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ABSTRACT — In this study, certain physical, chemical and biological conditions were observed in order to relate them to the development and survival of eggs and young northern pike in a small pond. The spawning period lasted one week and was interrupted by unfavorable weather. Low temperature caused the eggs to develop at a rate slower than the rate other workers have shown to be normal. Many eggs between stages II and III appeared to be developing abnormally and were perhaps reacting to an unsuitable environmental condition. Since 90% of all eggs completed development, neither slow nor abnormal development increased the egg mortality rate. The young pike fed selectively on Cladocera rather than other types of plankton present and did not utilize small rotifers as food. Scarcity of plankton appears to have been the major factor restricting northern pike production. Growth rates of pike on different sides of the pond correspond directly to the distribution of plankton. When plankton was not abundant, growth was slow, the quantity of food per stomach was low, and many fish had not fed. It is possible that most young pike died because they were attacked or eaten by other pike, but a low density of plankton shortly after hatching apparently triggered the outbreak of cannibalism.

There is little information about factors promoting good yield of northern pike (*Esox lucius* L.) from hatchery ponds. Such information is essential for improving pike production. The objective of this study was to describe the development of young northerns and to relate this development to conditions influencing it. To accomplish this objective relevant chemical, physical and biological conditions in the pond were observed to see what effects they had on spawning, development and survival of eggs, development and survival of young fish, and the number of young pike successfully reared in a small pond. The rearing pond studied is owned and managed by the Minnesota Conservation Department.

Franklin and Smith (1963) showed that the strength of northern pike year classes is determined both by the number of fingerlings and by the number of alevins (post yolk sac fry) that enter a lake. Strong year classes result when a large number of juveniles enter the lake, but the actual magnitude of the year class is greatly influenced by the number of alevins entering the lake. Carbine (1944) and Franklin and Smith (1963) conclude that the number of young pike does not depend upon the number of eggs spawned and hence is independent of the number of adult fish spawning. Franklin and Smith (1963) concluded that the thermal and chemical characteristics of the slough determined the number of pike produced. In all three years of study, they observed an ample food supply and a low incidence of cannibalism. Hunt and Carbine (1951) found that predation by other fish, cannibalism, and food competition were all important factors associated with high mortality in a natural situation.

The highest yield of young pike reported from hatchery ponds is 90,000 fish per acre (Hiner, 1961). This is more than ten times the best production reported in an unmanaged body of water. Better production is possible because more aspects of the artificial pond environment can be controlled. In rearing ponds the water level, and often the water source, can be regulated. Abundance of plankton can be increased through fertilization; bottom substrate can be made more suitable for developing eggs by planting terrestrial vegetation; predatory fish and insects can be excluded; and some chemical conditions in the pond can be controlled. In addition, the number of spawning fish can be changed, thereby determining egg production and hence the density of young northern pike. Before environmental control of rearing ponds is feasible, information about factors influencing northern pike production is essential. The study of Phalen Pond was undertaken with the hope of gaining some such information.

Materials and Methods

Field observations were made during April and May of 1965. Each day, information was recorded about the weather, water temperature, and water level in the pond. Samples of northern eggs were also collected each day. Several times each week observations were made on some chemical characteristics, plankton, and bottom organisms in the pond. Samples of the young fish were collected three times each week.

Only chemical conditions considered relevant to production of northern pike were observed. Oxygen concentration, total alkalinity, and hydrogen ion concentration were measured three days each week; the samples were analyzed in the field. Water samples for all chemical analyses were collected just above the pond bottom with apparatus providing more than a three-fold exchange of water. Standard techniques were used to determine oxygen concentration and total alkalinity (Anonymous, 1955). Hydrogen ion concentration (pH) was measured with a Hellige Comparator. Samples for determination of

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iron and ammonia concentration were analyzed by the Minnesota Conservation Department. Water samples were tested for hydrogen sulphide using the Hach Method.

Each plankton sample was collected by pouring 240 liters of water through a net constructed of 6X silk bolting cloth and preserved in 5% formalin. The abundance of planktonic organisms was determined with a counting chamber and dissecting scope. Adult pike of known weight were provided by the Minnesota Conservation Department. Upon removal, the stomachs of some adults were flushed with the apparatus of Seaburg (1957). Egg samples were collected with a scap net 25cm in diameter. The young pike were at first collected with scap nets (25 and 60cm diameter) but later with a 20-foot bobinet bag seine. Egg and fish samples were preserved in 10% formalin.

Results

Physical and Chemical Characteristics of Phalen Pond

Three sides are bounded by dikes separating Phalen Pond from the Phalen Chain of lakes. The surface area is 2.9 acres and the mean depth is about 70cm (maximum depth about 1m). The water level of the pond fluctuated slightly over the period of study. Extreme water temperatures were recorded at four locations in the pond. Table 1 summarizes this data. Five chemical characteristics of the water were studied: oxygen concentration, total alkalinity, hydrogen ion concentration, total iron concentration, and ammonia concentration (hydrogen sulphide was tested for, but no trace was found).

