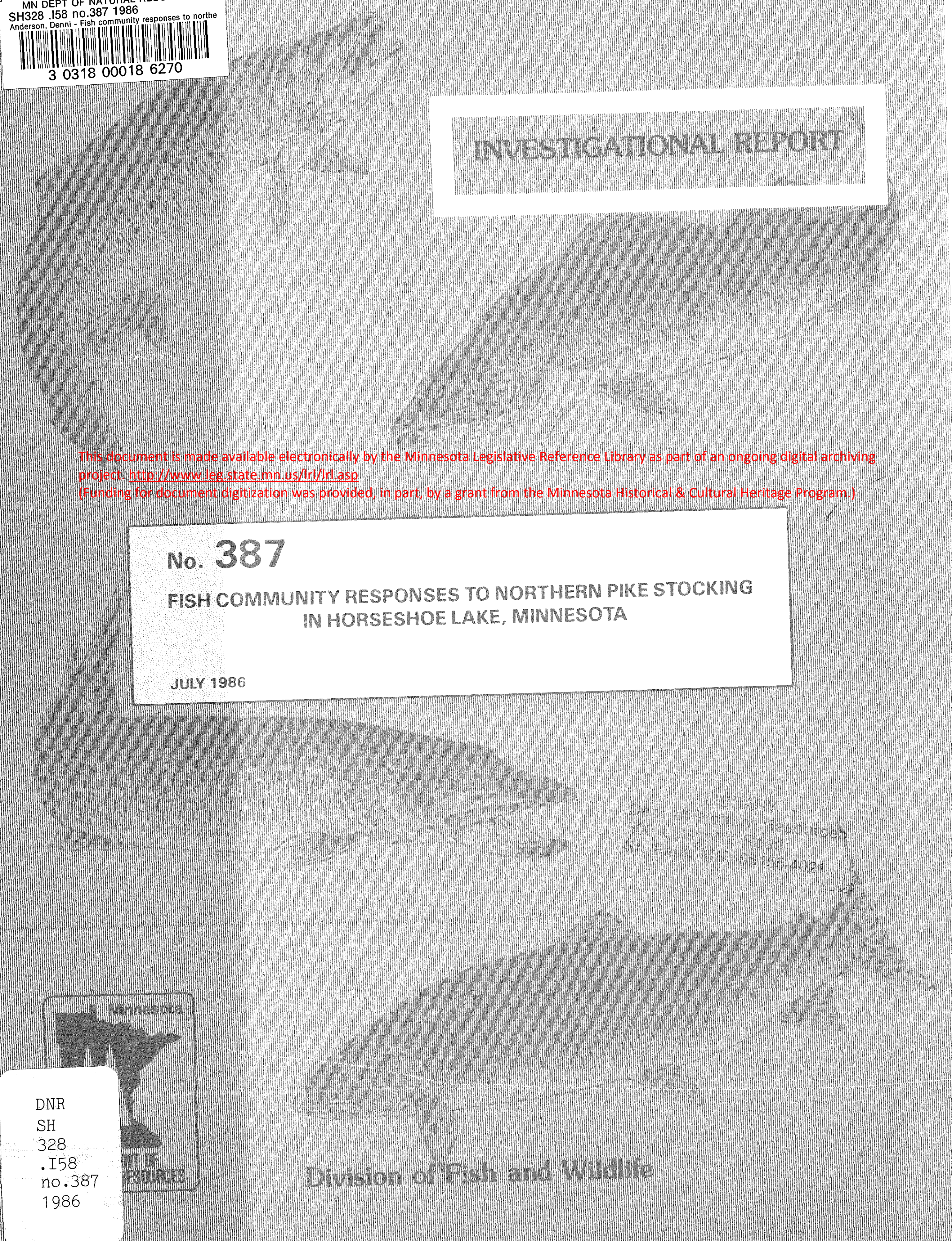

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FISH COMMUNITY RESPONSES TO NORTHERN PIKE STOCKING IN HORSESHOE LAKE, MINNESOTA

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DEPARTMENT OF NATURAL RESOURCES

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FISH COMMUNITY RESPONSES TO NORTHERN PIKE STOCKING IN HORSESHOE LAKE, MINNESOTA[1]

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ABSTRACT

The fish community in Horseshoe Lake was drastically influenced for more than 10 years by the stocking of northern pike. Changes in abundance, size distribution and growth rate of walleye, northern pike, yellow perch and centrarchids following the stocking of northern pike in 1969, 1973 and 1979 were documented. Abundance of perch, walleye, black crappie, largemouth bass and pumpkinseed declined while bluegill abundance increased significantly. Significant changes in growth, mostly negative, were observed for all species except northern pike. The observed changes in growth and abundance were judged to be related primarily to the reduction in abundance of perch. Perch were the most important prey species for pike, bass and walleye. Predation by pike on 5-6 inch perch, which nearly eliminated recruitment of perch to adult sizes, appeared to be the major factor causing a collapse of the perch population. Low abundance and small average size of perch coupled with high abundance and small average size of bluegill may be a symptom of excessive pike predation on perch.

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INTRODUCTION

Northern pike (Esox lucius) and walleye (Stizostedion vitreum vitreum) are often stocked in Minnesota lakes to establish new populations or to enhance resident populations. Both species have frequently been stocked in the same lake. Many of these lakes contain centrarchid communities where largemouth bass (Micropterus salmoides) is often the dominant predator. Information is lacking on the feeding interactions among walleye, northern pike and largemouth bass, the impact on prey resources, and the survival and growth of all sport species when northern pike populations are increased.

Literature accounts illustrate some of the possible relationships. In some fish communities, northern pike (Seaburg and Moyle 1964), largemouth bass (Clady 1974; Seaburg and Moyle 1964) and walleye (Johnson 1969; Seaburg and Moyle 1964) feed largely on yellow perch (Perca flavescens). A decline of yellow perch abundance in Horseshoe Lake was associated with the stocking of northern pike (Maloney and Schupp 1977). Northern pike (Johnson 1977) and walleye (Chevalier 1973; Forney 1974) may prey on walleye fingerlings when prey abundance is low.

Changes in yellow perch and centrarchid populations following establishment of walleye and then northern pike are well documented for Escanaba Lake, Wisconsin (Kempinger and Carline 1977). Population growth of introduced walleye was followed by an initial reduction in abundance of yellow perch and all centrarchids. All prey species were increasing to pre-walleye abundance when northern pike, introduced years earlier, became abundant. Once numerous smallmouth bass (Micropterus dolomieui) and bluegill (Lepomis macrochirus) became virtually extinct while pumpkinseed (Lepomis gibbosus), previously the dominant centrarchid in the sport fishing harvest, became rare. Rock bass (Ambloplites rupestris) and black crappie (Pomoxis nigromaculatus) declined greatly in the sport fishing harvest but became the most common centrarchids in the creel. The yellow perch population declined following the establishment of northern pike and remained at relatively low levels. Ultimately, northern pike growth rate declined but walleye growth rate did not.

Interactions that have occurred in other fish communities containing yellow perch and/or centrarchids are varied. Removal of white sucker (*Catastomus commersoni*) in Wilson Lake, Minnesota was followed by an expansion of the yellow perch population which eventually benefited walleye (Johnson 1977). Bluegill abundance increased and growth rate declined in Murphy Flowage following northern pike stockings (Snow 1974). Growth of perch increased, minnows were severely cropped and a desirable fishery for walleye and perch developed after stocking walleye in a small Michigan lake (Schneider 1979). Following walleye stockings in Manistee Lake, Michigan, perch abundance increased and growth rates declined but no consistent changes could be detected among other species (Laarman 1980). Abundance of Eurasian perch (*Perca fluviatilis*) in Lake Windermere, England declined when a gill net fishery reduced the average size of northern pike which in turn increased predation on younger perch (Bagenal 1977). Northern pike and American eel (*Anguilla rostrata*) declines in Oneida Lake, New York were accompanied by increases in walleye abundance and maintenance of high yellow perch populations. Walleye and yellow perch dominated fish communities have been regarded as less stable than more complex communities (Forney 1977). Clady (1978) noted that abundant perch may limit community diversity. Abundant yellow perch young-of-the-year (y-o-y) may have a buffering effect on other prey species y-o-y, allowing strong year-classes of other prey species coinciding with abundant perch y-o-y (Clady and Nielsen 1978; Forney 1974).

The abundance of perch and rock bass increased and bluegill recruitment decreased after sucker removal in Big Bear Lake, Michigan (Schneider and Crow 1980).

The purpose of this study was to evaluate the effects of stocking two predators (northern pike and walleye) on the success of the stockings and to document the impact on prey species and changes in the survival and growth of all sport species. The study extended the work reported by Maloney and Schupp (1977).

