SONAR transects were used to confirm plant presence. Air photos were taken in 1993 (most surveyed lakes), 1994 (cut lakes only), 1995 (cut lakes only), and 1996 (all study lakes). See Appendix 1 for copies of air photos.

In 1996, macrophyte sampling was modified from that of past years to better reflect the need to quantify channel persistence and macrophyte bed patchiness in the cut and control lakes. Air photos were taken mid-summer to assess channel persistence. In addition, two and three meter depth contours of each study lake were surveyed for channels using SONAR.

C. Macrophyte Harvesting:

Fish Lake (Dane County), Silver Lake (Waupaca County), Tuma Lake (Manitowoc County) and Heidmanns Lake (Kewaunee County) were harvested in the summer of 1994. Gibbs Lake (Rock County) was harvested in 1995, but was not included in the final data analyses. Details of the lake manipulations are summarized in Table 3.

Channels were cut through the macrophyte beds using both conventional macrophyte harvesters and a harvester equipped with a specially designed, deep-water cutting bar. In both cases, macrophytes were cut as close to the sediment-water interface as possible to reduce regrowth. The deep-cutting equipment was designed, built and operated by Ken Koscik, Joe Yeager and staff in the Dane County Public Works Lakes Management Program. The deep-cutting bar was used to cut channels 2 m in width from 2 to 5 meters in depth. The conventional harvester was used to cut 3 m wide channels in depths shallower than 2 m, and to collect floating macrophytes that had been cut using the deep-cutting bar. Channels were cut perpendicular to shore (Fig. 4) at approximately 10 m intervals. This cutting design was the simplest possible that satisfied the edge-creation and macrophyte-removal criteria, allowed anglers and boaters access to the open waters of the lake, and allowed the flexibility to cut some channels directly to private docks or boat landings.

D. Analyses:

<u>1. Fish Growth:</u>

Fish growth responses to the manipulation were evaluated from fish scale data collected in the spring of 1993, 1994 and 1996. Scales were used to back-calculate the change in total fish length during the 1992 growing season (two years before manipulations), the 1993 growing season (one year before the manipulations) and during the 1995 growing season (the first full year after the manipulations). Bluegill scales were read using an Optimus optical imaging system, and weight and length at age back-calculated from annuli using programs written by T. Ehlinger (University of Wisconsin- Milwaukee) and D. Fago (Wisconsin Department of Natural Resources). Largemouth bass scales were measured manually using a microfiche reader. Length at age and weight at age were back-calculated using the Fraser-Lee method (Tesch 1968) in a program written by Mark Olson (Cornell Biological Field Station). The 1994 growing season was not used in the analyses because the lakes were manipulated in the middle of that growing season.

Lakes were grouped by cut (treatment) and control. For each lake-year, the mean change in total length (= growth) was calculated for each age class. We then took the difference in mean growth between the years of interest for each age class in each lake. Student t-tests were then used to compare the difference in mean growth for each age class in cut vs. control lakes (Fig.5).

Student t-test results do not, however, provide any insight as to the magnitude and pattern of growth responses. Thus, results from the t-tests and associated standard errors were used to generate probability distributions of growth differences between cut and control lakes. These probability distributions are Bayesian posterior distributions based on a diffuse posterior distribution. They can be interpreted directly as the probability of a given effect, which in our case is the probability of increased or decreased fish growth. Figure 6 shows an example distribution, and can be interpreted as follows. The height of the curve at the peak (0.07) represents the probability of a change in growth of approximately 8 mm. For any given growth increment (x-axis value), the height of the curve gives the probability of the growth increment. For example, the probability that the growth increment is zero is about 0.025. The shaded area under the curve to the right of zero is the probability of increased growth in the cut lakes relative to control lakes. The area under the curve to the left of zero is the probability of decreased growth in cut lakes relative to the control lakes. In this case, the probability that the cut increased growth is considerably larger than the probability that the cut decreased growth.

In the results we have presented two analyses of the available data. For both analyses, largemouth bass and bluegill were treated in the same manner. In the first analysis, we have included data from Harpt and White Mound, the two lakes that were sampled throughout the project, but were not part of the original study lake group. Harpt and White Mound Lakes represent valuable sources of information on bluegill growth in Wisconsin lakes during the years of our study. Although Harpt and White Mound had initial growth rates greater than the other study lakes, we feel that the inclusion of the lakes in the final analyses is warranted because (a) we are looking at the *change* in fish growth across years not absolute growth rate in a particular year; (b) information on whole lake changes over time is rare, and thus we felt that we should utilize all data available; and (c) more lakes give the statistical analysis more degrees of freedom and therefore increases the statistical power to detect treatment effects.

