

Effects of Mechanical Harvesting of Eurasian Watermilfoil on Largemouth Bass and Bluegill Populations in Fish Lake, Wisconsin

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Abstract.—We examined changes in populations of largemouth bass *Micropterus salmoides* and bluegill *Lepomis macrochirus* associated with mechanical plant harvesting in a lake heavily infested with Eurasian watermilfoil *Myriophyllum spicatum*. In August 1994, 18% of the total plant biomass in Fish Lake, Dane County, Wisconsin, was removed in a radial pattern of 2-m-wide channels. Largemouth bass and bluegill abundance, survival, growth, and length frequency were compared between pretreatment (1992–1993) and posttreatment (1995–1996) years. Following vegetation removal, mean abundance of largemouth bass and bluegill did not change significantly, but growth increased for age-2–4 largemouth bass and declined for age-5 largemouth bass and age-4–5 bluegills. Survival increased for age-2, -3, and -5 largemouth bass and age-4–6 bluegills. Population size structure increased for both species. We conclude that removal of Eurasian watermilfoil may increase growth and survival of some age-groups of centrarchid populations without altering the abundance of either species. However, this study lacked replication and control that is needed to separate effects of plant harvesting from effects of other biotic and abiotic factors.

Vegetative habitat can influence largemouth bass *Micropterus salmoides* and bluegill *Lepomis macrochirus* abundance, survival, growth, and population size structure. Centrarchid abundance, density, and survival may increase in dense vegetation (Kilgore et al. 1989). Yet, most fish that use dense plant stands are juveniles (Keast 1983) that are attempting to avoid predators (Gocietas and Colgan 1987). Predator avoidance leads to increased survival of young centrarchids (Smith and Orth 1991), greater competitive interactions, and reduction in growth (Osenberg et al. 1987; Nibelink and Carpenter 1998). Reduced plant biomass is associated with reduced centrarchid abundance (Bettoli 1987; Colle et al. 1987; Lathrop et al. 1992) and survival (Durocher et al. 1984). Complete eradication of plants in Lake Conroe, Texas, led to reduced bluegill and largemouth bass density, and reduced bluegill population size structure (Bettoli 1987; Bettoli et al. 1993). Decreased recruitment of largemouth bass longer than 254 mm was observed in Texas reservoirs with plant cover less than 20% (Durocher et al. 1984).

The growth and population size structure of centrarchids may be influenced by vegetation density, the pattern of cutting, and amount of vegetation removed. Werner and Hall (1977) showed that increased growth of young sunfishes is related to increased plant density. But, the relationship is parabolic, so that fish foraging and growth is optimized at intermediate levels of plant density (Trebitz 1995). Clear-cutting plants and removing more than half the vegetation decreased fish growth, while cutting narrow channels and removing 20–40% of the vegetation increased bluegill feeding and growth rates (Trebitz and Nibelink 1996). Bluegills consumed more prey and grew faster at intermediate vegetation density than at high or low plant densities (Crowder and Cooper 1982). Intermediate-age bluegills grew better when narrow (2-m-wide) channels were cut and 20% of Eurasian watermilfoil *Myriophyllum spicatum* biomass was removed from several lakes (Olson et al. 1998). Reduced vegetation increased young largemouth bass growth (Engel 1985; Cross et al. 1992; Hoyer and Canfield 1996; Miranda et al. 1996). However, growth rates of largemouth bass were not different in cut (treatment) and uncut (control) lakes dominated by Eurasian watermilfoil (Carpenter et al. 1998; Olson et al. 1998).

Few studies have attempted to describe changes in fish abundance, survival, growth, and popula-

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Received September 22, 1998; accepted July 14, 1999