DESCRIPTION OF STUDY LAKE

Horseshoe Lake, in Crow Wing county, (Fig. 1) is similar to many lakes in Minnesota where walleye and northern pike populations are maintained or supplemented by stocking. The lake is moderately fertile and supports centrarchid and yellow perch populations. Maximum depth is 55 ft and total surface area is 850 A with an east basin of 530 A broadly connected to a west basin of 320 A. Total alkalinity ranges from 80 to 100 ppm. The metalimnion develops between 20 and 30 ft with summer dissolved oxygen becoming inadequate for fish life below a depth of 30 ft. There are no inlets or outlets. Spawning habitat for walleye and northern pike is poor. Maloney and Schupp (1977) described the lake in more detail. Walleye were introduced in 1948 and the population is maintained by stocking. A small population of native northern pike is present and has been supplemented at intervals to provide additional fishing. The status of the fish populations in recent years is well documented. Lake surveys in 1942 and 1948 and the study by Maloney and Schupp (1977) provide long-term perspective on change in the fish populations.

METHODS

Trap and gill net sets were replicated 12 times in 14 years (1968-81) during the first week of August. A semi-balloon otter trawl with a 28 ft head

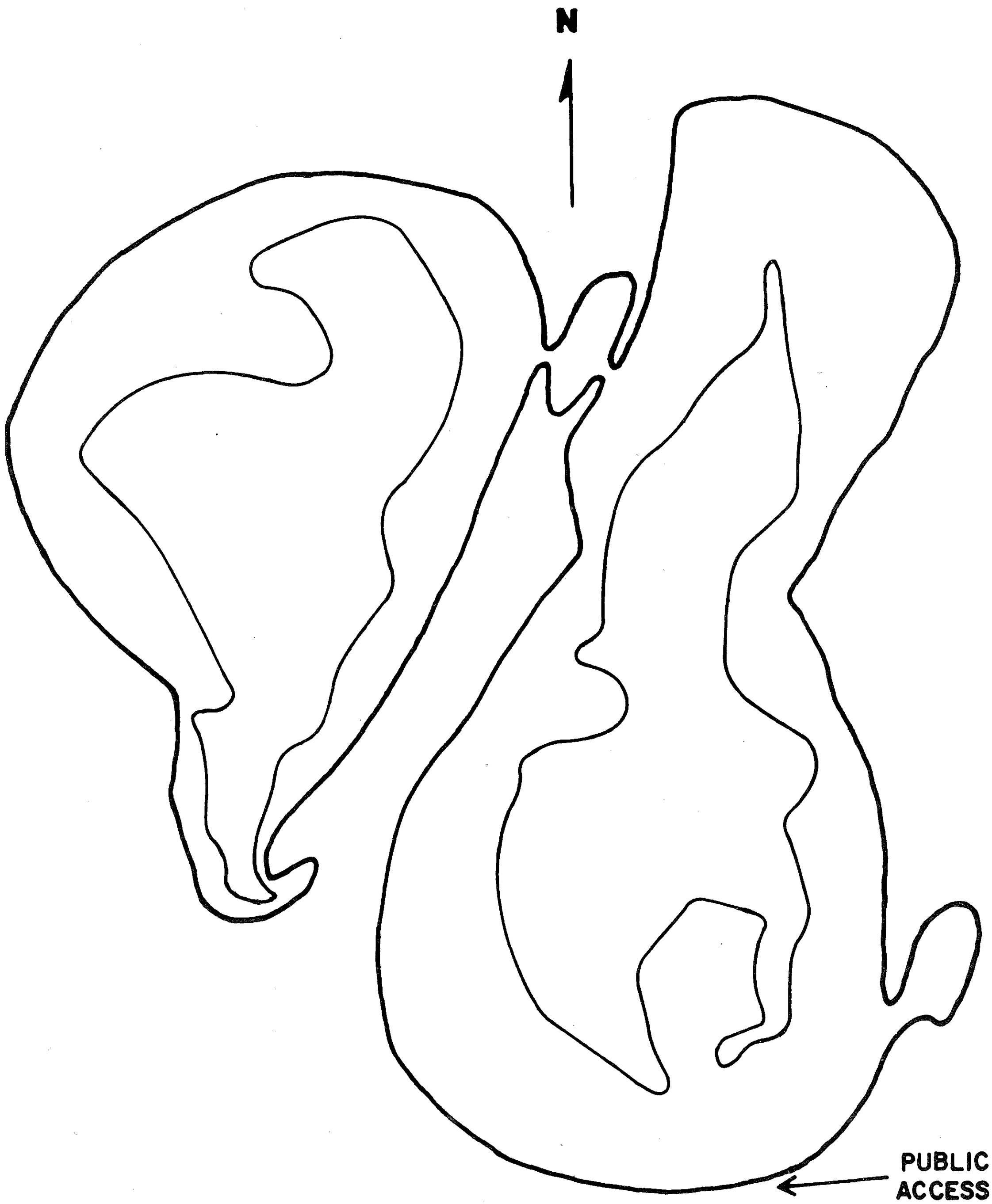

Figure 1. Horseshoe Lake, Crow Wing County, Minnesota, with 15 foot contour shown.

rope and a 0.75in mesh cod containing a 0.25in cod liner was fished weekly at three sampling locations from mid-May into early October 1977 through 1980. Trawl catches after 28 July 1981 were so poor that efforts were discontinued in favor of seining and electrofishing. Electrofishing was conducted weekly after sunset along the entire lake shoreline for the sample periods July 1979-October 1979, May-October 1980 and May-October 1981. Inadequate trawl and electrofishing sampling in 1981 was the result of a labor union work stoppage.

Additional samples for diet studies were taken with a 1.0in mesh 200 ft long by 14 ft deep seine containing a 0.25in mesh bag. Sampling periods were 4 June to 20 October 1980 and 6 May to 19 October 1981. The seine was set out over a depth of 12 to 16 ft of water or out 200 ft lakeward if water depth did not exceed 16 ft, roughly parallel to the shore and was pulled directly to shore, seining slightly less than 1 A each haul.

Schnabel population estimates were attempted for northern pike and walleye. Samples were obtained by trap netting during and shortly after ice break-up during the springs of 1977 through 1981.

Peterson population estimates were attempted for walleye and largemouth bass. Largemouth bass and walleye were marked as they were captured during early spring trapping and during subsequent spring seining. Recaptures of largemouth bass and walleye were from summer seining and electrofishing.

Walleye fingerlings were stocked from 1969-1975 to maintain the population (Table 1). Winter-rescue northern pike stocked during this period were being evaluated for contribution to the creel (Maloney and Schupp 1977). Walleye fingerlings were stocked from 1978 through 1980 to maintain stocking comparable to earlier levels. Northern pike were fin-clipped and stocked in 1979 at the rate of 3.0 lb per littoral acre.

Table 1. Fish stocking in Horseshoe Lake from 1969-1980.

Year	Species Stocked	Number
1969	N. pike	2,900
1970	Walleye	70,000
1971	Walleye	4,000
1973	N. pike	6,800
1974	Walleye	35,700
1975	Walleye	8,200
1976	Walleye	34,900
1978	Walleye	24,600
1979	N. pike	1,700
1980	Walleye	24,600

Daily consumption was estimated for largemouth bass, northern pike and walleye. Consumption estimates were based on procedures outlined by Swenson and Smith (1973; 1976). Known walleye digestion rates (Swenson and Smith 1973; 1976) were used for estimating consumption by bass and pike. This application of walleye digestion rates was accepted when it was obvious that calculated ingestion times were in agreement with what is known about northern pike and largemouth bass feeding periodicity. A Seaburg stomach pump (Seaburg 1957) was used to remove food from live bass, walleye and pike that were captured by trawling, electrofishing and seining. Prey were identified to species, total length was recorded and the percentage of digestion was estimated in the field for all ingested fish. Fish fry were identified as fry until field identification became practical and then they were were identified as y-o-y by species. Weight of ingested fish was determined from length-weight relationships derived from fresh caught samples of the important prey species. Total length and weight of all stomach-pumped fish was recorded. Consumption estimates were often based on small samples of fish and are generally regarded as imprecise best estimates.

Age and rate of growth was determined from scales for yellow perch and all sport species. The tables that are presented contain sample sizes, annual growth increments and standard errors from which data can be derived for most other approaches to age and growth analysis.

Mean lengths at capture were determined for the important sport species from the long-term series of gill and trap netting data. The mean was used as a measure of the quality of the population.

Abundance and growth rate data are presented and discussed according to early (1969-1973), middle (1974-1977) and late (1978-1981) time periods. The other sample methods apply only to the late period. Catch per unit of effort (CPUE) for electrofishing and trawling was smoothed by computing three-point moving averages of daily CPUE.

Changes in growth increments and in mean lengths at capture were tested using the Bonferroni Inequality ($P = 0.01$). Growth and mean length differences presented by time periods are significant at this level.

