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FISH COMMUNITY RESPONSES TO MANIPULATION OF NORTHERN PIKE AND YELLOW PERCH DENSITIES IN A MINNESOTA CENTRARCHID LAKE [1]

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Abstract.--Removal of 3894 small (<600 mm) northern pike *Esox lucius*, stocking of 419 large (≥600 mm) pike, and stocking of yellow perch *Perca flavescens* over a 6 year period were ineffective in altering pike densities, improving pike growth rates, or altering fish community structure in a 156 ha centrarchid lake. Widely dispersed, marginal pike spawning habitat and early, under-ice spawning may have contributed to the largely ineffective removal efforts--less than 15% of the northern pike population was removed during the annual netting. Annual mortality of pike in the study lake exceeded 50%, limiting the potential for improvements in population size structure. Larger stocked pike also exhibited high mortality and had little influence on pike population dynamics or fish community structure. The success of stocking yellow perch to establish a forage base was dependent on size of yellow perch available for stocking. Smaller perch stocked during earlier years of the study did not survive, presumably due to vulnerability to pike predation. Larger perch stocked later in the study were apparently large enough to escape heavy predation by pike, and survived to spawn several times and establish natural year classes. After 6 years of manipulations, desirable changes in fish growth and community structure could not be documented. The potential for managing for larger northern pike may be more promising in larger, deeper lakes having lower pike densities.

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Introduction

Many of Minnesota's small centrarchid lakes have high densities of slow-growing northern pike *Esox lucius* and size distributions of these populations are generally unacceptable to anglers. The fish community composition of these lakes frequently includes high densities of small, slow-growing bluegill *Lepomis macrochirus* and low densities of small yellow perch *Perca flavescens*. The fisheries management challenge for these lakes involves shifting these population size structures toward sizes more acceptable to anglers.

Diana (1987) proposed that stunted northern pike growth is caused by at least three mechanisms: overpopulation, inappropriate prey size, and lack of thermal refuges. Overpopulation was linked to competition for inadequate numbers of prey, resulting in slow growth of pike in Escanaba Lake, Wisconsin (Kempinger and Carline 1978). An 18 in minimum size limit in Escanaba Lake increased population density and reduced pike growth, suggesting that growth is density dependent.

The effects of exploitation on fish populations are well documented (Spangler et al. 1977) and can include increased growth rates and reduced age at maturity. Although exploitation may reduce competition, the increased energy available was allocated to gonadal growth rather than somatic growth in Houghton Lake, Michigan (Diana 1983), and lead to increased reproductive potential rather than larger fish. Additionally, exploitation may increase total mortality and result in a less desirable population size structure.

Inadequate prey size may also reduce pike growth. In Lac Ste. Anne, Alberta, large prey contributed 7% numerically to the pike diet, but accounted for 33% of the annual energy uptake (Diana 1979). Frost (1954) found that pike 60-70 cm FL selectively preyed on perch age 3 or older. Pike tended to feed on perch 20% of their own length, but can feed on perch up to 45% of their own length. In Lake Windermere, England, LeCren (1987) reported that older pike fed mostly on larger ($\geq$ 140 cm FL) and older adult Eurasian perch *Perca fluviatilis*. Northern pike will prey on larger yellow perch than will walleye where both are present (Forney 1977).

Reduced numbers of pike were associated with limited prey in Bucks Lake, Wisconsin (Snow and Beard 1972). The decline of smaller pike in Bucks Lake was attributed to a decline in panfish numbers, indicating that the size structure of the pike population was influenced by food supply.

Cannibalism may also be an important prey size mechanism influencing northern pike populations. Age 0 pike that failed to reach 200 mm FL by the end of the first summer were often preyed upon by older pike (Kipling and Frost 1970). Grimm (1981) reported the biomass of age 0 pike was negatively correlated with the biomass of older pike, and concluded that predation by older pike played an important role in the density dependent regulation of age 0 pike numbers.

Lake Windermere provides examples of the effects of both exploitation and inadequate prey size on northern pike populations (LeCren 1987). Prior to 1941, Eurasian perch and northern pike populations were both long-lived, with much of the perch mortality due to pike predation. Few perch reached large sizes because of predation. A perch fishery began in 1941, and a pike fishery started in 1944. Pike recruitment increased due to reduced cannibalism, and perch showed increased growth rates. After the perch fishery ended in 1948, perch numbers did not increase because the large pike population and the older perch suppressed perch year class survival. Eventually, perch year classes were primarily fast growing and short-lived, providing a poor food source for northern pike. The northern pike then had several poor year classes and declined in numbers.

Thermal tolerance has been proposed as a third factor potentially influencing northern pike growth (Diana 1987). Northern pike are temperate mesotherms showing optimum growth at 18-24°C. If these temperatures are exceeded for extended periods during summer months, and a well-oxygenated metalimnion refuge is not available, reduced or negative growth could result. Minnesota's statewide lake survey database confirms that larger northern pike size correlates positively with lake size and depth (D. Schupp, personal communication). These lakes likely maintain thermal refuges for northern pike even during the warmest months.

Fisheries ecologists have suggested manipulation of top level piscivores to change community structure. Evans and Waring (1987) noted the decline of lake trout and subsequent increase of rainbow smelt in Lake Simcoe, Ontario, and concluded that lake trout (a top predator) had a large degree of control over the structure of the fish community. Evans et al. (1987) stated that large piscivores stabilize prey abundances due to longevity and periodic strong recruitment, and their reduction may result in density dependant changes in growth and abundance of other species. Northern pike can function within the fish community as this dominant predator (Pimm and Hyaman 1987; McQueen et al. 1986;) He and Kitchell 1990), showing a preference for perch as prey (Anderson and Schupp 1986; LeCren 1987; Maloney and Schupp 1977), and selecting for prey items of optimum size (Domaneskii 1962; Christie et al. 1987; Wahl and Stein 1988). He and Kitchell (1990) documented changes within the fish community caused by northern pike predation, and both Evans et al. (1987) and Walters (1987) advocate deliberate manipulation of top level piscivores to achieve favorable community structures.