The extreme concentrations of oxygen (Table 1) are perhaps the aspects of this particular chemical characteristic having the greatest effect on developing eggs and fish. The maximum concentration observed was 12.6ppm (140% saturation) on the afternoon of May 1; the minimum concentration observed prior to drainage was 5.4ppm (60% saturation) at sunrise, May 16. As indicated by Table 1, the minimum oxygen concentration shows a decreasing trend. The abundance of aquatic plants, particularly filamentous algae, greatly increased during the study, thus increasing oxygen consumption and probably causing the observed decrease in minimum oxygen concentration. When the pond was being drained the minimum concentration fell below 1ppm in a few areas of the pond. The volume reduction decreased the pond's capacity for containing oxygen without proportionate decrease in demand for oxygen.

TABLE 1. Extreme temperature readings and oxygen concentrations observed in Phalen Pond (by 4-day intervals). Each temperature is the average value shown by four thermometers placed at different locations in the pond. Asterisks denote oxygen concentrations which were observed at sunrise.

Dates (inclusive)		Temperature (°F) Min.	Max.	Mean Min.	Mean Max.	Oxygen Concentration (ppm) Min.	Max.
April	11-14	40	56	42	49	9.6	10.9
	15-18	40	58	42	52	8.3*	10.3
	19-22	44	59	47	55	8.4	10.4
	23-26	41	58	46	53	9.6	10.4
	27-30	45	68	50	61	10.3	11.6
May	1- 4	59	71	60	70	7.0*	12.6
	5- 8	57	72	63	70	5.7*	7.4*
	9-12	52	74	56	71	9.3	9.3
	13-16	64	76	—	—	5.4*	11.8
	17-20	60	75	64	73	5.5*	7.4*
	21-23	57	80	—	—	0.7*	6.8*

Total alkalinity increased gradually and steadily from about 30 to 70ppm during the developmental period of the eggs and young fish. During drainage, total alkalinity nearly doubled, reaching 130ppm. Smith, Franklin and Kramer (1958) report that total alkalinity frequently increases as water volume decreases. Although pH6 was observed shortly after water was pumped into the pond, the pH remained at or above pH7 during the period of egg and fry development. The lowest hydrogen ion concentration (pH 9.5) was observed during drainage.

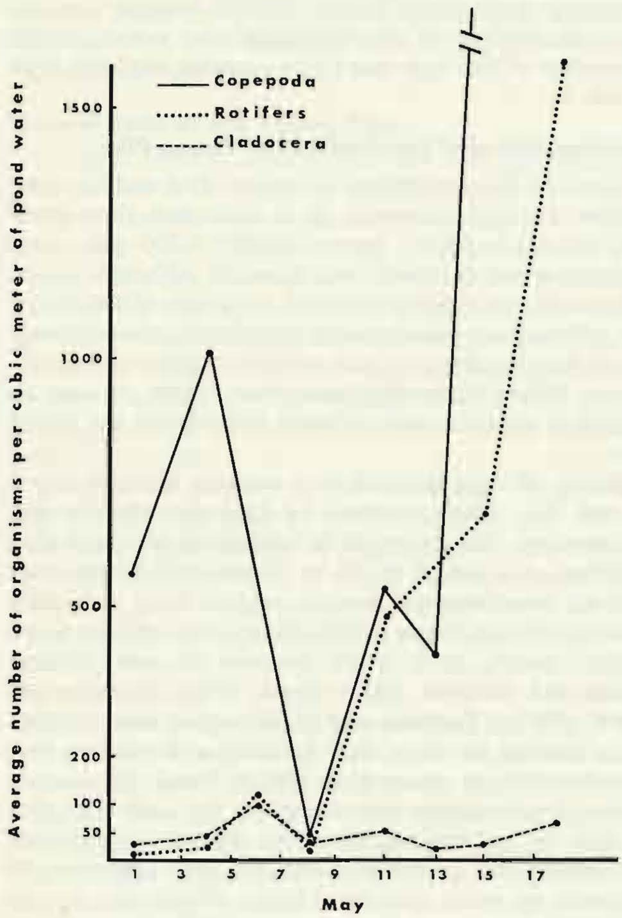
In order to measure the maximum concentration of iron to which the eggs and young fish might be exposed, some water samples were collected above a mud substratum which had been thoroughly stirred up. The iron concentration in such samples was usually higher than in samples collected above undisturbed bottom. The minimum and maximum total iron concentrations observed above undisturbed bottom were 0.13 and 0.37ppm, while the extreme concentrations observed above thoroughly agitated bottom were 0.32 and 5.32ppm. It is significant that the highest total iron concentrations were observed in areas where few eggs or fish were present.

Maximum concentrations of ammonia were also measured by thoroughly agitating the bottom before collecting a water sample. Extreme ammonia concentrations observed above undisturbed bottom were 0.14 and 0.22ppm; whereas extremes observed above thoroughly agitated bottom were 0.04 and 0.62ppm. There was little difference in the ammonia concentration at different stations on a particular day — above undisturbed bottom. This suggests that the ammonia concentration in the pond at a particular time may have been fairly uniform. As with total iron, no trends in ammonia concentration were apparent, but the samples were inadequate to describe any trends that may have occurred.

