This is to certify that the

thesis entitled

The Effects of Eurasian Watermilfoil Reductions
on Largemouth Bass Diet and Growth

presented by

Steven Martin Hanson

has been accepted towards fulfillment
of the requirements for

M.S. degree in Fish. & Wildl.

Mary T Bremigan
Major professor

Date August 14, 2001

THE EFFECTS OF EURASIAN WATERMILFOIL REDUCTIONS ON LARGEMOUTH BASS DIET AND GROWTH

By

Steven Martin Hanson

AN ABSTRACT OF A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Fisheries and Wildlife

2001

Professor Mary T. Bremigan

ABSTRACT

THE EFFECTS OF EURASIAN WATERMILFOIL REDUCTIONS ON LARGEMOUTH BASS DIET AND GROWTH

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Eurasian watermilfoil (hereafter EWM) is thought to alter largemouth bass/bluegill interactions in systems it invades by reducing bass mobility, visibility, and encounter rates with bluegill. Thus, bass foraging ability on bluegill is reduced potentially resulting in poor bass growth. The selectivity of aquatic herbicide SONAR® for EWM, allowed me to evaluate whole-lake EWM reductions on largemouth bass diet and growth. Specifically, I compared the diet and growth of largemouth bass in lakes treated with SONAR® in 1997 to that of reference lakes during pre-and post-treatment time periods. Bass diets from a subset of the study lakes in 1999 indicated there was no differences in bass foraging on bluegill between treatment and reference lakes. However, bass growth increased in the treatment lakes relative to the reference lakes post treatment. The increase in bass growth was limited to bass <200 mm and the projected length at age of bass in the treatment lakes suggested the effect of increased growth would be diminished by the time the bass reach legal capture size. My results suggest EWM negatively effects growth of bass <200 mm and its selective reduction using SONAR® herbicide is an effective tool for aquatic plant and fisheries management.

ACKOWLEDGEMENTS

I would like to thank my wonderful wife Jennie, my adorable daughter Mayah, and my new son Noah for their patience and understanding as I struggled to complete my education and research. I hope I have made them as proud as they have made me. I would also like to thank my major advisor Dr. Mary Bremigan for her always cheerful and encouraging nature, for her patience and understanding, and mostly for taking a chance on me. Without her help, I would have never succeeded in this venture and probably would not have pursued a graduate degree. I also want to thank my friends and family who supported and encouraged me over the past few years. I want to thank all of the people who I had the opportunity to work with on this project, including T. Brunger, K. Cheruvelil, Justin Chiotti, K. Hoffman, A. Mahan, C. Meier, V. Moore, K. Rogers, and R. Valley. Thank you to my committee members, Dr. Geoffrey Habron, Dr. Daniel Hayes, and Dr. Patricia Soranno for all of their help and guidance. I would also like to acknowledge the funding sources for this research including the Aquatic Ecosystem restoration Fund, Aquatic Plant management Society, MSU Agricultural Station, MSU Extension, and the MSU Department of Fisheries and Wildlife. And finally, to Dr. Thomas Coon who leads by example and has shown a genuine concern for myself and the other students in this department. This department would not be the same without his presence.

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INTRODUCTION

Largemouth bass (*Micropterus salmoides*; hereafter bass) are top predators in lake communities. Because bass are primarily piscivorous, their growth and survival depend on prey fish availability (Bettoli et al. 1992, Olson 1996). Although prey fish abundance typically increases with macrophyte density (Crowder and Cooper 1982), the ability of largemouth bass to capture prey has been shown to decline as structural complexity increases (Saiki and Tash 1979, Savino and Stein 1982, Anderson 1984, Gotceitas and Colgan 1989, Savino and Stein 1989, Bettoli 1992, Lillie and Bud 1992, Valley and Bremigan in review). In dense macrophytes, bass cannot use their highly adapted form of searching for bluegill prey and are restricted to using an ambush strategy, thus reducing their foraging success (Savino and Stein 1982).

Macrophytes are a major component of the physical structure in many lakes. Methods for quantifying macrophytes and their effects on largemouth bass populations have varied depending upon the scale of the study. Laboratory and small scale experiments have typically evaluated bass foraging success using different densities of artificial plants (Savino and Stein 1982, Anderson 1984, Gotceitas and Colgan 1989, Savino and Stein 1989, Hayse and Wissing 1996, Valley and Bremigan in review). In contrast, whole-lake and reservoir studies have commonly quantified macrophyte abundance using metrics such as percent cover of macrophytes and have focused primarily on bass abundance (Durocher et al. 1984, Bain and Boltz 1992, Bettoli et al.1993, Hoyer and Canfield 1996, Maciena 1996, Maciena and Reeves 1996, Wren and Lowery 1996, Miranda and Pugh 1997, Pothoven 1999, Unmuth and Hansen 1999). Arguably, intermediate levels of structural complexity (stem density or percent cover) should be optimal for largemouth bass foraging and growth (Wiley et al.1984), although the synthesis of results from lake, reservoir and lab studies is problematic because of differences in scale and the differences in macrophyte communities across the laboratories, lakes, and reservoirs.

Macrophyte growth form may also mediate predator-prey interactions (Diehl 1988, Dionne 1991, Dibble and Harrel 1997, Valley and Bremigan in review). Due to varying growth forms of macrophyte species, macrophyte beds containing multiple species are generally architecturally diverse. Within these beds, interstitial spaces vary in size and shape and provide habitat for macroinvertebrates and fishes (Kershner and Lodge 1990, Dibble 1996, Weaver et al. 1997). Changes in macrophyte species composition from a diverse native assemblage to a dense monoculture of exotic macrophytes may reduce interstitial space size, hindering predator efficiency through reduced visibility and encounter rates with prey (Lilly and Budd 1992, Valley and Bremigan in review).

The exotic aquatic plant, Eurasian watermilfoil (*Myriophyllum spicatum*; hereafter EWM), introduced to North America in the 1940's, can form dense monospecific beds where macrophyte density increases and interstitial space is reduced. The leaflets and dense stems of EWM screen prey fish from predators (Engel 1995), and thus may increase prey fish abundance (Holland and Houston 1985) while hindering the ability of bass to forage on bluegill potentially resulting in low bass growth and abundance.

In addition to its effects on fish, EWM may also displace native vegetation, reduce water quality, and impede recreational activities (Couch and Nelson 1985, Smith and Barko 1990, Madsen 1991). Given the adverse effects of EWM on lake foodwebs and the decreased recreational and aesthetic value of lakes in which it invades, several control methods of EWM have been employed, including mechanical harvesting (Unmuth and Hansen1999), biological agents (Creed and Sheldon 1994, Newman et al. 1996), and chemical herbicides (Smith and Barko 1990, Madsen 1997, Netherland 1997, Smith and Pullman1997, Pothoven 1999). Of these, chemical control has demonstrated a potential for whole-lake reductions of EWM for at least 1-2 years (Smith and Pullman 1997, Pothoven 1999, Schneider 1999). Specifically, SONAR® (active ingredient fluridone, SePRO Corp. Indianapolis, IN) has been shown in experimental conditions to be selective for EWM when applied at low concentrations (5-7 ppb; Netherland et al.1997).

However, whole-lake evaluations of SONAR® to date have been limited to concentrations exceeding its recommended dose for the selective removal of EWM, demonstrating negative effects on native vegetation and the potential for food web dynamics to be altered (Pothoven et al. 1999, Schneider 1999). Pothoven et al. (1999), documented the direct and indirect effects of SONAR® when applied to whole-lake systems at 23 ppb. Not only was EWM reduced, but native vegetation was adversely affected as well, altering food web dynamics through a substantial loss of structural complexity.

Our study is the first to document foodweb responses to low concentrations of SONAR® (< 7ppb), intended to selectively remove milfoil without removing native vegetation. The selective potential of SONAR® at low concentrations (5-7 ppb) creates a unique opportunity to investigate the indirect effects of SONAR®-induced EWM reductions on lake foodwebs.