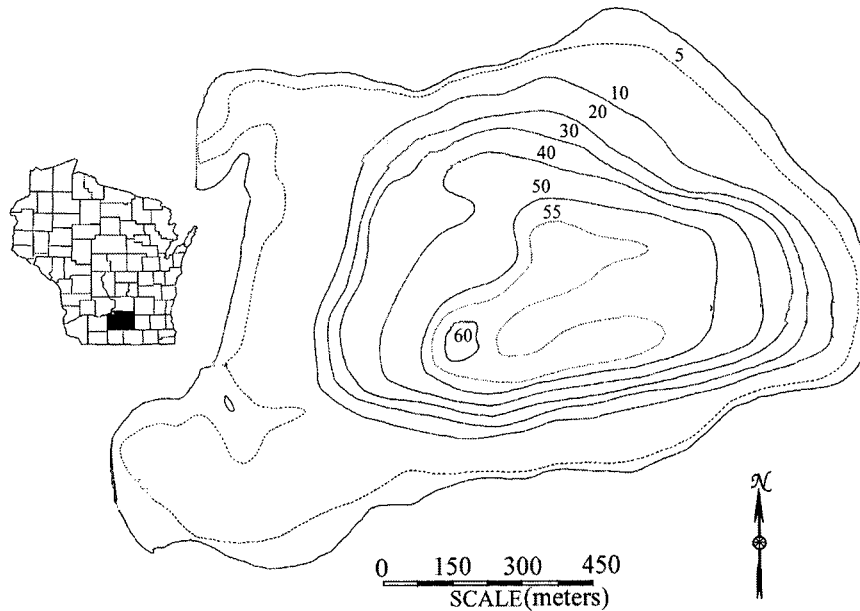


FIGURE 1.—Fish Lake, Dane County, Wisconsin; depth contours are in meters.

tion size structure when channels are used to increase vegetated edge habitat and reduce total plant biomass. Our objectives were to determine if largemouth bass and bluegill abundance, survival, growth, and population size structure changed when 18% of the biomass of Eurasian watermilfoil was harvested from a heavily vegetated lake in southern Wisconsin. We expected that abundance and survival would increase for largemouth bass and decrease for young bluegills. Consequently, we expected that growth and population size structure would increase for both species. We compared fish population parameters in years before (1992–1993) and after (1995–1996) vegetation removal, and discuss the implications of reduced Eurasian watermilfoil on largemouth bass and bluegill population dynamics.

Methods

Study site.—Fish Lake, Dane County, Wisconsin, is a 101-ha seepage lake 50 km northwest of Madison, Wisconsin (Figure 1). The lake has a maximum depth of 19.5 m and a mean depth of 6.6 m, and is characterized as mesotrophic-eutrophic. Fish Lake has a diverse fish fauna, with largemouth bass and bluegill the dominant predator and prey species. The littoral zone was dominated by a dense stand of Eurasian watermilfoil, which formed a contiguous ring around the lake's perimeter at depths ranging from 1.5 m to 4.5 m

(Lillie 1996). Eurasian watermilfoil constituted 90% of the total plant biomass and covered approximately 40% of the total lake bottom (Budd et al. 1995; Lillie 1996). Estimated total plant biomass within Eurasian watermilfoil stands just before plant removal was $283 \pm 13 \text{ g/m}^2$ (Lillie 1996). Coontail *Ceratophyllum demersum* formed a dense band at the deepwater edge of the Eurasian watermilfoil bed, and a mixture of native species grew in shallow water, inshore from the Eurasian watermilfoil bed (Unmuth et al. 1998).

Bioenergetic modeling suggested that removal of 20–40% of vegetation biomass would optimize growth of bluegills and largemouth bass in Fish Lake (Trebitz 1995; Trebitz and Nibbelink 1996). In August 1994, after 2 years of collecting baseline data, 262 channels, 2 m in width, were cut in a radial pattern through the Eurasian watermilfoil beds of Fish Lake with a mechanical plant harvester that was modified to cut plants close to the bottom (Unmuth et al. 1998). Total plant biomass was reduced 18% and 36,200 m of vegetated edge habitat was created. Direct mortality of fish, primarily small bluegills, was estimated at 36 fish/ha. By 1996, remnants of 170 channels persisted, totaling 7,700 m of channel length (21% of the original channel length cut; Unmuth et al. 1998). Also, mean Eurasian watermilfoil biomass was reduced 50% from 1992–1993 to 1994–1995 (Lillie 1996). Reduced plant biomass was thought to be

associated with an attack by the watermilfoil weevil *Eurhrychiopsis lecontei*; however, by 1996, Eurasian watermilfoil biomass recovered to pre-treatment levels.

Fish sampling.—Fyke nets and electrofishing were used to sample fish during 3 months in spring, 1992 through 1996. Three to 10 fyke nets were randomly set and fished for bluegills from March, after ice-out, through mid-May, and again in June. As spring progressed and more fish moved into shallow water, the number of fyke nets was reduced to reflect the amount that the crew could process in a given day. We electrofished for largemouth bass at night for a 2-week period from the middle to end of May, and shocked two to three laps of the entire shoreline. A Wisconsin Department of Natural Resources DC electrofishing boat was used, and depending on water conditions, amps ranged from 9 to 11, volts from 180 to 350, and pulse rate from 53 to 60. Fish captured were measured (mm, TL), and subsamples were weighed (g). Scale samples were taken from at least 10 fish of each species per 10-mm length-class to estimate growth rates. Largemouth bass longer than 100 mm, and bluegills longer than 80 mm were marked by removal of a pectoral or ventral fin for estimating abundance, except in 1994, the year of the plant removal. Largemouth bass longer than 249 mm were also marked with T-bar tags.