Biological Characteristics of Phalen Pond

Plankton in Phalen Pond never became very abundant. The density of all planktonic organisms did not rise above two per liter (2000/m^3) until May 15 (Figure 1). The density of plankton reached a minimum on May 8 when the average density was no more than one organism per ten liters of water. No phytoplankton and only a few genera of zooplankton were collected in the pond. Copepods (*Cyclops sp.* and *Diaptomus sp.*) were the most abundant planktonic forms; Cladocera (*Daphnia sp.*, *Bosmina sp.*, and *Simocephalus sp.*, in decreasing order of abundance) were present in small numbers. Rotifers and Nauplii were also found in the plankton samples, but Nauplii were not numerous. Large rotifers (*Asplanchna sp*) were prevalent at first, but these rotifers were replaced by smaller forms (*Keratella sp.*) about the time when the density of plankton reached a minimum (May 8).

Figure 1. Plankton in Phalen Pond. Each point is the mean of four samples (240 liters each) collected on a particular day from four sides of the pond.



Very few organisms suspected of preying on the eggs or young northern pike were observed in the pond. The adult pike were present in the pond only while the eggs were developing. Half the adult pike were examined for food as they were removed, but none contained any. Only one amphibian (a frog) was observed in the pond and no fish-eating birds were observed in the vicinity of the pond until it was being drained. Dytiscidae larvae, which prey on small fish, became more abundant toward the end of the study, but their maximum density was only $0.16/m^2$ (observed May 15).

Few aquatic plants were present in the pond until May 5, when filamentous algae became very apparent. In just a few days, much of the pond bottom was covered with algae which became more dense in subsequent weeks. On May 12 and 13, submergent and emergent vascular plants became very noticeable. These plants also became larger and more abundant during the course of the study.

Spawning

After northern pike are ripe, their spawning is environmentally controlled by temperature, light, and nature of the substratum. Several workers have noted that spawning does not occur at temperatures below 50-55°F (Clark, 1950; Fabricius and Gustafson, 1958; Franklin and Smith, 1963). Spawning normally ceases at sunset, but experiments show that it will resume at night under artificial light, provided the temperature is sufficiently warm (Fabricius and Gustafson, 1958). Experiments also indicate that spawning is controlled by the bottom substratum—northern pike show a definite order of preference for particular bottom types. Terrestrial or dense aquatic vegetation are the most preferred substratum types, but the fish will spawn above other substrata when these are not available.

The spawning period in Phalen Pond lasted about one week. Ripe fish were placed in the pond on April 9, but no spawning was observed nor any eggs found until the water temperature reached 55°F on April 13. Although the water temperature was well above 55°F no spawning activity was observed after April 19. The spawning period was interrupted April 14, 15 and 16 when the water temperature did not exceed 50°F and no spawning was observed. As the experiments of Fabricius and Gustafson (1958) predict, eggs were concentrated in areas of terrestrial vegetation. No eggs were found on mud substratum, or in dense stands of cattails.

The number of eggs spawned in Phalen Pond was estimated from data showing the relationship between size of female and egg production which was collected by other workers (Vessel and Eddy, 1941; Carbine, 1944). A statistical technique known as ratio estimation was used to derive an equation showing this relationship. Ratio estimation is like linear regression but is particularly useful because it makes fewer assumptions about the variance of either the dependent or independent variable (Cochran, 1963). The total number of eggs spawned is approximately 1,065,000. A 95% confidence interval indicates that the minimum and maximum number can be expected to lie between 998,000 and 1,131,000 eggs.

Development and Survival of Eggs

Information about egg development and survival was obtained by laboratory study of the egg samples collected. The eggs in each sample were classified following the system outlined by Franklin and Smith (1963). Only opaque eggs were considered to be dead. Unfertilized eggs were not distinguished because they could not be identified without microscopic study. Development had been initiated in all eggs examined.

The rate of development depends upon both genetical environmental factors. The rate of development varies directly with temperature, and extended exposure to low temperature may cause death of eggs (Smith, Franklin and Kramer, 1958). An index of developmental rate is given by the fraction of eggs reaching a particular developmental stage at a particular time. This index shows that there was little difference in rates on different sides of the pond. A difference in rate of development might reflect a difference in environmental conditions.

Several workers have indicated the overall rate of development by noting the number of days from fertilization to hatching. In Nebraska rearing ponds, fourteen days is the normal interval between spawning and hatching (McCarraher, 1957). In a slough near Phalen Pond, Franklin and Smith (1963) found that the eggs usually hatch 10 to 11 days after fertilization. In Phalen Pond, 16 days passed from the time the first eggs were spawned to the time when the first fry hatched, and 12 days elapsed between the last day when spawning is known to have occurred and the day when the last eggs hatched.