To evaluate food web responses to low concentrations (5-7 ppb) of SONAR®, I compared reference and treatment lakes during pre and post-treatment periods. Specifically, I evaluated the indirect effects of SONAR®-induced EWM reductions on largemouth bass growth and diet. I addressed three questions: 1) how did the macrophyte community respond to SONAR® treatment?, 2) how did bass growth respond to changes in the plant community caused by SONAR®?, and 3) can largemouth bass diet characteristics explain differences in growth among lakes?

I hypothesized that reduction of EWM in infested lakes would positively affect bass foraging success and growth. Specifically, I expected: (1) reductions of EWM and increases in native macrophytes in treatment lakes (2) Higher bass consumption of bluegill in the treatment lakes relative to reference lakes, and (3) an increase in bass growth in treatment lakes relative to reference lakes post-treatment

METHODS

Study Lakes and Design

In early May 1997, four southern Michigan lakes received whole-lake applications of SONAR®, target concentrations of 5-7 ppb (Big Crooked, Camp, Lobdell and Wolverine lakes; for details see Getsinger et al. 2000). Three additional lakes were chosen as reference lakes and received no SONAR® treatment (Big Seven, Clear, and Heron lakes). In 1999, one additional lake was treated with SONAR® and incorporated into the diet component of my research. All study lakes contained EWM, are of glacial origin, and are considered mesotrophic (Table 1).

Macrophyte surveys were conducted in early May 1997 before SONAR® application, to quantify pre-treatment conditions. Subsequent macrophyte sampling occurred during August 1997-1999, post-treatment. In 1999, I collect bass diets from five of the study lakes to determine the magnitude and duration of treatment effects on bass diets. For bass growth analysis, I sampled bass and collected bass scales in seven of the study lakes to make comparisons in bass growth between reference and treatment lakes during pre and post-treatment periods.

Macrophyte Sampling

We used the point intercept method to evaluate the direct effects of SONAR® on the macrophyte community (Madsen 1999). Within each lake, we determined sampling points by mapping a grid of 192-256 evenly distributed 50 meter quadrants using a global positioning system. The sampling points were determined to be at the center of each quadrant. In May and August 1997 and August only in 1998 and 1999, macrophyte species presence or absence was determined at each site using either visual identification and/or by throwing and dragging a double-headed rake through the vegetation. By dividing the number of sample points containing EWM-only, EWM/native plant mix, or native plants only, by the total number of vegetated sample points, I calculated the percentage of the vegetated sites comprised of each plant combination.

To determine differences between reference and treatment lakes for each of the three plant groups, I arcsin square-root transformed the percentages of vegetated sites comprised of each of the three plant groups from each lake and sampling survey, and conducted t-test, between reference and treatment lake values.

Fish Sampling

Largemouth bass were collected during night electrofishing (120 volt pulsed DC) in spring 1998-2000. Transects averaged ten minutes in duration and were conducted parallel to shore. Transects were distributed around each lake and several sample site characteristics, including depth, substrate composition, and cover type were included in each lake survey. In general, vegetated sites were chosen more frequently than non-vegetated sites. Each lake survey began shortly after dusk and continued until approximately 50 bass were captured. Usually three to five, ten minute transects were necessary to capture 50 bass; however, approximately 30% of the sampling surveys produced fewer than 50 bass.

To characterize bluegill populations, we sampled bluegill simultaneously with bass during spring electrofishing surveys. Bluegill were measured to the nearest millimeter and catch per unit effort (CPUE) and size distributions were calculated for each lake.

Bass Growth Analysis

Length and weight of each largemouth bass was recorded, and approximately ten scales were taken from below the lateral line and posterior to the pectoral fin before bass were released. In the lab, bass scales were mounted for age determination and growth analysis. Scale incremental growth distances were measured using an Optimas 6.5 image analysis system and a Nikon Eclipse E600 compound microscope and camera at 20x magnification.

Of 1381 bass collected, I back-calculated lengths at previous ages for 1044 bass using the Fraser-Lee method (Carlander 1982). Approximately 24% of the total number

of bass captured were not used in growth analysis due to unreadable and/or regenerated scales. A common intercept value for the Fraser-Lee back-calculations was estimated for all bass captured from all seven lakes. For each bass, I estimated a back-calculated length (mm) at each scale annulus and determined incremental growth (mm/yr) by the difference in estimated bass total lengths between consecutive annuli.

I tested for Lee's phenomenon, wherein younger fish from a sample would appear to be exhibiting greater growth than fish of the same age from an earlier year-class, using conventional qualitative methods (DeVries and Frie 1996) and methods adapted to our study design. No strong Lee's phenomenon was evident (see results). However, to minimize possible errors associated with erroneous back-calculated lengths, I restricted growth analysis to back calculated lengths-at-age up to four years prior-to-capture, and growth years from 1995 to 1999.

To determine if bass growth changed in response to treatment, I first compared the relationships between bass growth increments (mm/year) as a function of back-calculated total length (mm) across levels of treatment (reference and treatment) and time (pre and post) using a PROC MIXED model in SAS (SAS Institute Inc.1990). Fixed variables in the model were treatment and time, and lake was chosen as a random variable to allow extrapolation of the results to other systems. I was specifically interested in the three-way interaction of back-calculated length*time*treatment, as a significant interaction would document an effect of SONAR® treatment on bass growth increments in addition to interannual variability in bass growth as represented by the reference lakes.

To further explore the magnitude and direction of bass incremental growth changes between time periods in reference and treatment lakes, I calculated the regression coefficients separately for reference and treatment lakes during pre- and post-treatment time periods. I then plotted the projected length at age of largemouth bass in both reference and treatment lakes using the slope and intercepts obtained from pre- and post-treatment time periods.

Diet Analysis

To determine if bass diets varied with treatment (reference, year-of-treatment, and 2 years post-treatment lakes) I collected samples from five of the study lakes during the summer of 1999. Diets from two reference lakes (Big Seven, Heron) allow me to draw inferences about bass diets in treatment lakes during pre-treatment conditions; diets from Bass Lake (treated in 1999) allow me to draw inferences about bass diets during the year-of-treatment in our treatment lakes; and diets from the two years post-treatment lakes allow me to draw inferences regarding the duration of treatment effects on bass diets.

Bass diet samples were collected monthly from June to September. Bass >150 mm were weighed, measured and subjected to gastric lavage using an electric water pump (12 volt, 60gal/hr). Some diet items, such as crayfish and large fish, were not consistently extracted by the pump and were removed either by hand or with the aid of forceps. Diet items from each bass were funneled into individual 4x6 inch cloth bags. Bags containing diet items were then placed in 95% ethanol for preservation. Bass <150 mm were put on dry ice or preserved in 95% ethanol for gut extraction and analysis in the lab.

In the lab, diet items were identified to species for fish, and to order for invertebrates and crayfish. Some further distinctions were made below order for invertebrates when it was necessary to provide more accurate dry weight regressions for analysis. To determine dry weights using regressions (G.G. Mittlebach, Michigan State University, Kellogg Biological Station, unpublished data, R.D.Valley unpublished data), I measured head capsule width for most invertebrates, carapace length for crayfish, total length for zooplankton, and standard length for fish. To ensure that any given prey item was not counted twice, each prey item that contained a head was considered complete and was measured, if possible, whereas any prey item that did not contain a head was not counted and measured. Measurements were recorded using a digitizing tablet connected to a Nikon microscope magnified at 0.75x. Diet items too large to be measured using the digitizer were measured to the nearest millimeter.

I calculated the percentage of empty bass stomachs during each sampling event and averaged this value for each lake across all sampling periods. For further diet analysis I only considered bass that had consumed prey. I then divided diet items into five primary prey groups (bluegill, other fish, macroinvertebrates, zooplankton, and crayfish). I determined percent diet composition by prey group dry weight (mg), averaging across sample periods in each lake to reflect overall diet characteristics throughout the growing season. I made comparisons of bass growth increments (mm/yr) in the 1999 growing season as a function of both mean total dry weight of prey consumed (mg) per bass weight (wet weight in g), and average total dry weight of bluegill consumed per bass weight to draw inferences on how diet characteristics may influence bass growth.