Statistical analysis.—Abundance of largemouth bass and bluegills was estimated in 1992–1993 and 1995–1996 to assess the effects of reduced vegetation on fish abundance in Fish Lake. Fish were collected over a 3–7 week period each year. Abundance (N_t) and 95% confidence limits were estimated for each year using the modified Schnabel estimator (Ricker 1975). Mean abundance was compared before (1992–1993) and after (1995–1996) vegetation removal using analysis of variance, in which variation in abundance between years was used to estimate variance within the two periods (Zar 1999).

Population growth rates were estimated for largemouth bass of ages 2–5 and bluegills of ages 4–6 to assess the effects of reduced vegetation on fish growth in Fish Lake. Mean lengths at age of largemouth bass and bluegills were estimated from fish collected in March through June before (1992–1993) and after (1995–1996) vegetation removal. Annual growth increments were estimated for each age-group by subtracting the mean length at age x from the mean length at age $x + 1$ (Ricker 1975). Confidence limits (95%) were estimated for dif-

ferences in mean length at ages x and $x + 1$ using pooled variances if variances were equal, or not pooled if variances were unequal (Zar 1999). The same method was used for largemouth bass weight (g), but not for bluegills because weights were not measured for all age-groups in 1992. Changes in mean length and weight after vegetation removal were tested with t -tests, in which variances were pooled between periods if variances were equal, and not pooled if variances were unequal (Zar 1999).

Annual survival rates of largemouth bass and bluegills were estimated for largemouth bass of ages 2–5 and for bluegills of ages 4–6 to assess the effects of reduced vegetation on fish survival in Fish Lake. The catchability (q) of fish collected during surveys differed between years because plant bed density affected gear-efficiency, and thereby masked the true mortality rate. This was taken into account before estimating mortality by first estimating catchability:

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

where q_t (catchability) is the fraction of the population taken by one unit of fishing effort in year t , C_t is the catch of fish in year t , f_t is fishing effort in year t , and N_t is the estimated number in the population in year t (Ricker 1975). The catchability (q_t) was then averaged among years to standardize the catch for each age-class:

$$C'_t = C_t \frac{\bar{q}}{q_t},$$

where C'_t is the adjusted catch of a particular age-group in year t , C_t is the actual catch of fish of a particular age in year t , q_t is the catchability of fish in the gear in t , and \bar{q} is average catchability among years. Survival rates for largemouth bass and bluegills were then estimated for fish at specific age-classes with the equation:

$$S = \frac{C'_{t+1}}{C'_t},$$

where S is the rate of survival, C'_t is the adjusted catch of fish of a given age in year t , and C'_{t+1} is the adjusted catch of fish of a given age in year $t + 1$ (Ricker 1975). Exact confidence limits (95%) were estimated for survival rates and differences in survival before and after vegetation removal were tested with Z -tests (Zar 1999).

Length distributions were compared for large-

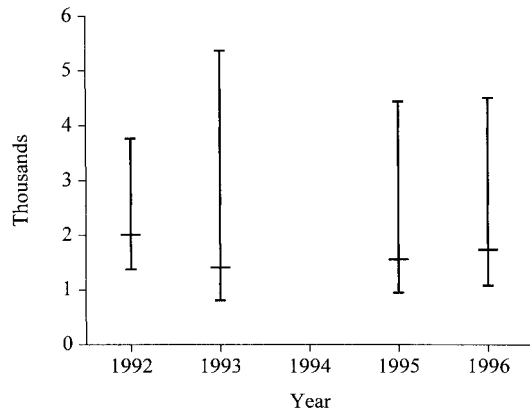


FIGURE 2.—Spring abundance of largemouth bass in Fish Lake, Wisconsin, before (1992 and 1993) and after (1995 and 1996) vegetation removal. Data are means (short horizontal bars) and 95% confidence intervals (vertical lines).

mouth bass 100–500 mm long (ages 2–8) and bluegills 80–210 mm long (ages 2–8) to assess the effects of reduced vegetation on fish population size structure in Fish Lake. Length distributions were tallied by 10-mm length groups for each year, but were compared between pretreatment (1992–1994) and posttreatment (1995–1996) years with the Kolmogorov–Smirnov test, D , for differences in distributions (Zar 1999).