Low temperature appears to have inhibited development of the first eggs spawned in the pond. Franklin and Smith (1963) report that usually less than two days is required to reach stage III (germinal ring of blastoderm near the meridian of the egg) and that normally, less than three days is required to reach stage V (germinal ring or blastopore nearly closed and the embryo distinguishable). In Phalen Pond, spawning occurred on April 13, but probably none on the 14, 15 or 16. Although the eggs spawned on April 13 had been developing for three days, only 4% of them had reached stage III on April 16 (Table 2). Both the minimum and maximum water temperatures were low during this time. After April 16, the rate of development proceeded as the observations of Franklin and Smith (1963) predict (Table 2), with a possible exception discussed in the next paragraph. Because stages VI, VII and VIII are not as easy to distinguish as the earlier stages, the rate of development from stage VI to stage VIII may not be accurately reflected by the data in Table 2.

Many eggs (about 90%) collected before April 19 do not appear to have been developing normally. The blastoderm of these eggs was a compact mass of cells balled up on top of the yolk. The yolk and blastoderm appeared to be contained in separate membranes. This abnormal appearance may be an artifact produced by preservation in formalin. It is also possible that the abnormal eggs were reacting to an unfavorable environmental condition (perhaps low temperature), and that subsequently, the blastoderm reorganized and continued normal development.

Of all eggs spawned, 90% are thought to have hatched. This estimate is based only on samples of eggs collected between April 22 and 28 (1600 eggs). In samples collected before April 22, there was no good criterion for distinguishing live and dead eggs because eggs that may have been dead had not become opaque. Samples collected after April 28 were not used because the fraction of opaque eggs decreased (Table 2). It is unlikely that many eggs decomposed before April 28 because few eggs in advanced stages of decomposition were noted and the percentage of live eggs was fairly constant until this time (Table 2).

Development and Survival of the Young Pike

Based on the percentage of egg survival and the total number of eggs spawned, it is estimated that about 960,000 fry hatched. Approximately 8,700 pike were removed when the pond was drained. Although it was not possible to make population estimates of the young fish, information about growth and feeding provides evidence showing the time and probable causes of this decrease. Before discussing these observations, it may be helpful to consider some general behavior of the young pike.

Nearly all eggs hatched in a two-day interval (April 29 and 30), which occurred 16 days after the first day of spawning. The fry began to feed about five days after hatching, at a length of 12 to 13mm, and before their yolk sac was absorbed. Several workers have previously reported that fry begin feeding before the yolk sac is absorbed, usually at a length between 11 and 12.5mm (Hunt and Carbine, 1951; Frost, 1954; Franklin and Smith, 1963). Franklin and Smith report that the pike began feeding ten days after hatching and not five days after hatching as observed in Phalen Pond. Plankton in Phalen Pond became very scarce by the ninth day after the first fry had hatched (May 8). By May 9, cannibalism among the young pike became very apparent. As observed by other workers, (Frost, 1954), the fry did not swim about freely, but remained hidden, apparently attached to vegetation for the first week after hatching.

A week after hatching, many pike were observed swimming about near the edges of the pond. Shortly afterwards, however, the young pike again became less evident. Each day fewer of them were seen swimming

TABLE 2. Development of eggs in Phalen Pond.

Date	April 16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	May 1
Fraction (%) of live eggs reaching:																
stage I																
stage II	96	92	86	88	81	42	13	5								
stage III	4	4	3	2	4	18	3									
stage IV		4	3	1	6	16	10	1								
stage V			6	3	0	12	5	1								
stage VI			1	6	8	11	64	83	88	55	24	7				
stage VII						1	6	9	12	45	76	86	78	10	1	
stage VIII												7	22	57	4	
fry stage														32	95	100
Total number of eggs collected	118	192	144	372	381	234	313	194	184	193	264	236	211	185	246	
Fraction (%) alive	100	100	100	100	100	100	90	93	89	88	91	91	88	95	98	

about the pond. Although the number of fish in the pond undoubtedly diminished during this time, part of the reason for the disappearance of the young pike was another behavioral change. Two weeks after hatching, more and more of them remained near the bottom of the pond, freqnently under the dense mat of filamentous algae. By the third week after hatching, most young pike remained hidden under the algal mat.

Growth Rate of the Young Pike

Carbine (1945) reports that few fish are known to grow as fast as the northern pike. He found that, during the first summer, young pike had a mean growth rate of 2.6mm per day (2.69gm per day), when they were provided with what he considers an unlimited food supply. The growth rate was slower in subsequent years. The growth of young pike is a sigmoid function and thus the rate varies with age. There are two aspects of growth rate observed in Phalen Pond that may be of interest: growth in the pond as a whole, and growth of fish on particular sides of the pond.

In order to compare growth of fish in Phalen Pond with growth reported by other workers, the average growth rate from the day of hatching to the day of pond drainage was calculated. It should be remembered however, that growth occurs before the fish begin to feed. They increase in length by about 3 to 4mm and increase in weight from 70 to 100% before feeding. (Presumably, the large increase in weight results from the addition of water as new protoplasm is formed from the yolk.) The average growth rate of all fish in the pond was about 0.65mm per day from hatching to the time just prior to drainage. Several workers have reported comparable growth rates for fish of the same size and age (Smith, Franklin and Kramer, 1958). In different years the average rate during the first 20 days after hatching ranged from 0.5 to 0.7mm per day. The minimum and maximum growth rates observed in Phalen Pond prior to drainage were 0.5 and 1.6mm per day.