To assess the size of bluegill consumed as a function of bass total length, I converted bluegill standard length (mm) to total length (mm) and plotted the results for all lakes and sampling periods. From spring 1999 electrofishing surveys, I calculated bluegill catch per unit effort, (CPE) and size distributions for each lake. I also examined the relationships of grams of bluegill per bass weight as a function of bluegill CPE for all diet study lakes.

RESULTS

Macrophyte Community

Eurasian watermilfoil in one treatment lake (Wolverine Lake) did not exhibit a strong negative response to SONAR® treatment. The percent of EWM-only sites was reduced by 19.69% in Wolverine Lake during year of treatment, which is within the natural variation exhibited in the reference lakes. More importantly, we did not observe any increases in native-only sites like we did in other treatment lakes(44.04% to 43.42%) or decreases in mixed sites (36.27% to 47.21%) across sampling periods as with other treatment lakes. Due to the lack of treatment effect on EWM in Wolverine Lake, I chose to exclude Wolverine Lake from further plant analysis, and instead included Wolverine Lake as a reference lake for bass growth analysis. The relatively similar patterns of plant group percentages in Wolverine Lake and the reference lakes argues Wolverine lake's value as a reference lake based on the primary research question which evaluates the response of bass growth to EWM reductions.

For each lake, the percent total (lake wide) vegetative cover averaged across all sampling periods ranged from 38.85% to 91.67% and, in general, did not vary across sampling periods (Table 2). Prior to treatment, the percent of the littoral vegetation comprised by each of the three plant groups was not significantly different between reference and treatment lakes (EWM = $p<0.31$, Mix = $p<0.62$, Native = $p<0.34$; Fig 1A). From May to August 1997, the percentage of EWM-only sites appeared to decline in both reference and treatment lakes. During this same time period, the percent of native-only sites increased from 39.66% to 80.86% and the percent of mixed sited decreased from 44.75% to 15.18% in treatment lakes. In reference lakes, the opposite trend occurred wherein native sites decreased from 34.99% to 26.58% and mixed sites increased from 34.32% to 61.7%. (Figure 1B).

During sampling periods in August 1998 and 1999 similar trends persisted. The average percent of EWM-only sites remained low in both reference and treatment lakes and was not significantly different between the two. The average percentage of native-only sites remained high in treatment lakes (69.19% and 54.91%) and low in reference lakes (37.13% and 22.64%). Mixed sites during August 1998 and 1999 in treatment lakes averaged 27.28% and 34.53% respectively, whereas in reference lakes mixed sites averaged 54.04% and 64.63% respectively (Figure 1C and 1D).

Bass Diet

The percentage of empty bass stomachs varied across lakes and sampling periods, but not consistently across diet study lakes. The lowest percent of empty bass stomachs averaged across sampling periods was found in Big Crooked (two years post-treatment) and Bass lakes (year-of-treatment) at 34.2% and 34.6%, respectively. Big Seven and Heron (reference lakes), and Camp (two years post-treatment) percentages were 39.0%, 47.7%, and 51.3%, respectively.

Bluegill comprised the majority of prey dry weight (mg) of bass diets across lakes and sample periods ranging from 32%-96% across sampling events. Other fish, including cyprinids, yellow perch (*Perca flavescens*), and largemouth bass comprised the next largest component of diet dry weight, ranging from <1%-37%. Crayfish consumption was variable across lakes, with Heron Lake (a reference lake) diets containing the greatest percentage of crayfish ranging from 12%-42% across sample periods and averaging 27% for the summer. In the other lakes, crayfish comprised from 0%-33% of bass diets across sample periods and averaged <10% of summer totals. The diet dry weight percentages of macroinvertebrates were consistently low across sample periods and lakes and never comprised more than 8.6%. Zooplankton dry weight percentages never exceeded 0.0001% of diet dry weight (Figure 2).

Total milligrams of prey (dry weight) per gram of bass (prey mg/bass g) averaged across sampling periods for each lake ranged from 1.238 to 1.473 and did not explain differences in bass growth increments across reference and treatment classifications (reference, year-of-treatment, and 2 years-post-treatment; $p>0.08$, $r^2= 0.69$; Figure 3). Likewise, total milligrams of bluegill (dry weight) per gram of bass averaged across sampling periods for each lake ranged from 0.519-1.047 and did not explain bass growth increments across lakes ($p>0.91$, $r^2= 0.004$; Figure 4). Bluegill catch per unit efforts from spring 1999 electrofishing surveys appeared to be positively correlated with milligrams of bluegill per gram of bass ($p<0.06$; Figure 5).

The linear relationship of size of bluegill consumed as a function of bass total length was significant ($p<0.001$, $r^2 = 0.51$; Figure 6) and suggested bass selectively chose for bluegill size. The estimated proportion of the size of bluegill consumed to bass

ranged from 0.18 to 0.25. The relationships of the length of other fish consumed as a function of bass total length was less predictable, although still significant ($p<0.001$, $r^2 = 0.26$).

Bass Growth

Results from qualitative analysis to detect Lee's phenomenon in the estimated back calculated lengths at age for bass indicate no conclusive evidence that Lee's phenomenon occurred (Table 3). However, in some cases, estimated length-at-age tended to decrease with increasing capture year for a given year class (e.g. estimated length-at-age for age-1 bass, born in 1996, decreased from 85 mm (capture year 1998) to 77 mm (capture year 2000)). Also, in some cases, estimated length-at-age for a given age of bass and capture year tended to decline for earlier year classes (e.g. estimated length-at-age for age-1 bass based on 1998 capture date was 85 mm for the 1996 year class, but 75 mm for the 1993 year class; Table 3).

The SAS mixed model analysis documented a significant three way interaction of back-calculated total length*time*treatment ($p<.001$) confirming that bass growth increments in reference and treatment lakes did not respond similarly across time periods and indicating a SONAR® treatment effect. To further examine the effects of treatment, I compared the relationship of growth increment (mm/yr) as a function of back-calculated total length of bass(mm), between time periods, for treatment and reference lakes separately.

In reference lakes there was no time effect ($p<0.93$) and no interaction ($p<0.69$). Conversely, analysis of treatment lakes revealed a significant time effect ($p<0.001$) and a significant interaction of time*back-calculated length ($p<0.001$) between pre-and post-treatment periods in treatment lakes. The slope and intercept of the relationship of growth increment as a function of back-calculated length changed in treatment lakes from 67.54 and -0.1235, respectively (n=459, $r^2 = 0.30$) among pre-treatment years to 79.86 and -0.1873, respectively (n=784, $r^2 = 0.45$) during post treatment years. An increased negative slope and a greater intercept value, such as observed for treatment lakes, indicate growth increments of bass <200 mm increased post treatment (Figure 7).

By plotting the projected length-at-age curves generated from the slope and intercept values from each lake, trends in bass growth from both reference and treatment lakes both pre- and post-treatment can be estimated (Figure 8). A slight increase in bass growth in treatment lakes following treatment is apparent.

The benefit of increased growth appears to be limited to bass ages 1-5, with the difference in growth estimated to be approximately 10-15 mm. The estimated age at which bass will reach legal capture size (14 inches, 355 mm) did not vary between pre- and post-treatment time periods in treatment lakes (~7.5 years), whereas in reference lakes the estimated age at legal capture length increased by approximately 0.5 years (8.0 to 8.5 years).

DISCUSSION

To date, research assessing bass growth and population characteristic responses to macrophyte reductions at the whole-lake scale have reduced total vegetation through methods that are not species selective, such as mechanical harvesting, or non-selective concentrations of aquatic herbicides (Olson 1998, Engel 1995, Pothoven 1999, Schneider 1999, Unmuth et al.1999). Furthermore, many studies have been conducted in southern reservoirs where macrophyte coverage is typically low (2-44%) due to increased turbidity and water level fluctuations (Durocher et al.1984, Bain and Boltz 1992, Bettoli et al. 1992, Bettoli et al. 1993, Maciena and Reeves 1996, Wrenn and Lowery 1996, Miranda and Pugh 1997). In contrast, percent vegetative cover in our study lakes ranged from ~ 40% to ~90%.