Total mortality rates were estimated for stocked northern pike by comparing population estimates from year to year. Efforts to estimate mortality of other species were unsuccessful since adequate population estimates were not made and the assumption of constant recruitment for catch curve analysis could not be met.

A matrix of simple correlations was developed to analyze relationships between growth and abundance data from gill and trap netting data. Simple correlations were determined for all possible pairings of growth year (GY) and CPUE for the years that paired data existed. For example, GY 1 of a species was paired with CPUE of a species for the same set of years.

RESULTS

Population estimates

Maloney and Schupp (1977) noted that increases in northern pike populations resulting from stocking were short-term. Pike tended to return to low population levels within a few years after the cessation of stocking (Table 2). Pike stocked in 1969 reached low abundance by 1973 and those stocked in 1973 reached low abundance by 1978. The effectiveness of the winter 1979 stocking was documented by the spring 1980 population estimate but by spring 1981 the population was declining rapidly.

Table 2. Northern pike population estimates, Horseshoe Lake, 1978-81. C.I. stands for confidence interval.

	Stocked Northern pike		Native Northern Pike	
Year	Number	95% C.I.	Number	95% C.I.
1978	296	233 - 405	173	128 - 264
1979[a]	214	180 - 263	229	196 - 274
1980	1672	1408 - 2058	290	199 - 539
1981	1067	953 - 1212	256	206 - 340

[a] Northern pike were stocked December 1979.

The reliability of estimates for largemouth bass and walleye was low because of small sample sizes and low recapture numbers. A Schnabel estimate of 2,139 (95% C.I. = 1,596-3,239) walleye was made during spring 1985 and a Peterson estimate for largemouth bass of 7,736 (95% C.I. = 6,186-14,435) during 1981. These estimates were judged to be the best made for these species during the entire study.

Consumption

Walleye, northern pike and largemouth bass consumption rates approximated 1.0% of their body weight per day (Table 3). Total consumption by walleye appeared to be constant from June through October. Consumption by pike lagged noticeably during late summer and early fall but was high during early summer and again in October. Largemouth bass consumption tended to be highest during early summer, lagged through late summer and partially recovered during the fall.

Table 3. Daily prey consumption as a percentage of predator weight, Horseshoe Lake, 1978-1981.

	Species		
Month	Northern pike	Largemouth bass	Walleye
June	1.1	1.1	0.9
July	1.4	0.9	1.2
August	0.7	0.4	1.2
Sept	0.3	0.6	1.1
Oct	1.6	0.9	1.2

Yellow perch and bluegill were the primary species consumed by walleye (Table 4). Estimates of consumed yellow perch often exceeded 50% of the estimated total and exceeded 80% for some portion of most years. During most years, daily consumption of panfish by walleye exceeded 30% of the total for at least one estimate period. Minnows and darters were usually less than 30% of daily consumption. Perch fry were a major component for several sample periods in June and July and largemouth bass fingerlings were important in the electrofishing samples of August 1980.

Table 4. Monthly percentages of prey species as a fraction of total daily consumption by walleye captured by trawl and electrofisher (shocker) Horseshoe Lake, 1978-1981.

	Year						
	1978	1979		1980		1981	
Month	Trawl	Trawl	Shocker	Trawl	Shocker	Trawl	Shocker
			Yellow perch				
May	48.6	40.1	---	61.5	---	5.9	---
June	33.2	57.0	---	38.2	27.5	73.1	7.8
July	28.5	66.0	89.1	88.9	87.9	93.6	0.1
Aug	18.9	42.3	32.5	---	0.0	---	---
Sept	57.3	81.8	59.5	---	0.0	---	2.7
			Panfish[a]				
May	15.7	15.7	---	34.7	---	0.0	---
June	4.6	4.1	---	7.5	37.2	---	0.0
July	19.4	3.1	0.1	---	0.0	---	53.2
Aug	10.1	35.2	26.5	---	0.0	---	---
Sept	7.8	8.9	1.4	---	35.5	---	94.4
			Minnows and darters				
May	12.4	31.4	---	0.1	---	0.3	---
June	9.5	11.1	---	0.0	32.4	7.0	0.0
July	15.8	5.1	5.5	0.0	0.0	0.0	3.1
Aug	61.5	11.3	8.6	0.0	24.9	---	---
Sept	8.1	3.5	4.6	0.0	0.0		0.0
			Others				
May	23.3	12.8	---	3.7	---	93.8	---
June[b]	52.7	27.8	---	54.3	2.9	19.9	92.2
July[b]	36.3	25.8	5.3	11.1	12.1	6.4	43.6
Aug	9.5	11.2	32.4	---	75.1[c]	---	---
Sept	26.8	5.8	34.5	---	64.5	---	2.9

[a] Panfish includes sunfish spp. and black crappie.
[b] Yellow perch fry comprised the bulk of these estimated for all years.
[c] Largemouth bass y-o-y comprised the bulk of this estimate.

Northern pike consumed a less diverse array of species. Consumption of yellow perch and panfish combined, nearly always exceeded 90% of total consumption with perch usually being the major portion (Table 5). The highest consumption of panfish was recorded for August 1980, a summer following a plant of pike and the lowest estimate was for August 1981. The highest consumption of darters was recorded for May 1981.

Table 5. Monthly percentages of prey species as a portion of total daily consumption by northern pike sampled by seine, Horseshoe Lake, 1978-1981.

Month	Year 1980	1981
	Yellow Perch	
May	----	8.8
June	92.0	49.8
July	72.0	100.0
Aug	0.0	93.6
Sept	70.8	32.2
Oct	56.3	33.9
	Panfish	
May	----	70.0
June	3.2	40.1
July	23.3	0.0
Aug	97.5	0.0
Sept	26.4	38.2
Oct	43.0	65.0
	Other	
May	----	21.2[a]
June	4.8	10.1
July	4.7	0.0
Aug	2.5	6.4
Oct	0.7	1.1

[a] Darters comprised the bulk of this estimate.

Largemouth bass consumed important quantities of a larger variety of prey (Table 6). Yellow perch often comprised 50% or more of the total. The median estimate of panfish consumed was 18-20% of the total and often exceeded 30%. All other categories estimated were as high as 30% of total daily consumption for at least one estimate.

Northern pike consumed the largest prey, walleye consumed smaller sizes and largemouth bass consumed the smallest prey (Table 7). Within a species, the larger sized predator tended to ingest larger prey.

Walleye were found in so few stomachs that consumption of walleye could not be estimated. Walleye fingerlings were found in stomachs of two 10-11in largemouth bass shortly after walleye had been stocked in the fall of 1980. No other predation on walleye was noted, though digestion of some largemouth bass stomach contents had proceeded too far to distinguish between yellow perch and walleye.

Crude estimates of total prey fish consumed by northern pike, largemouth bass and walleye indicated that bass were the largest consumer (Table 8). Bass ate 66.7% of the estimated 32.3 lbs/A consumed. Yellow perch was the major prey of all three piscivores and comprised 57% of the total consumed.

Abundance Indices

Gross changes in abundance of all important sport fish species occurred following northern pike stocking (Table 9). Northern pike CPUE was usually low but increased following each stocking and then declined gradually to low levels. Gill net indices (Table 9) tended to follow but did not vary in direct proportion to the pike population estimates (Table 2). Walleye abundance declined. Walleye gill net CPUE exceeded 5.0 per set for all but one year during the early and middle time periods but was less than 5.0 per

Table 6. Monthly percentages of prey species as a fraction of total daily consumption by largemouth bass sampled by seine and electrofisher (shocker), Horseshoe Lake, 1978-1981.