Results

Largemouth Bass

Average abundance of largemouth bass did not change significantly after vegetation was removed from Fish Lake ($F = 0.043$; $df = 1, 2$; $P > 0.05$). The estimated number of largemouth bass in Fish Lake ranged from 1,405 to 2,012 (14–20 fish/ha) during 1992–1993, before vegetation was removed, and from 1,556 to 1,730 (15–17 fish/ha) during 1995–1996, after vegetation was removed (Figure 2).

Growth in length (mm) of largemouth bass increased for ages 2 ($t = -15.67$; $df = 220$; $P \leq 0.05$), 3 ($t = -11.57$; $df = 186$; $P \leq 0.05$), and 4 ($t = -3.47$; $df = 91$; $P \leq 0.05$), but decreased for age 5 ($t = 2.56$; $df = 59$; $P \leq 0.05$), after vegetation was removed from Fish Lake. Fish of ages 2 and 3 grew slower in length than fish of ages 4 and 5 before vegetation was removed, but increased significantly thereafter such that growth was similar among ages 2–5 (Figure 3).

Growth in weight (g) of largemouth bass paralleled growth in length, as weight gain increased

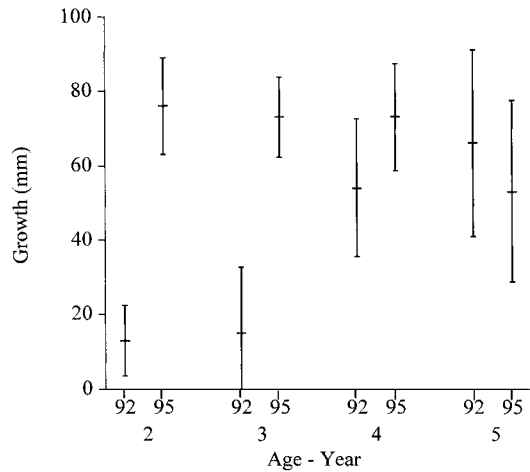


FIGURE 3.—Mean annual growth increment (TL, mm) of four age-classes of largemouth bass in Fish Lake, Wisconsin, before (92 = 1992–1993) and after (95 = 1995–1996) vegetation removal. Data are means (short horizontal bars) and 95% confidence intervals (vertical lines).

significantly for age-2 fish ($t = -16.55$; $df = 57$; $P \leq 0.05$) and for age-3 fish ($t = -11.45$; $df = 74$; $P \leq 0.05$), after vegetation removal from Fish Lake. Weight gain did not change significantly for age-4 fish ($t = 0.27$; $df = 23$; $P > 0.05$) and declined for age-5 fish ($t = 16.65$; $df = 57$; $P \leq 0.05$). Fish of ages 2–3 grew slower than fish of ages 4–5 before

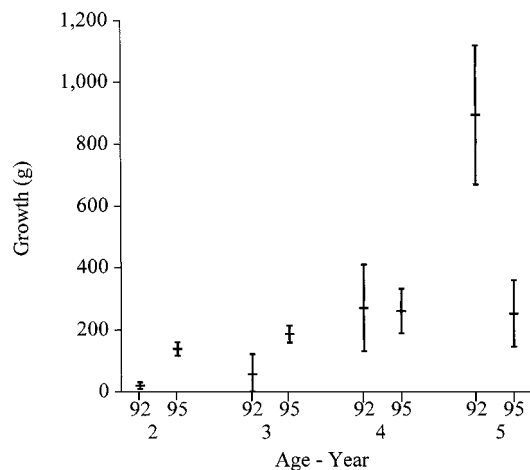


FIGURE 4.—Mean annual growth increment (biomass, g) of four age-classes of largemouth bass in Fish Lake, Wisconsin, before (92 = 1992–1993) and after (95 = 1995–1996) vegetation removal. Data are means (short horizontal bars) and 95% confidence intervals (vertical lines).

