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MACROPHYTE REMOVAL TO ENHANCE BLUEGILL, LARGEMOUTH BASS AND NORTHERN PIKE POPULATIONS[1]

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Abstract.--We examined effects of systematic macrophyte removal on bluegill, largemouth bass, and northern pike in three Wright County lakes with dense populations of slow growing bluegill. In Mary and Ida lakes, 6 to 11% of the macrophyte cover was mechanically harvested during 1988 and 1989. Macrophyte cover was harvested in quadrants (0.8 and 1.0 ha) at rates of 50, 75, and 100 percent. Macrophytes were not harvested in Bass Lake. Lakewide changes in density, size structure, and growth of bluegill, largemouth bass, and northern pike were not significantly affected by macrophyte harvesting. Only first-year growth of largemouth bass was improved. Bluegill populations were strongly affected by factors other than macrophyte harvesting that caused variability in year-class strength. Mechanical harvesting as a management tool to improve fish populations may be restricted by cost and harvesting equipment capabilities.

Introduction

Lakes that contain many small bluegill *Lepomis macrochirus* but not enough large bluegill to satisfy anglers are common in Minnesota. Excessive aquatic macrophyte cover in these lakes is thought to be a major factor affecting bluegill size. At high densities, macrophyte cover protects bluegill from predation and allows them to proliferate, leading to density-dependent growth reduction. Hypothetically, removal of excess aquatic macrophyte cover will improve conditions for bluegill populations and their predators. The amount of macrophyte cover in lakes has been shown to influence growth of bluegill (Engel 1985); year class formation of bluegill (DiCostanzo 1957); largemouth bass *Micropterus salmoides* (Reynolds and Babb 1978; Durocher et al. 1984) and northern pike *Esox lucius* (Holland and Huston 1984); and physical condition of bluegill and largemouth bass (Colle and Shireman 1980).

For decades, improvements in growth and size structure of bluegill populations have been fishery management goals. Experimental removal of bluegill to increase the growth and size structure of bluegill has not been effective or has resulted in only

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temporary improvements (Beckman 1950; Scidmore 1959; Layzer and Clady 1981). The most effective technique has been to maintain predation on bluegill at a level that results in a balanced population (Swingle and Smith 1942; Anderson 1973). Predation on bluegill is most effective when concentrated on small fish (Novinger and Legler 1978; Clark and Lockwood 1990; Guy and Willis 1990).

Predator effectiveness decreases with the increased structural complexity of cover (Glass 1971; Stein 1977; Saiki and Tash 1979). Savino and Stein (1982) determined that largemouth bass became less efficient at capturing small bluegill as stem density increased in experimental ponds. Feeding rates of predator fish are optimized in cover that holds high densities of prey while still providing adequate space for predator fish to maneuver and capture prey (Crowder and Cooper 1979a). Wiley et al. (1984) showed that largemouth bass grew best with intermediate densities (52 g dry weight/m^2) of aquatic macrophyte cover in experimental ponds.

Predation and cover complexity affect growth and feeding of bluegill. In response to predatory pressures, bluegill < 100 mm TL were restricted to areas with dense macrophyte cover in littoral zones of lakes (Hall and Werner 1977). Larger bluegill were less susceptible to predation and occupied areas away from macrophyte cover where more food was easier to obtain (Mittlebach 1981; Werner et al. 1983). Excessive macrophyte cover restricts the ability of bluegill to use invertebrate foods (Mittlebach 1981). In experimental ponds, Crowder and Cooper (1979b) showed that bluegill grew best at intermediate macrophyte densities (111 stems/m^2).

Manipulation of bluegill populations in lakes with dense macrophyte cover may be possible with macrophyte removal. In Minnesota lakes, mechanical harvesting is the preferred technique to remove macrophytes. Mechanical harvesting is similar in cost to herbicide treatment for large areas (Smith 1979) and is the most efficient technique where the use of chemicals is undesirable. Mechanical harvesting can also be used to selectively harvest areas within macrophyte beds to create areas for boating and fishing, and to enhance habitat for predator fish (Smith 1986).

Changes in fish populations due to manipulation of macrophyte densities with mechanical harvesting have rarely been documented. Engel (1987) showed that largemouth bass used channels cut through macrophyte beds by a mechanical harvester. Conversely, Theisfield (1989) determined that the distribution of largemouth bass and bluegill was not influenced by macrophyte removal. Improvements in condition of bluegill and largemouth bass were observed by Colle and Shireman (1980) following mechanical harvesting of *Hydrilla* spp. in a Florida lake. Mechanical harvesting of aquatic macrophytes also removes some juvenile fish associated with the macrophytes (Mikal 1985; Haller et al. 1980).

In this study we evaluated the effects of systematic mechanical harvesting of aquatic macrophytes on fish populations. The objective was to improve the size structure and growth of bluegill, largemouth bass, and northern pike in two Minnesota lakes with dense macrophyte cover.

Study Area

Three Wright County lakes, Mary, Ida, and Bass, were selected for this study. These lakes are representative of small, central Minnesota lakes that contain an abundance of small bluegill. Physical characteristics of the study lakes were similar, although Lake Mary was more fertile and less transparent than either Ida or Bass lakes (Table 1). In Lake Mary, few emergent macrophytes were found and submerged macrophytes were usually limited to depths less than 3 m. The macrophyte community in Lake Mary was dominated by *Potamogeton crispus* and *Myriophyllum exalbescens* (Table 2). In Ida and Bass lakes, emergent macrophyte forms were common and a diverse submergent macrophyte community occurred to 9 m (Table 2).

Table 1. Selected physical and chemical characteristics of Mary, Ida, and Bass lakes.

Selected characteristic	Mary	Ida	Bass
Surface area (ha)	72.9	93.6	86.3
Maximum depth (m)	14	18.3	10.4
Percent littoral (<4.6 m)	53	47	45
Percent macrophyte coverage[a]	24	20	30
Secchi disk transparency (m)	1.3	4.1	5.0
Chlorophyll a (ug/l)	29.5	7.9	5.6
Total phosphorous (mg/l)	0.025	0.012	0.011
Specific conductance (umhos/cm)	266	292	324

[a] Determined from aerial photos taken 8 August 1989.

