MICHIGAN DEPARTMENT OF NATURAL RESOURCES
Research and Development Report No. 184*

November 16, 1972

DYNAMICS OF YELLOW PERCH IN SINGLE-SPECIES LAKES[1]

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Abstract

Experimental populations of yellow perch were established in Cassidy and Jewett lakes after the existing fish populations of these lakes were eliminated. Abundance, growth, recruitment and mortality of the perch were followed for several years. Additional observations were made on food habits, fecundity and spawning of perch, and on the plankton and benthos of the lakes.

An extremely large year class of perch was produced in each lake. Members of the class stopped growing at a length of 4-5 inches because they had depleted the supply of benthic food organisms. The large year classes dominated the populations, by number and weight, and prevented recruitment of subsequent year classes. As a result, few perch grew to a large size and angling, if it had been permitted, would have been of unsatisfactory quality. A mathematical model was developed which showed that recruitment of both small- and medium-sized perch would have to be controlled by predation (by another species of fish or by man) to optimize the number of large perch in the population and the yield to anglers.

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* Institute for Fisheries Research Report No. 1791.

[1] A contribution from Dingell-Johnson F-29-R-6, Michigan.

Introduction

The yellow perch (Perca flavescens) is one of the most important sport and food fish in Michigan. Unfortunately, in many lakes few grow large enough to support a fishery.

Eschmeyer (1938) was among the first to study a problem perch population. He found that the perch were of uniformly small size, that their growth was poor, and that the population was dominated by one year class. In 1964, I started an intensive study of the population dynamics of perch, to find ways to correct these population characteristics.

It was reasoned that the dynamics of perch could be studied more readily by isolating them in single-species populations, thereby eliminating the effects of other species of fish. Consequently the native fish populations of Cassidy Lake and Jewett Lake were removed, the lakes were stocked with perch, and the development of the populations was followed for several years.

Early results of the Cassidy Lake experiment appeared in a thesis by Shaffer (1966). Most of the data in the thesis have been reworked and reanalyzed in the light of more recent findings. The Jewett Lake study, under the direction of Mercer H. Patriarche the first year, was begun in 1966, two years after the onset of the Cassidy Lake study. Although the two studies were intended to be parallel, green sunfish became a contaminant of major importance in Cassidy Lake, whereas perch were the only fish in Jewett Lake throughout the study.

Methods

Cassidy Lake is a landlocked, marl lake in Washtenaw County (T. 1 S., R. 3 E., Sec. 33). It has a surface area of 46 acres, a maximum depth of 11 feet, and an alkalinity of 134 ppm. The soft bottom has extensive beds of Chara. Because of its shallowness, trap nets could be fished anywhere. Electrofishing gear, on the other hand, was ineffective in water over 5 feet deep (17% of the lake).

Jewett Lake is a landlocked, brown-water lake in Ogemaw County (T. 23 N., R. 3 E., Sec. 11). It has a surface area of 12.9 acres, a maximum depth of 17 feet, and an alkalinity of 34 ppm. The pulpy peat bottom supports only a sparse growth of higher aquatic vegetation. All but the deepest portion of the lake could be netted effectively; electrofishing was ineffective in 33% of the lake.

Both lakes are state-owned and were closed to fishing during the studies with one modification. During May 1965, residents of the Cassidy Lake Technical School were allowed to fish, with the provision that their catch be saved for my inspection. Fishing privileges were retracted after one month when it became apparent that the stocked perch population could be depleted. Even though the perch population was small, it was surprisingly vulnerable to angling, especially since the residents were willing to put in long hours of fishing, even at low catch rates.

Cassidy Lake was treated with 1 ppm rotenone in June 1964, to remove the native warmwater fish population. The native population consisted of the bluegill[2] (72 pounds per acre), yellow perch (24 pounds per acre), pumpkinseed (19 pounds per acre), largemouth bass (17 pounds per acre), plus about 34 pounds per acre of other fish. The treatment was repeated in September because some fish had survived. In October 1964, and April 1965, the lake was stocked with adult perch from Saginaw Bay, Lake Huron, and with adult and fingerling perch from Sugarloaf Lake, Washtenaw County. The goal was to plant enough perch of different sizes so as to establish a population of normal structure at the carrying capacity of the lake (estimated to be 60 pounds per acre). Survival of perch from Saginaw Bay was poor, however, and it was impractical to collect the tens of thousands of juvenile perch required. Consequently, the population starting the experiment in the spring of 1965 was only 2 pounds per acre.