In many small centrarchid lakes, dense slow-growing northern pike populations have been observed to coincide with dense bluegill populations dominated by small, slow-growing individuals. Small yellow perch exist in low densities, if present at all. The reasons for this type of community assembledge are speculative, but available information suggests that northern pike play a key role as the top predator in these systems. The purpose of this study was to invoke favorable changes within the fish community of a small centrarchid lake by manipulating the northern pike population, and introducing adult yellow perch to establish a prey base.

Methods

Study Site

Hammal Lake is a mesotrophic centrarchid lake with a surface area of 156 ha (374 A), located in Aitkin County of east-central Minnesota (Figure 1). The lake has a maximum depth of 16.1 m (44 ft) with 70% littoral area. The fish community composition of Hammal Lake made it a suitable study site since high densities of small northern pike dominated the sport fishery. Many small, slow-growing bluegill were also present.

Field methods

The northern pike population was manipulated by removal of pike <600 mm (24 in) TL during spring spawning. Pike were captured with trap nets which were set perpendicular to the shoreline of the lake at all suitable locations. Netting began as ice left the lake and continued until daily catches dropped dramatically. Pike ≥600 mm TL were marked with an anchor tag near the dorsal fin and released.

Northern pike population statistics were documented during each year of removal (1986-1991) by recording individual length and weight data, and collecting scales and cleithra for age and growth analyses. Data were collected from fish removed from Hammal Lake and from fish that were tagged and released.

The northern pike population was further manipulated in December of 1989 and 1990 by stocking pike ≥600 mm TL which were removed from a nearby reservoir being managed for waterfowl. These fish were

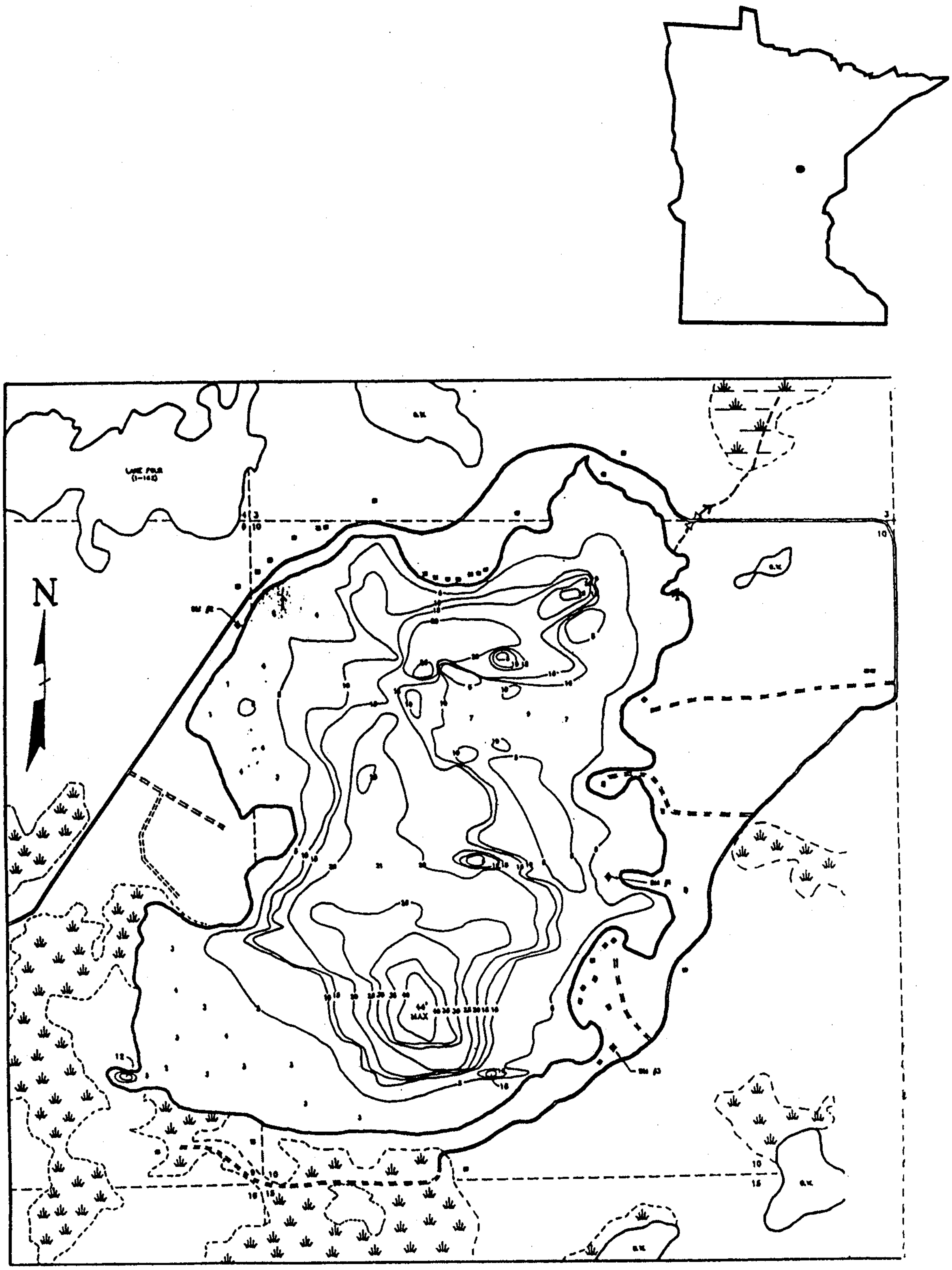

Figure 1. Hammal Lake in Aitkin County of east-central Minnesota.

also marked with anchor tags. Yellow perch were stocked into Hammal Lake from 1986 through 1990 to increase pike forage and initiate desirable responses within the fish community.