However, a possible criticism of this analysis is that Harpt and White Mound Lakes did not meet many of the original criteria set for lake selection. Bluegill growth was relatively good in both lakes, and, at least in White Mound, some macrophyte harvesting was done during the course of the project. Although we have no reason to believe that these lakes are not representative, we have also presented the analysis without the Harpt and White Mound data for comparison. The differences between the two analyses are slight.

2. CPUE and Length at Age:

We did not analyze CPUE, length frequency, or length at age data, but we did calculate and compile these data. We summarized CPUEs for all species (Appendix 3) and length-frequencies for largemouth bass and bluegill (Appendix 4). Both summaries were compiled from data for fishes collected during the first 30 minute electroshocking run performed on each lake, because additional runs were often use to fill out bass and bluegill size classes. Length at age summaries (combined from all spring shocking runs in a lake) are compiled in Appendices 5 and 6.

3. Channel Persistence

Channel persistence was derived from air photos taken in 1994, immediately after the cuts were made, and photos taken in 1995 and 1996. 1995 was a low water clarity year in all lakes, making channel detection difficult. We counted the number and length of visible channels from the air photos, but were not able to compare the persistence of individual channels. SONAR was used to detect the presence of channels along 2 and 3 m depth contours.

4. Results

A. Fish Growth Responses:

We chose to analyze age-specific growth rates (age-specific growth) because we determined from a modeling exercise that our statistical power to detect effects would highest if we used age-specific growth as our response variate (Carpenter et al. 1995).

Student t-test results of bluegill growth comparisons between cut and control lakes indicates that macrophyte harvesting significantly improves the growth of age-4 bluegill in both analyses, and both age-3 and age-4 bluegill when Harpt and White Mound Lakes are included in the analysis (Table 4). See Appendix 8 for t-test results including other years.

A Bayesian analysis of bluegill growth results shows that macrophyte harvesting has a high probability of increasing age-3 and age-4 bluegill growth, on average, 10 mm (Fig. 8a &b). A 10 mm increase in growth for an age-3 or age-4 bluegill represents a 40% improvement in fish growth. With the exception of the age-2 bluegill in the analysis in which Harpt and White Mound were not included (Fig. 8b), all age classes did slightly better in the cut lakes.

Macrophyte harvesting had more variable effects on largemouth bass growth. In general, bass in the cut lakes did not grow significantly better or worse than those fish in the control lakes (Table 5). However, there is some indication that age-4 and age-5 fish grew better, on average, in lakes where macrophytes were harvested (Fig. 9a&b).

B. Channel Persistence:

Channels were still visible from the air in 1996 in all but Heidmanns Lake. From 1994 to 1996, there was a dramatic decrease in the number of channels visible from the air (Fig. 10) due to macrophyte regrowth. We did not quantify channel persistence in 1995 because there seemed to be a study-wide drop in water clarity in 1995, making it difficult to distinguish macrophytes in the 1995 air photos. We were not able to use SONAR as estimates of channel persistence. Although channels were often visible on the SONAR charts, the detectability of the channels depended strongly on the depth of the SONAR and the condition of the macrophytes. For example, it is difficult to follow specific depth contours when using SONAR due to the irregular bottom of lakes. Often data is collected in sections of the lake deeper than the specified depth strata. This data is unusable and the channel survey becomes incomplete. SONAR also becomes impractical when plants come to the surface because the transducer gets caught in the plants which interferes with the signal. Interpreting SONAR graphs also becomes problematic when older plants fold over channels and natural patchiness can make it difficult to discern between artificial and natural channels. It should be noted that the best channel persistence seemed to occur in the lakes more heavily dominated with milfoil (Fish Lake, and, from visual inspection, Gibbs Lake). We also found that cutting into bog mats (Heidmanns Lake) loosens and breaks up the mats, causing bits of bog mat to break loose and float around the lake up to a year after the manipulation.

5. Conclusions

The macrophyte manipulation in our study lakes was a pulse experiment. The system was manipulated in a substantial way, but only once. Fewer than 25% of the channels were visible two years after the manipulation. Channels would have to be re-cut occasionally for long term channel persistence due to the rapid regrowth and recolonization of aquatic macrophytes.