Jewett Lake was treated to remove an experimental bluegill population in July 1966. Perch obtained from a nearby lake were stocked in the spring and fall of 1967. A small year class was produced in 1967. In

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[2] Common names of fishes follow the American Fisheries Society official list.

the spring of 1968, at the start of the experiment, there were 16.9 pounds per acre of perch present. The size distribution of the starting populations is given in Tables 1 and 5.

The number of perch in the lakes was estimated in the spring and fall of each year. Spring estimates were conducted in late April and early May; fall estimates were conducted in late September and early October. Little growth occurs at these times, and diseases which could result from handling of the fish, were inhibited by low temperatures. Very little mortality was ever observed during the estimates.

Trap nets with either 3/4-inch or 1 1/2-inch stretched mesh in the pots, and 220-volt, a-c electrofishing gear were used to capture perch. Estimates were based on the mark-and-recapture technique, using either Schumacher-Eschmeyer or Petersen type formulas (Ricker, 1958). Fish were marked by clipping off a lobe of the caudal fin. Usually a separate estimate was made for each inch group of perch to compensate for size selectivity of the fishing methods. Sometimes adjacent size groups were combined to increase sample size, or because the perch in them were of the same age.

Typically, in these estimates, a much higher proportion of the large perch in the populations would be caught than of the small perch. Since the large perch were also much less abundant than the small perch, the confidence limits on the estimates of large perch are narrower. However, close limits should not be equated with precision of the estimates. It has been my experience that systematic errors, due to behavior of fish or to gear selectivity, can be much greater than random errors which can be predicted statistically. A better criterion for judging the reliability of an estimate is if it is consistent with preceding and succeeding data. Some estimates of perch were found to be inconsistent, and these were either replaced with other estimates (if available) or modified by smoothing survival curves.

Up to 30 scale samples were collected from each size group of perch during the estimates. The percentage frequency of an age group within a size group was used to apportion estimates by size groups into estimates by age groups.

Scale sample collections were used to determine also the average length of the age group. Whenever the samples were not taken randomly, the data were weighted by the abundance estimates. Corresponding average weights were calculated from length-weight regressions. Ripe females were excluded from the regressions and, consequently, estimates of spring standing crop apply after spawning was completed.

The length-weight regression for Cassidy Lake perch was:

$$\text{Log } W = -0.8913 + 3.146 \log L$$

Where W = weight in grams

L = total length in inches

Data from six collection dates, which did not differ significantly from each other, were pooled for this regression.

For Jewett Lake the length-weight regression for perch was:

$$\text{Log } W = -0.8596 + 3.089 \log L$$

Twenty-one collections of fingerling and adult perch were made from Cassidy Lake for a study of food habits. Altogether, 933 specimens were taken by electrofishing and angling. Collections were made in all four seasons of 1966 and 1967, in two seasons of 1965 and 1969, and in three seasons of 1968. Most of the perch were small, 2.0-4.9 inches, as this was the predominant size in the population. Few large perch were examined in late 1965 and early 1966 because I wanted to keep the population of potential cannibals as high as possible in order to reduce recruitment of young perch as much as possible. I also examined the stomach contents of 52 perch collected from Jewett Lake in September 1968, and of 171 green sunfish taken from Cassidy Lake during the period from October 1966 to February 1969.

Organisms in the stomachs were identified to the lowest taxon possible, or practical, and then counted. Length of intact specimens was measured, to determine if perch were selecting food by size. Data were stratified by inch group of perch, season and year.

In 1966, a study was made by W. T. Shaffer of the food habits of perch fry. Using the technique described by Schumann (1963), fry were attracted to an artificial light and collected in a fine-mesh net. Collections were made on 16 May (22 specimens), 19 May (18 specimens) and 6 June (7 specimens). Succeeding attempts to collect fry were unsuccessful due to the small size of the 1966 year class and the loss of positive phototaxis by the fry as they changed from pelagic to benthic habits. Due to an oversight, the size of the perch fry which we collected was not measured; however since hatching occurred about 25 April, the fry were approximately 21 days old on 16 May, 24 days old on 19 May, and 42 days old on 6 June.

Perch collected for food habit studies from Cassidy, Jewett and Sugarloaf lakes were examined also to determine their sex and maturity. The gonads of perch which would have been mature in the spring could be recognized the preceding fall or winter. A total of 507 females, and over 281 males were examined. Data were eventually stratified by size of fish (10-mm groups) and number of growing seasons.

Female perch were collected from Cassidy Lake during the late winter and early spring of 1964, 1967, 1968 and 1969 for a fecundity study. Collections were made from Sugarloaf Lake in 1965 and 1966 also because this lake was the main source of perch planted in Cassidy Lake. A total of 86 ovaries were examined.