A voluntary creel survey station was placed at the Hammal Lake public access in 1990 and 1991 to obtain estimates of northern pike exploitation.

The fish community was sampled with a 2.54 cm (1 in) mesh, 61 m (200 ft) long by 4.3 m (14 ft) deep seine containing a 0.64 cm (0.25 in) mesh bag. Three seining stations were established on Hammal Lake, and each station was seined three times during early September from 1986 to 1991. The seine was laid out generally parallel to shore and then pulled directly to shore, seining about 0.4 ha (0.92 A).

Seine hauls were subsampled to collect 10 scale samples per cm length group for yellow perch, bluegill, largemouth bass *Micropterus salmoides*, pumpkinseed *Lepomis gibbosus*, and black crappie *Pomoxis nigromaculatus*. Standard lake survey sampling using experimental gill nets and trap nets was conducted in August of 1988, 1989, and 1991, with historical netting data existing from 1982 and 1986.

Analytical Methods

Annual length-frequency distributions of northern pike from spring trapping were compared using the Kruskal-Wallis test. Population estimates of pike ≥600 mm TL were computed using the modified Schnabel method (Ricker 1975). Estimates of the total pike population were computed by dividing the population estimate of pike ≥600 mm TL by the proportion of pike ≥600 mm TL in the total annual catch.

Condition of northern pike was examined using relative weight (Willis 1989). The Kruskal-Wallis test was used to assess differences in condition between years.

Growth before pike removal and perch stocking was compared with growth after pike removal and perch stocking by analyzing annual growth increments from scales (computed from back-calculated lengths). Northern pike growth was analyzed separately for males and females. Growth of other species was analyzed in a similar manner.

Age-structured (Ricker 1975) and length-structured (Pauly 1984) catch curves were used to estimate northern pike mortality during each year of study for males and females. Mortality of large pike stocked into Hammal Lake was calculated by comparing Schnabel population estimates in successive years after stocking.

Catch data for each year of seining was expressed as catch per unit-of-effort (CPUE) for each species. ANOVA was used to test for significant differences in CPUE between years. Tukey's test was used to discern significant differences within ANOVAs. All results were evaluated at the $P = 0.05$ level.

Results

Numbers of northern pike removed during spring trapping were highly variable for the 6 years of netting (Table 1). The total 6 year catch was 4,116 pike with 3,894 small (<600 mm TL) fish removed and 209 pike ≥600 mm TL marked and released. The proportion of the total annual catch ≥600 mm TL ranged from 1.9-9.1%, showed no consistent trend over the study period, and resulted in a 6 year mean of 5.1% (Table 1).

Table 1. Removal data for northern pike from Hammal Lake, Minnesota, 1986-1991.

Year	Total catch	Number removed	Number marked	% of catch >600 mm
1986	1,251	1,171	80	6.4
1987	253	235	18	7.1
1988	796	761	35	4.4
1989	930	905	18	1.9
1990	418	376	38	9.1
1991	468	446	20	4.3
TOTAL	4,116	3,894	209	5.1

Low numbers of northern pike were recaptured during spring trapping on Hammal lake during the 6 years of study

(Table 2). Population estimates computed in 4 of the 6 years ranged from 27 to 164 pike $\geq$600 mm TL. No trends were apparent during the study period (Table 2). Estimates of the total pike population based on the proportional expansion of large fish population estimates were 2,564 (1986), 3,048 (1988), 1,395 (1989), and 1,760 (1990).

Table 2. Population estimates (modified Schnabel method) for northern pike $\geq$600 mm TL in Hammal Lake, Minnesota, 1986-1991.

Year	Number recaptured	Population estimate	95% Confidence interval
1986	14	164	99-294
1987	0	--	--
1988	3	134	53-539
1989	7	27	14-64
1990	3	160	63-639
1991	0	--	--

Northern pike length frequency distributions differed from 1986 to 1991. The 1989 male size distribution had proportionally more large pike than either the 1986 or 1988 male size distributions, and the 1991 male size distribution had proportionally more large pike than any previous size distribution except 1990 (Figure 2). The 1986 female size distribution had proportionally more small pike than in any subsequent years, and the 1991 female length distribution showed proportionally more small pike than the 1990 length distribution (Figure 3). The 1990 size distributions of both males and females had proportionally more large pike than any previous year.

Northern pike showed fairly consistent age distributions for each year of sampling (Table 3). Age 1 pike were rarely sampled for both males and females. Male pike showed consistent age distributions for each sampling season. The 1988 sampling season showed a higher proportion of older females than other years.

Mean relative weight for male and female northern pike captured during the spring ranged from 80-92 and 83-96, respectively (Table 4). Significant between-year differences in relative weight, by sex, were apparent, with the highest condition occurring in 1990 for both males and females.