	Year					
	1979		1980		1981	
Month	Seine	Shocker	Seine	Shocker	Seine	Shocker
			Yellow perch			
May	----	----	----	----	38.4	0.0
June	43.3	----	55.8	44.3	57.4	2.8
July	64.1	----	60.5	36.3	41.3	1.3
Aug	59.0	57.3	73.9	36.3	86.7	----
Sept	----	65.3	49.7	26.2	52.1	11.4
Oct	----	50.4	69.8	----	81.2	----
			Panfish			
May	----	----	----	----	24.9	36.5
June	32.0	----	3.6	25.4	5.5	0.0
July	21.6	----	16.2	17.2	35.4	50.2
Aug	26.9	29.2	12.0	4.0	6.6	----
Sept	----	16.6	35.5	32.6	15.9	76.1
Oct	----	0.0	19.6	----	6.5	----
			Fry			
May	----	----	----	----	0.0	0.0
June	1.0	----	3.9	1.9	3.4	97.2
July	0.0	----	14.4	0.0	2.1	31.7
Aug	0.0	0.0	0.0	0.0	0.0	----
Sept	----	0.0	0.0	0.0	0.0	0.0
Oct	----	0.0	0.0	----	0.0	----
			Minnows and Darters			
May	----	----	----	----	15.6	24.2
June	10.3	----	31.9	3.4	12.0	0.0
July	5.2	----	4.9	10.1	0.6	9.4
Aug	0.0	1.5	11.2	12.6	0.0	----
Sept	----	2.7	4.4	17.6	1.6	0.0
Oct	----	0.0	1.1	----	3.7	----
			Largemouth bass			
May	----	----	----	----	0.0	0.0
June	0.0	----	0.0	0.0	0.0	0.0
July	0.6	----	0.0	6.4	4.6	0.0
Aug	3.0	4.6	1.4	12.9	0.0	----
Sept	----	3.9	1.1	6.3	1.5	0.0
Oct	----	44.1	0.0	----	0.0	----
			Other			
May	----	----	----	----	21.1	39.3
June	13.4	----	4.8	25.0	21.7	0.0
July	8.8	----	4.0	30.0	15.5	7.4
Aug	11.1	7.4	1.5	34.2	6.7	----
Sept	----	11.5	9.3	17.3	28.9	12.5
Oct	----	5.47	9.5	----	8.6	

Table 7. Relationship between predator sizes (mean TL) for northern pike, largemouth bass, and walleye and ingested prey sizes (mean TL), Horseshoe Lake, 1977-1981.

	Mean length (inches)									
	1977	S.E.	1978	S.E.	1979	S.E.	1980	S.E.	1981	S.E.
Northern pike	---[a]		---		21.7	0.93	19.7	0.33	20.1	0.48
Northern pike prey										
Panfish	---		---		4.8	0.58	4.4	0.33	4.6	0.33
Perch	---		---		4.4	0.46	4.0	0.19	4.2	0.30
All prey	---		---		4.6	0.53	4.0	0.17	3.7	0.19
Largemouth bass	---[a]		---		10.1	0.12	9.7	0.09	9.6	0.11
Largemouth bass prey	[a]									
Panfish	---		---		3.1	0.23	2.2	0.15	1.9	0.14
Perch	---		---		2.3	0.11	2.1	0.08	2.3	0.09
All prey	---		---		2.5	0.08	2.2	0.06	2.3	0.06
Walleye	12.6	0.30	9.9	0.18	12.7	0.22	14.0	0.38	12.4	0.51
Walleye prey										
Panfish	1.6	0.27	2.0	0.19	3.4	0.26	3.2	0.42	2.6	0.35
Perch	4.2	0.19	1.2	0.03	3.4	0.18	3.7	0.23	2.1	0.21
All prey	3.1	0.22	1.3	0.03	3.1	0.11	3.3	0.17	2.3	0.15

[a] So few pike and bass were sampled by trawling that estimates could not be made.

Table 8. Estimated total consumption (lbs) of prey fish from May through October by northern pike, largemouth bass and walleye, Horseshoe Lake.

	Northern pike	Largemouth bass	Walleye	Total	Pounds/ Acre
Standing crop	2,000	10,000	3,000	15,000	17.6
Total consumption	3,660	18,300	5,490	27,450	32.3
Yellow perch	2,086	10,614	2,855	15,555	18.3
Panfish[a]	1,391	3,294	571	5,256	6.2
Other	183	4,392	2,064	6,639	7.8

[a] Panfish includes sunfish sp. and black crappie.

set in the late period. Largemouth bass CPUE declined with increases in the pike population.

Yellow perch abundance declined and recovered with northern pike population increases and decreases. Abundance of adult perch (Table 9) declined during and following periods of peak pike abundance, recovered partially after pike abundance returned to natural levels and then declined further after late period pike stocking.

Changes in abundances of panfish species were variable (Table 9). Bluegill abundance declined initially but then recovered to high levels. Trap net CPUE's declined in the early period, remained low for all but one year during the middle period and increased and then declined in the late period (Table 9). Pumpkinseed abundance indices were erratic but generally declined. Black crappie older than yearlings increased during the middle period and declined through most of the late period.

Table 9. Gill net and trap net CPUE's, Horseshoe Lake, 1968-81.[a]

Year	Gill net: Northern pike No. Sets	Northern pike Mean No.	Northern pike S.E.	Yellow perch No. Sets	Yellow perch Mean No.	Yellow perch S.E.	Walleye No. Sets	Walleye Mean No.	Walleye S.E.
1968	9	1.4	0.77	9	31.1	8.33	9	2.9	1.45
1969	9	1.3	0.53	9	40.3	12.78	9	8.9	1.77
1971	9	4.2	0.91	9	17.8	6.52	9	10.0	1.38
1972	9	2.4	0.65	9	13.3	4.19	9	5.3	1.07
1974	9	6.6	1.02	9	4.7	1.37	9	8.0	2.45
1975	9	3.9	0.87	9	4.0	0.97	9	7.2	1.62
1976	9	1.1	0.35	9	3.1	1.40	9	11.5	1.90
1977	9	2.4	0.67	9	0.2	0.22	6	11.0	2.49
1978	9	0.9	0.26	9	2.6	0.94	9	4.4	1.17
1979	9	2.2	0.74	9	8.1	2.03	9	4.0	0.83
1980	9	3.1	0.77	9	4.8	1.39	9	4.2	0.55
1981	9	3.4	0.41	9	1.9	0.51	9	2.7	0.73

Year	Trap net: Largemouth bass No. Sets	Largemouth bass Mean No.	Largemouth bass S.E.	Bluegill No. Sets	Bluegill Mean No.	Bluegill S.E.	Pumpkinseed No. Sets	Pumpkinseed Mean No.	Pumpkinseed S.E.
1968	15	6.2	1.60	15	144.8	26.86	15	25.7	7.74
1969	10	11.7	3.08	10	153.6	47.52	10	19.4	5.39
1971	10	7.0	1.67	10	82.9	14.11	10	8.2	1.55
1972	11	4.3	1.82	11	35.2	8.67	11	26.3	9.41
1975	10	1.3	0.54	10	40.3	6.52	10	6.0	1.61
1976	10	2.3	0.67	10	126.1	33.92	10	15.9	3.14
1977	6	1.7	0.84	6	29.5	1.09	6	14.2	4.13
1978	8	1.2	0.65	8	102.3	14.76	8	6.6	1.28
1979	8	7.0	3.20	8	273.1	45.94	8	15.9	3.93
1980	10	3.9	1.36	10	151.7	18.14	10	13.2	2.87
1981	10	1.7	0.52	10	115.9	18.48	10	2.3	0.68

Year	Black crappie No. Sets	Black crappie Mean No.	Black crappie S.E.
1968	15	0.2	0.44
1969	10	0.2	0.13
1971	10	1.5	0.13
1972	11	1.2	0.62
1975	10	7.0	0.68
1976	10	8.4	3.00
1977	6	1.3	0.49
1978	8	0.2	0.16
1979	8	0.8	0.25
1980	10	0.8	0.59
1981	10	2.0	0.80

[a] Centrarchid data from trap nets and rest from gill net samples.

Sampling by trawling and eletrofishing was done only during the late period so no long-term trends could be evaluated. In general, CPUE's of sampled adult fish varied similarly to catches of the same species in gill and trap nets (Tables 10 and 11). There was some evidence of recovery of the yellow perch population. Trawl catches of perch y-o-y and yearlings were highest at the end of the period (Table 11).

Table 10. Peak electrofishing CPUE (three-point moving averages) for northern pike, largemouth bass and walleye, Horseshoe Lake, 1979--1981.

	Peak CPUE(no/hr)			Peak catch date		
	1979	1980	1981	1979	1980	1981
Northern pike	1.7	2.4	2.1	9-11[a] 9-17	9-25	9-9
Largemouth bass y-o-y	23.7	20.2	12.3	7-26	6-17	6-16
Walleye	15.3	3.72	7.3	8-12[a] 8-23	9-3	7-23

[a] The same peak CPUE was observed on both dates.

Growth Rates

Significant changes in growth were observed for all species except northern pike. In general, growth rates of species that preyed extensively on small yellow perch (young walleye and largemouth bass) declined during the mid-period and increased during the late period (Table 12). Growth of species that are not known to feed on small perch tended to continue to decline or failed to recover in the late period.

Table 11. Peak trawling CPUE's (three-point moving averages) and peak catch dates, Horseshoe Lake, 1978-1981.