Table 2. Relative abundance of aquatic macrophytes in Mary, Ida, and Bass lakes (*a*-abundant, *c*-common, *o*-occasional, *r*-rare, *p*-present).[a]

Plant species	Mary	Ida	Bass
Ceratophyllum demersum	*o*	*a*	*o*
Chara spp.	*c*	*a*	*a*
Elodea canadensis		*a*	*r*
Myriophyllum exalbescens	*a*	*a*	*a*
Najas flexilis	*c*		*o*
Nuphar microphylumm			*p*
Nuphar variegatum		*a*	*r*
Nymphaea tetragona		*a*	
Nymphaea tuberosa		*a*	
Potamogeton amplifolius	*o*	*o*	*r*
Potamogeton crispus	*a*		*o*
Potamogeton foliosus	*o*		
Potamogeton natan		*o*	
Potamogeton pectinatus	*c*		*o*
Potamogeton praelongus			*a*
Potamogeton richardsonii		*a*	*o*
Potamogeton zosteriformis	*a*	*a*	*r*
Scirpus acutus		*c*	
Sparganium eurycareum		*r*	
Ranunculus spp.		*a*	*r*
Utricularia vulgaris			*o*
Vallisneria americana		*a*	*o*

[a] Compiled from MNDNR lake survey file information.

Below average precipitation in 1988 and 1989 resulted in a 1 m drop in water levels in these study lakes. Corresponding changes in macrophyte growth patterns were also observed. Emergent macrophyte stands were largely reduced in the study lakes. A reduction of *P. crispus* in Lake Mary was observed in 1989.

Lake Mary is managed by the MNDNR Fisheries Section as a centrarchid-walleye lake. This lake has been stocked with northern pike (125 - 500 fingerlings/littoral ha and 125 adults/ha, annually), walleye *Stizostedion vitreum* (0.47 - 0.89 kg fingerlings and yearlings/littoral ha, alternate years; 200 - 400 fry/littoral ha in 1983 and 1985), yellow perch *Perca flavescens* (1.87 kg - fingerlings/ha, between 1987 and 1988), and black crappie *Pomoxis nigromaculatus* (1.16 kg adults/ha, 1986). Lakes Ida and Bass are managed as centrarchid lakes and have not been stocked with fish since 1979.

Fish populations in Bass and Ida lakes were similar to each other and different from fish populations in Lake Mary. Higher catches of walleye, largemouth bass, and black crappie are characteristic of Lake Mary (MN DNR file data). Catches of bowfin *Amia calva*, northern pike, yellow perch, brown bullhead *Ameiurus nebulosus*, green sunfish *Lepomis cyanellus*, pumpkinseed *L. gibbosus*, and sunfish hybrids *Lepomis spp.* are highest in Ida and Bass lakes (MN DNR file data). Fish diversity is higher in Ida and Bass lakes than in Lake Mary (MN DNR file data).

Methods

Macrophyte Removal

Macrophytes in selected sites within Lakes Mary and Ida were removed with mechanical harvesters in 1988 and 1989. Mechanical harvesting was not done in Bass Lake during this period. Private firms were contracted to perform the harvest. Harvesting started when macrophyte growth neared the water surface (late June) within the selected sites. Harvesting was conducted again approximately one month later when the regrowth of macrophytes neared the surface of the lake.

Sites and removal patterns for macrophyte harvesting within each lake were identical in both years. In Lake Mary, macrophytes from two 0.8 ha quadrants were harvested in a grid pattern, forming square islands of vegetation. Fifty percent of the surface area was harvested in one quadrant and 75 percent of the surface area was harvested in the other quadrant. In Lake Ida, two 1.0 ha sites were clearcut. Approximately 6% and 11% of the macrophyte cover in Lakes Mary and Ida, respectively, were removed (Table 3). More edge (interface between harvested and unharvested areas) was created with the grid pattern than with clear cutting (Table 3).

Fish Population Assessment

Fish populations in all three study lakes were sampled two years immediately before macrophyte harvesting (1986-1987) and two years with harvesting (1988-1989). In 1986, sampling was done in August and September. From 1987 to 1989, sampling was done from May through September.

Six trap nets with 1.9-cm mesh and a 76-m, five panel (1.9-, 2.5-, 3.2-, 3.8-, and 5.1-cm mesh) experimental gill net were set at permanent stations in each lake. Captured fish were identified to species, counted, and measured (TL mm). Scale samples and weights were taken from bluegill subsamples, and from all largemouth bass and northern pike. Cleithra were collected from northern pike killed during capture.

Fish were also sampled with a boat mounted electrofisher. A Coffelt VVP-15 unit was used for pulsed DC current output, except during mechanical failure, when pulsed AC current was substituted. Voltage ranged from 300 to 600 volts and current ranged from 4 to 6 amps. Differences in catches between the two current types were not observed; therefore, all data were treated identically. Macrophyte harvest quadrants, adjacent unharvested quadrants (representa-

Table 3. Total area of experimental quadrants, percent harvested, and length of interface between harvested and unharvested areas (edge) at Mary and Ida lakes.

Removal pattern		Total area (m^2)	Percent harvested	Edge length
		Lake Mary		
Site 1	grid	8,000	75	920 (340%)[a]
Site 2	grid	8,000	50	1176 (435%)[a]
		Lake Ida		
Site 1	clearcut	10,000	100	300
Site 2	clearcut	10,000	100	300

[a] Percentage increase in edge over total removal with clearcut.

tive of harvested quadrants without treatment), and selected trap net locations (representative of the littoral zone in each lake) were electrofished in 1988 and 1989. Each site was electrofished for 10 minutes during the day and again at night. All fish species were collected except that only largemouth bass and northern pike were collected during night runs in 1987. After each run, fish were identified and measured (TL mm). Scale samples and weight (g) were collected from all captured largemouth bass and northern pike. Stomach samples were dissected from a representative sample of bluegill and largemouth bass < 200 mm TL. Stomach contents of largemouth bass > 200 mm and northern pike were collected with a stomach pump (Seaburg 1957).

All scale samples were pressed on acetate strips. Annual marks on northern pike cleithra were used to confirm ages determined with scales. Food items contained in stomach samples were identified to the nearest practical taxon.

Data Analysis

Data collected in this study were used to describe differences in bluegill, largemouth bass, and northern pike populations before and after treatment with mechanical harvesting as well as among sites within each lake. Relative abundance, length distribution, physical condition, age distribution, growth, and diet were determined.