Table 3. Age frequency of northern pike from Hammal Lake, Minnesota, 1986-1991

MALES

	Age(%)							
Year	1	2	3	4	5	6	7	8+
1986	4.2	13.9	9.7	32.4	24.1	12.3	2.8	1.0
1987	0	21.9	37.0	26.9	10.9	3.4		
1988	0	1.0	16.5	31.3	28.0	16.5	4.4	2.4
1989	0	4.3	15.0	37.3	29.4	10.0	2.7	1.2
1990	0	2.2	7.4	35.3	33.4	15.2	4.1	1.9
1991	1.7	5.0	13.3	28.1	32.8	15.4	2.7	1.0

FEMALES

	Age(%)							
Year	1	2	3	4	5	6	7	8+
1986	2.1	7.5	21.6	37.7	17.0	7.5	3.3	3.7
1987	0	7.1	27.0	36.5	21.4	4.8	2.4	1.0
1988	0	0	2.7	18.1	25.5	14.2	14.2	25.2
1989	0	0	9.6	28.5	40.2	12.1	6.4	2.8
1990	0	0	4.6	13.7	17.5	35.9	16.0	12.2
1991	0	0	18.4	39.5	20.2	7.9	4.4	9.6

Table 4. Mean annual relative weight for northern pike collected from Hammal Lake, Minnesota, 1986-1991. For each sex, years with no letters in common are significantly different.

Year	Males(n)	Females(n)
1986	90 (36)[abc]	89 (47)[abc]
1987	89 (89)[ab]	87 (113)[ac]
1988	84 (123)[ac]	88 (153)[ac]
1989	80 (125)[c]	83 (105)[a]
1990	92 (116)[b]	96 (121)[b]
1991	81 (159)[c]	91 (110)[bc]
TOTAL	85 (648)	89 (649)

Growth of northern pike during the study showed little change (Table 5). Female annual increments for growth years 1, 2, and 3 before the 1986 growth season were not significantly different from those after 1986. Male annual increments for growth years 1 and 2 before 1986 were not significantly different from those after 1986, although annual increments for growth year 1 were significantly higher before 1986 than after 1986.

Northern pike mortality estimates for Hammal Lake were similar for age-based and length-based computations (Figure 4). Annual mortality from the length-based model was 0.57 for males and 0.43 for females. The age-based model yielded annual mortality estimates of 0.65 for males

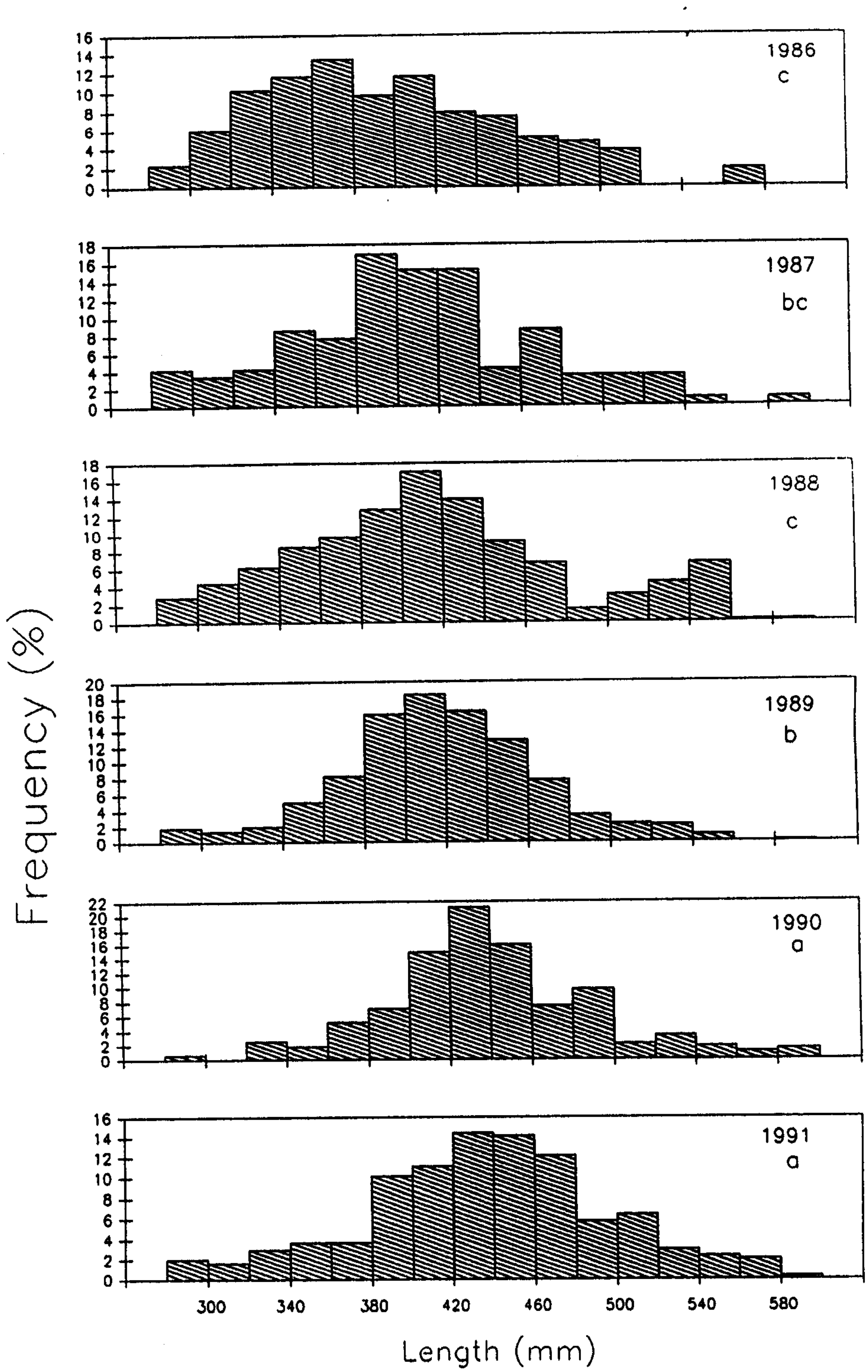

Figure 2. Male northern pike length frequency distribution, Hammal Lake, Minnesota, 1986-1991. Years with no letters in common are significantly different.