The egg complement of each ovary was either counted entirely or estimated, depending on its size. Usually, all the eggs in small ovaries (less than 5 g) were counted, 3- to 5-g samples of medium-sized ovaries (5-25 g) were counted, and about 5% of the large ovaries (greater than 25 g) were counted. This procedure usually produced an estimate with a standard error of about 10%. Ovaries were subsampled by weighing them, cutting them into several pieces, and randomly selecting three pieces to be weighed and counted. The number of eggs per gram was then computed for each ovary and prorated to obtain an estimate of the total number of eggs.

It was noted that the number of eggs per gram of ovary was highly variable. It depended on the degree of maturation, size of ovary (and fish), and unknown variables as well. For analysis of the data, a plot of $\log_{10}$ fecundity versus $\log_{10}$ perch length, or $\log_{10}$ perch age, produced a straight line which could be tested by multiple regression techniques.

Perch eggs spawned in Cassidy Lake in 1966, 1967 and 1968 were surveyed from a boat. Observations were made of time of spawning, number of eggs, fertilization and survival rates, and hatching. Supplemental observations were made in the laboratory on size of egg and fry in relation to parent size.

An intensive program of plankton sampling was begun on Cassidy Lake in 1966. The objective of this program was to relate abundance of plankton to recruitment rate of perch over a series of years. Plankton sampling was discontinued after one season when it became apparent that recruitment was going to be negligible while the 1965 year class dominated the perch population.

Between 25 April and 15 July 1966, vertical tows were made with a 1-meter, No. 10, Nytex plankton net twice each week. Triplicate samples were taken at four stations, 10, 10, 6 and 3 feet deep, during daylight hours. Subsamples of plankton were identified, counted and measured. The data were subjected to extensive statistical analysis to: (1) determine the appropriate transformation to normalize the data for parametric analysis and (2) determine, by analysis of variance, if there were significant differences among stations and dates.

The benthic fauna of Cassidy Lake was sampled at 13 stations. Stations were established by superimposing a grid over a map of the lake. Depth of the stations ranged from 8 inches to 9 feet. Samples were taken on 15 April, 29 June and 31 October 1966; 14 April and 6 July 1967, and 22 April 1968. Three replicates were taken on the first date and two replicates on each of the other dates. Samples, one-quarter square foot in area, were taken with an Eckman dredge fitted with a long handle. Samples were washed through a 30-mesh screen and preserved in formalin. Later the organisms were picked from the debris, sorted, identified, counted and their lengths measured.

A similar program of benthic sampling was followed at Jewett Lake except that samples (usually 29) were taken randomly. Sampling dates were 4 October 1966; 3 May, 27 June, 3 October 1967; 1 May, 2 July, 24 September 1968; and 13 May 1969.

Results

Errors in perch estimates

The greatest difficulty experienced during the perch studies was in obtaining good population estimates. Difficulties were experienced in both lakes, but large systematic errors were especially evident in the estimates made at Jewett Lake in the fall of 1968 and spring of 1969. Such errors were present in the estimates of 4- to 9-inch perch which were caught mostly in trap nets, and were not evident in the estimates of smaller perch which were caught by electrofishing. These errors affected the estimates of perch which started the experiment (1967 and older year classes) but not the estimates of those year classes (1968 and 1969) born during the experiment.

Evidence of a systematic over-estimation of the larger perch in the fall of 1968 and the spring of 1969 comes from two sources. First, when these estimates by size groups were converted to estimates by age groups, the estimated number of survivors from the planted year classes exceeded the number actually stocked in the lake. Second, estimates made in the fall of 1968 were verified by check estimates made in the spring of 1969. The check estimates were derived from the ratio of marked (in the fall) to unmarked perch in the spring catch. The estimate made in the fall and the check estimate made in the spring should have given the same population figure, since there was no growth (in length) over winter and the mortality rates of marked and unmarked fish were believed to have been similar.

The fall estimates were consistently higher than the check estimates. For 4.0- to 6.9-inch perch, the fall estimate was 2,468 and the check estimate was 1,619; for 7.0- to 12.9-inch perch, the estimates were 1,246 and 1,042, respectively, The "check" estimates (made in the spring) were used in subsequent calculations of year class size, natural mortality, and standing crop. The regular estimates made in the spring of 1969 could not be checked. I assumed that the estimates of perch larger than 4 inches were too high; so I did not use them.