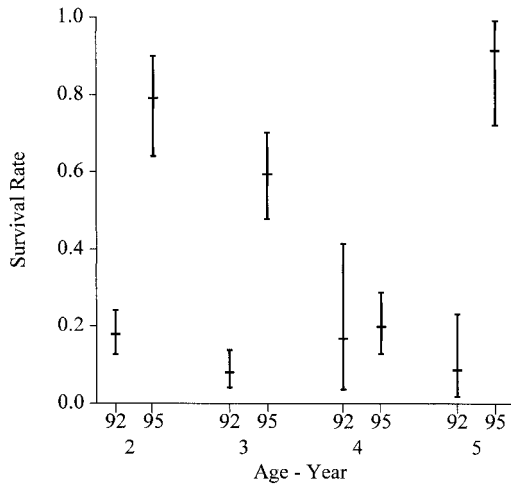


FIGURE 5.—Annual survival rate of four age-classes of largemouth bass in Fish Lake, Wisconsin, before (92 = 1992–1993) and after (95 = 1995–1996) vegetation removal. Data are means (short horizontal bars) and 95% confidence intervals (vertical lines).

vegetation was removed, but grew similarly among all ages after the removal (Figure 4).

Survival of largemouth bass increased for fish of ages 2 ($Z = 7.75$; $P \leq 0.05$), 3 ($Z = 8.13$; $P \leq 0.05$), and 5 ($Z = 5.99$; $P \leq 0.05$), but did not change significantly for fish of age 4 ($Z = -0.01$; $P > 0.05$), after vegetation was removed from Fish Lake. Fewer than 20% of the fish in each age-class

survived between years before vegetation removal, but more than 60% of fish in age-classes 2, 3, and 5 survived between years after vegetation removal (Figure 5).

The population size structure of largemouth bass longer than 100 mm increased after vegetation was removed from Fish Lake ($D = 0.314$; $N_1 = 883$; $N_2 = 364$; $P \leq 0.01$). Small fish, ranging in length from 150 to 210 mm (ages 2–3), predominated in years before vegetation removal, whereas larger fish, ranging in length from 170 to 310 mm (ages 2–5), predominated in years after vegetation removal (Figure 6).

Bluegills

Average abundance of bluegills did not change significantly before and after vegetation was removed from Fish Lake ($F = 0.602$; $df = 1, 2$; $P > 0.05$). One year before cutting, bluegill abundance nearly doubled, but mean abundance before and after cutting was similar. The estimated number of bluegills in Fish Lake ranged from 76,707 to 141,785 (759–1,404 fish/ha) during 1992–1993 before vegetation was removed and from 82,078 to 85,822 (813–850 fish/ha) during 1995–1996 after vegetation was removed (Figure 7).

Growth in length of bluegills declined for fish of ages 4 ($t = 5.21$; $df = 29$; $P \leq 0.05$) and 5 ($t = 8.06$; $df = 59$; $P \leq 0.05$), but did not change significantly for fish of age 6 ($t = 1.65$; $df = 15$; $P > 0.05$) after vegetation was removed from Fish

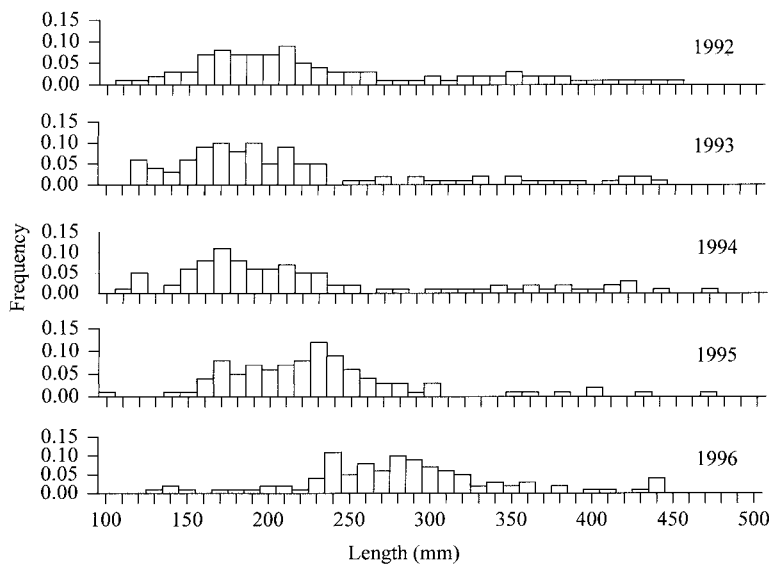


FIGURE 6.—Length distribution of largemouth bass captured in spring by electrofishing in Fish Lake, Wisconsin, before (1992–1994) and after (1995–1996) vegetation removal.