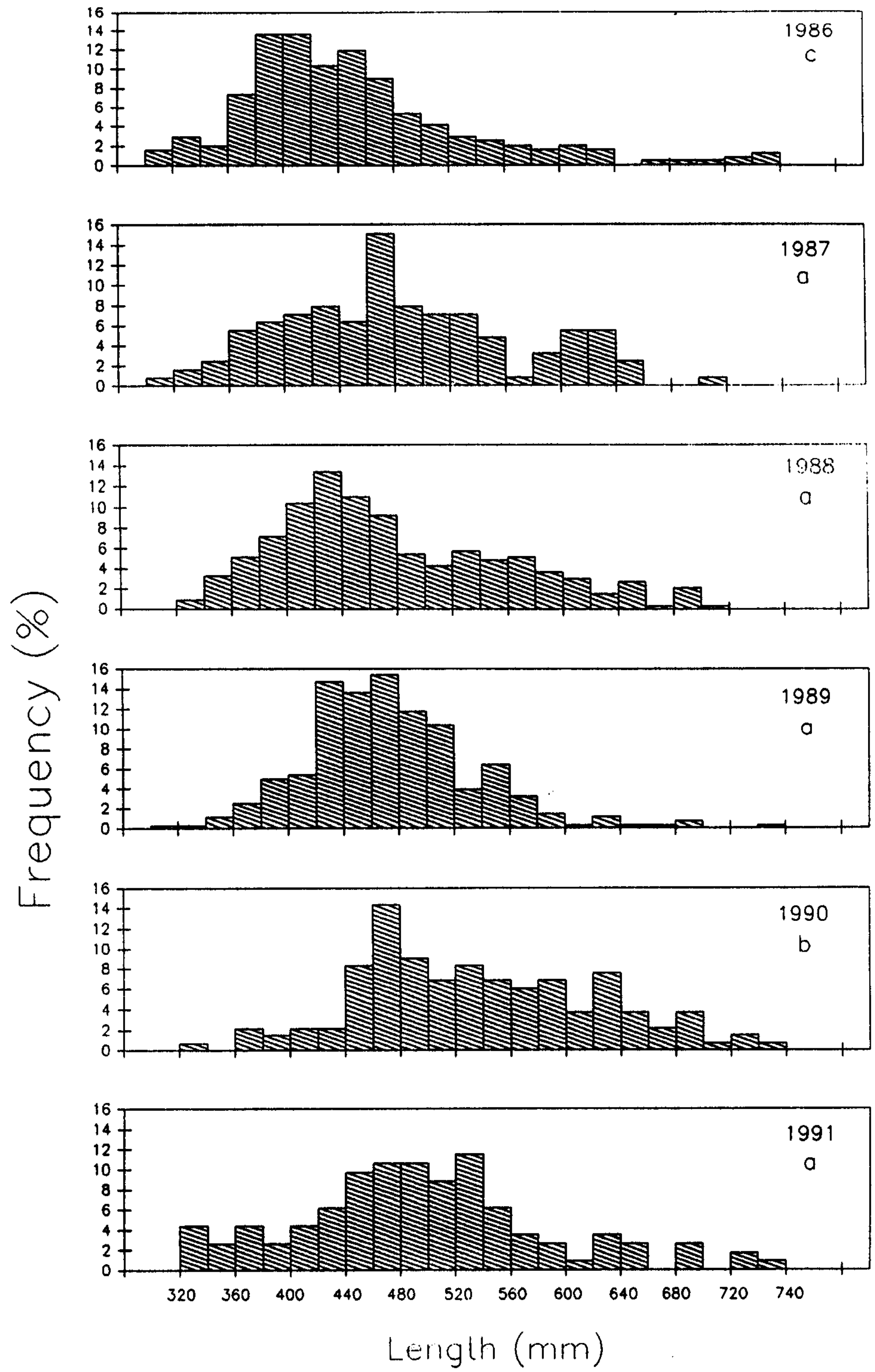

Figure 3. Female northern pike length frequency distribution, Hammal Lake, Minnesota, 1986-1991. Years with no letters in common are significantly different.

Table 5. Hammal Lake northern pike growth expressed as mean annual increments (mm) by growth year with data collected from 1986-1991.