	CPUE (No/min)				Peak Catch Date			
	1978	1979	1980	1981	1978	1979	1980	1981
Minnows	3.0	7.4	11.1	5.0	9-22	9-25	8-11	5-21
Sunfish y-o-y	15.0	39.5	108.8	7.0	9-11	9-20	8-27	8-28
Pumpkinseed	----	3.8	1.1	0.5	----	7-24	6-10	6-23
Bluegill y-o-y	12.1	28.9	12.6	6.9	6-17	8-14	8-19	6-19
Largemouth bass y-o-y	1.4	5.7	61.5	0.15	8-28	8-21	8-11	8-28
Black crappie y-o-y	----	2.4	71.4	0.2	----	9-5	8-19	8-28
Darters	1.0	6.8	11.6	15.0	8-22	9-17	8-27	6-2
Yellow perch yrl	a	25.2	10.4	7.4	a	7-6	5-19	5-22
Yellow perch yrl	20.1	19.0	32.2	30.9	7- 5	6-12	5-19	5-26
Perch y-o-y	7.0	36.7	294.3	528.1	7-18	8-14	8-11	7-15
Walleye	1.0	0.7	0.2	0.3	6-22	6-5	5-19	5-26

[a] Perch yearlings were included with the perch yrl for 1978.

Walleye growth (Table 12) declined and rose in concert with changes in yellow perch abundance. The mean GY (growth year) 2 increment in 1977, when perch abundance was low, was 51% of that in 1968. The GY 2 increment in 1979, when perch abundance was recovering, improved to 88% of the 1968 increment. The GY 3 increment varied similarily and GY 4 growth may also have been influenced. Based on the summation of mean annual increments through GY 4, walleye were 33% smaller during the middle period than they had been in the early period but had recovered to within 11% in the late period.

The first year of in-lake growth for walleye is GY 2 and this was usually the largest annual increment. However, during 1977-1978 the increment for GY 3 exceeded GY 2. The mean increment for GY 2 in 1977 was lower than all but one GY 3 increment and lower than five of seven GY 4 increments.

Table 12. Growth expressed as mean annual increments (inches), Horseshoe Lake, 1968-1980.

	Growth Year														
	1			2			3			4			5		
Year	Incr.	n	S.E.	Incr.	n	S.E.	Incr.	n	S.E.	Incr.	n	S.E.	Incr.	n	S.E.
							Northern pike								
68	11.69	28	0.41	6.86	15	0.54	3.77	25	0.27	2.58	9	0.36			
69	13.78	71	0.15	8.21	24	0.63	2.89	14	0.29	1.99	17	0.14			
70	11.87	14	0.31	6.94	34	0.19	3.14	8	0.47	1.42	2	0.13			
71	12.40	34	0.45	8.36	14	0.52	3.68	14	0.22	3.42	3	0.71			
72	10.04	38	0.46	8.69	30	0.43	3.24	13	0.22	1.66	2	0.16			
73	12.10	6	1.27	9.56	34	0.34	2.48	11	0.28	0.74	4	0.13			
74	11.86	17	0.53	8.69	6	1.27	3.54	22	0.21	2.41	8	0.48			
75	13.69	6	0.68	9.90	16	0.40	3.32	5	0.21	2.79	11	0.66			
76	13.02	18	0.49	7.31	6	1.80	3.50	8	0.32	2.98	1	----			
77	12.53	75	0.23	6.49	18	0.41	3.53	6	0.58	2.20	4	0.48			
78	11.86	111	0.21	8.82	71	0.30	3.76	18	0.54	2.97	4	0.53			
79	10.63	102	0.21	7.97	56	0.35	3.13	27	0.36	1.59	3	0.70			
80	10.28	18	0.52	8.76	84	0.18	3.21	35	0.22	1.78	15	0.29			
							Pumpkinseed								
68	1.48	28	0.04	0.96	24	0.03	1.00	55	0.03	0.89	17	0.06	0.94	15	0.06
69	1.52	36	0.03	1.09	28	0.03	1.15	22	0.05	0.98	15	0.06	----	--	----
70	1.48	18	0.03	1.11	36	0.04	1.18	28	0.03	1.14	22	0.06	1.13	15	0.07
71	1.21	1	----	0.92	18	0.04	1.13	27	0.05	1.07	17	0.06	0.98	15	0.15
72	1.49	6	0.04	0.83	1	----	1.12	14	0.05	1.32	2	0.08	----	--	----
73	1.61	9	0.03	1.11	6	0.08	1.22	1	----	1.30	14	0.07	1.11	2	0.18
74	1.43	10	0.06	1.00	9	0.06	0.98	6	0.07	1.54	1	----	1.12	14	0.04
75	1.50	20	0.04	0.92	10	0.10	0.90	1	----	----	--	----	----	--	----
76	1.50	22	0.04	0.97	20	0.05	1.09	10	0.08	0.90	1	----	----	--	----
77	----	--	----	1.13	22	0.06	1.10	20	0.05	0.98	10	0.09	0.50	1	----
78	----	--	----	----	--	----	0.80	22	0.04	0.82	20	0.05	0.81	10	0.08
79	----	--	----	----	--	----	----	--	----	----	--	----	----	--	----
80	----	--	----	----	--	----	----	--	----	----	--	----	----	--	----
							Bluegill								
68	0.86	7	0.08	0.82	14	0.03	0.90	51	0.04	1.21	10	0.13	1.07	21	0.03
69	1.66	29	0.03	0.98	7	0.07	1.05	13	0.06	1.21	29	0.05	1.10	8	0.11
70	1.58	14	0.03	1.12	29	0.04	1.12	7	0.10	1.31	13	0.09	1.29	28	0.05
71	1.57	19	0.03	0.90	14	0.06	1.13	14	0.10	0.93	3	0.26	1.24	5	0.19
72	1.44	14	0.05	0.99	19	0.03	1.13	11	0.05	1.20	3	0.13	----	--	----
73	1.63	39	0.02	0.97	14	0.06	1.10	19	0.04	1.45	11	0.10	1.10	3	0.06
74	1.64	21	0.03	0.92	39	0.03	1.10	14	0.07	0.98	19	0.08	1.19	11	0.08
75	1.57	36	0.02	0.82	21	0.04	0.87	30	0.03	1.30	7	0.14	1.04	6	0.03
76	1.76	89	0.03	1.10	36	0.04	0.88	21	0.05	1.20	19	0.06	0.84	4	0.14
77	1.63	23	0.05	0.95	89	0.02	1.06	36	0.04	1.16	21	0.05	0.86	11	0.07
78	1.50	22	0.02	0.93	23	0.05	0.83	88	0.02	0.92	36	0.04	0.98	21	0.06
79	1.40	24	0.04	0.90	22	0.03	0.76	21	0.04	0.73	65	0.03	0.81	26	0.06
80	1.70	16	0.06	0.99	18	0.05	0.93	16	0.04	0.73	16	0.04	0.75	38	0.04

Table 12. Continued.