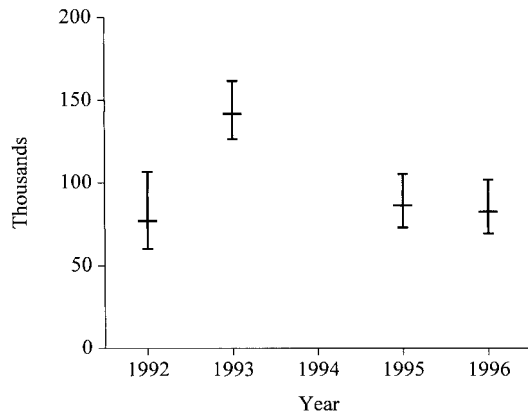


FIGURE 7.—Spring abundance of bluegill in Fish Lake, Wisconsin, before (1992–1993) and after (1995–1996) vegetation removal. Data are means (short horizontal bars) and 95% confidence intervals (vertical lines).

Lake. Age-5 bluegills grew twice as fast in years before vegetation removal, when their length increased by more than 30 mm per year, than in years after vegetation removal, when their length increased only 15 mm per year (Figure 8).

Survival of bluegills increased for fish of ages 4 ($Z = 36.64$; $P \leq 0.05$), 5 ($Z = 16.92$; $P \leq 0.05$), and 6 ($Z = 28.77$; $P \leq 0.05$) after vegetation was removed from Fish Lake. Fewer than 35% of bluegills in each age-class survived between years before vegetation removal, but more than 50% of fish in each age-class survived between years after vegetation removal (Figure 9).

The population size structure of bluegills longer than 80 mm increased after vegetation was removed from Fish Lake ($D = 0.347$; $N_1 = 27,196$; $N_2 = 23,494$; $P < 0.01$). Small fish, ranging in length from 110 to 170 mm (ages 2–7), predominated in years before vegetation removal, whereas larger fish, ranging in length from 140 to 190 mm (ages 4–7), predominated in years after vegetation removal (Figure 10).

Discussion

We expected abundance of largemouth bass to increase and of young bluegills to decrease after vegetation removal from Fish Lake, but mean abundance of largemouth bass and bluegills did not change significantly. In a Texas reservoir, largemouth bass abundance did not change, but bluegill abundance declined significantly, when vegetation was reduced (Bettoli et al. 1993). In Fish Lake, cutting the plants in a channel configuration may have increased largemouth bass access to bluegills, yet the ratio of bluegills to large-

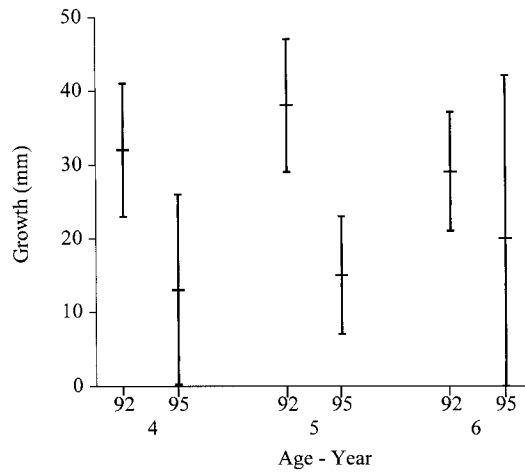


FIGURE 8.—Mean annual growth increment (TL, mm) of three age-classes of bluegills in Fish Lake, Wisconsin, before (92 = 1992–1993) and after (95 = 1995–1996) vegetation removal. Data are means (short horizontal bar) and 95% confidence intervals (vertical lines).

mouth bass may have remained high enough that increased predation did not noticeably reduce total bluegill abundance. Also, we estimated abundance in only 2 years before and 2 years after vegetation removal, so the probability of detecting a change in mean abundance was poor (Carpenter et al. 1998).

We expected survival of largemouth bass to increase and of young bluegills to decrease after re-

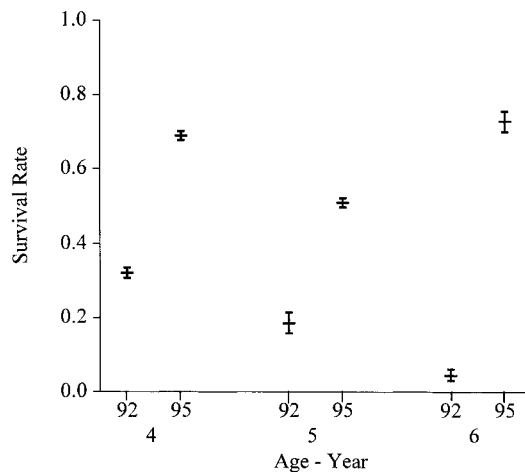


FIGURE 9.—Annual survival rate of three age-classes of bluegills in Fish Lake, Wisconsin, before (92 = 1992–1993) and after (95 = 1995–1996) vegetation removal. Data are means (short horizontal lines) and 95% confidence intervals (vertical lines).