		Growth Year							
FEMALES		1	2	3	4	5	6	7	8
Year Class									
1983	Inc.	170.9	130.2	87.86	61.69	41.89	46.81	43.05	31.80
	N	143	143	143	120	80	46	28	6
	SE	2.72	3.28	2.42	2.18	1.76	2.21	3.27	2.79
1984	Inc.	173.0	133.8	82.87	56.37	44.69	39.47	34.52	
	N	143	143	132	103	77	52	5	
	SE	2.94	3.04	2.21	2.31	2.14	2.52	8.91	
1985	Inc.	169.1	135.5	94.36	56.30	47.03	44.57		
	N	67	62	6 53	45	27	10		
	SE	5.06	4.83	4.59	3.75	4.23	5.91		
1986	Inc.	168.5	138.7	86.14	58.95	45.24			
	N	55	55	55	36	21			
	SE	4.12	4.59	3.96	4.34	4.61			
1987	Inc.	168.8	133.7	93.84	63.54				
	N	48	48	47	42				
	SE	4.89	6.64	4.35	4.38				
1988	Inc.	156.6	125.9	102.6					
	N	19	19	19					
	SE	5.87	5.97	4.37					
MALES									
Year Class									
1983	Inc.	163.9	120.5	80.60	49.36	38.68	35.55	24.59	33.51
	N	101	101	101	90	65	34	12	2
	SE	2.88	3.87	2.54	2.05	2.16	2.27	2.60	--
1984	Inc.	170.1	130.5	78.88	41.40	34.37	36.81	32.03	
	N	124	124	108	81	47	27	7	
	SE	3.05	3.48	2.45	1.90	2.00	3.06	5.18	
1985	Inc.	168.3	115.9	73.98	53.71	36.70	28.10		
	N	148	138	115	75	50	27		
	SE	3.17	3.54	2.67	2.79	1.83	2.19		
1986	Inc.	158.4	133.6	72.42	46.72	36.70			
	N	99	99	95	72	42			
	SE	3.01	3.83	2.47	2.02	1.95			
1987	Inc.	154.8	128.9	80.89	46.30				
	N	71	71	51	35				
	SE	3.06	4.08	3.45	3.32				
1988	Inc.	148.0	120.0	88.36					
	N	32	32	26					
	SE	4.14	5.70	3.78					
1989	Inc.	176.8	106.4						
	N	14	14						
	SE	10.65	7.25						
1990	Inc.	239.8							
	N	5							
	SE	9.00							

and 0.58 for females. The means of mortality estimates computed in individual years by both methods were not statistically different (t test, $P > 0.05$).

The pike population size structure in Hammal Lake was artificially improved by stocking 243 fish $\geq$600 mm TL in 1989. Modified Schnabel population estimates for these introduced pike in April 1990 and April 1991 were 159 and 35, respectively, with 95% confidence intervals (CI) of 130-194 and 16-97, respectively. Annual mortality of these stocked pike from 1989 to 1991 was 0.62. In 1990, 176 pike $\geq$600 mm TL were stocked. The population estimate for these fish in April 1991 was 224 with a 95% CI of 161-312.

Densities and sizes of yellow perch stocked into Hammal Lake were highly variable during the 6 years of stocking (Table 6). Densities ranged from 1.5-7.4 kg/ha (2.3-11.4 kg/littoral ha), and sizes varied from 6.8-22.0 fish/kg. Density and size variability was due solely to availability of yellow perch for stocking.

Table 6. Yellow perch stocking record for Hammal Lake Minnesota, 1985-1990[a].

			Size
Year	kg/ha	kg/littoral ha	(no/kg)
1985	1.5	2.3	22.0
1986	3.7	5.8	11.4
1987	5.4	8.0	25.9
1988	4.3	6.4	6.8
1989	2.3	3.6	13.0
1990	7.4	11.4	10.0

[a] Pounds/acre=0.89 x kg/ha

A voluntary creel survey revealed a minimum estimate of 37 stocked pike from 1989 being caught in 1990 with 7 being harvested. Exploitation was 23% and instantaneous fishing mortality was 0.36 (from u=FA/Z, Ricker 1975).

Six years of fall seining indicated few changes occurred within the fish community of Hammal Lake (Table 7). Between-year differences in CPUE were not significant for bluegill, largemouth bass, and black crappie. Significant differences were apparent for northern pike CPUE, although Tukey's test could not discriminate between the means at the $P < 0.05$ level. The 1989 CPUE of yellow perch was significantly different from

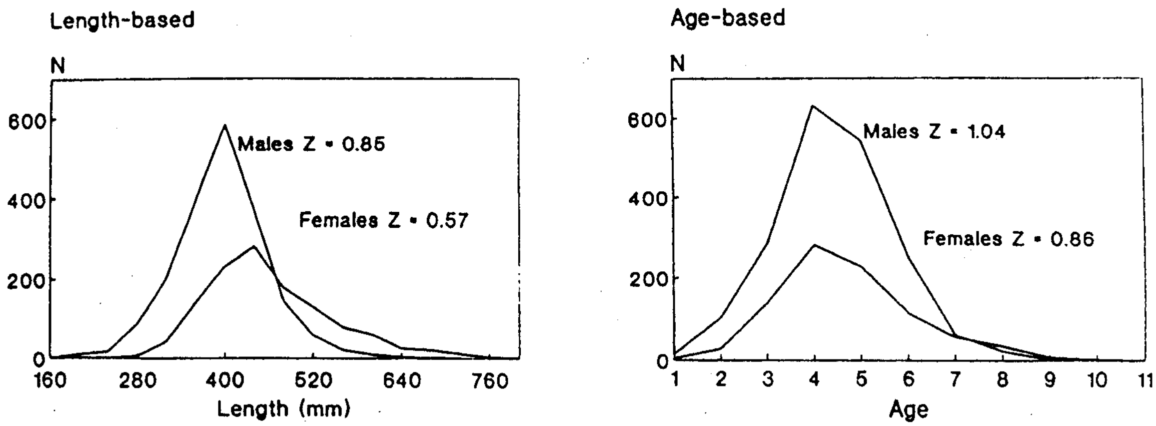

Figure 4. Length-and age-structured mortality estimates from cumulative catch data for northern pike from Hammal Lake, Minnesota. 1986-1991.