Our approach of quantifying macrophyte communities by considering frequency of occurrence by species, allowed us to more closely bridge the gap in knowledge between what has been learned in small scale experiments involving bass foraging success as a function of structural complexity, and large scale macrophyte reductions, where the mechanisms driving bass responses are less well known. By selectively removing EWM, we can more specifically attribute responses in bass foraging and growth to the aquatic plant community species composition shifting from a EWM/native mix to a native dominated plant community.

In our study lakes, EWM was most commonly found interspersed with native plant species and rarely formed surface canopies or dense monospecific beds. Based on the similarities between reference and treatment lake vegetation surveys conducted during May 1997, I suspect the reference lakes truly represented the treatment lake vegetation conditions during pre-treatment periods. Post-treatment, the resulting decline in EWM/native mixed sites and the increase in native-only sites in treatment lakes relative to reference lakes indicate SONAR® selectively removed EWM without adversely affecting the native vegetation. Thus, our results can be safely applied to other lakes where EWM does not form dense monocultures and native macrophyte communities are present.

Although our study was designed to evaluate the effects of EWM removal, I though it would be valuable to determine whether bass growth varied predictably with percent cover, given the wide range of percent cover values across lakes in our study. I examined the average growth increment (mm/yr) of bass from 1997-1999 in each lake as a function of the percent of lake vegetated from August sampling surveys across those same years and found no correlation between the two. In fact, Clear Lake consistently had the highest percent cover (averaging 91.52%), but also had the highest average bass growth increments. One explanation for this phenomenon is most likely the size distribution of bass sampled for growth analysis. Clear Lake bass size distributions from spring electrofishing were noticeably skewed towards smaller bass (<200 mm) relative to the other study lakes. Given that bass growth increments are negatively correlated to increasing bass size, larger average estimated growth increments would be expected. To better understand how bass populations respond to changes in environmental conditions, such as reduced vegetative cover, knowledge of bass abundance, growth increment and size distribution would lend valuable insight.

I suspect the maximum negative effects of EWM on lake food webs were not realized in our lakes prior to treatment, and thus it is logical that the magnitude of the positive indirect effects of treatment on bass growth were modest, given the relatively small scale changes in aquatic plant assemblages following treatment. In fact, the post-treatment rehabilitation of plant assemblages dominated by native species lead to only minimal changes in bass growth.

Estimated growth increments of bass <200 mm increased modestly as a result of treatment. Based on estimated growth curves, the realized benefits of this increase resulted in a 10-15 mm increase in bass length-at-age for ages 1-6. Although the biological implications of these increases are not known, one possible benefit may be increased overwinter survival and recruitment of larger age-0 bass (Gutreuter and Anderson 1985, Post 1998). As estimated by growth curves, the positive effect of treatment on bass growth likely diminished by the time bass reached legal capture size indicating that early increases in growth will not translate to substantially reduced age at entry to the fishery.

Comparisons between our results and other studies which evaluated responses of bass growth to macrophyte reductions using SONAR® are difficult to make due to the magnitude of macrophyte reductions and the non-species selective manner used in previous studies, and differences in methods quantifying bass growth (Pothoven 1999, Schneider 1999). For example, Pothoven et al. (1999) observed 67% and 37% reductions in vascular plant coverage one year post treatment in their two study lakes. An increase in largemouth bass growth was reported but this increase was not translated to a metric known to be of biological importance, such as mm/yr or g/yr was made. Without knowing the magnitude of growth change it is difficult to interpret the biological impacts of such treatments on aquatic systems.

Studies evaluating the effects of mechanical harvesting to increase macrophyte bed edge have found increases in bass growth to be size-specific, indicating not all members of the bass population will be affected similarly (Engel 1987, Olson et al. 1998). Our study also concluded size specific benefits to reduced EWM and increased native-only sites, implying mechanisms favoring small bass foraging. Accordingly, in a complementary component of this study, Valley (2000) documented a larger size of age-0 bass in some treatment lakes, relative to reference lakes, that also had a high abundance of age-0 bluegill.

Contrary to my expectations, no patterns in diet composition were evident across reference, year-of-treatment, or 2 years post-treatment conditions. Bluegill consistently composed the greatest percentage of diet dry weight, with other fish constituting the next largest percentage across all lakes and sample periods. The contribution of crayfish was variable but greatest in Heron Lake. Other studies evaluating bass diets have found similar levels of percent empty stomachs and piscivory (Summers 1982, Cochran and Adelman 1982, Olson 1996, Ward and Neumann 1998, Pothoven 1999).

No correlation was found for bass growth increment (averaged across all bass sizes captured) as a function of either total prey weight per gram of bass, or bluegill weight per gram of bass. One possible explanation is that the observed growth increments are influenced by differences in bass size distributions from spring 1999 electrofishing (i.e. a size distribution containing a majority of small bass would result in a high estimated growth increment, whereas a size distribution containing mostly large bass would result in a smaller estimated growth increment).

Another possible explanation of the lack of relationship between prey consumption and bass growth increment may be day-to-day variation in bass consumption as described by Smagula and Adelman (1982). Sampling diets monthly may not have been adequate to truly represent the diet characteristics and consumption of bass in our study lakes, especially given that treatment effects were more subtle than we expected.

The similarity in diets across lakes most likely indicates EWM did not reach levels adequate to inhibit bass foraging ability on bluegill on a lake-wide basis as predicted, or differences in bluegill abundance may have countered any effect of EWM. However, due to the positive response of growth to EWM removal for bass <200mm TL, it is more likely that the bass diet component of this study was inadequate to detect minor or short-term changes in diet due to EWM removal.

The results from this study indicate that SONAR®, when applied at low concentrations (5-7 ppb) can be very effective at reducing EWM and rehabilitating a native aquatic plant assemblage for up to two years post-treatment, provided native plants are fairly abundant prior to treatment. However, the effects of repeated SONAR® treatment need further evaluation. The positive effects of treatment on largemouth bass growth were minimal but important to document as such evaluations of the selective removal of exotics aquatic plants, such as EWM, are limited. Policy regarding aquatic herbicide use needs to incorporate studies such as this one, to better predict the direct and indirect effects of macrophyte management on aquatic food webs. The relatively narrow range of SONAR® concentrations required for selective removal of EWM calls for strict guidelines regarding its use and the continued cooperation and communication among

state agencies, lake managers, and land owners to insure the responsible use of SONAR®
to rehabilitate and protect our aquatic resources.

APPENDIX

Tables and Figures

Lake	County	Ref/Trt	Size (ha)	Mean Depth (m)	Max Depth (m)	% Littoral Area
Bass*	Kent	Treatment	74	2.4	6.1	100
Big Crooked	Kent	Treatment	64	4.5	18.3	55
Big Seven	Oakland	Reference	64	3.2	15.0	82
Camp	Kent	Treatment	44	7.3	15.0	39
Clear	Barry	Reference	73	2.2	4.6	89
Heron	Oakland	Reference	53	3.4	12.2	80
Lobdell	Genesee	Treatment	197	2.7	21.3	83
Wolverine†	Oakland	Reference	101	2.9	17.9	80

Table 1. General lake characteristics for the eight study lakes. Percent littoral area is the percent of all sample sites within each lake which were within the depth contour in which aquatic vegetation commonly grew.

* Bass Lake was treated in 1999 and used in the diet analysis conducted in 1999 to characterize bass diets during the year of treatment.

† EWM in Wolverine Lake was not removed by SONAR®, therefore Wolverine Lake was included as a reference lake for bass growth analysis, but was included in the macrophyte analysis.