	Growth Year														
	1			2			3			4			5		
Year	Incr	n	S.E.	Incr	n	S.E.	Incr	n	S.E.	Incr	n	S.E.	Incr.	n	S.E.
							Largemouth bass								
68	3.42	57	0.08	3.35	31	0.09	2.86	40	0.09	1.89	3	0.50			
69	3.64	23	0.12	3.76	15	0.17	3.03	11	0.36	2.73	24	0.09			
70	3.81	64	0.08	3.74	23	0.08	2.52	11	0.31	2.21	1	----			
71	3.82	33	0.13	3.61	27	0.14	2.36	8	0.19	1.82	7	0.11			
72	3.05	11	0.19	3.64	8	0.27	----	--	----	----	--	----			
73	3.06	13	0.18	3.47	11	0.15	2.85	8	0.13	----	--	----			
74	2.73	36	0.06	3.30	13	0.16	2.71	2	0.25	2.45	8	0.14			
75	2.78	175	0.02	3.86	32	0.09	3.10	69	0.08	3.22	2	0.08			
76	2.91	102	0.04	3.18	174	0.04	3.45	30	0.12	2.58	3	0.40			
77	2.71	96	0.03	2.37	80	0.08	2.60	136	0.06	2.95	26	0.16			
78	3.16	54	0.09	3.39	96	0.05	3.10	69	0.08	2.28	28	0.10			
79	2.99	56	0.08	3.24	40	0.09	2.41	40	0.08	2.08	18	0.17			
80	2.91	41	0.08	3.60	47	0.07	2.83	24	0.09	2.24	22	0.12			
							Black crappie								
68	1.76	7	0.04	2.23	11	0.18	3.04	22	0.05	2.08	6	0.37	0.71	1	----
69	1.99	3	0.11	2.88	7	0.29	3.25	11	0.10	2.17	16	0.06	1.50	5	0.17
70	2.33	4	0.07	3.99	3	0.08	3.12	7	0.25	2.03	11	0.12	1.16	3	0.16
71	2.11	7	0.05	3.64	4	0.10	----	--	----	2.17	1	----	----	--	----
72	1.74	1	----	----	--	----	----	--	----	----	--	----	----	--	----
73	2.05	40	0.03	2.34	1	----	----	--	----	----	--	----	----	--	----
74	3.68	3	0.37	1.99	40	0.08	3.44	1	----	----	--	----	----	--	----
75	2.08	7	0.06	2.84	3	0.25	2.48	17	0.11	1.70	1	----	----	--	----
76	2.18	25	0.04	2.45	6	0.21	2.29	3	0.15	2.07	6	0.12	----	--	----
77	2.11	27	0.05	2.54	25	0.06	2.26	5	0.12	----	--	----	----	--	----
78	1.96	76	0.02	2.48	27	0.10	2.22	25	0.06	1.62	5	0.18	----	--	----
79	2.00	6	0.08	2.08	74	0.04	2.28	15	0.10	1.66	12	0.06	1.31	2	0.02
80	2.17	15	0.03	1.85	3	0.13	2.42	34	0.08	1.61	9	0.14	----	--	----
							Yellow perch								
68	1.57	3	0.08	1.31	5	0.12	1.76	19	0.11	1.35	19	0.10	1.03	12	0.09
69	----	--	----	1.01	3	0.20	0.98	5	0.05	1.23	8	0.16	----	--	----
70	1.26	6	0.05	----	--	----	2.02	3	0.19	1.13	5	0.08	1.22	8	0.08
71	1.91	6	0.12	1.10	6	0.13	----	--	----	----	--	----	----	--	----
72	1.99	12	0.11	1.12	6	0.14	1.12	6	0.10	----	--	----	----	--	----
73	2.16	26	0.05	1.05	12	0.15	1.12	6	0.09	1.15	6	0.09	----	--	----
74	2.04	86	0.03	1.14	26	0.09	1.11	12	0.15	0.89	6	0.11	0.93	6	0.06
75	2.18	51	0.05	1.13	86	0.04	1.13	25	0.08	1.29	12	0.17	0.96	6	0.12
76	2.38	49	0.04	1.37	51	0.07	1.06	86	0.03	0.99	21	0.10	0.87	8	0.15
77	2.19	23	0.07	1.38	44	0.05	1.13	39	0.05	0.79	55	0.04	0.66	5	0.09
78	2.18	35	0.05	1.40	23	0.09	0.99	43	0.05	0.83	31	0.06	0.80	35	0.04
79	2.01	26	0.05	1.16	23	0.06	1.13	20	0.06	0.98	19	0.09	0.81	11	0.10
80	2.30	10	0.07	1.28	12	0.07	1.11	16	0.07	1.33	18	0.10	0.94	13	0.13

Table 12. Continued.

	Growth Year														
	1			2			3			4			5		
Year	Incr.	n	S.E.	Incr.	n	S.E.	Incr.	n	S.E.	Incr.	n	S.E.	Incr.	n	S.E.
							Walleye								
68	4.33	16	0.15	4.84	56	0.15	2.63	1	----	----	---	----			
69	4.50	20	0.16	4.52	14	0.27	3.90	34	0.14	2.84	1	----			
70	5.09	26	0.14	4.44	20	0.29	3.91	13	0.31	2.67	12	0.33			
71	5.08	1	----	4.58	16	0.36	4.07	10	0.23	2.76	2	0.22			
72	----	--	----	----	--	----	----	--	----	----	--	----			
73	----	--	----	----	--	----	----	--	----	----	--	----			
74	3.35	65	0.13	----	--	----	----	--	----	----	--	----			
75	3.68	81	0.09	3.51	65	0.22	----	--	----	----	--	----			
76	3.29	148	0.04	2.94	80	0.11	2.36	44	0.11	----	--	----			
77	4.74	7	0.46	2.46	125	0.07	2.54	38	0.14	1.98	6	0.36			
78	3.47	119	0.10	3.37	7	0.51	3.46	91	0.10	2.25	25	0.16			
79	----	--	----	4.28	84	0.09	2.63	5	0.39	2.98	32	0.19			
80	4.37	31	0.12	----	--	----	4.23	34	0.13	2.87	4	0.24			

Growth of largemouth bass also declined during the years of low perch abundance (Table 12). The largest declines were for GY 1 and GY 2. Largemouth bass growth increments were greatest in GY 2 for all years except 1976 and 1977 when GY's 3 and 4, respectively, had the greatest increments. These 1976 and 1977 increments were near the long-term highs for GY's 3 and 4 and occurred when the bluegill population was expanding. The summation of increments through GY 4 was 7% lower in the middle and late periods than in the early period.

Growth of native northern pike was highly variable among age groups and among years (Table 12). GY 3 growth was the most consistent. The most notable growth declines were those of GY's 1 and 2 near the end of the study period. No relationship between pike growth and changing abundances of other fish species was apparent.

Bluegill growth was relatively stable during the early period but notable changes subsequently occurred (Table 12). GY 1 increments increased during the middle period and then declined into the late period. GY 2 increments were quite consistent throughout all study periods. GY 3 increments remained near 1.1in for most of the early period, declined to less than 1.0in during the middle period and reached the long-term low during the late period. GY 4 increments were always below 1.0in during the late period, reaching lows for the study, but for all other years fell below 1.0in only twice. GY 5 increments fell below 1.0in during the years 1976-1980 after being larger than 1.0in for all prior years. The sum of annual increments through GY 5 was 18% lower in the late period than in the early period.

Bluegill growth increments after GY 1 were greatest for GY 4 most years. The exceptions occurred in 1971, 1974, 1978 and 1979 when 5th year increments were greater and in 1980 when 2nd year increments were greater (Table 12).

Yellow perch growth rates fluctuated widely with GY 1 and 2 increments reaching highs during the middle and late periods but declining again near the end of the study (Table 12). GY 3 increments changed little during the entire study while GY 4 and 5 increments reached lows in the middle period. The sum of annual increments through GY 5 was 9% below the early period during the middle and late periods.

Yellow perch GY 1 increments were usually greatest followed by declining increments with increasing age (Table 12). GY 3 increments were similar to GY 2 through 1975 but GY 2 increased in later years while GY 3 increments remained stable.

Growth rates of black crappie and pumpkinseed were lowest in the late period (Table 12). Crappie growth increments were highest for GY's 2 and 3 and pumpkinseed growth after GY 1 was fastest during GY's 3 and 4. The sum of annual increments for crappie through GY 5 was 18% below the early period during the late period while pumpkinseed were 14% shorter.

Mean length

Mean lengths at capture varied over time, by species, and in a variety of fashions (Table 13). Northern pike mean lengths showed little trend through 1978 and then declined significantly. Bluegill lengths declined significantly during the middle period and recovered during the late period. Pumpkinseed lengths followed a similar pattern but reached a long-term maximum in 1981. There was a significant inverse relationship between yellow perch lengths and bluegill and pumpkinseed lengths (P 0.05). Perch lengths increased to a long-term high during the middle period and declined steadily to a long-term low by 1981. Black crappie and largemouth bass lengths at capture were represented by such small sample sizes and high variability for most years that little can be said about changes with any degree of confidence.

Mean TL of age 4 walleye in 1978 was less than mean TL of age 3 walleye from 1969-1971. Mean TL at age 2 (the sum of GY 1 and 2 increments) reached long-term lows during the middle period and improved during the late period. Mean TL of age 4 largemouth bass averaged over 12.0in for most early and middle years but dropped to 10.0in or less in the late period. The 1973 and 1974 bass year-classes had very slow first-year growth but recovered to equal or exceed the long-term TL by age 4.

Growth and CPUE Correlations

Yellow perch were involved in 16 of 24 significant correlations (Table 14). Perch GY 1 increments were negatively correlated with perch GY's 3 and 5, GY 2 of walleye, GY 1 of largemouth bass, and with bass and perch CPUE's. Positive correlations of perch GY 4 and 5 increments were found with bass GY 1 and 2 increments. Perch CPUE's correlated positively with walleye GY 2 increments, bass GY 1 increments and bass CPUE.