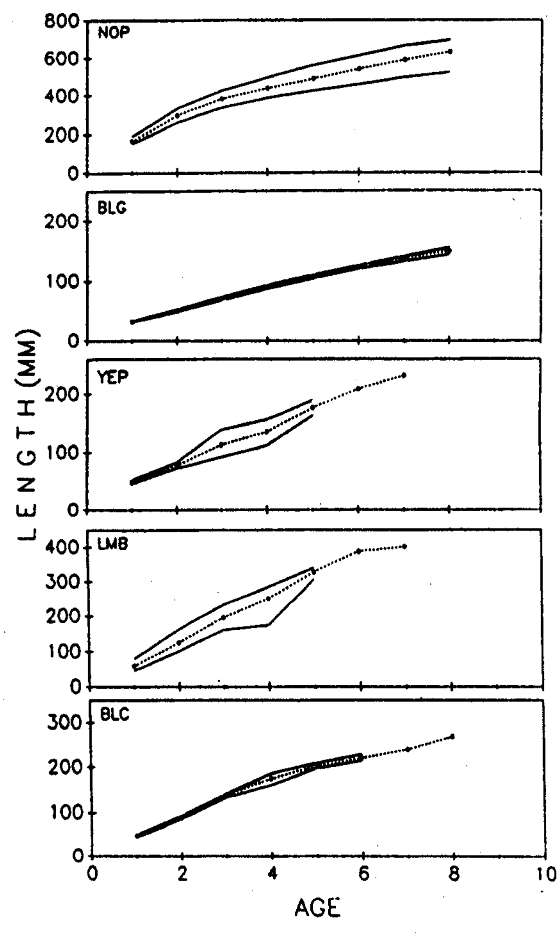

Figure 5. Six-year means of back-calculated lengths at age for Hammal Lake fish sampled from 1986 to 1991. The range of annual means is indicated by upper and lower lines.

1988 and 1987. No trends were apparent for northern pike or yellow perch CPUE from 1986-1991 (Table 7).

Growth of bluegill, largemouth bass, black crappie, and yellow perch showed little change from 1986-1991 (Figure 5). Differences in annual means of back-calculated lengths at age appeared within the range of normal variability.

Table 7. Fall seining Catch per seine haul (CPUE) data for fish in Hammal Lake, Minnesota, 1986-1991. Years with no letters in common are significantly different[a].

		CPUE			
Year	NOP	BLG	YEP	LMB	BLC
1986	9.7	785.8	302.8[ab]	11.9	136.2
1987	12.9	687.2	116.6[a]	9.9	136.1
1988	11.0	783.2	86.4[a]	15.3	55.0
1989	12.1	1208.3	581.7[b]	10.0	239.5
1990	7.3	721.3	219.3[ab]	15.9	94.8
1991	6.9	539.9	289.8[ab]	11.4	22.0
MEAN	10.0	787.6	266.1	12.4	113.9

Taxa are abbreviated as NOP (northern pike), BLG (bluegill), YEP (yellow perch), LMB (largemouth bass), and BLC (black crappie).

Standard lake survey gill net and trap net assessments showed no significant changes in CPUE of northern pike from 1988 to 1991 and bluegill from 1989 to 1991 (Table 8). Yellow perch were first captured in gill nets in 1989 and the perch CPUE showed some increase in 1991.

Table 8. Population assessment netting results for northern pike (number/gill net), yellow perch (number/gill net), and bluegill (number/trap net) from Hammal Lake, Minnesota.

Year	Northern pike	Yellow perch	Bluegill
1982	8.3	0	20.2
1986	7.0	0	12.4
1988	6.7	0	–
1989	7.7	1.5	38.7
1991	7.5	3.7	24.4

Discussion

Removal of 3,894 northern pike from Hammal Lake over a 6 year period did not substantially reduce population density. Pike densities on similar lakes in north-central Minnesota have ranged from 11/ha to 55/ha (R. B. Pierce, personal communication), and density observed in Bucks Lake, Wisconsin was 68/ha (Snow and Beard 1972). The total population estimate for Hammal Lake could be as high as 8,000 northern pike based on an estimate of 50/ha. The numbers of pike removed from Hammal Lake ranged from 3-15% of this estimate. Our population estimates (ranging from about 1,400 to 3,000) were probably gross underestimates of the actual population size. Biomass of pike removed from Hammal Lake ranged from 0.97-4.56 kg/littoral ha during the 6 years of study. In Horseshoe Lake, Minnesota, undesirable fish community responses were apparently caused by stocking 3.2-8.3 kg/littoral ha of pike during three different years (Anderson and Schupp 1986). Removal on Hammal Lake was generally inefficient due to a combination of widely dispersed spawning habitat and weather-related timing. The Hammal Lake shoreline is composed of a high proportion of emergent aquatic vegetation, resulting in widely dispersed pike spawning. Also, many of the first fish collected during netting at ice-out were spent, indicating that spawning had already been occurred under the ice. The proportion of spawning completed before ice-out and the influence of spawning on pike behavior as related to trapping vulnerability remains unknown. Pike removal was also ineffective on 259 ha Heming Lake, Manitoba, with 219,817 m of gill nets in a single year (Colby et al. 1987). Pike removal was successful in 136 ha Harriet Lake, Minnesota after 5 years of spring netting. This lake, however, had no natural pike spawning habitat, with only an artificially flooded, controlled spawning area that was not used once the removal project began (D.H. Schupp, personal communication).