We found that channels significantly improved the growth of some age classes of bluegill and there is a good probability that the growth rates of most age classes of bluegill were increased in the cut lakes.

We also found that bass were not significantly affected by the manipulation, although most age classes showed a positive change in growth in the cut lakes relative to the control lakes.

These results show that removing about 20% of the fine-leafed macrophytes, such as Eurasian watermilfoil, in a series of evenly-spaced channels from the littoral zone of heavily infested lakes with slow growing bluegill and largemouth bass populations may be a valuable tool for improving the growth rates of some age classes of bluegill and largemouth bass. These channels simultaneously improve fish growth, reduce nuisance macrophytes and improve the recreational value of the lake by improving access to fishing areas, docks and swimming beaches.

If Gibbs Lake were sampled in 1997, we recommend that all the study lakes (cut and control) be sampled for age-specific growth rates of bluegill and largemouth to account for year to year variability in growing conditions. If Gibbs were sampled in 1997, we could obtain one full year of growth data following the manipulation, but the other four treatment lakes which would be pooled with the Gibbs Lake data and compared to growth in the control lakes are an additional year removed from the manipulation. The effects of the manipulation may have a minimal influence on fish growth in the four lakes manipulated in 1994 as most of the channels no longer exist in these lakes. This would tend to decrease the probability of finding improved fish growth in 1996 due to the manipulation.

6. Cumulative Project Personnel

Principal Investigators:	Dr. Stephen R. Carpenter[1]
	Dr. John J. Magnuson[1]
Research Associate:	Dr. Mark H. Olson[2]
	Dr. Sarig Gafny[3]
	Dr. Thomas Martin[4]
Graduate Students:	Nathan P. Nibbelink, MS (advisor: Dr. Carpenter)[5]
	Anett S. Trebitz, Ph.D. (advisor: Dr. Carpenter)[6]
	Melissa J. Weaver, Ph.D. (advisor: Dr. Magnuson)[7]
	Karen A. Wilson, MS (advisor: Dr. Magnuson)[1]
Research Technicians:	Brian R. Herwig[8]
Undergraduate Students:	Jon Hricik
	Sarah Huhta
	Catherine McClellan
	Steve Mrazik
	Kyle Tanger

Martha Wessels

Beth Zaniewski

[1]University of Wisconsin-Madison, Center for Limnology, 680 N. Park Street, Madison, WI 53706

[2]Cornell Field Station, 900 Shackelton Point Road, Bridgeport, NY 13030

[3]Institute for Nature Conservation Research, George S. Wise Faculty for Life Sciences, Tel-Aviv University, Ramat-Aviv, TA 69978, Israel

[4]The Pennsylvania State University, 212 Ferguson Building, School of Forest Resources, University Park, PA 16802

[5]University of Wyoming, Department of Zoology and Physiology, PO Box 3166, Laramie, WY 82071

[6]United States Environmental Protection Agency, 6201 Congdon Blvd, Duluth, MN 55804

[7]The Institute for Environmental Modeling, Department of Ecology and Evolutionary Biology, University of Tennessee-Knoxville, 569 Dabney Hall, Knoxville, TN 37996-1610

[8]Illinois Natural History Survey-Center for Aquatic Ecology, University of Illinois, Natural Resources Building, 607 E. Peabody Drive, Champaign, IL 61820

7. **References** (also see Appendix 10 for project related publications)

Carpenter, S. R., Cunningham, P., Gafny, S., Munoz-del-Rio, A., Nibbelink, N., Olson, M., Pellet, T., Storlie, C., Trebitz, A. 1995. Responses of bluegill to habitat manipulations: power to detect effects. North American Journal of Fisheries Management 15:519-527.

Deppe, E.R. and R.C. Lathrop. 1992. A comparison of two aquatic macrophyte rake survey techniques. Research/Management Findings No. 32. Wisconsin Department of Natural Resources, Madison, Wisconsin.

Tesch, F.W. 1968. *In* W.E. Ricker, Methods for Assessment of Fish Production in Fresh Waters. Blackwell Scientific Publications.

Trebitz, A.S. 1995. Predicting bluegill and largemouth bass response to harvest of aquatic macrophytes. Dissertation. University of Wisconsin-Madison.

8. Tables

Table 1. Plant characteristics for lakes surveyed in 1993. Species abbreviations can be found in Appendix 2.