Figure 2 charts the growth rate of fish collected on different sides of the pond. There is a marked decrease in growth rate on all sides during the interval May 7 to 10. This decrease was concurrent with a plankton shortage. Another characteristic of growth in the pond as a whole is that the range in size increases with time. This is indicated by a steady increase of the variance in size of the young pike. Carbine (1945) also reports that divergence in growth rates developed early and increased during the course of study.

Growth rates of fish on different sides of Phalen Pond differed considerably during particular time intervals (Figure 2). These differences in growth rates are inferred from differences in mean sizes as shown by analyses of variance in combination with t-tests between the fish on a particular side and those on the other three sides pooled together. In the interval May 3 to 5, the fish on the east side grew much faster than the fish on the other sides. There was no significant difference in growth from May 5 to 7, but between May 7 and 12, the fish on the west side grew slower than the rest. Similarly, the fish on the north side grew slower than the fish on the other sides during the interval May 12 to 15. All differences are significant at the 1% level.

Another aspect of growth difference is that fish on different sides lost their yolk sacs at different times. The fish on the east and south sides lost their yolk sacs sooner than those on the north and west Table 3).

TABLE 3. Fraction of fish retaining a yolk sac.

	May 5				May 7				May 10			
	W	N	E	S	W	N	E	S	W	N	E	S
percent fish with yolk sac	86	94	100	92	50	48	7	12	0	0	0	0

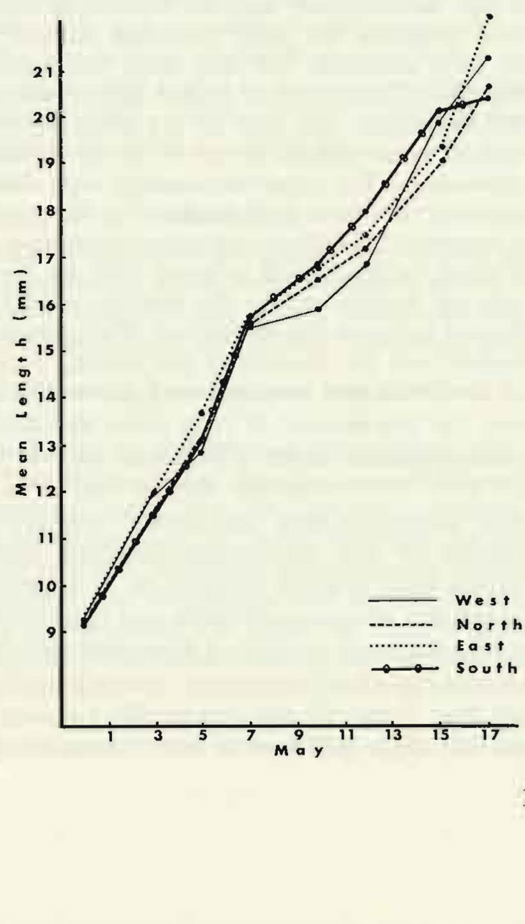
The fish on the east had grown faster (Figure 2), and the fish on the south and east sides had eaten considerably more than those on the north and west sides. These observations might indicate that the fish on the east and south sides were using more energy than the other fish.

Food of the Young Pike

In order to analyze their food habits, fish collected from each side of the pond were subsampled systematically. The fish in each subsample were measured (to 0.5mm), weighed (to 0.0001 gm), and dissected. The number and kind of organisms in each stomach were recorded.

Hunt and Carbine (1951) and McCarraher (1957) report that the food habits of young pike show a series

Figure 2. Growth of northern pike on different sides of Phalen Pond. Each point is the mean total length of fish collected at two or three day intervals.



of changes. Fish less than 26mm feed chiefly on plankton; fish between 27 and 60mm feed mainly on insects and other invertebrates; after pike reach 60mm, vertebrates become progressively more important food items. Frost (1954) reports that young pike in Lake Windermere do not feed on insects but make plankton their chief food until they reach 50mm, when fish become important food items. Franklin and Smith (1963) found that young pike continued to feed heavily on plankton and insects, preying very little on tadpoles and other young pike present in the slough. In Phalen Pond, the young fish fed mainly on plankton until they reached 18 to 19mm when chironomids became increasingly important items in their diet.

There are conflicting reports about whether or not young pike feed on planktonic organisms in direct proportion to their abundance. Hunt and Carbine (1951) compared the plankton abundance with food of young pike in Michigan and concluded that the young pike did not feed selectively. McCarraher (1957) observed that pike in Nebraska rearing ponds did not feed on ostracods even though they were very abundant. Franklin and Smith (1963) found little consistent correlation between the relative abundance of particular food items in the plankton and the stomachs of young pike; they concluded that either the pike did feed selectively, or the plankton samples did not reflect the food actually available to them.