Early summer (May - July 9) and late summer (July 10 - September) trap net samples were analyzed separately because substantial differences in catch rates and size structure were observed. Trap net and gill net CPUE were expressed as the number of fish caught per set. Proportional stock density (PSD) and relative stock density (RSD) were calculated (Anderson and Gutreuter 1983). Statistical differences in trap net CPUE and PSD of bluegill between preharvest and harvest years were determined with paired T-tests. Relative weight (Wr) of northern pike captured in gill nets were calculated as suggested by Willis and Scalet (1989).

Electrofishing CPUE was expressed as the number of bluegill < 80 mm, bluegill ≥ 80 mm, largemouth bass < 200 mm, largemouth bass ≥ 200 mm to < 300 mm, and largemouth bass ≥ 300 mm captured per h. Day and night electrofishing samples were analyzed separately. Differences in electrofishing CPUE of bluegill and largemouth bass were summarized using two-way ANOVA (macrophyte harvest treatments by sampling date) with LSD pairwise comparison of means. The Kolmogorov-Smirnov test was used to examine differences between length frequencies of bluegill and largemouth bass captured with electrofishing. Relative weight (Wr) were calculated (Anderson and Gutreuter 1983) and significant differences in mean Wr between harvest and preharvest periods were determined with Tukey HSD tests.

Growth was determined with the Frazer-Lee method using standard *a* intercept values (Carlander 1982) and the Disbcal computer program (Frie 1982). Two sample T-tests were used to determine differences between average back-calculated annual growth increments. Age, environment, and age*environment interaction effects on annual scale growth increments were identified using linear models developed by Weisburg and Frie (1989).

Percent occurrence of food items in stomachs of bluegill ≤ 60 mm, bluegill > 60 mm, largemouth bass < 100 mm, largemouth bass ≥ 100 mm, and northern pike collected from July through September were calculated. After macrophyte harvest, we looked for increases of zooplankton in stomachs of bluegill, and increases of *Lepomis* spp. in stomachs of largemouth bass and northern pike. To estimate similarities in diet of bluegill ≤ 60 mm and > 60 mm among harvested and unharvested quadrants within Ida and Mary lakes, Spearman rank coefficients were calculated (Fritz 1974).

Statistical significance were set at $P < 0.05$ for all tests unless otherwise stated.

Results

Lakewide comparisons

Bluegill.--Macrophyte harvesting did not appear to affect density, age or size structure, condition, growth, or diet of bluegill. Bluegill CPUE and PSD in trap nets at Lake Ida during preharvest years were not significantly different than during harvest years (Tables 4 and 5). Late summer PSD of bluegill was significantly lower in Lake Mary during harvest years, but no other significant differences were found. Trap net CPUE during early summer at Bass Lake was significantly higher during harvest years, but no other significant differences in catch indices were observed.

Year class strengths of bluegill were highly variable within each lake and inconsistent among lakes (Table 6). Lake Mary bluegill was dominated by 1982, 1985, and 1986 year classes; Lake Ida bluegill was dominated by the 1982 and 1983 year classes; and Bass Lake was dominated by the 1983 and 1986 year classes. These strong year-classes were established before we started macrophyte harvesting and did not appear to change as a result of harvesting.

Average Wr of bluegill were lower for harvest years than preharvest years in all three lakes (Table 7). Significant decreases in Wr were found for all sizes of bluegill in Lake Ida and for bluegill in the 80 - 150 mm size class in Bass Lake.

An increase in bluegill growth rates corresponding to macrophyte harvesting was not found. Annual growth increments for 1988 were usually less than growth increments in previous (unharvested) years in all three lakes (Table 8). Environmental effects were indicated for changes in age 1 to 3 bluegill in Bass Lake, age 2 bluegill in Lake Ida, and age 1 and 3 bluegill in Lake Mary (Table 9). However, environmental effects did not correspond to harvesting in 1988 and 1989.

Macrophyte harvest did not appear to affect diet of bluegill. Before and during macrophyte harvesting, copopods, *Daphnia* spp., amphipods, and dipterans were the more frequently observed food items in stomachs of bluegill ≤ 60 mm in each lake (Table 10). Bluegill > 60 mm fed mostly on amphipods, dipterans, trichopterans, and vegetation before and during years of macrophyte harvest (Table 10). Increased occurrences of copopods and cladocerans were not observed (Table 10).

Largemouth bass.--Macrophyte harvesting did not affect density, age or size structure, condition, or diet, but could have affected first-year growth of largemouth bass in Mary and Ida lakes. Electrofishing CPUE of all size groups of largemouth bass

Table 4. Mean daily trap net CPUE (no./lift) of bluegill sampled early summer and late summer in Mary, Ida, and Bass lakes before mechanical harvesting (1986-1987) and after (1988-1989).

Lake	Preharvest N	Preharvest Mean CPUE	Preharvest SE	Harvest N	Harvest Mean CPUE	Harvest SE
			Early summer			
Mary	5	64	20.7	2	30	10.4
Ida	4	84	30.6	2	100	12.9
Bass	3	51	9.5	2	156	13.9
			Late summer			
Mary	3	12	4.1	4	21	7.6
Ida	3	19	4.8	4	19	4.6
Bass	4	20	9.3	4	17	2.9

Table 5. Mean, standard error (SE), and sample size (N) of daily average bluegill PSD sampled during early and late summer in Mary, Ida, and Bass lakes before mechanical harvesting (1986-1987) and after (1988-1989).

Lake	Preharvest N	Preharvest Mean PSD	Preharvest SE	Harvest N	Harvest Mean PSD	Harvest SE
			Early summer			
Mary	5	57	6.1	2	50	13.7
Ida	4	40	9.5	2	69	4.8
Bass	3	38	7.2	2	69	16.1
			Late summer			
Mary	3	48	3.6	4	6*	4.4
Ida	3	13	6.8	4	37	8.8
Bass	4	49	10.5	4	26	9.0

* Indicates significant ($P < 0.05$) difference between preharvest and harvest means.

Table 6. Percent of bluegill at age in trap net samples in Mary, Ida, and Bass lakes, 1986-1989.