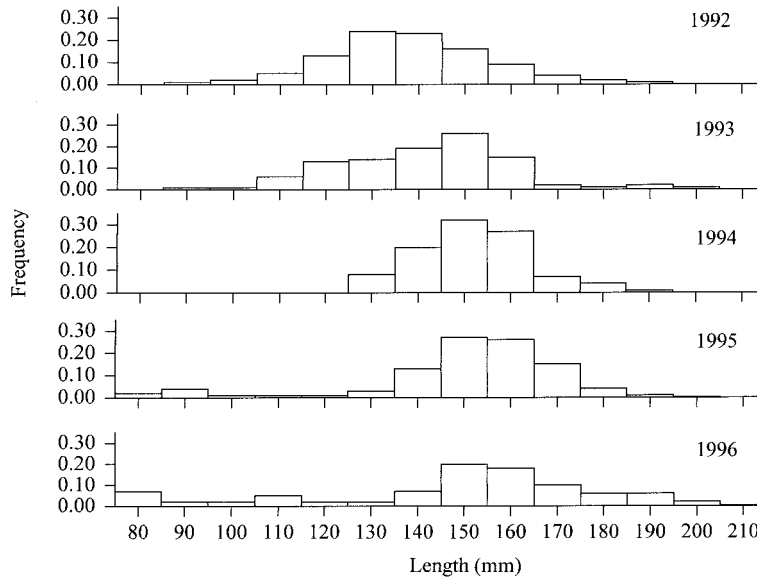


FIGURE 10.—Length distribution of bluegills captured in spring by fyke-netting in Fish Lake, Wisconsin, before (1992–1994) and after (1995–1996) vegetation removal.

moving vegetation from Fish Lake, but survival of both species increased. Cutting channels through vegetation in Fish Lake may have reduced cannibalism and competition among largemouth bass by allowing them to spread out into formerly unoccupied areas of Fish Lake. Largemouth bass remained widely separated in experimental enclosures when plant bed edge habitat was doubled, but fish were more concentrated when vegetation was left untouched (Smith 1993, 1995). Also, reduced vegetation may have increased survival of age-4–6 bluegills in Fish Lake by allowing largemouth bass to switch to eating smaller, younger bluegills, thereby reducing predation on larger, older bluegills and increasing their survival. Increased plant bed edge and reduced vegetation density led to higher capture rates of small bluegills by largemouth bass (Savino and Stein 1982; Smith 1995). In Fish Lake, bluegills older than age 3 survived better after vegetation removal, as high as 72% for age-6 bluegills, which fell within the range of adult bluegill survival in other Wisconsin lakes (Beard 1982).

We expected growth of all ages of largemouth bass to increase after plants were reduced in Fish Lake, but growth increased for ages 2–4 and decreased for age 5. Before plant removal, dense vegetation may have limited growth rates of young largemouth bass, when their growth rates were lower than of regional populations (Engel 1985;

Johnson et al. 1995). After plant removal, growth rates of age-2 largemouth bass in Fish Lake were within the range of those from 300 waters in Wisconsin and nearby states (Engel 1987). In healthy populations, centrarchids commonly experience rapid growth during early life and slower growth later in life (Ricker 1975). In Fish Lake, the opposite was true, as age-2 and age-3 fish grew slower than age-4 and age-5 fish, which suggests resources limited growth of younger fish. After plant removal, growth increased for age-2 and age-3 largemouth bass, which is consistent with other studies that have shown increased growth of young fish after vegetation reduction (Engel 1985; Cross et al. 1992; Hoyer and Canfield 1996; Miranda et al. 1996). The earlier shift to piscivory after the vegetation reduction may have contributed to increased growth of young largemouth bass in Fish Lake.