Lake	Year	Survey Date	Max. Depth of Veg. (m)	Ave. Rake Score	Secchi (m)	1st Dominant Species Rel. Freq.	1st Dominant Species Spp.	2nd Dominant Species Rel. Freq.	2nd Dominant Species Spp.
Becker	1993	July 29	2	0.55		0.333333	lilys	0.190476	pcris
Carsten	1993	July 14	4	3.054		0.55914	cdeme	0.301075	mspic
Carsten	1994	July 14	4	0.846	1.75	0.689076	cdeme	0.176471	pcris
Cedar	1993	July 16	4	1.107		0.177885	chara	0.158654	probb
Comstock	1993	June 30	4	2.231		0.268817	uvulg	0.247312	chara
E. Alaska	1993	July 27	3	1.3		0.277778	mspic	0.212963	ppect
E. Alaska	1994	July 19	5	1	2.75	0.297521	cdeme	0.214876	ppusi
E. Alaska	1995	July 25	5	0.91	1.25	0.348123	cdeme	0.187713	ppusi
East	1993	July 07	4	2.857		0.322034	chara	0.169492	cdeme
Ennis	1993	June 21	3	1.388		0.465347	chara	0.188119	pprae
Fish	1993	Aug. 24	4	1.455		0.614173	mspic	0.188976	cdeme
Fish	1994	July 05	5	1.085	0.75	0.497525	mixedm	0.339109	cdeme
Fish	1995	July 05	4.5	0.973		0.431953	mspic	0.340237	cdeme
George	1993	July 12	2	0.821		0.476923	najas	0.215385	chara
Gibbs	1995	July 21	4	1.607	2.8	0.577778	cdeme	0.372222	mspic
Harpt	1993	July 22	3	2.604		0.770492	cdeme	0.04918	lilys
Harpt	1994	July 20	5	0.892	3	0.659574	cdeme	0.143617	chara
Harpt	1995	July 10	5	0.773	1.75	0.60625	cdeme	0.1375	msibi
Heidmann	1993	July 23	4	1.391		0.233945	mspic	0.206422	cdeme
Heidmann	1994	July 12	5	1.081	2.25	0.245	cdeme	0.21	mixedm
Heidmann	1995	July 11	5	1.058	3.33	0.201342	cdeme	0.154362	pfoli
Hooker	1993	July 19	4	1.033		0.235294	chara	0.228758	mspic
Horseshoe	1993	July 14	4	1.023		0.227273	mspic	0.181818	chara
Horseshoe	1994	July 18	4	0.951	2.25	0.258065	chara	0.141935	prich
Horseshoe	1995	July 26	3	0.793	1.25	0.26087	chara	0.157609	pfoli
Krohns	1993	July 28	3	1.417		0.463918	chara	0.226804	lilys
Kusel	1993	June 06	5	2.342		0.382514	mixedm	0.245902	chara
Kusel	1994	June 28	5	0.934	2.5	0.290698	chara	0.271318	mspic
Kusel	1995	July 18	5	0.888	2.9	0.320557	mspic	0.205575	chara
Lilly	1993	July 28	3	1.091		0.25641	chara	0.230769	cdeme
Mauthe	1993	Aug. 02	3	3.75		0.27027	mspic	0.260135	cdeme
Mauthe	1994	July 07	3	1.06	2.25	0.367021	cdeme	0.170213	mspic
Mauthe	1995	July 27	5	0.988	2.3	0.212871	cdeme	0.19802	mspic
Mayflower	1993	Aug. 18	4	1.011		0.238095	chara	0.228571	prich
Montello	1993	July 06	3	3.713		0.284615	cdeme	0.211538	ecana
Napowan	1993	Aug. 09	4	1.938		0.232068	mspic	0.177215	ecana
Napowan	1994	June 28	5	1.038	4.33	0.213884	mspic	0.155722	cdeme
Napowan	1995	July 19	5	1.044	3.25	0.192385	mspic	0.190381	cdeme
Potter	1993	July 20	3	1.25		0.24812	cdeme	0.180451	chara
Random	1993	July 08	4	0.828		0.295455	chara	0.193182	mspic
Rice	1993	July 06	3	1.667		0.395062	mspic	0.308642	cdeme
School	1993	July 02	3	2.354		0.555556	chara	0.253968	najas