Year	Age 1	2	3	4	5	6	7	8	9
				Mary					
1986[a]	0	3	10	48	26	12	0	0	0
1987	2	7	3	12	50	15	10	0	0
1988	0	8	45	8	14	23	2	<1	<1
1989	<1	6	38	21	2	7	22	3	1
				Ida					
1986[a]	1	10	45	29	13	2	0	0	0
1987	<1	5	21	33	30	6	4	0	0
1988	0	2	7	22	36	24	9	1	<1
1989	0	5	4	4	14	45	19	8	<1
				Bass					
1986[a]	0	0	6	10	78	3	3	0	0
1987	0	6	37	39	9	6	1	2	0
1988	0	24	1	14	33	25	2	1	0
1989	<1	5	17	<1	15	51	11	<1	<1

[a] Only one sample date (August) was used in 1986.

Table 7. Mean relative weight (Wr) of bluegill 80 to 150 mm and bluegill ≥ 150 mm collected in Mary, Ida, and Bass lakes before (preharvest) and during mechanical harvest (harvest) of macrophytes.

Size group	Mary		Ida		Bass	
	Wr	N	Wr	N	Wr	N
			Preharvest			
80 - 150 mm	106	46	118	23	122	14
> 150 mm	116	20	116	4	120	5
			Harvest			
80 - 150 mm	109	256	107*	150	111*	156
> 150 mm	111	28	106*	84	115	45

* Indicates significant ($P < 0.05$) differences between harvest and preharvest means.

Table 8. Average back-calculated annual growth increments (inc.), sample size (N), and standard error (SE) for each age of bluegill collected in Mary, Ida, and Bass lakes from 1986 through 1989.

	1985			1986			1987			1988		
Age	Inc.	N	SE	Inc.	N	SE	Inc.	N	SE	Inc.	N	SE
Lake Mary												
1	37	8	1.1	41	11	1.9				42	1	
2	28	1		24	37	0.7**	28	3	1.9**	20	18	0.6
3	25	4	3.3	31	13	1.5**	24	14	1.4*	22	51	0.6
4	33	16	1.2**	31	19	1.5**	29	7	1.9	27	76	0.7
5	31	7	2.2**	29	40	1.2**	27	8	2.0	24	8	1.7
6	31	3	1.5**	22	12	1.4	26	27	1.4**	19	11	2.3
Lake Ida												
1	43	1		41	7	1.2						
2	17	3	1.8	22	13	0.7**				19	34	0.5
3	24	20	1.1**	20	27	0.7	15	4	2.2**	20	28	0.6
4	30	22	1.7**	22	42	0.8	22	15	2.2	23	25	1.0
5	26	7	1.1**	23	29	1.2	28	29	1.3**	23	45	0.8
6	16	1		20	6	2	22	19	1.6	22	58	0.8
Bass Lake												
1										46	13	1.2
2	22	1		33	5	2.2**	31	9	0.9**	25	25	0.5
3	29	1		32	13	2.1**				28	73	0.7
4	24	15	1.1	27	24	1.2	24	15	1.1	26	2	5.6
5	24	3	2.7	21	4	5.5	23	34	1.2	22	36	1.1
6	24	3	1.8**	13	4	2.2**	21	26	0.8**	16	52	0.6

* Indicates a significant $P < 0.05$* or $P < 0.01$** difference from the 1988 mean increment at age.

Table 9. Results of analysis of variance on scale increments between bluegill cohorts at the same age indicating a growth effect due to environmental factors.

	F statistic		
Age	Lake Mary	Lake Ida	Bass Lake
1	2.30*	0.90	5.80**
2	3.34**	4.84**	1.97
3	10.61**	1.14	4.61**
4	1.56	2.00	1.58
5	0.24	1.10	1.96
6	2.74	4.14	10.50*

* Indicates a significant $P < 0.05$* or $P < 0.01$** F statistic.

Table 10. Percent occurrence of food items in stomachs of bluegill ≤ 60 mm and > 60 mm collected at Mary, Ida, and Bass lakes during summer (July - September) 1987, 1988, and 1989.

Item	Mary 1987	Mary 1988	Mary 1989	Ida 1987	Ida 1988	Ida 1989	Bass 1987	Bass 1988	Bass 1989
				≤ 60 mm					
Copopoda	10	-	38	0	-	34	0	-	22
Bosmina spp.	20	-	3	0	-	6	20	-	27
Daphnia spp.	30	-	12	17	-	23	50	-	35
Amphipoda	10	-	25	0	-	31	30	-	32
Ostrocoda	0	-	56	0	-	25	0	-	43
Hydracarina	0	-	8	0	-	20	0	-	22
Diptera	33	-	63	83	-	77	20	-	59
Trichoptera	3	-	14	0	-	29	10	-	35
Ephemeroptera	0	-	22	0	-	23	0	-	8
Odonata	0	-	2	0	-	0	0	-	0
Terrestrial insects	0	-	7	0	-	1	0	-	3
Other insects	0	-	2	0	-	1	0	-	0
Gastropoda	0	-	7	0	-	6	0	-	22
Pelecyopoda	0	-	2	0	-	0	0	-	0
Vegetation	3	-	6	33	-	11	0	-	5
Empty	23	-	8	0	-	8	20	-	5
Sample size	30	0	259	6	0	142	10	0	122
				> 60 mm					
Copopoda	0	0	11	1	0	10	6	0	10
Bosmina spp.	0	1	0	10	0	0	9	0	1
Daphnia spp.	0	4	4	9	6	14	13	9	50
Amphipoda	0	16	25	26	35	31	4	71	31
Ostrocoda	0	6	19	0	1	9	0	0	5
Hydracarina	0	1	9	1	7	14	0	5	15
Diptera	24	64	80	44	72	75	24	88	70
Trichoptera	7	26	40	24	16	27	6	4	21
Ephemeroptera	0	1	18	0	16	24	0	16	14
Odonata	2	3	3	0	0	8	2	0	1
Terrestrial insects	5	6	20	0	29	24	11	12	10
Other insects	5	2	2	3	2	0	2	7	1
Gastropoda	2	16	20	4	18	13	0	5	11
Pelecyopoda	0	1	4	0	0	7	0	0	2
Vegetation	48	44	51	39	51	51	41	73	36
Empty	24	8	4	21	6	4	7	4	2
Sample size	42	110	611	70	189	540	54	56	331

in the study lakes, after macrophyte harvesting, did not appear to differ from CPUE before harvesting (Table 11). Age structures in all three lakes also remained relatively unchanged during the study period (Table 12). Changes in largemouth bass Wr were similar among all three lakes indicating that change occurred irrespective of macrophyte harvesting. Wr after macrophyte harvesting was lower for largemouth bass < 200 mm and higher for largemouth bass > 300 mm (Table 13).