In Phalen Pond, two kinds of plankton selectivity are apparent. The young pike selected for Cladocera (chiefly *Daphnia sp.*) and selected against small rotifers (*Keratella sp.*). Table 4 shows that except when the plankton population was low (May 8) and when the fish had just begun to feed, the fraction of Cladocera in the stomachs was much greater than the fraction in the population of plankton. By May 11, small rotifers had become very abundant, but they were not eaten by the young pike (Table 4). Chi-square tests enable rejection of the hypotheses that pike do not select for Cladocera or against small rotifers at the 0.1% ($p=0.001$) level of significance. The expected numbers were obtained by multiplying the fraction of plankton in the pond by the total number of planktonic organisms consumed.

A plankton shortage is reflected both by the fraction of fish not feeding and by the average amount of food consumed by those fish having fed. The amount of food consumed and the fraction of fish feeding both correspond to the amount of plankton present (Table 5 and Figure 1). The amount of food eaten also corresponds to the growth rate during a particular interval (Table 5 and Figure 2). During the interval May 7 to 12, the average amount of food per stomach was low and the percentage of fish with empty stomachs rather high. Based on three years of observation in a slough where plankton was abundant, Franklin and Smith (1963) report that the mean number of Copepods and Cladocera consumed by fish of comparable size is 24 per fish. Between May 7 and 12, the average fish (average of only those fish which had food in their stomach) contained only about one-sixth as much food as the average fish observed by Franklin and Smith (Table 5).

The fraction of empty stomachs (Table 5) is based on fish longer than 12.5mm and presumably capable of feeding. The percentage of empty stomachs was high (20-60%) for the whole pond on May 7, but it had decreased to zero by May 15. By May 15, plankton had again become abundant and most fish had started feeding on chironomids. Groups of fish showing a high percentage of empty stomachs later showed an average size significantly smaller than fish on other sides of the pond (Table 5). On May 5 and 7, many of the fish on the west side had empty stomachs and their size on May 10 and 12 was significantly smaller than the size of the rest of the fish in the pond. Similarly, the fish on the north side showed a high percentage of empty stomachs on May 12 and a significantly smaller size on May 15.

Although cannibalism (predation among the young pike) was not observed for twelve days after the first fish had hatched, some probably occurred at least one and possibly two days earlier. In addition to fish containing other young pike, a considerable number of dead pike

TABLE 4. Feeding selectivity of young northern pike. Plankton data was computed from the average of samples (each consisting of 240 liters) from the four sides of the pond. The stomach samples are each based on at least 50 fish collected on all four sides of the pond. The expected number is the number which should have been observed if the pike did not feed selectively.

	Plankton Samples		Stomach Samples		
	Density (number/m³)	Fraction of Plankton in Pond	Observed number in stomachs of all fish sampled	Expected number in stomachs of all fish sampled	Fraction of Plankton Consumed
			Cladocera		
May 4	52	5%			
5			35	35	5%
6	114	14%			
7			42	12	49%
8	42	48%			
9					
10			97	119	39%
11	53	5%			
12			67	10	34%
13	54	1%			
14					
15	28	0.1%	169	7	25%
16					
17			134	1	34%
			Rotifers		
May 4					
5					
6					
7					
8					
9					
10					
11	466	44%			
12			3	86	2%
13	580	58%			
14					
15	696	2%	0	380	0
16					
17			0	9	0

TABLE 5. Relationship between food available, food consumed, and size of young pike on particular days.

Date		Density of Plankton[1]	Average No. of organisms per stomach	Fraction of empty stomachs	Mean Length of all fish (mm)[2]
			West Side		
May	5	. . .	9.9	29%	12.8
	7	290	3.3	57%	15.5
	10	510	5.6	29%	15.9**(smallest)
	12	920	8.2	7%	16.8**(smallest)
	15	4,900	23.3	9	19.8
	17	13,800	11.6	0	21.2
			North Side		
May	5	480	14.6	9%	13.1
	7	160	1.5	20%	15.6
	10	110	4.9	12%	16.6
	12	510	2.4	30%	17.2
	15	4,090	17.6	0	19.0**(smallest)
	17	6,200	14.0	0	20.6
			East Side		
May	5	1,320	19.9	0	13.7**(largest)
	7	410	1.4	60%	15.8
	10	376	4.9	8%	16.8
	12	870	2.1	12%	17.5
	15	83,800	12.7	0	19.3
	17	88,000	12.8	0	21.9
			South Side		
May	5	1,340	20.0	11%	13.1
	7	470	3.3	35%	15.7
	10	1,520	4.9	13%	16.9
	12	2,040	3.7	0	18.0**(largest)
	15	6,210	14.4	0	20.1
	17	48,000	2.4	0	20.4

[1] Density of plankton is expressed in the total number of planktonic organisms per cubic meter of water. The value shown is the average of the two densities observed the day preceding and the day following the date listed.