Table 2. Percent of total sampling points per lake that contained each of the three plant groups (EWM-only, native-only, or EWM/native mixed) and the percent vegetated area of each lake for each sampling period. Average percent vegetated is the average across all sampling periods May 1997- August 1999.

Lake	Sample Date	Treatment	% EWM	% Native	% Mix	% Lake Vegetated	Average % Vegetated
Big Seven	May-97	Reference	12.14	37.65	26.31	76.1	81.505
Big Seven	Aug-97	Reference	8.06	14.92	59.27	82.25	
Big Seven	Aug-98	Reference	4.49	30.2	48.98	83.67	
Big Seven	Aug-99	Reference	8	4.4	71.6	84	
Clear	May-97	Reference	48.8	25.39	17.6	91.79	91.5275
Clear	Aug-97	Reference	4.48	28.36	64.18	97.02	
Clear	Aug-98	Reference	5.14	30.83	60.47	96.44	
Clear	Aug-99	Reference	7.42	9.375	64.06	80.86	
Heron	May-97	Reference	2.7	13.5	30.6	46.8	62.62
Heron	Aug-97	Reference	0.813	14.63	39.84	55.28	
Heron	Aug-98	Reference	1.73	35.26	37.57	74.56	
Heron	Aug-99	Reference	2.325	33.72	37.79	73.84	
Big Crookec	May-97	Treatment	0	24.48	23.67	48.15	49.125
Big Crookec	Aug-97	Treatment	0	52.82	0	52.82	
Big Crookec	Aug-98	Treatment	0	46.31	4.098	50.41	
Big Crookec	Aug-99	Treatment	0	43.9	1.22	45.12	
Camp	May-97	Treatment	2.58	6.86	28.75	38.19	38.9875
Camp	Aug-97	Treatment	0	38.2	1.72	39.92	
Camp	Aug-98	Treatment	0	34.91	5.6	40.51	
Camp	Aug-99	Treatment	0.429	30.04	6.86	37.33	
Lobdell	May-97	Treatment	12.2	29.7	23.9	65.8	69.2625
Lobdell	Aug-97	Treatment	0.469	62.9	2.347	65.72	
Lobdell	Aug-98	Treatment	0.93	62.14	7.94	71.01	
Lobdell	Aug-99	Treatment	1.88	33.96	38.68	74.52	
Wolverine	May-97	Treatment	10.88	35.23	27.46	73.57	78.193333
Wolverine	Aug-97	Treatment	0	49.74	31.28	81.02	
Wolverine	Aug-98	Treatment	2.7	36.75	40.54	79.99	
Wolverine	Aug-99	Treatment	NA	NA	NA	NA	

Table 3. Back-calculated lengths for largemouth bass from all study lakes by year-of-capture (1998-2000) and year-class. Lee's phenomenon would be indicated when the estimated size at a particular age declines within a year class with increasing year of capture or within a year of capture with decreasing year class. I used only bass from year classes 1994-1999.

Year Class	Age 1			Age 2			Age 3			Age 4			Age 5			Age 6		
	98	99	00	98	99	00	98	99	00	98	99	00	98	99	00	98	99	00
1998	.	89	90	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
1997	.	83	83	.	137	139	.	.	.	.	.	.	.	.	.	.	.	.
1996	85	83	77	.	139	134	.	180	182	.	.	.	.	.	.	.	.	.
1995	88	78	73	151	134	124	.	178	172	.	217	218	.	.	.	.	.	.
1994	76	78	.	137	134	125	189	183	174	.	227	220	.	256	262	.	290	.
1993	75	.	.	124	125	.	178	177	163	225	225	210	.	267	252	.	.	290
1992	.	.	.	125	.	.	173	185	.	219	228	195	262	269	234	.	306	270
1991	.	.	.	.	.	.	181	.	.	225	198	.	269	238	.	305	277	.

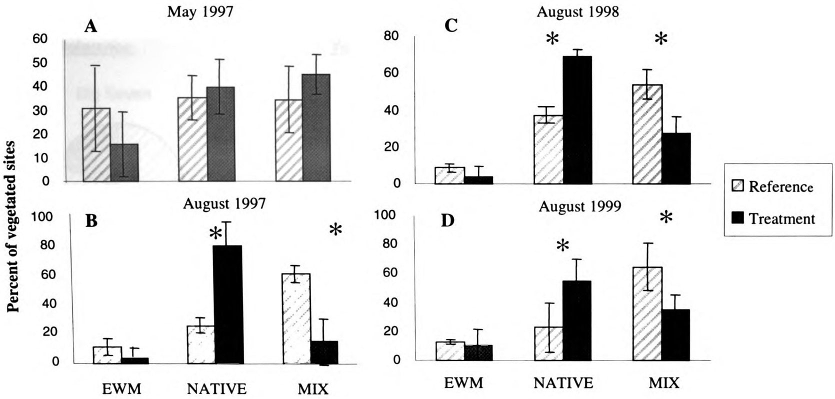

Figure 1. Littoral zone aquatic plant community characteristics in reference and treatment lakes (A) pre-treatment in May 1997 and post-treatment in (B) August 1997, (C) August 1998, and (D) August 1999. Percentages represent the number of sites within the littoral zone that contained EWM-only, native-only, or EWM/native mixed plants divided by the total number of littoral points. Asterisks indicate significant differences in percentages of plant groups between reference and treatment lakes. Analysis excludes Wolverine Lake.

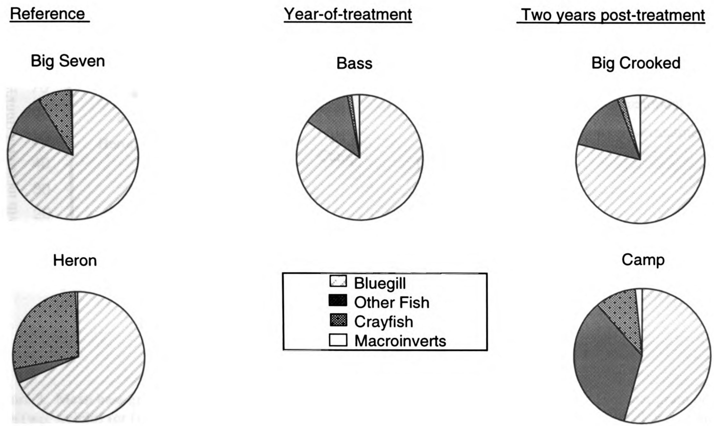

Figure 2. Composition by dry weight of bass diets in reference, year -of-treatment, and two years post-treatment lakes averaged across the four sampling periods. Zooplankton never comprised more than 1% of bass diets and are therefore not includedin this analysis.