Table 11. Electrofishing CPUE (no./h) of largemouth bass < 200 mm, 200-300 mm, and > 300 mm during night and day in Mary, Ida, and Bass lakes, August-September, 1986-1989.

		Night Size group (mm)			Day Size group (mm)		
Lake	Year	<200	200-300	>300	<200	200-300	>300
Mary	1986	23	18	0	27	6	1
	1987[a]	24	46	12	32	6	4
	1988	41	16	5	25	0	1
	1989	25	11	5	36	7	4
Ida	1986	9	7	6	10	1	2
	1987[a]	13	13	1	14	0	0
	1988	26	2	1	19	0	0
	1989	33	8	2	13	1	0
Bass	1986	10	6	3	14	1	1
	1987[a]	14	10	3	16	5	5
	1988	20	4	1	14	0	0
	1989	10	7	1	8	1	1

[a] During night sampling in 1987 only largemouth bass and northern pike were collected, whereas all species were collected in other years.

Table 12. Percent of largemouth bass at age in electrofishing samples in Mary, Ida, and Bass lakes, 1986-1989.

	Age								
Year	1	2	3	4	5	6	7	8	9
				Mary					
1986	25	40	14	15	6	1	0	0	0
1987	19	23	13	21	16	7	2	0	0
1988	25	29	21	10	10	6	0	0	0
1989	44	13	19	12	8	1	1	2	0
				Ida					
1986	21	30	13	13	11	7	6	0	0
1987	38	22	25	9	4	3	0	0	0
1988	56	16	10	8	6	2	2	0	0
1989	20	36	30	10	0	0	3	0	1
				Bass					
1986	35	21	15	13	8	4	2	0	2
1987	28	18	36	8	5	5	0	0	0
1988	42	26	12	12	7	0	2	0	0
1989	40	8	20	21	6	2	3	0	2

Table 13. Mean relative weight (Wr) of three size groups of largemouth bass collected in Mary, Ida,and Bass lakes, before and during mechanical harvest of macrophytes.

Size group	Mary		Ida		Bass	
	Wr	N	Wr	N	Wr	N
			Preharvest			
< 200 mm	105	137	97	35	112	62
200 - 300 mm	106	84	99	23	102	24
> 300 mm	102	17	95	13	96	12
			Harvest			
< 200 mm	94*	133	93	67	96*	44
200 - 300 mm	100	55	97	12	103	20
> 300 mm	107	15	104*	3	98	7

* Indicates significant ($P < 0.05$) differences between harvest and pre-harvest means.

First year growth of largemouth bass may have been affected by macrophyte harvesting. In both Mary and Ida lakes, first year growth increments were significantly ($P < 0.01$) greater during macrophyte harvesting than in previous years (Table 14). This increase in first year growth was not observed in Bass Lake. Consistently higher annual growth increments with macrophyte harvesting were not observed for largemouth bass older than age 1. A significant ($P < 0.01$) environmental effect on first year growth in lakes Mary and Ida were indicated (Table 15).

Diet of largemouth bass was also unaffected by macrophyte harvesting. Largemouth bass < 100 mm at Ida and Mary lakes, and largemouth bass ≥ 100 mm at each lake fed mostly on fish before and during years of macrophyte harvest (Table 16). Largemouth bass < 100 mm at Bass Lake fed mostly on zooplankton and small insects during each period (Table 16). Occurrence of *Lepomis* spp. in largemouth bass stomachs did not increase after macrophyte removal (Table 16).

Northern Pike.--Macrophyte removal did not affect density, size structure, age structure, growth, or diet of northern pike. Gill net CPUE and length distribution of the catch before and after mechanical harvesting were similar (Table 17). The age structure of northern pike in the study lakes also did not appear to change (Table 18). A dominant 1988 year class was found in Lake Mary which correlates with a high stocking rate of large (77/kg) northern pike fingerling that year. Changes in northern pike Wr were similar among study lakes (Table 17).

The 1988 growth increments of Age 2 northern pike in Ida and Bass lakes were significantly ($P < 0.01$) higher than previous years, but not in Lake Mary (Table 19). Furthermore, growth increments for age 3 fish decreased in 1988 for all three lakes and decreased significantly ($P < 0.01$) in Ida and Mary lakes. Significant differences among years were not found for other ages of pike. A significant environmental effect on growth was not identified.

We did not observe changes in diet of northern pike attributable to macrophyte harvesting. *Lepomis* spp. and other fish species were not found more frequently in northern pike stomachs after macrophytes were harvested (Table 20). Although fish comprised all of the food eaten by northern pike, most stomachs were empty (Table 20).

Table 14. Average back-calculated annual growth increments (inc), sample size (N), and standard error (SE) for each age of largemouth bass collected in Mary, Ida, and Bass lakes from 1986 through 1989.

	1985			1986			1987			1988		
Age	Inc.	N	SE	Inc.	N	SE	Inc.	N	SE	Inc.	N	SE
							Lake Mary					
1	77	41	1.7	78	29	1.9**	85	12	2.1**	92	32	2.4
2	60	14	3.6**	79	19	3.4**	58	12	3.3**	69	42	2.1
3	63	17	3.4	73	14	4.1**	53	10	5.8**	63	39	2.1
4	57	7	5.2	66	12	4.3**	57	6	6.4	53	27	1.9
5				53	4	5.1	60	7	5.6*	50	9	3.1
							Lake Ida					
1	60	20	2.0**	51	19	2.6**	61	7	2.1**	74	38	1.8
2	50	7	5.3**	103	12	5.6**	44	5	6.4**	64	72	3.0
3	61	8	5.9	84	6	4.7**	80	4	8.45*	64	13	3.4
4	53	7	3.3	74	1		83	4	9.8	65	2	16.8
5	33	4	2.3	66	2	11.8	42	3	14.7	42	7	6.1
							Bass Lake					
1	69	11	2.9	73	17	4.7*	67	6	0.6	65	9	1.4
2	49	7	10.4	89	20	3.6	44	2	3.9**	65	14	3.6
3	60	6	7.3*	90	3	8.7*	47	5	1.9**	75	20	4.7
4	51	2	9.9	71	1		39	1		61	9	6.1
5	62	1		49	1		18	1		49	3	9.4

* Indicates a significant $P < 0.05$* or $P < 0.01$** difference from the 1988 mean increment at age.