Manipulating northern pike and yellow perch densities in Hammal Lake did not result in improved pike growth during the study. Although the pike length distributions showed minor changes during the study, pike growth did not increase. Incremental growth data showed little change from before the 1986 growth year to after the 1986 growth year, suggesting the observed changes in length were not due to increased growth rates. Furthermore, the changes in length that were statistically significant would likely not be perceptible to anglers; the modal length for females increased from 400 mm to 480 mm, or less than four inches. Mean relative weight for northern pike showed no definitive trends during the study period. The increased relative weight in 1990 for both males and females was not observed in 1991, and changes in relative weight did not demonstrate definitive improvements in pike condition. Increased growth rate is widely accepted as a classical population response to exploitation and was observed for an intensively fished pike population in Heming Lake, Manitoba, but only after mean size had been markedly reduced (Colby et al. 1987). This response was not observed in Hammal Lake. Removal apparently never achieved sufficient levels to elicit this population response.

Stocking large ($\geq$60 cm) northern pike had little effect in altering the long-term population size structure in Hammal Lake. The intention of these introductions was to artificially alter the pike size distribution toward proportionally more large pike. Any influence of these large fish on pike population parameters or community characteristics during the last two years of the study was not perceptible. Annual mortality estimates indicated abundance of these larger fish was substantially reduced within a relatively short time. The exploitation rate of 23% for these stocked pike was less than one half of the annual mortality rate of 0.62. A similar trend has been observed in other pike lakes in north-central Minnesota where exploitation rates range from 0.04-0.22 and annual mortality rates range from 0.45-0.64 (R. B. Pierce, personal communication).

The low proportion of the total annual mortality attributable to angling in Hammal Lake precludes improvement of the pike size structure using size or numerically based fishing regulations. A 56 cm minimum length limit failed to produce more large pike in Escanaba Lake, Wisconsin (Kempinger and Carline 1978). A protective slot-length regulation has shown some promise with a high density largemouth bass population (Eder 1984). The high natural mortalities observed with high density pike populations may, however, effectively prevent pike from growing through the slot to a quality size before succumbing to natural mortality. Ricker's yield per recruit model (Ricker 1975) showed that much of the increase in population biomass would be from two and three year old pike as instantaneous fishing mortality changed from 0 to 0.03. No apparent gains would be realized in older, larger fish.

Six years of yellow perch stocking appeared to have greatly increased perch numbers after larger individuals were stocked, but desirable perch-related interactions have not been documented. During early years of the study, stocking of smaller perch was ineffective since the existence of these individuals within Hammal Lake was short-lived. Predation by pike was assumed to have reduced perch numbers drastically within just a few months after stocking. When larger perch became available and were stocked during the last years of the study, they persisted in Hammal Lake long enough to reproduce and establish year classes which were evident during seining. Vollestad et al. (1986) noted slow pike growth in lakes of the Haldan River System, Norway, where the prey is primarily $\leq$15 cm, whereas pike growth in nearby Lake Tyrifjorden was rapid with whitefish 30-34 cm the most common prey. The perch population in Hammal Lake apparently did not achieve the numbers or sizes necessary for improved pike growth during the six years of study. Anderson and Schupp (1986), Goeman et al. (1990), and LeCren (1987) have discussed the importance of prey size as it relates to predator dynamics and community interactions. Interactions between yellow perch and bluegill, which could ultimately influence bluegill size structure and abundance, have been suggested by Anderson and Schupp (1986) and Goeman et al. (1990), but no interactions were documented during this study. Community interactions, however, often may not be readily evident over a short time period. The possibility exists that favorable changes may have been initiated by perch stocking during this study, but conclusive results may not be evident for several more years.

Other species within the Hammal Lake fish community showed few changes in growth and abundance, and those minor changes were considered within the ranges of normal variability. Effective manipulations of northern pike and yellow perch would be expected to produce changes throughout the fish community if hypotheses drawn by Anderson and Schupp (1986) are correct. Intensity of manipulations required to initiate community responses remains unknown.

The aquatic vegetation in Hammal Lake may have influenced the efforts to produce large pike. Cannibalism may be an important density-dependent mechanism governing pike populations (Kipling and Frost 1970). Hammal Lake has extensive areas of dense aquatic vegetation which could provide substantial areas of refuge for small pike and other prey fish to escape from predatory pike. Chapman and MacKay (1984) observed that pike <25 cm were found almost exclusively in shallow vegetated areas, while larger pike were found on the vegetationopen water interface. They concluded that small pike chose vegetation for predator avoidance, whereas large pike were more versatile in their use of habitat.

Six years of study and attempted manipulations in Hammal Lake suggested that lakes with similar characteristics may have little potential for altering the population characteristics of northern pike. The physical and chemical characteristics of Hammal Lake may largely dictate the potential of a lake to produce large pike. The morphology and trophic status of Hammal Lake may negate any attempts to manage this lake for larger pike. The small physical size, large littoral area, relatively shallow basin, and eutrophic status are all characteristics that do not typically coincide with large pike production (D.H. Schupp, P.C. Jacobson, personal communication). For example, maximum summer water temperatures in Hammal Lake typically exceed the optimum range for pike growth. Since no coolwater refuge exists, growth may be limited by these summer temperatures (Diana 1987).

Management Recommendations

1. Spring trapping as a means of northern pike removal on centrarchid lakes with high densities of northern pike may not be effective, particularly if marginal spawning habitat is widespread around the lakeshore.

2. Stocking yellow perch to establish a prey base for northern pike to improve pike growth may not be effective, particularly where high pike densities exist. This technique may have the most potential if larger perch are stocked where pike densities are lower.

3. High natural mortality is characteristic of most high-density northern pike populations in small centrarchid lakes, thereby limiting the applicability of special fishing regulations for improving pike size structure.

4. Favorable changes within a fish community may not readily occur using northern pike removal and yellow perch stocking as the primary techniques, particularly in centrarchid lakes with high densities of slow-growing pike.

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