Other estimates of perch in Jewett Lake, based on trap netting data, were close to the true population size. The estimate of 1,010 perch in the spring of 1968 is judged to be accurate, because 929 different perch were caught during the estimate, and only 1,083 were planted in the lake. The fall, 1969, estimates are reasonable also.

Since a high fraction of the perch population was caught in nets during both the good and the poor estimates, inadequate sample size was not the cause of the errors. The two poor estimates (and also one good one) were conducted over a relatively short period of 5 days. Perhaps this did not give the marked perch enough time to resume their normal behavior patterns and, consequently, they were less vulnerable to recapture than unmarked perch. In future mark-and-recapture studies, it is recommended that a rest period of several days duration precede the recapture run.

Perch in Jewett Lake

The fingerling perch stocked in Jewett Lake in the spring of 1967 experienced high survival (96%) and good growth (achieving an average length of 8.0 inches) the following 12 months. Most of these perch were males. The few females that were stocked were thought to be spent or immature; however, such was not the case since a small year class was produced in 1967. Perch in this year class also grew rapidly in 1967, reaching a length of 5.4 inches in one year. Additional fingerlings, 3.2 inches long, were planted in the fall of 1967. When the experiment actually got started, in the spring of 1968, there were 249 perch per acre. All of them belonged to the 1967, or older, year classes (Tables 1 and 2).

Natural mortality of the starting population was low between April 1968 and October 1968. After correcting for a removal of 36 perch for a food-habit study, natural mortality was 16.4%. Mortality was highest (32.4%) among the older and larger perch which belonged to the group stocked in the spring of 1967. This group did not grow during 1968. Perch in the 1967 year class (native to Jewett Lake) grew much slower in 1968 than they did the year before. During 1968 they grew from 5.4 to 6.7 inches. Perch stocked in the fall grew much better than the larger perch, increasing from 3.2 to 6.1 inches.

Growth of all components of the starting population was poor during 1969; their weighted average length increased from 6.7 to 7.0 inches. Their natural mortality rate was 27.2% from fall, 1968, to fall, 1969.

The first year class which hatched during the experiment, the 1968 year class, was exceptionally strong (Table 2). It originated from 85,000 eggs produced by the starting population. About 6.5% of their progeny survived until October 1968. At that time they were only 2.6 inches long, but they had an aggregate biomass of 34 pounds per acre which was 60% of the standing crop of all perch.

About 15% of the 1968 year class died overwinter, and 10% died during the summer of 1969. The corresponding annual mortality rate was 24%. Mortality was not high enough to reduce the population to a level which would allow good, or even average, growth of the survivors. The average size of these perch in the fall of 1969 was 3.2 inches, or 2 inches less than the state average (Laarman, 1963). Their standing crop had increased to 48.5 pounds per acre, which was 71% of the total perch population.

The second year class brought-off during the experiment, the 1969 year class, was exceptionally weak; in fact, none were found in October of that year. Since there were over 50,000 small perch in Jewett Lake at that time, a small population of them could have been overlooked.

A more than adequate amount of brood stock was present in the spring of 1969. Depending on the exact size of the adult population (as explained earlier, these population estimates were not accurate), between 194,000 and 271,000 eggs were produced per acre. This is 2-3 times the number which established the large year class in 1968.

Food of perch in Jewett Lake

The stomach contents of 92 perch collected from Jewett Lake are summarized in Table 3. Small perch, especially those 2 and 3 inches long, fed extensively on zooplankton. Chironomids and amphipods were important foods also. Medium-sized perch fed mostly on midges and amphipods. Large perch ate a few large organisms, such as perch about 2 inches long, crayfish and leeches. A progressive increase in size of food with size of perch was evident.

Jewett Lake benthos

The amphipod *Hyallela azteca* was the most abundant benthic invertebrate (Table 4). Its population dipped in the spring of 1969 due, perhaps, to predation by the large 1968 year class of perch which changed to a benthic diet at about that time.

Midges were the second most abundant benthic form. They appeared to be increasing during the study despite fish predation. The low number of them at the beginning of the study is attributed to residual effects of the treatment. The same explanation is offered for the low numbers of dragonflies and damselflies in 1966 and early 1967; however their decline in later years was probably due to perch predation.

Worms (Annelida) reached a peak abundance in the summer of 1967, then declined. The phantom midge, *Chaoborus* (contained in the category of "other"), showed an opposite trend. Changes in these organisms were likely triggered by the chemical treatment of the lake, since neither one was found in perch stomachs.

To summarize, the effect of perch predation on the bottom fauna of Jewett Lake was not extremely pronounced; however the analysis is confounded by a long recovery period following treatment of the lake. Amphipoda, Odonata and possibly Ephemeroptera and Trichoptera may have declined due to perch predation. Midges, which may still be recovering from the lake treatment, increased despite perch predation.