Table 15. Results of analysis of variance on scale increments between largemouth bass cohorts at the same age indicating an effect on growth due environmental factors.

	F statistic		
Age	Lake Mary	Lake Ida	Bass Lake
1	4.39**	3.90**	0.76
2	1.81	1.09	1.10
3	0.83	1.49	0.29
4	1.46	0.86	0.38
5	2.19	2.30	1.00
6	0.12	0.76	0.56

* Indicates a significant $P < 0.05$* or $P < 0.01$** F statistic.

Table 16. Percent occurrence of food items in stomachs of largemouth bass < 100 mm and ≥ 100 mm collected at Mary, Ida, and Bass lakes during summer (July - September) 1987, 1988, and 1989.

	Mary			Ida			Bass		
Item	1987	1988	1989	1987	1988	1989	1987	1988	1989
				< 100 mm					
Zooplankton	0	0	3	15	0	16	33	0	76
Small insects (< 10 mm)	12	0	14	20	0	21	57	50	76
Large insects (> 10 mm)	0	0	3	5	0	11	0	0	0
Crawfish	0	0	0	5	17	0	0	0	0
Lepomis spp.	50	40	10	5	33	0	5	50	0
Other fish species	0	0	4	5	33	11	0	0	3
Unidentified fish	25	47	28	20	17	37	5	0	10
Empty	12	20	33	30	17	32	24	50	10
Sample size	8	15	69	20	6	19	21	2	29
				> 100 mm					
Zooplankton	0	0	2	0	0	0	2	0	0
Small insect (< 10 mm)	2	4	7	0	5	8	14	0	8
Large insects (≥ 10 mm)	2	3	14	0	0	5	5	0	0
Crawfish	2	3	3	0	11	1	2	0	2
Lepomis spp.	35	24	31	0	11	24	7	6	10
Other fish species	15	7	8	11	37	16	9	18	16
Unidentified fish	12	46	30	44	37	30	5	24	24
Empty	38	33	29	44	16	33	54	53	49
Sample size	48	67	133	9	19	79	44	17	49

Experimental Quadrant Comparisons

Electrofishing catches in harvested and unharvested quadrants indicate that macrophyte harvesting could have affected bluegill density, but not size distribution or diet. Significant differences in bluegill electrofishing CPUE between harvested and unharvested quadrants were found in both Mary and Ida lakes (Table 21). In Lake Mary, CPUE was the highest in the 50% removal quadrant for both sizes of bluegill during both day and night sampling. Night electrofishing showed higher CPUE than daytime electrofishing for bluegill > 80 mm, primarily in quadrants with macrophytes removed. In Lake Ida, CPUE for bluegill > 80 mm was similar between harvested and unharvested quadrants during day sampling, but significantly higher in the clearcut (100% removal) quadrant at night. The CPUE for bluegill < 80 mm in Lake Ida was significantly higher in the unharvested quadrant during day sampling but was higher in the clearcut quadrant at night. No significant differences were found in the size distribution or diet of bluegill collected by electrofishing between harvested and unharvested quadrants (Tables 22 and 23).

Largemouth bass electrofishing catches in experimental quadrants revealed little difference between harvested and unharvested areas (Table 24). In Lake Mary, no significant differences in day CPUE were found among experimental quadrants. The night CPUE for largemouth bass < 200 mm

Table 17. Number (N), catch-per-unit-effort (CPUE), mean length with standard deviation (SD), maximum length, proportional stock density (PSD), relative stock density-preferred (RSDP), and relative weight (Wr) of northern pike <35 cm, 35 to 53 cm, and >53 cm captured in gill nets in Mary, Ida and Bass lakes from 1986-1989.

				Length					Wr		
Lake	Year	N	CPUE	Mean length (mm)	SD	Maximum length (mm)	PSD	RSDP	<35 cm	35-53 cm	>53 cm
Mary	1986	4	4	647	134	768					99
	1987	25	5	548	124	830	40	20			100
	1988	20	7	556	59	697	40	0		97	96
	1989	24	6	528	100	785	38	8		99	99
Ida	1986	2	2								
	1987	62	12	463	62	633	12	0	87	94	104
	1988	31	10	470	72	652	19	0		89	97
	1989	68	17	444	73	705	8	0		92	91
Bass	1986	16	16	503	65	666	31	0		101	103
	1987	104	21	516	91	725	51	1	95	101	107
	1988	69	23	496	78	764	26	2		95	102
	1989	105	26	507	84	765	37	2		100	99

Table 18. Percent of northern pike at age in gill net samples from Mary, Ida, and Bass lakes, 1986-1989.

Year	Age 0	1	2	3	4	5	6	7
Mary								
1987	0	10	43	19	10	19	0	0
1988	14	9	32	36	91	0	0	0
1989	0	63	15	17	3	2	0	0
Ida								
1986	18	9	9	55	9	0	0	0
1987	0	14	22	35	17	13	0	0
1988	0	7	30	22	11	19	11	0
1989	3	14	43	27	7	4	1	1
Bass								
1986	0	0	28	44	17	11	0	0
1987	0	7	20	32	30	9	3	0
1988	0	9	41	24	7	14	5	2
1989	4	8	17	37	18	12	2	3

Table 19. Average back-calculated annual growth increments (inc.), sample size (N), and standard error (SE) for each age of northern pike collected in Mary, Ida, and Bass lakes from 1986 through 1989.

Age	1985 Inc.	N	SE	1986 Inc.	N	SE	1987 Inc.	N	SE	1988 Inc.	N	SE
Lake Mary												
1	165	1		308	2	20.0	196	2	25.7**	300	37	10.2
2				172	9	16.4	178	7	13.8*	144	9	11.3
3				125	4	17.1**	166	8	11.1**	71	10	12.0
4	58	1		76	2	5.9	37	2	10.4	56	2	11.9
5	109	1		35	4	10.3				28	1	37.8
Lake Ida												
1	155	1		20	10	10.5	198	2	13.2	189	14	11.4
2	214	1		145	16	6.4*	142	8	8.7**	161	42	4.7
3	107	6	17.6*	102	25	8.2**	108	6	18.5*	77	26	5.2
4	72	1		58	12	4.5	61	3	7.7	52	7	5.7
5				50	9	8.3*	26	5	1.6	32	4	4.5
6							45	3	11.7	37	1	
Bass Lake												
1				208	5	21.7	187	5	15.1	192	8	19.7
2	134	5	11.8**	162	14	8.2**	167	24	6.4**	188	18	8.3
3	124	8	12.3**	121	23	8.6**	106	14	6.6	99	40	5.2
4	93	3	30.3	69	21	4.3	60	4	13.7	61	19	4.7
5	81	2	2.4**	62	6	10.1*	45	8	8.4	41	13	3.2
6				52	2	21.5	41	3	8.3	20	2	1.5

* Indicates a significant $P < 0.05$* or $P < 0.01$** difference from the 1988 mean increment at age.