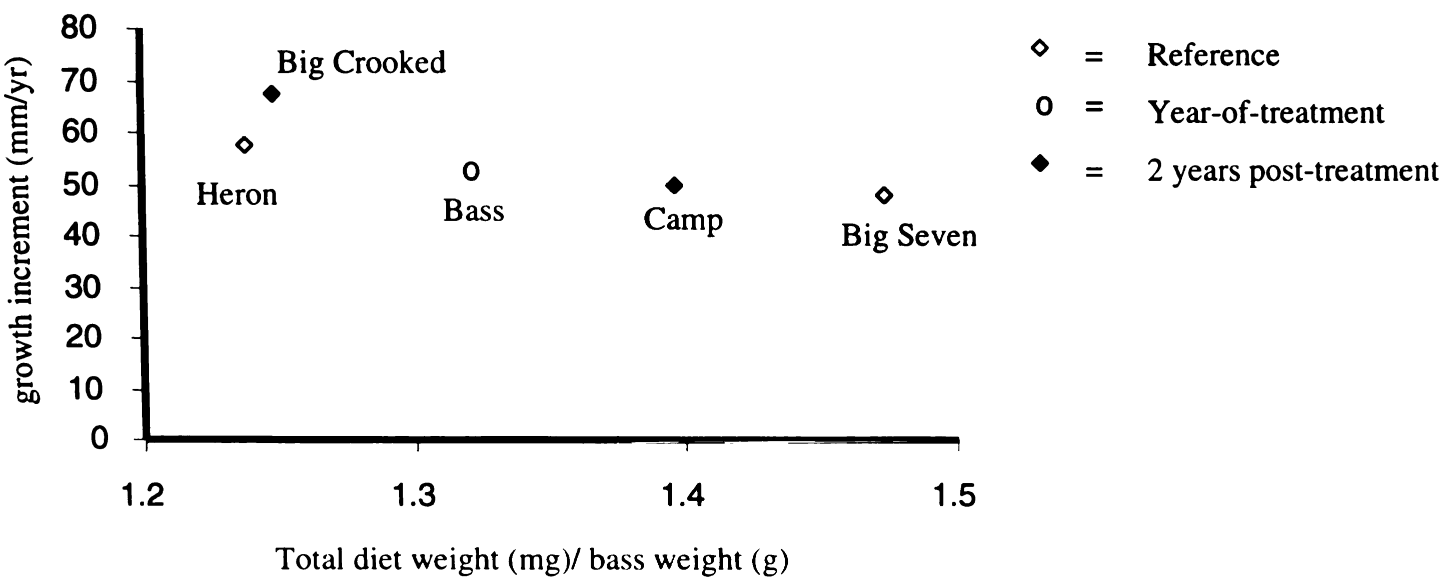

Figure 3. Mean bass growth increment (mm/yr) as a function of average total diet dry weight (mg) per gram of bass (wet weight) for five study lakes during the 1999 growing season. Total diet weight includes all prey groups.

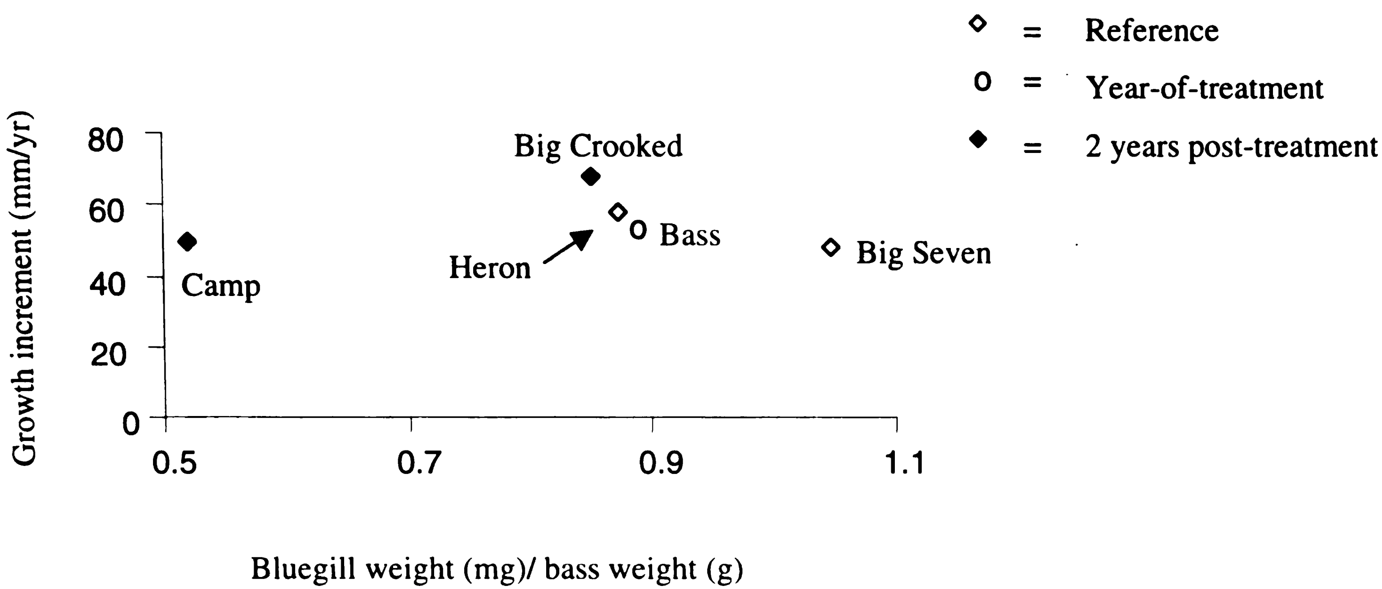

Figure 4. Mean bass growth increment (mm/yr) as a function of the average total dry weight of bluegill (mg) per gram of bass wet weight for five study lakes during the 1999 growing season as a function.

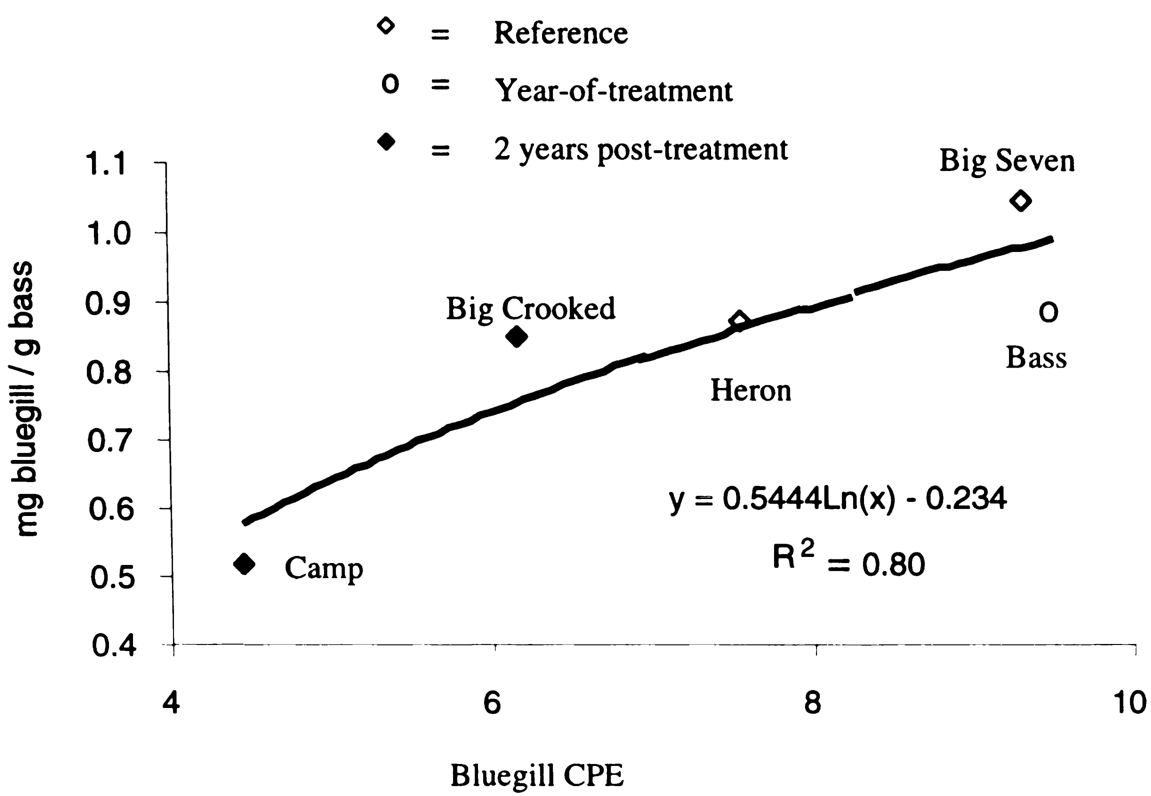

Figure 5. Milligrams of bluegill (dry weight) per gram of bass (wet weight) as a function of bluegill catch per unit effort (CPE) from spring 1999 electrofishing.