[2] Double asterisks indicate that the mean of a particular group of pike differs from the pooled mean of all other pike at the 1% significance level.

were found which appeared to have been partly digested. Of all fish collected on May 10, 3% had eaten others and 13% were dead and partly digested. Although 5% of the fish collected May 12 were dead and partly digested, no pike were found in the stomachs examined. Stomach analysis showed that 4% of the fish collected May 15 and 17 had fed on other pike. All six of the cannibals found in samples collected May 15 and after, contained no food other than fish in their stomachs.

Survival of the Young Pike

Approximately 8,700 fish were removed from the pond when it was drained. This number was an estimate calculated from the volume of fish removed and the number of fish per unit of volume. The number of fish per unit volume was determined separately each day by counting the number in a random sample of all fish removed that day. Because the level of the Phalen Lake Chain was above the bottom of the pond, it was necessary to pump water out of the pond to drain it, and water continuously seeped into the pond while it was being drained. Consequently, an undetermined number of young pike were left in the pond, and some unusual environmental conditions were set up.

Unusual Conditions During Pond Drainage

Because it was not anticipated that so much time would be required for drainage, neither the fish nor the environmental conditions in the pond at this time received as much study as would have been desirable. The oxygen concentration during drainage was observed to decrease to less than 1ppm just before sunrise. Although no measurements were made, rather high maxima may have occurred May 24 and 25 when at least half the day was sunny. The total alkalinity nearly doubled during drainage. This suggests that the concentration of other solutes in the pond may have changed considerably also. Some birds (seagulls, crows, and killdeer) walked about the bottom of the pond as it was being drained, but they were not feeding on drifting pike.

Except for migration behavior, there was little change in the characteristics of the pike during the drainage period. Migrating pike found their way to the drainage ditches, after which most of them were carried passively by the current to a pool in front of the outlet. Although drainage was begun on May 19, few fish came to the outlet before May 23, and most migrated the following two days (May 24 and 25). As the water level fell and the edge of the water receded, some fish became stranded. Careful observation revealed few such fish, but a considerable number may have been hidden from sight in the dense algal mat covering the bottom of the pond. The food habits of fish collected during drainage were the same as just before drainage—smaller fish fed extensively on both plankton and chironomids, whereas larger fish fed chiefly on chironomids. A subsample of fish (collected May 23) indicates that the incidence of cannibalism did not increase during drainage. Growth rates during drainage were similar to those reported by Franklin and Smith (1963) who found that the growth rate of young pike comparable in size is about 1.9 to 2.3mm per day.

Discussion

The major objective of this project was to gain information about factors which restrict northern production. In the next section, the roles of such factors operating in Phalen Pond are considered and their importance judged.

Factors Influencing Development and Survival of Eggs

Egg mortality rate was constant once opaque eggs appeared. This indicates that whatever mortality occurred was limited to shortly after the eggs were spawned. It seems probable that most of the egg mortality can be attributed to infertility. Chemical characteristics, temperature, predation, and substratum have all been shown to affect egg development. The effects of these factors on egg development in Phalen Pond are not very apparent, but their influence on survival appears to have been slight.

If any chemical factors were killing eggs, one would expect the mortality rate to have increased; no increase is reflected by the egg survival data. Furthermore, none of the observed chemical characteristics were measured at concentrations thought to be lethal. The minimum oxygen concentration observed during egg development is 8.5ppm. Concentrations of iron, ammonia, hydrogen sulfide, and hydrogen ions were never observed at critical levels. Low temperature appears to have decreased the rate of egg development and may have caused abnormal development. Neither slow nor abnormal development seems to have affected survival, since 90% of the eggs completed development. Stomach samples indicate that adult pike did not prey on eggs. Because very few bottom organisms or amphibians were observed in the pond, it is doubtful that eggs were consumed by organisms of any sort.

Factors Infuencing Survival of Young Pike

If the abiotic (physical and chemical) environment was not limiting, there are two factors which may have caused pike mortality: insufficient food supply and predation. These biotic factors seem to have been the most important ones restricting northern pike production, but unfortunately, their role is difficult to evaluate. Not only must the food supply include organisms which the pike can see, catch, and digest, but the organisms must also be present in numbers sufficient that the pike do not have difficulty in locating them. Failure to feed on small rotifers, for instance, may have resulted either because the pike couldn't see them or because the rotifers were too small to capture efficiently. It is difficult to judge just how dense the plankton population must be in order that pike are not required to expend more energy catching food than they could gain from consuming it. A related question is how long young pike can withstand a plankton shortage without severe mortality from starvation.

Likewise, it is difficult to evaluate the influence of predation on survival of the young fish. A good evaluation requires that the density of the predator be known and also that the rate of predation — the number of pike consumed during a particular time interval — be known. Since the rate of predation frequently will depend upon the number of pike present, it may also be necessary to know the density of the pike population at a particular time. In the study of Phalen Pond, few of these conditions were determined, so the evaluation of the roles of food supply and predation will necessarily be based on speculation. Possible effects of chemical and physical characteristics are considered last because they do not appear to have had a significant influence on northern pike production.