Lake	Year	Survey Date	Max. Depth of Veg. (m)	Ave. Rake Score	Secchi (m)	1st Dominant Species Rel. Freq.	1st Dominant Species Spp.	2nd Dominant Species Rel. Freq.	2nd Dominant Species Spp.
Sharon	1993	July 25	5	2.338		0.377926	chara	0.133779	najas
Shea	1993	July 23	3	3.227		0.535211	cdeme	0.169014	mspic
Shea	1994	July 11	5	1.307	1.6	0.452282	cdeme	0.165975	chara
Shea	1995	July 12	5	1.241	1.75	0.425414	cdeme	0.226519	chara
Silver	1993	Aug. 19	4	1.267		0.322034	ecana	0.316384	mspic
Silver	1994	June 27	5	1.076	2	0.352751	mspic	0.320388	ecana
Silver	1995	July 17	4	1	2.2	0.457399	mspic	0.242152	ecana
Tuma	1993	July 22	4	1.063		0.284916	mspic	0.24581	pampl
Tuma	1994	June 13	5	0.95	4.25	0.286111	pampl	0.227778	mspic
Tuma	1995	July 24	5	0.917	3.2	0.238845	chara	0.183727	pampl
Twin	1993	July 30	3	1.065		0.327354	chara	0.206278	najas
W. Alaska	1993	July 27	3	2.396		0.325926	chara	0.22963	mspic
Wallace	1993	July 13	4	1.391		0.565217	mspic	0.217391	chara
Wilke	1993	July 14	4	1.211		0.461187	mspic	0.310502	chara
Wingra	1993	Aug. 16	2.5	0.919		0.225	mspic	0.1875	cdeme
Wingra	1994	June 22	3	0.804	1	0.238095	mspic	0.152381	chara
Wingra	1995	June 28	3.5	0.922		0.386243	mspic	0.132275	pzost
Wh.Mound	1993	July 29	3	2.125		0.215517	mspic	0.198276	cdeme
Wh.Mound	1994	June 21	5	1.611	4.3	0.312292	pcris	0.222591	pfoli
Wh.Mound	1995	July 20	5	0.926	1.125	0.266892	pfoli	0.226351	pcris
Wood	1993	June 23	7	2.125		0.36478	chara	0.289308	nitel

Table 2. Description and sampling summary for all lakes sampled for fish or macrophytes during the duration of the study. Lake abbreviations can be found in Appendix 2. Bolded lakes are the thirteen lakes used in the multi-year study of fish growth. Manipulated lakes are indicated as “cut” and unmanipulated lakes are indicted as “control”.

		Approximate		**Lake**		**Years Surveyed**								
		Lat.	**Long.**	**Area**	**Max.**	**Fish**				**Macrophytes**				
Lake	**County**	**(deg.)**	**(deg.)**	**(ha)**	**Depth (m)**	**93**	**94**	**95**	**96**	**93**	**94**	**95**	**96**	**Status**
Becker	Calumet	44.13	88.05	13	16.2	X				X				survey
Big Roche A Cri	Adams	44.06	89.82	83	6.1	X								survey
Big Twin (Twin)	Waushara	44.23	89.13	38	4	X	X							survey
Carstens	Manitowoc	44.03	87.77	9	8.5	X	X			X	X			survey
Cedar	Manitowoc	43.93	87.93	57	6.4	X				X				survey
Comstock	Marquette	43.88	89.27	11	8.9	X				X				survey
East Alaska	**Kewaunee**	**44.55**	**87.5**	**22**	**15.3**	**X**	**X**	**X**	**X**	**X**	**X**	**X**		**control**
East Lk. Flowage	Kenosha	42.62	88.12	47	3.7	X				X				survey
Ennis	Marquette	43.68	89.4	10	9.5	X				X				survey
Fish	**Dane**	**43.28**	**89.65**	**102**	**19**	X_1	X_1	$X_{1,2}$	**X**	**X**	**X**	**X**	*****	**cut**
Friendship	Adams	43.98	89.76	46	4.6	X								survey
George	Kenosha	42.52	88.03	28	4.9	X				X				survey
Gibbs	Rock	42.78	89.18	26	7		X	X	X				*	late cut
Harpt	**Manitowoc**	**44.3**	**87.73**	**13**	**15**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	*****	**control**
Heidmanns	**Kewaunee**	**44.35**	**87.72**	**11**	**9.2**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	*****	**cut**
Hooker	Kenosha	42.55	88.1	41	7.3	X				X				survey
Horseshoe	**Manitowoc**	**43.93**	**87.88**	**9**	**16.5**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	*****	**control**
Krohns	Kewaunee	44.58	89.48	9	11.6	X				X				survey
Kusel	**Waushara**	**44.17**	**89.17**	**32**	**8.9**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	*****	**control**
Lilly	Brown	44.43	87.85	17	5.8	X				X				survey
Mauthe	**Fond du Lac**	**43.6**	**88.18**	**32**	**7.1**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	*****	**control**
Mayflower	Marathon	44.92	89.25	40	4.9	X				X				survey
Montello	Marquette	43.8	89.33	132	5.2					X				survey
Napowan	**Waushara**	**44.15**	**89.15**	**21**	**5.5**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	*****	**control**
Potters	Walworth	42.82	88.35	66	7.9	X				X				survey
Random	Sheboygan	43.55	87.95	85	6.4					X				survey
Rice	Walworth	42.77	88.7	56	3.1	X				X				survey
School Section	Marquette	43.95	89.55	15	3.1	X				X				survey
Sharon	Marquette	43.98	89.45	24	9.2	X				X				survey
Shea	**Kewaunee**	**44.37**	**87.72**	**13**	**7.3**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	*****	**control**
Silver	**Waupaca**	**44.47**	**89.17**	**27.5**	**5.2**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	*****	**cut**
Tuma	**Manitowoc**	**44.28**	**87.73**	**8**	**9.2**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	*****	**cut**
West Alaska	Kewaunee	44.53	87.52	9	9.2	X				X				survey