Table 13. Mean TL (inches) at capture for various fish species, Horseshoe Lake,
1968-1981.[a]

Year	Northern pike Mean TL	Northern pike 95% CI	Pumpkinseed Mean TL	Pumpkinseed 95% CI	Bluegill Mean TL	Bluegill 95% CI
1968	24.6	22.8-26.5	5.7	5.6-5.8	5.9	5.8-5.9
1969	25.2	23.9-26.6	5.1	4.9-5.2	5.1	5.0-5.2
1971	23.5	22.5-24.5	5.1	4.8-5.3	5.7	5.6-5.9
1972	25.9	24.8-27.0	5.5	5.3-5.6	5.2	5.1-5.4
1974	21.3	20.7-21.9	---	-------	---	-------
1975	24.4	23.5-25.3	4.6	4.3-4.8	5.1	5.0-5.2
1976	27.5	25.8-29.1	4.7	4.5-4.9	4.8	4.8-4.9
1977	25.4	24.5-26.3	5.5	5.4-5.7	5.3	5.2-5.4
1978	30.3	26.5-34.0	5.5	5.3-5.7	5.3	5.2-5.4
1979	22.5	20.5-24.5	5.1	4.9-5.2	5.1	5.0-5.2
1980	20.5	19.2-21.8	5.4	5.3-5.5	5.6	5.5-5.7
1981	22.0	21.1-23.0	5.9	5.7-6.2	5.6	5.5-5.6

Year	Largemouth bass Mean TL	Largemouth bass 95% CI	Black crappie Mean TL	Black crappie 95% CI	Yellow perch Mean TL	Yellow perch 95% CI
1968	8.0	7.7-8.2	7.0	6.3-7.7	6.5	6.3-6.7
1969	6.6	6.3-6.8	9.9	6.7-13.1	7.6	7.4-7.8
1971	6.8	6.5-7.0	10.3	-------	7.2	7.0-7.5
1972	8.3	7.8-8.7	6.3	5.1-7.5	7.1	6.8-7.3
1974	---	-------	---	-------	8.0	7.4-8.5
1975	8.4	7.0-9.8	6.2	6.1-6.4	8.2	7.6-8.9
1976	8.4	7.4-9.4	8.0	7.8-8.1	7.3	6.8-7.8
1977	8.1	6.9-9.2	8.3	7.5-9.1	---	-------
1978	7.2	7.0-7.5	7.9	-------	7.2	6.5-7.9
1979	7.9	7.5-8.3	6.6	4.9-8.4	6.8	6.7-7.0
1980	7.5	7.0-8.0	7.7	6.2-9.2	6.6	6.4-6.8
1981	7.2	6.4-7.9	6.3	5.5-7.1	6.2	5.6-6.8

Year	Walleye Mean TL	Walleye 95% CI
1968	18.2	16.7-19.6
1969	17.0	16.1-17.9
1971	16.9	16.0-17.9
1972	15.1	14.1-16.2
1974	16.3	15.9-16.6
1975	17.3	16.6-18.0
1976	16.2	15.5-16.9
1977	15.9	15.2-16.6
1978	18.9	17.7-20.1
1979	19.3	18.3-20.2
1980	17.6	16.2-19.0
1981	20.2	18.2-22.2

[a] Centrarchid data are from trap net samples and northern pike, walleye and yellow perch from gill net smaples.

Table 14. Correlation matrices between annual growth increments and CPUE's for northern pike, bluegill, largemouth bass, yellow perch and walleye, Horseshoe Lake, 1968-1980.

	Bluegill					
	GY 1	GY 2	GY 3	GY 4	GY 5	CPUE
Northern pike						
CPUE	-0.224	-0.289	0.458	-0.182	0.450	-0.318
Bluegill						
GY 2	0.395					
GY 3	-0.150	0.443				
GY 4	0.413	0.184	0.436			
GY 5	-0.284	-0.024	0.718[a]	0.453		
CPUE	-0.275	-0.088	-0.557	-0.595	-0.324	
Largemouth bass						
GY 1	-0.304	0.176	0.423	0.131	0.637[b]	0.168
GY 2	-0.162	-0.021	0.076	0.112	0.442	0.088
GY 3	0.501	0.087	-0.418	0.345	-0.277	-0.235
GY 4	0.286	0.018	-0.058	0.484	-0.210	-0.523
CPUE	-0.283	-0.050	0.265	-0.086	0.409	0.511
Yellow perch						
GY 1	0.242	-0.075	-0.455	-0.235	-0.676[b]	-0.147
GY 2	0.437	0.191	-0.476	-0.152	-0.638[b]	-0.087
GY 3	0.040	0.153	0.372	0.304	0.537	0.116
GY 4	0.296	-0.224	0.023	0.209	0.197	0.136
GY 5	0.114	0.228	0.474	0.394	0.695[b]	0.168
CPUE	-0.041	-0.187	0.074	0.293	0.481	0.236
Walleye						
GY 2	-0.391	-0.217	0.215	-0.101	0.652	0.610
GY 3	-0.220	0.162	0.509	-0.214	0.425	0.206
GY 4	-0.244	0.005	-0.111	-0.363	-0.771[b]	0.780
CPUE	0.176	0.454	0.451	0.374	0.164	-0.406

	Largemouth bass					
	GY 1	GY 2	GY 3	GY 4	GY 5	CPUE
Northern pike						
CPUE	-0.250	0.107	-0.407	0.048	----	-0.151
Largemouth bass						
GY 2	0.473				----	
GY 3	-0.539	0.115			----	
GY 4	-0.542	-0.149	0.247		----	
CPUE	0.747[b]	0.352	-0.345	-0.356	----	
Walleye					----	
GY 2	0.798[a]	0.653	-0.407	-0.654	----	0.789[a]
GY 3	0.573	0.882[a]	-0.241	-0.452	----	0.363
GY 4	0.389	0.742	-0.214	-0.565	----	0.722
CPUE	-0.019	-0.338	0.123	0.456	----	0.059

Table 14. Continued.

	Perch					
	GY 1	GY 2	GY 3	GY 4	GY 5	CPUE
Northern pike						
CPUE	-0.044	-0.429	-0.081	0.047	0.248	-0.269
Yellow perch						
GY 1						
GY 2	0.227					
GY 3	-0.943[a]	0.227				
GY 4	-0.277	-0.352	0.324			
GY 5	-0.756[b]	-0.343	0.800[a]	0.591		
CPUE	-0.918[a]	-0.465	0.377	0.549	0.617	
Walleye						
GY 2	-0.767[b]	-0.650	0.224	0.503	0.701	0.800[b]
GY 3	-0.208	-0.497	0.064	0.447	0.487	0.264
GY 4	-0.240	-0.783	0.100	0.716	0.670	0.493
CPUE	0.452	0.029	-0.450	-0.398	-0.460	-0.129
Largemouth bass						
GY 1	-0.758[a]	-0.329	0.616	0.342	0.739[b]	0.788[a]
GY 2	-0.301	-0.511	0.157	0.702[b]	0.751[b]	0.403
GY 3	0.494	0.308	-0.394	0.153	-0.074	-0.051
GY 4	0.486	0.005	-0.465	-0.119	-0.447	-0.271
CPUE	0.693[b]	-0.699[b]	0.099	0.393	0.335	0.869[a]

	Walleye					
	GY 1	GY 2	GY 3	GY 4	GY 5	CPUE
Northern pike						
CPUE	----	0.112	0.479	0.274	----	0.095
Walleye						
GY 2	----				----	----
GY 3	----	0.514			----	----
GY 4	----	0.932[b]	0.452		----	----
CPUE	----	-0.504	-0.105	-0.395	----	----

[a] Significant at the 99% level.
[b] Significant at the 95% level.

Mortality rates

Estimates of total mortality of northern pike in this study were lower than previous estimates. Total mortality from spring 1978 to spring 1979 for pike stocked before 1979 was 28%. Mortality of 1979 stocked pike between spring 1980 and spring 1981 was 36%. So few pre-1979 stocked pike were sampled in 1980 that a separate population estimate of this stock was not attempted but unusually high mortality was suspected. Maloney and Schupp (1977) estimated total mortality of pike in Horseshoe Lake to average 51%.

DISCUSSION

The artificially induced increase in the northern pike population was accompanied by a sharp decline in the yellow perch population, a decline in the largemouth bass and walleye populations, an eventual population explosion of bluegill and changes in growth rates of bass, bluegill, pumpkinseed, perch and walleye. It is hypothesized that predation by pike on perch that were recruiting to mature sizes caused the virtual collapse of the perch population. The perch population in Harriet Lake, Minnesota increased dramatically when the pike population was reduced (D. Shodeen, MN DNR personnal communication 1985). Perch abundance and average size declined in Grace Lake, Minnesota following pike stocking (MN DNR files).

Northern pike, largemouth bass and walleye were all major consumers of yellow perch in Horseshoe Lake but pike probably had the greatest effect on perch abundance. Walleye and largemouth bass were predatory forces that existed before pike were stocked. Both walleye and bass prey on perch at life stages when there are large surpluses while pike prey on perch at life stages when surpluses may be less likely.

Estimates of yellow perch consumed by walleye and largemouth bass were under-estimates. Perch fry were included in the total consumption estimates but were not identified as such and later summer consumption estimates included unidentified fish with a size and form similar to perch.

Periodically, prey other than yellow perch were important to northern pike, largemouth bass and walleye. Panfish, minnows, darters and y-o-y bass alternated as important items in the diet, particularily in late summer.