Before the plant reduction in Fish Lake, largemouth bass longer than 250 mm ate bluegills and pumpkinseeds (Sloey and Schenck 1997), whereas largemouth bass shorter than 200 mm ate mostly insects (Storlie et al. 1995). After vegetation removal, the incidence of fish, mostly centrarchids, in stomachs of largemouth bass shorter than 200 mm increased from 8% to 62% (J. M. L. Unmuth, unpublished data). In contrast, growth did not increase for age-5 largemouth bass because most of these fish were primarily piscivorous before the

plant manipulation (Storlie et al. 1995). Slow growth of young largemouth bass in pretreatment years likely resulted from low availability of small bluegills, since small bluegills were less common before the plant removal and were also less available before the cutting of channels into plant beds.

We expected growth of bluegills to increase after vegetation was reduced in Fish Lake, but growth declined for age-4–5 bluegills. Reduced growth of age-4–5 bluegills after vegetation removal may have resulted from reduced availability of zooplankton as prey for bluegills and increased competition among bluegills for zooplankton prey. Bluegills longer than 150 mm typically feed near plant bed edges or in open water (Trebitz et al. 1997). Biomass of prey eaten by bluegills longer than 130 mm (>age-3) before the plant manipulation in Fish Lake, when age-4–5 bluegills grew faster, was 98% zooplankton (Sloey and Schenck 1997). In the year of the plant manipulation, bluegills longer than 130 mm were more general in their food habits, because zooplankton made up only 53% of the total prey biomass (Sloey and Schenck 1997). This suggests that zooplankton abundance declined or that zooplankters were shared among greater numbers of bluegills. When plant bed edge was increased, and bluegills were risk-neutral in their foraging, growth increases were more even among all sizes of bluegills (Trebitz et al. 1997), which suggests greater competition for prey items.

We expected population size structure of both largemouth bass and bluegills to increase after vegetation was removed from Fish Lake, and population size structure of both species did increase as anticipated. Increased population size structure was likely caused by increased survival of some age-groups of both species. Recruitment of largemouth bass to harvestable size was correlated with plant cover of up to 26% in 30 Texas reservoirs (Durocher et al. 1984). Increased size of largemouth bass and bluegills after vegetation removal in Fish Lake was unrelated to changes in exploitation of largemouth bass, which was negligible in all years, or of bluegills, which was lower before vegetation removal than afterwards (Unmuth 1997; Unmuth, unpublished data).

Natural variation in plant biomass and climatic conditions may have contributed to observed changes in growth, survival and population size structure of largemouth bass and bluegills in Fish Lake. Lack of replication and control in our study makes it impossible to attribute observed changes in fish populations to vegetation reduction versus

other environmental changes. For example, plant biomass in Fish Lake fluctuated among years from natural causes that were not associated with cutting, which could have caused changes in largemouth bass and bluegill growth, survival and population size structure. Also, changes in water temperature may have influenced growth of largemouth bass and bluegills in Fish Lake. Fish consumption and growth are related to water temperature (Hathaway 1927; Le Cren 1958; Snow and Staggs 1994; Staggs and Otis 1996). Average annual surface and bottom water temperatures in Fish Lake were similar in years before vegetation removal, while bottom temperature was cooler in one year after vegetation removal (Unmuth, unpublished data). Bluegill growth declined with cooler temperatures, but, surprisingly, largemouth bass growth increased, which suggests that water temperature influenced bluegill growth, while largemouth bass growth was influenced by prey availability.

Removal of vegetation in channels may be a useful fishery management tool to increase largemouth bass and bluegill survival and population size structure, and largemouth bass growth. Increasing the amount of edge habitat in densely vegetated lakes through selective removal of plants may be effective for improving largemouth bass populations, albeit less consistent for improving bluegill populations. In hindsight, it would be valuable to evaluate fish population dynamics over all age-classes, from pre- to posttreatment. We recommend that future vegetation manipulation experiments include documentation of changes in fish abundance, as well as changes in growth and survival for each age-class in the population. We also recommend replicate treatment and control lakes to separate the effects of vegetation reduction from natural variation that is inherent in lake communities.

Acknowledgments

Funding was provided by the Federal Aid in Sport Fish Restoration Act, project F-95-P, the Wisconsin Department of Natural Resources, and the University of Wisconsin, Center for Limnology. Dave Dreikosen, Bill Halverson, Dick Lillie, Richard Narf, Randy Piette, Terry Schenk, Dave Sloey, and Christine Storlie assisted in many aspects of laboratory work, field work, and data analysis. We gratefully acknowledge Ken Kosciak and Joe Yaeger of Dane County Public Works for the design and fabrication of the close-cut plant harvester.

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