Scarcity of plankton shortly after hatching seems to be the primary factor which limited production of young pike. A food shortage is evidenced not only by scarcity of plankton, but also by decreased growth rates on all sides of the pond and by paucity of food in the stomachs of the young pike. In order to appreciate the magnitude of this shortage, it may be helpful to compare the probable size of the plankton population to the probable size of the pike population. Plankton samples indicate that density of plankton on May 8 was less than 100 planktonic organisms (of all sorts) per m^3. Since Phalen Pond contains about $8{,}150m^3$, the standing crop of plankton on that date would probably not exceed 815,000 organisms. If the estimate of young fish hatching is valid, and if all of these fish survived the first 8 or 9 days after hatching, then the number of young fish in the pond at the time of the scarcity would be between 900,000 and 1,000,000.

The figures presented in the preceding paragraph may suggest that either the estimate of the number of fish in the pond or the estimate of plankton density is poor. However, if it is assumed that both estimates are reasonably close, then it is clear that the food supply at this time was time was sufficiently low to make feeding very difficult. Whether the plankton population was low long enough to cause mortality through starvation is another question. Concurrent with this food shortage was an outbreak of cannibalism which may have been the immediate cause of most pike mortality.

Carbine (1945) studied northern pike growth in a pond in which he tried to maintain an unlimited food supply and concluded that cannibalism was the major factor limiting production. In a three-year study of pike production in an unmanaged slough with an ample food supply, Franklin and Smith (1963) concluded that cannibalism had slight influence on production. It is quite apparent that cannibalism could be very effective in controlling production. If, for example, only 4% of the fish were eaten in each two-day interval, then the population would be halved in about 33 days.

Even if both the fraction of cannibals and their rate of predation on other pike were known, the exact role of cannibalism could not be determined since many pike may be killed without being eaten. Up to 13% of the fish collected in the pond appeared to have been dead and partly digested on collection, and two young pike were observed to attack others without successfully eating them. When the fish are of nearly the same size, a cannibal may kill several pike before successfully capturing one. Consequently, the number of pike in stomach analyses may not reflect the number killed by other pike. Stomach samples suggest that no more than 4% of the young pike were eaten during a two-day interval, but the importance of cannibalism in controlling production cannot be determined since neither the rate of predation nor the number of pike killed but not eaten is known.

Dytiscid larvae are the only organisms other than cannibalistic pike that may have significantly reduced the number of young fish. Few amphibians or fish eating birds were observed near the pond, and none of the adult pike had fed on fry. Dytiscid larvae became more abundant as the study progressed. The maximum density observed with scap net transects is $0.16/m^2$. The effect of dytiscid predation on northern production cannot be estimated, but it seems unlikely that they were sufficiently abundant to limit production.

Neither the chemical nor the physical properties of Phalen Pond had any demonstrable effect on the young fish. No lethal concentration of any solute was found (until drainage), and no fish kills were observed. Since most fish remained out of sight under the algal mat during the last week and a half of the study (including drainage), it is possible that fish kills occurred at this time without being noticed.

Conclusions and Management Recommendations

The results of this study suggest that biotic factors are more important than abiotic factors in controlling northern pike production. The food supply, cannibalism, or some combination of these two, appears to have determined the number of young pike produced in Phalen Pond. The importance of food supply may be tested by raising pike in ponds with different amounts of food. If food supply is the only important factor, then production should be independent of pike density provided the ratio between abundance of food and young pike is sufficiently great. It seems likely that cannibalism will prove to be important, at least when the pike density reaches a certain level. The importance of cannibalism may be evaluated by noting the incidence of cannibalism at different densities of pike and levels of food supply.

The implications for management which result from this study involve regulating the density of the fish relative to the density of their food supply. Production could have been improved by increasing the plankton population, by cropping the young fish, or by placing fewer brood fish in the pond initially. The plankton population in Phalen Pond did not become very dense. The reason why a larger population was not built up is not clear, but more plankton may have developed had the pond been fertilized. On several days plankton samples were collected in Round Lake, which is adjacent to Phalen Pond. Plankton in the lake was often more than ten times as dense as in the pond. On such days plankton density could have been increased by pumping lake water into the pond.

The data showing food habits of the young pike, together with those showing plankton density and probable fry production, suggest that the young fish caused the decline of the plankton population. Had fewer eggs been spawned in Phalen Pond, the population of young pike would not have been so dense. Had the pike population been less dense, the plankton population might have been productive enough to support it. Paradoxical as it may sound, better production could have resulted from planting fewer brood fish.

A manager who plans to increase plankton production may be reluctant to reduce the brood stock, since he may increase productivity of plankton sufficiently to feed more fish. Cropping the young pike at appropriate times would allow control of pike density without initial restriction of production. Franklin and Smith (1963) suggest that water control structures be so designed that escapement of young fish is permitted. The structure should permit enough flow that the young pike can emigrate freely when the instinct to do so has been evoked. Since most pike migrate on days when light intensity triggers this behavior (Hunt and Carbine, 1951; Franklin and Smith, 1963), the flow of water may need be maintained only part of the time. If the density of the pike population is to be regulated by cropping, the density of the plankton population must be observed frequently to be sure that it is large enough to support the pike.

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