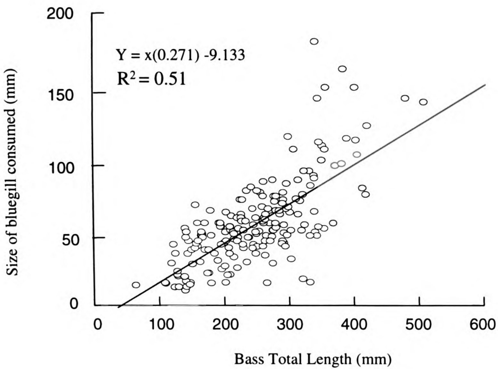

Figure 6. Total length (mm) of bluegill consumed as a function of bass total length (mm) across all diet study lakes and sampling periods.

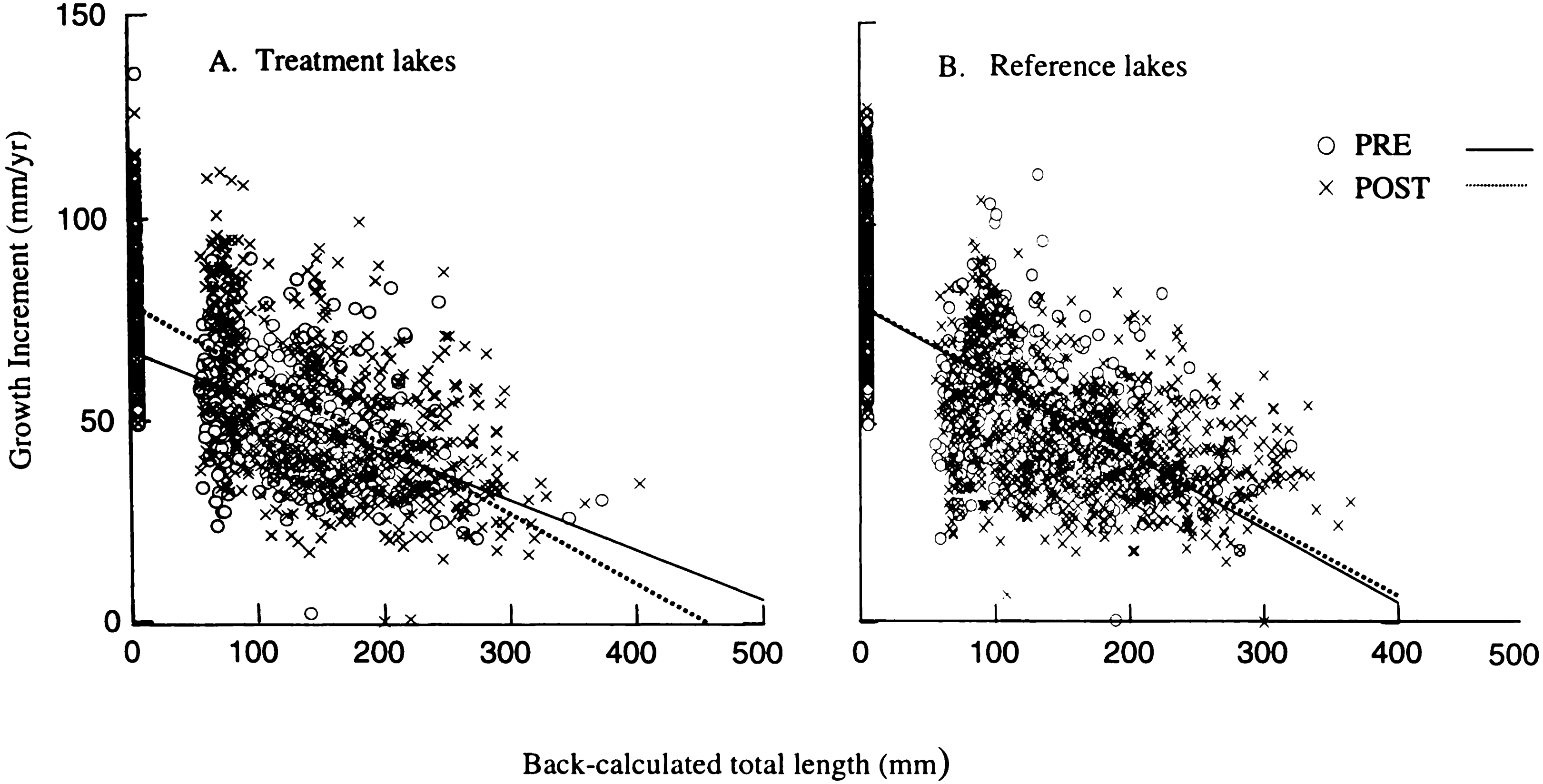

Figure 7. Comparisons of estimated relationships of bass growth increment as a function of back-calculated total length for (A) treatment and (B) reference lakes during pre- and post-treatment periods.

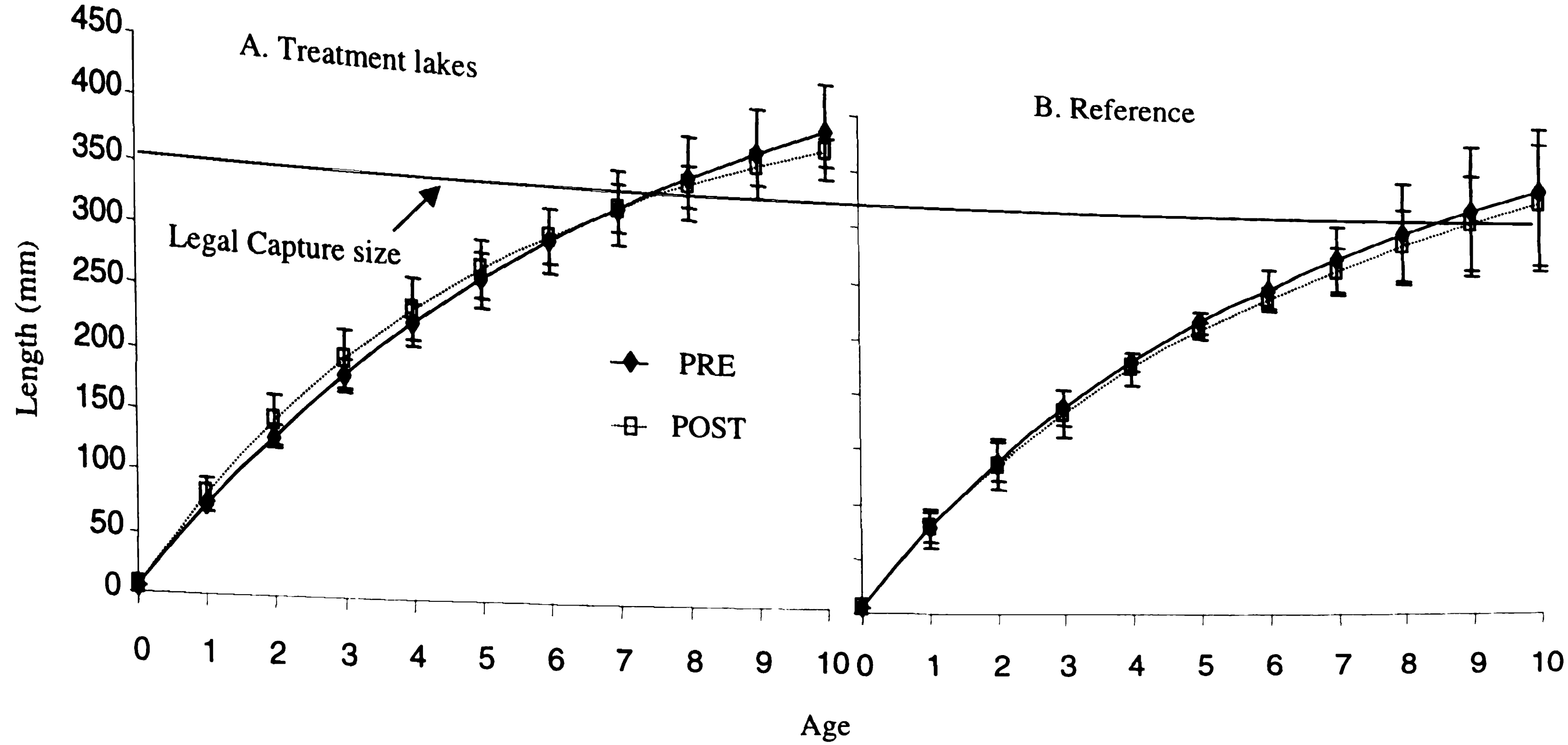

Figure 8. Estimated bass growth curves for treatment and reference lakes calculated by averaging the estimated length at age derived from the relationship of growth increment as a function of back-calculated total length for (A) treatment and (B) reference lakes during pre- and post-treatment periods. Error bars indicate one standard deviation.