		Approximate		Lake		Years Surveyed								
		Lat.	Long.	Area	Max.	Fish				Macrophytes				
Lake	**County**	**(deg.)**	**(deg.)**	**(ha)**	**Depth (m)**	**93**	**94**	**95**	**96**	**93**	**94**	**95**	**96**	**Status**
Wallace	Washington	43.45	88.17	21	10.7					X				survey
White Mound	**Sauk**	**43.37**	**90.08**	**42**	**8.5**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	*****	**control**
Wilke	Manitowoc	43.97	87.97	40	5.3	X				X				survey
Wingra	**Dane**	**43.05**	**89.42**	**140**	**4.3**		**X**	**X**	**X**	**X**	**X**	**X**	*****	**control**
Wood	Marquette	43.98	89.48	37	16.2	X				X				survey

1- We do not have original fish data files for Fish Lake (see WDNR).
2- We do not have an original fish data file for Fish Lake,1995, but we do have our own growth file for 1995.
* 1996 air photos available for all study lakes. Channel data (obtained with sonar and air photos) available for all treatment lakes.

Table 3. Summary of Macrophyte Manipulations. Person hours were calculated as the total number of people who worked on the lake times the number of hours each of those people worked at the lake.

Lake	Date	Person hours	Channel(s) Number	Width (m)	Mean length (m)	Total length (m)	Edge created (m)	% of littoral zone cleared
Fish	8/8/94-8/16/94	240	285	2	123.0	35,055	70,110	18.0
Heidmann	8/30/94-9/1/94	104	172	2	43.7	7,516.4	15,032.8	21.3
Silver	8/19/94-8/23/94	178	127	3	93.2	11,836.4	23,672.8	15.2
Tuma	8/25/94-8/29/94	121	108	2	46.5	5,022	10,044	17.0

Table 4: Bluegill t-test Results. Student t-test compares mean growth differences (growth in post-manipulation year minus growth in pre-manipulation year) between cut and uncut lakes. Student t-test statistics are presented as cut minus control.

a. Student t-test results including all lakes.

	G95-G93			
Age	***t***	***Pooled SD***	***d.f.***	***Prob.***
2	0.368	5.706522	9	0.721
3	2.291	4	11	0.043
4	2.978	3.496642	11	0.013
5	1.008	4.22619	11	0.335
6	1.232	3.103084	8	0.253

b. Student t-test results without Harpt and White Mound Lake.

	G95-G93			
Age	***t***	***Pooled SD***	***d.f.***	***Prob.***
2	-0.507	4.921105	7	0.628
3	1.853	4.252563	9	0.097
4	2.47	3.597976	9	0.036
5	0.652	4.107362	9	0.531
6	1.232	3.103084	8	0.253

Table 5: Largemouth bass t-test Results. The t-test compares mean growth differences (growth in post-manipulation year minus growth in pre-manipulation year) between cut and uncut lakes. Student t-test statistics are presented as cut minus control.

a. Student t-test results including all lakes.