Table 20. Percent occurrence of food items in stomachs of northern pike collected at Mary, Ida, and Bass lakes during summer (July - September) 1987, 1988, and 1989.

Item	Mary 1987	Mary 1988	Mary 1989	Ida 1987	Ida 1988	Ida 1989	Bass 1987	Bass 1988	Bass 1989
Lepomis spp.	17	50	7	0	0	24	20	20	23
Other fish species	17	0	0	11	33	24	0	0	8
Unidentified fish	17	50	20	11	0	14	40	40	15
Empty	50	50	73	78	67	52	60	40	62
Sample size	6	2	15	9	6	21	5	5	13

Table 21. Mean day and night electrofishing CPUE[a] (no./h) of bluegill < 80 mm and ≥ 80 mm in experimental quadrants (0%, 50%, 75%, and 100% of surface area mechanically harvested) in Mary and Ida lakes, 1988-1989.

Percent surface area harvested	Day <80 mm	Day >80 mm	Night <80 mm	Night >80 mm
Mary				
0	112 a	82 a	93 a	117 a
50	224 b	97 a	216 b	180 b
75	175 ab	99 a	168 ab	173 ab
Ida				
0	106 a	51 a	113 a	67 a
100	58 b	52 a	152 a	157 b

[a] CPUE means inside each bracket without a letter in common were significantly different.

was significantly higher in the 75% harvested quadrant than in the unharvested quadrant. However, significant differences were not found for other size groups of largemouth bass sampled at night in Lake Mary. In Lake Ida, the CPUE of largemouth bass < 200 mm were not significantly different between harvested and unharvested quadrants. Largemouth bass ≥ 200 mm were not sampled in sufficient numbers to allow statistical comparison. No significant differences in length distributions were found among the experimental quadrants in either Mary or Ida lakes (Table 25).

Discussion

Systematic harvest of 6 to 11 percent of the macrophyte cover in Mary and Ida lakes did not affect a measurable lakewide change in bluegill, largemouth bass, or northern pike populations. Positive changes in bluegill and bluegill predator populations should occur at levels of macrophyte cover that

Table 22. Mean, median, and maximum length, standard deviation (SD), and sample size (N) of bluegill captured by electrofishing in experimental quadrants (0%, 50%, 75%, and 100% of surface area mechanically harvested) during July and August subsequent to macrophyte removal, 1988-1989.

Site description	N	Mean length (mm)	SD	Maximum length (mm)	Median length (mm)
		Mary			
Quadrant with 0% harvested	183	73	23.8	157	72
Quadrant with 50% harvested	250	75	22.5	133	72
Quadrant with 75% harvested	302	70	21.4	152	70
		Ida			
Quadrant with 0% harvested	90	88	37.7	203	77
Quadrant with 100% harvested	72	81	28.1	150	77

increase predation on bluegill. The absence of an effect could have been the result of insufficient macrophyte harvesting, ineffective predators, or variable bluegill year class strength.

Sufficient macrophyte cover to provide refuge for bluegill from predation was apparently available in the study lakes despite macrophyte harvesting. Diet of bluegill was not significantly different among harvested and unharvested sites, and was similar to the diet of bluegill in other lakes with high macrophyte density (Seaburg and Moyle 1964; Engel 1985). Mittelbach (1984) reported that bluegill apparently prefer *Daphnia* spp. in open water habitats over dipteran prey in vegetation because of more favorable return energetically; however, strong predation pressure will force bluegill into cover. Juvenile bluegill will seek refuge in the most dense macrophyte cover even when forage opportunities are better in less dense cover (Gotceitas and Colgan 1990).

In our study, predation on bluegill by largemouth bass and northern pike did not appear to directly control bluegill populations. Harvesting macrophytes did not change the selection of fish in the diet of largemouth bass and northern pike. Furthermore, bluegill population dynamics were similar among the study lakes despite large differences in largemouth bass and northern pike populations. This provides indirect evidence that bluegill populations are regulated by mechanisms other than predation by northern pike and largemouth bass.

Our results corroborate with other studies that indicate northern pike are not effective bluegill predators. Beyerle (1971) concluded that northern pike populations did not control bluegill populations, and Anderson and Schupp (1986) observed increased bluegill densities when northern pike densities were increased. Other studies have shown that spiny laterally compressed fish are not preferred prey of northern pike (Beyerle and Williams 1968; Coble 1973; Inskip 1982; Wahl and Stein 1988). Mauck and Coble (1971) observed that bluegill were less vulnerable to northern pike predation than several species of minnows, yellow perch, and largemouth bass. Anderson and Schupp (1986) speculated that the reduction of yellow perch through northern pike predation allowed bluegill numbers to increase. In our study, most northern pike were sampled on the outside edge of macrophyte beds in depths of 3 to 6 m during the period of macrophyte cover (June - August), and were rarely captured in areas with macrophytes removed.

Table 23. Percent occurrence of food items in stomachs of bluegill ≤ 60 mm and > 60 mm in quadrants where macrophytes were harvested (cut) and in adjacent unharvested quadrants (uncut) during summer (July - September) 1988 and 1989. r = Spearman rank correlation coefficient determined for each cut-uncut pair; * denotes r significantly different ($P < 0.05$; df = 14) from zero.