LITERATURE CITED

Anderson, O. 1984. Optimal foraging by largemouth bass in structured environments. Ecology 65: 851-861.

Bain, M. and S.E. Boltz. 1992. Effects of aquatic plant control on the microdistribution and population characteristics of largemouth bass. Transaction of the American Fisheries Society 121:94-103.

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

Bettoli, P.W., M.J. Maceina, R.L. Noble, and R.K. Betsill. 1993. Response of a reservoir fish community to aquatic vegetation removal. North American Journal of Fisheries Management 13: 110-124.

Cochran, P.A. and I.R. Adelman. 1982. Seasonal aspects of daily ration and diet of largemouth bass, Micropterus salmoides, with an evaluation of gastric evacuation rates. Environmental Biology of Fishes 7: 265-275.

Couch, R. and E. Nelson. 1985. Myriophyllum spicatum in North America. pp. 8-18. In: Proc. First Int. Symp. On watermilfoil (Myriophyllum spicatum) and related Haloragaceae species. July 23-24. Vancouver, BC, Canada. Aquatic Plant Management Society, Inc.

Creed, R.P., and S.P. Sheldon. 1994. The effects of two herbivore insect larvae on Eurasian watermilfoil. Journal of Aquatic Plant Management 32: 21-26.

Crowder, LB., and W.E.. Cooper. 1982. Habitat structural complexity and the interaction between bluegills and their prey. Ecology. 63:1802-1813.

Dibble, E. D., S.L. Harrel. 1997. Largemouth bass diets in two aquatic plant communities. Journal of Aquatic Plant Management 35: 74-78.

Dibble, E. D., K. J. Killgore, and S. L. Harrel. 1997. Assessment of Fish-Plant Interactions. American Fisheries Society Symposium 16: 357-372.

Diehl, S. 1988. Foraging efficiency of three freshwater fish: effects of structural complexity and light. Oikos 53: 207-214.

Dionne, M., and C.L. Folt. 1991. An experimental analysis of macrophyte growth forms as fish foraging habitat. Canadian Journal of Fisheries and Aquatic Sciences. 48:123-131.

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 Fisheries Management 4: 84-88.

Engel, S. 1987. The impact of submerged macrophytes on largemouth bass and bluegills. Lakes and Reservoir Management. 3:227-234.

Engel, S. 1995. Eurasian watermilfoil as a fishery management tool. Fisheries 20: 20-27.

Gotceitas, 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.

Hayse, J.W., and T.E. Wissing. 1996. Effect of stem density of artificial vegetation on abundance and growth of age-0 bluegills and predation of largemouth bass. Transactions of the American Fisheries Society. 125: 422-433.

Holland, L.E., M.L. Houston.1985. Distribution and food habits of young-of-year fishes in a backwater lake of the Upper Mississippi River. Journal of freshwater Ecology. 3: 81-91.

Hoyer, M.V., 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.

Lillie, R.A., and J. Budd. 1992. Habititat architecture of Myriophyllum spicatum L. as an index to habitat quality for fish and macroinvertebrates. Journal of Freshwater Ecology 7: 2, 112-125.

Maciena, M.J. 1996. Largemouth bass abundance and aquatic vegetation in Florida lake: An alternative interpretation. Journal of Aquatic Plant Management 34: 43-47.

Maciena, M.J. and W.C. Reeves. 1996. Relations between submersed macrophyte abundance and largemouth bass tournament success in two Tennessee River impoundments. Journal of Aquatic Plant Management 34: 33-38.

Madsen, J.D., J.W. Sutherland, J.A. Bloomfield, L.W. Eichler, and C.W. Boylen. 1991. The decline of native vegetation under dense Eurasian watermilfoil canopies. Journal of Aquatic Plant Management 29: 94-99.

Madsen, J.D. 1997. Methods for management of nonindigenous aquatic plants. pp. 145-171 *in* J.O. Luken and J.W. Thieret (eds.) Assessment and management of plant invasions. Springer, New York.

Madsen, J.D., L.W. Eichler, and C. W. Boylen. 1988. Vegetative spread of Eurasian watermilfoil in Lake George, New York. Journal of Aquatic Plant Management 26:47-50.

Miranda, L.E., and L.L. Pugh. 1997. Relations between coverage and abundance, size, and diet of juvenile largemouth bass in winter. North American Journal of Fisheries Management 17: 601-609.

Netherland, M.D., K.D. Getsinger, and J. D. Skogerboe. 1997. Mesocosm Evaluation of the Species-Selective Potential of Fluridone. Journal of Aquatic Plant Management [J. Aquat. Plant Manage.]. 35:41-50.

Newman, R.M., K.L. Holmberg, D.D. Biesboer, and B.G. Penner. 1996. Effects of a potential biocontrol agent, *Euhrychiopsis lecontei*, on Eurasian watermilfoil in experimental tanks. Aquatic Botany 53: 131-150.

Olson, M.H. 1996. Predator-prey interactions in size-structured fish communities: Implications of prey growth. Oecologia. 108:757-763.

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. 23:6-12.

Pothoven, S.A., B. Vondracek, and D. L. Pereira. 1999. Effects of Vegetation Removal on Bluegill and Largemouth Bass in Two Minnesota Lakes. North American Journal of Fisheries Management. 19:748-757.

SAS Institute Inc. 1990. SAS user's guide: statistics, version 6.12. SAS institute, Cary, North Carolina.

Saika, M.K., and J.C. Tash. 1979. Use of cover and dispersal by crayfish to reduce predation by largemouth bass. pp. 44-48 *in* D.L. Johnson and R.A. Stein (eds.). Response of fish to habitat structure in standing water. North Central Division, American Fisheries Society, Special Publication 6, Bethesda, Maryland, USA.

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

Savino, J. F., and R. A. Stein. 1989. Behavioral interactions between fish predators and their prey: Effects of plant density. Animal Behaviour. 37:311-321.

Schneider, J.C. 1999. Preliminary evaluation of the effects of the herbicide Sonar on sport fish populations in Michigan Lakes. Michigan Department of Natural Resources. Fisheries Technical Report No. 99.

Smagula, C.M., and I.R. Adelman. 1982. Day-to-day variation in food consumption by largemouth bass. Transactions of the American Fisheries Society 111 (5): 543-548.

Smith, C.S., and J. W. Barko. 1990. Ecology of Eurasian watermilfoil. Journal of Aquatic Plant Management. 28: 55-64.

Smith, C.S., and G.D. Pullman. 1997. Experiences using Sonar registered A.S. aquatic herbicide in Michigan. Lake and Reservoir Management. 13: 338-346.

Summers, G.L. 1982. Food of adult largemouth bass in a small impoundment with dense aquatic vegetation. Proceedings from the Annual Conference of S.E. Association of Fish and Wildlife Agencies 34: 130-136.

Unmuth, J.M.L., M.J. Hansen, and T.D. Pellet. 1999. Effects of mechanical harvesting of Eurasian watermilfoil on largemouth bass and bluegill populations in Fish Lake, Wisconsin. North American Journal of Fisheries Management 19: 1089-1098.

Valley, R.D., M.T. Bremigan. In review? Need title?

Weaver, M.J., J.J.A. Magnuson, and M. K. Clayton. 1997. Distribution of littoral fishes in structurally complex macrophytes. Canadian Journal of Fisheries and Aquatic Sciences/Journal Canadien des Sciences Halieutiques et Aquatiques. Ottawa. 54:2277-2289.

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

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