Northern pike consumption patterns were probably related to the species cool water nature and decreasing temperature optima with increasing age (Casselman 1978). Sunfish, primarily bluegill, were often ingested in important quantities in spring and fall but were probably unavailable to the cool water seeking pike in mid-summer. Smaller pike were more available to our sampling gears in mid-summer than were larger pike. The low consumption of yellow perch in August 1980 and the concurrent high consumption of panfish probably reflected the abundance of recently stocked small pike that inhabited the warmer waters where panfish were available. The opposite observation in 1981 may be explained by the larger pike in the lake at this time.

Walleye apparently fed heavily on panfish and minnows in mid-summer. However, mid-summer walleye samples were inadequate so a critical analysis of consumption was not possible.

Consumption by largemouth bass appeared to decline toward mid-summer and recover in late summer and fall. Bass fed heavily on panfish, darters and minnows during some mid-summer periods. The general mid-summer decline of consumption by bass may be more a function of prey availability than of a disinclination to feed.

Despite the difficulties in reliably estimating fish population sizes and food consumption rates, some sense of the magnitude of predator-prey interactions was possible. The largemouth bass population estimate appeared reasonable when compared to other studied Minnesota lakes (Maloney et al.

1962; Newburg 1986). The northern pike estimates were reliable and the walleye estimate appeared to be reasonable. Consumption estimates were regarded as imprecise and estimates of daily consumption rates for bass and walleye were in the low end of the ranges reported (Lewis et al. 1961; Swenson and Smith 1977).

There was no evidence of direct competition for food between northern pike and the other piscivores. The pike population consumed less total prey than either largemouth bass or walleye. However, predation by pike on yellow perch sizes critical to recruitment of spawners magnified the effect of pike predation on the perch population and ultimately on bass and walleye food resources beyond the absolute amount of food consumed. Furthermore, the population of pike during the early 1970's, when declining perch abundance first became evident, was higher for several years than at any time during this study. The biomass of bass and walleye could probably have increased without having the same drastic effect on perch resulting from pike predation.

It appears that the decline of yellow perch allowed bluegill abundance to increase by filling habitat previously occupied by perch. Bluegill abundance declines during the early years of these studies could have been a direct result of northern pike stocking and increased predation and/or a response to changes in the perch population. The low bluegill CPUE's during the years 1969 through 1972 represented year-classes that developed when perch were abundant. The peak abundance of bluegill in 1979 consisted of year-classes that were developed when perch abundance was low. Increasing perch abundance, beginning in 1977, was followed by declining bluegill abundance in 1980 and 1981.

Yellow perch appear to be critical to the efficient transfer of energy to piscivores within a lake and bluegill may be at least a partial energy trap. Growth of sport fish species in the lake generally declined when the bluegill population reached its peak and the perch population its low.

Slow walleye growth was evident for GY's 2 and 3 during years of extreme low perch abundance, increasing by a year or more the time necessary for walleye to recruit to the fishery. Added mortality caused by the increased time to reach acceptable size probably reduced walleye recruitment. Walleye growth beyond age 3 appeared to be less affected by perch abundance. Apparently larger walleye were able to substitute other available prey for perch.

Walleye growth, particularily at age 2, was negatively affected by the faster growth and larger size of y-o-y yellow perch which may have made them unavailable to at least a portion of the juvenile walleye. Fast growth of y-o-y perch has been shown to have negative effects on the growth of walleye (Schupp 1978; Paxton and Stevenson 1978).

Largemouth bass growth was also negatively affected by reduced yellow perch abundance. Ages 1 and 2 were affected more than were the older ages. Growth rates of the 1973 and 1974 year-classes of bass appeared to benefit from the strong 1976 year-class of bluegill but mean TL's of bass reached long-term lows during the period of peak adult bluegill abundance.

Yellow perch growth appeared to be primarily related to the abundance of adult perch. First-year growth of perch increased as the abundance of adults declined. Growth rate of perch during GY's 3 - 5 increased as adult CPUE increased, indicating that growth of older perch was positively related to the abundance of adults. The greater surplus of y-o-y produced when there were more adults may have been important as food to adult perch. Perch sometimes prey heavily on fish and can be cannibalistic (Seaburg and Moyle 1964; Clady 1974).

Bluegill growth appeared to be related to the abundance of yellow perch and bluegill. Growth declines for GY's 2, 3 and 4 began when the bluegill population expanded and was probably an intraspecific, density dependent response. There was some indication that higher abundances of adult perch were associated with increased bluegill growth.

Black crappie and pumpkinseed growth was not readily related to fish community changes; however, when growth rate data was grouped into early, mid, and late periods, it was evident that growth declines occurred during the periods of low yellow perch and peak bluegill abundance.

Growth rate of native northern pike did not appear to be related to changes in the fish community though growth did decline near the end of the study.

The age of maximum growth increment may be used as an indicator for evaluating the prey base influencing growth of younger fish or for diagnosing changes in the prey base. For example, the age of maximum growth for Horseshoe Lake bluegill older than y-o-y was nearly always GY 4 or GY 5. Apparently larger bluegill had a growth advantage, possibly because of an increased ability to utilize larger prey. Werner (1979) offered evidence that larger prey was related to faster bluegill growth. The GY 3 increment of largemouth bass was larger than GY 2 in 1976 and 1977 when abundance of small yellow perch was low but was less than GY 2 in all other years.

Growth rate changes were apparently influenced more by changes in community structure after northern pike stocking than by climatic effects. Climatic effects would be expected to favor growth for most ages of most species simultaneously but no consistent positive correlations were evident among GY comparisons. The inverse relationships between yellow perch GY 1 and other perch GY's is evidence of intraspecific interactions that are probably not climatically induced.

Failure of yellow perch recruitment to breeding size resulted in increases and then decreases in mean lengths at capture. Increases in perch mean lengths occurred as many of the 5-6in yellow perch were being cropped through predation while individuals reaching 9-10in were relatively safe. As gradual attrition reduced the numbers of large perch, only a remnant of small fish remained and mean lengths declined. This effect is similar to that noted for Eurasian perch in Lake Windermere when the northern pike size structure was shifted to smaller fish (Bagenal 1977).

Declines in bluegill mean lengths at capture during the middle period were associated with the decline in yellow perch abundance and the increased bluegill population density.

Northern pike and walleye mean lengths generally remained high and changes were probably influenced more by stocking than by any other factor. The sudden decline in pike mean length from 1978 to 1979 coincided with the apparent high mortality of old stocked pike from the spring of 1979 to the spring of 1980. However, increases in walleye mean length in the late period may have been the result of slower and/or survival of smaller walleye reducing recruitment to the sampling gear.

Inferences about community interactions drawn from netting indices alone may be risky. The suggestion that yellow perch abundance influences abundance of bluegill is difficult to verify. For example, if perch affect survival of y-o-y bluegill, a change in bluegill abundance would usually not be detected with standard lake survey gear until three to four years later. The CPUE's for y-o-y and yearlings captured by trawling and seining during the latter years of the study were probably reliable indices of initial year-class strength. The trawling indices for y-o-y perch coincided with faster growth of walleye but did not give the long-term perspective necessary to make judgments about community changes.

The fish community was affected for over 10 years by the two initial stockings of northern pike. The yellow perch population was recovering by 1979 but it would be reasonable to expect several more years to pass before previous abundances would return. All of the species that had responded to declines in perch abundance would then have to respond to increasing perch abundance. Thus several more years might pass before a stable community structure was established.

MANAGEMENT IMPLICATIONS

Notable northern pike fisheries can be created by stocking winter-rescued pike, especially in lakes like Horseshoe Lake that have low natural populations of pike and a high population of prey such as yellow perch (Maloney and Schupp 1977). However, fishery managers should be wary of the probable destabilizing and possible deleterious effects of such management efforts on other fish species. Perch appear to be a key component of fish communities like this and a reasonable level of perch abundance should be maintained.

The estimates of consumption for northern pike, largemouth bass and walleye (see also Swenson and Smith 1977) coupled with some knowledge of standing crops of predator fish in lakes should enable approximations of biomass consumption. From this, managers can conceptualize the prey resources that are necessary to support a fishery.

Fishery managers should be on guard for two indicators of prey problems in centrarchid lakes:

1. Low yellow perch populations that have very few adults; and/or

2. High bluegill populations with small mean lengths.

The most useful data generated by these studies was gathered during repeated short-term gill and trap netting conducted at the same time each year. Though more intensive sampling helped, the netting indices and data on age and growth changes derived from these repeated short netting periods reflected most of the changes that occurred in Horseshoe Lake.

Caution should be used in interpretion of information about fish population abundance from a single sample or even several samples over a one or two year period. At one point during this study, yellow perch and northern pike abundances reached low points concurrently. It might have been deduced that low perch abundance occurred even though pike abundance was also low or that pike abundance was low because perch abundance was low when in fact the perch population was low because the pike population had been high. A single survey of a fish community is a reflection of the community structure at the present time. Trend through time data developed from periodic surveys is needed to infer cause and effect relationships.

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