	Lake Mary						Lake Ida					
	<60 mm		≥60 mm				<60 mm		≥60 mm			
	1989		1988		1989		1989		1988		1989	
Food items	Cut	Uncut	Cut	Uncut	Cut	Uncut	Cut	Uncut	Cut	Uncut	Cut	Uncut
Copopoda	35	39	0	0	8	12	43	22	0	0	12	15
Bosmina spp.	6	0	3	0	0	0	10	16	0	0	0	0
Daphnia spp.	26	9	6	5	2	2	10	6	4	0	12	11
Amphipoda	25	20	21	11	25	18	27	44	25	28	41	41
Ostrocoda	58	59	12	16	19	24	30	38	4	6	21	14
Hydracarina	12	7	0	0	11	7	27	19	12	0	17	20
Diptera	55	61	68	58	71	76	25	25	83	83	94	84
Trichoptera	13	13	32	32	42	30	17	31	17	17	20	36
Ephemeroptera	20	39	0	0	14	21	23	25	4	11	28	21
Odonata	3	2	3	0	5	4	0	0	0	0	6	9
Other insects	0	0	3	0	2	1	0	0	4	6	2	0
Terrestrial insects	2	7	0	0	15	16	3	0	33	44	13	19
Gastropoda	11	9	21	26	12	22	0	4	21	44	14	19
Pelycypoda	4	0	3	0	5	6	0	0	0	0	15	7
Vegetation	8	7	41	37	62	63	20	6	67	67	72	60
Empty	9	9	6	16	3	3	3	9	4	0	0	3
r	0.90*		0.93*		0.96*		0.83*		0.87*		0.89*	
Sample size	100	46	34	19	236	109	30	32	24	18	108	100

Table 24. Mean day and night electrofishing CPUE[a] (no/h) of largemouth bass < 80 mm and > 80 mm in experimental quadrants (0%, 50%, 75%, and 100% of surface area mechanically harvested) in Mary and Ida lakes, 1988-1989.

Percent surface area harvested	Day Length (mm) <200	Day Length (mm) 200-300	Day Length (mm) >300	Night Length (mm) <200	Night Length (mm) 200-300	Night Length (mm) >300
Mary						
0	24 a	3 a	4 a	18 a	15 a	4 a
50	14 a	5 a	5 a	30 ab	16 a	10 a
75	18 a	3 a	4 a	38 b	19 a	10 a
Ida						
0	4 a	1	1	19 a	4	7
100	11 a	0	1	24 a	4	2

[a] CPUE means inside each bracket without a letter in common were significantly different.

Table 25. Mean, maximum, and median length, standard deviation, and sample size of largemouth bass captured by electrofishing in experimental quadrants (0%, 50%, and 75% of surface area mechanically harvested) in Lake Mary during July and August subsequent to macrophyte removal, 1988-1989.

Statistic	Experimental quadrants Percent cover removed (75%)	(50%)	(0%)
N	50	49	23
Maximum length	370	364	393
Median length	174	167	176
Mean length	182.0	187.4	183.9
Standard deviation	79.5	79.8	101.2

Bluegill size structure in our study lakes was mostly determined by variability in year class strengths set early in life. Bluegill year class strength appears to be regulated at an early life history stage, before recruitment to our trap nets at age 1 or 2. Our results agree with others that found bluegill population dynamics controlled by highly variable cohort strengths over time (Crowe 1955; Clark and Lockwood 1990). Clark and Lockwood (1990) observed reproductive success to be negatively correlated to the number of bluegill below 100 mm and positively correlated to the numbers of fish in the 120-130 mm size range.

Localized effects of macrophyte harvesting on fish populations were seen among experimental quadrants. We were more effective at capturing bluegill and small bass in harvested quadrants, particularly at night when bluegill and small largemouth bass have been observed to move inshore (Baumann and Kitchell 1974; Werner et al. 1977). Highest catch rates occurred in the quadrant with an intermediate level (50%) of macrophyte harvest following observations of Crowder and Cooper (1979b) indicating the greatest potential for predation at intermediate cover levels. Despite agreement in the literature, sampling bias associated with electrofishing could also have caused the differences we observed.

Systematic harvesting of macrophyte cover in Mary and Ida lakes may have contributed to increased first year growth of largemouth bass. This may have been a localized effect because largemouth bass used for growth determinations were collected mostly at sites at or near macrophyte harvesting. Macrophyte harvesting could have increased vulnerability of young bluegill and large macroinvertebrates to predation by young-of-the-year largemouth bass. Savino and Stein (1982) reported that vulnerability of bluegill to predation was inversely related to plant stem density. Wiley et al. (1984) reported growth of largemouth bass in ponds was higher at intermediate densities than at high densities of macrophyte cover in response to food availability. Other environmental affects or random error (considering the multiple comparisons) may also account for the observed growth differences in largemouth bass between the harvested lakes and Bass Lake.

Several limitations of systematic macrophyte removal with mechanical harvesters were identified in addition to restrictive cost ($790/acre). We found harvesting with available equipment was confined to water depths ranging from 0.5 to 2.0 m. Wind and wave action hindered the ability to control the harvester and cut precise patterns in macrophyte beds. In many areas, the action of the cutting bar and propulsion unit of the harvester resulted in suspension of bottom sediments. This reduced water clarity made it difficult to cut precise patterns.

Some fish (mostly small centrarchids, and a few northern pike and bullhead) were removed by the macrophyte harvesting equipment. In other lakes, mechanical harvesting of macrophytes has removed 2 to 30% of the fish (mostly juvenile) and 11 to 20% of the macroinvertebrates from harvested areas (Haller et al. 1980; Mikol 1985; Engel 1990a). The removal of fish with harvesting was probably insignificant in our study since only a small proportion of macrophyte cover was removed.

Management Implications

Improvement of fish populations through systematic removal of macrophytes with mechanical harvesting is probably not an appropriate fisheries management technique for most Minnesota lakes. In most lakes, a perceptible change in bluegill, largemouth bass, and northern pike populations would require continuous removal of substantial amounts of macrophyte cover for an extended number of years. At this point the risk of negatively altering fish and plant communities is high (Engel 1990b). Furthermore, mechanical harvesting equipment currently available is relatively expensive and not suited for macrophyte removal in lakes with macrophytes located in depths greater than 3 m or less than 1 m.

Removal of small areas of vegetation (up to at least 11% of the macrophyte cover) with mechanical harvesting for boating lanes and other recreational uses does not adversely affect fish populations in lakes with greater than 20% macrophyte coverage. In addition, removal of macrophytes from small areas may provide some localized benefits to largemouth bass.

To understand the behavior of bluegill populations in lakes managed for bluegill fishing, there is a need to obtain more information on variability in bluegill year class strengths and the influence of angling on populations of bluegill and bluegill predators. Further research should be done to identify factors that regulate bluegill recruitment in the complex environment of Minnesota centrarchid lakes. Current information is limited to a few interactions that occur during the warm water months.

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