	G95-G93			
Age	***t***	***Pooled SD***	***d.f.***	***Prob.***
2	1.16	15.294827	6	0.29
3	-0.137	7.8613138	8	0.894
4	1.496	8.4598930	10	0.166
5	1.955	5.6895140	9	0.082
6	0.71	8.0309859	7	0.5
7	0.107	12.373831	6	0.918

b. Student t-test results without Harpt and White Mound Lake.

	G95 -G93			
Age	***t***	***Pooled SD***	***d.f.***	***Prob.***
2	0.901	17.18535	5	0.409
3	-0.661	8.747352	6	0.533
4	1.559	6.20077	8	0.158
5	2.046	4.694037	7	0.08
6	0.472	9.726695	5	0.657
7	0.107	12.37383	6	0.918

9. Figures

Fig. 1. Map of study lake locations. Stars indicate location of cut lakes and open circles represent the location of control lakes.

Fig. 2. The intercept and slope of the bluegill growth curve for each of the 1993 survey lakes. The large oval encloses those lakes not significantly different from Fish Lake, the original lake in the study. Smaller ovals enclose sets of lakes not significantly different from each other. Student t-tests were used to compare regressions of bluegill growth (length at age) for each lake. Bolded letters represent lakes chosen for the study. Lake name abbreviations are as follows. B= Becker, BR= Big Roche a Cri, BT= Big Twin, C=Comstock, Ca= Carsten's, Ce= Cedar, EA= East Alaska, F=Fish, G= George, Gb= Gibbs, Hd= Heidmanns, Ho= Hooker, Hp= Harpt, Hs= Horseshoe, K= Kusel, Kr= Krohn's, L= Lilly, M= Mauthe, Mf= Mayflower, N= Napowan, P= Potter, R= Rice, S= Silver, Sc= School, Sh= Shea, Sr= Sharon, T= Tuma, Wg= Wingra, WM= White Mound, Wo= Wood, Wi= Wilke, Wa= Wallace, WA= West Alaska.

Fig. 3. Diagram of rake transects in a hypothetical lake. Depth contours (meters) indicate sampling sites along each transect.

Fig. 4. Cut channels in Gibbs Lake, taken 9 Sept. 1995, at 4,250 ft mean sea level.

Fig. 5. Example of calculations of mean growth.

Fig. 6. A Bayesian posterior probability distribution. In this example, there is a high probability (0.07) of a 8 mm change in growth between cut and control lakes. The shaded area under the curve represents the probability of a positive change in growth in the cut lakes; the non-shaded area under the curve represents the probability of a negative change in growth in the cut lakes.

Fig.7. Probability distribution of difference in growth (mm) between cut and control lakes for bluegill age classes, comparing 1995 to 1993. a. Including Harpt and White Mound Lakes. b. Excluding Harpt and White Mound Lakes.

Fig. 8. Probability distribution of difference in growth (mm) between cut and control lakes for largemouth bass age classes, comparing 1995 to 1993. a. Including Harpt and White Mound Lakes. b. Excluding Harpt and White Mound Lakes.

Fig. 9. Macrophyte channel persistence. Channels were counted and measured from air photos taken in August of 1994 and August 1996.

10. Appendices

Appendix 1. Selected air photos.

Appendix 2. Abbreviations for fish species, plant species and lake names found in data sheets and summary files.

Appendix 3. Summary of catch-per-unit-effort for all lakes and years. Data are from the first 30 minute electroshocking run in the spring sampling period.

Appendix 4. Length frequency distributions for bluegill and largemouth bass for the resampled lakes. Lengths are compiled from the first 30 minute electroshocking run made on each lake. In many lakes, we conducted more than one 30 minute shocking run, such that the data presented here does not represent all length/weight/age data for an given lake. Total length is given in 10 mm increments, such that, for example, a 133 mm fish is counted as a 130 mm fish. For each graph, the x-axis scale is from 20 mm to 530 mm.

Appendix 5. Length-at-age summary for bluegill in the study lakes.

Appendix 6. Length-at-age summary for largemouth bass in the study lakes.

Appendix 7. Theses abstracts.

Appendix 8. Student t-tests comparing 1995-1992 and the pretreatment years 1993-1992. There were no significant differences in growth between pre-treatment years.

Appendix 9. Computer files descriptions.

Appendix 10. Project publications (submitted, in press, and published).