Perch in Cassidy Lake

The perch population of Cassidy Lake expanded from 50 fish per acre in the spring of 1965 to over 2,500 fish per acre in the fall of 1965, the highest level observed during the study (Tables 5 and 6). The increase was due to recruitment of the large 1965 year class. The perch population was dominated by this year class throughout the rest of the study.

Growth of all perch, including the dominant year class, was good in 1965. From 1966 on, however, small perch grew extremely slow; after four growing seasons, the 1965 year class averaged only 4.4 inches in length. Growth of medium-sized perch (in the 1964 year class) also slowed down in 1966, but not so much. Large perch (in the 1963 and older year classes) grew fairly well throughout the study. The difference in growth of small, medium and large perch is attributed to the decline of the benthos population, the principal food of small perch, and to the ability of larger perch to change to a fish diet. Production was highest in 1966, and by the fall of that year, the highest standing crop was reached, 57.5 pounds per acre (Table 6). The 1965 year class comprised 92% of the total biomass.

Recruitment of young perch was low following the large year class in 1965. Estimates of the 1966, 1967 and 1968 year classes were not consistent but they suggest that these classes were extremely small. Inconsistencies were caused by difficulties in aging (due to slow growth) and dilution of the weak classes among the strong one. Often as many as three annuli would be missing from the scales of perch of known age. Their age was known because of the characteristic pattern of rapid growth laid down on their scales in 1965. Members of the 1966-1968 year classes grew surprisingly fast their first year, averaging 3.0-3.4 inches by fall. Like the 1965 year class, they grew slowly thereafter. Poor recruitment cannot be attributed to insufficient reproduction. The strong year class was produced from 20,000 eggs, the weak year classes from 154,000-907,000 eggs (Table 6).

The number of perch 7.0 inches and longer changed little after the fall of the first year, ranging from 14 to 22 per acre. Most of these had been planted (at a smaller size), but some were fast growing native perch. A decline in the number of large perch was expected to occur shortly after the study terminated because it was unlikely that older individuals which die out would be replaced by new recruits.

Population estimates for the 1965, 1964 and 1963 and older year classes were sometimes inconsistent. Therefore they were graphed, and smoothed survivorship curves were fitted by eye (Fig. 1). Total annual mortality rates (spring to spring) were calculated from the smoothed estimates (Table 7). These are essentially estimates of natural mortality (n), since mortality due to biological sampling was negligible. Only 4.0, 4.3 and 0.7% of all mortality of the 1963 and older, 1964, and 1965 year classes, respectively, was due to sampling. Smoothing obscures what appears to be a seasonal pattern of low mortality overwinter and high mortality during the growing season; however the data are not precise enough to merit a more rigorous analysis.

Natural mortality of the adult perch stock (1963 and older year classes) ranged from 37 to 49% per year. The 1964 year class, planted as 3-inch fingerlings, experienced very low mortality (5%) during age 1, the year of fast growth (1965); however, their mortality increased to 31% during age 2, and 52% during age 3.

About 12% of the eggs carried by the parental stock in the spring of 1965 were laid, hatched and survived to age 1. A comparable figure for the 1966-1968 year classes would be much smaller, a fraction of 1%.

From age 1 on, the denser slower-growing 1965 year class had somewhat higher rates of mortality at comparable ages than the sparser, faster-growing planted year classes. The difference was not proportional to population density, however. During age 1, for example, the 1965 year class had a mortality rate 5 times higher than the 1964 year class but it was 76 times more abundant. A pattern of relatively low mortality during the second year of life (5-26%) compared to older ages (31-53%) existed for both fast- and slow-growing year classes. Since there were no large predators in Cassidy Lake and fishing was banned, all mortality beyond age 1 was due to unspecified or natural causes.

Dead fish were rarely observed in either Cassidy Lake or Jewett Lake. The largest die-off, about two dozen perch, was seen in Cassidy in June 1967. Six perch, 3.9-8.4 inches long, which had just died, were autopsied. Most had been growing well and were in good condition. Four fish had been hemorrhaging into the brain and two had infections originating from skin or fin damage. A smaller number of dead perch were picked up in April 1968. Their cause of death was not determined.

Possible causes of mortality were studied to a limited extent. Perch introduced into Cassidy Lake from Saginaw Bay, Lake Huron, in October 1964, contained the redworm (Philometra cylindracea). This nematode, located in the viscera, is reputedly a pathogen (Dechtiar, 1972); however I did not observe any mortality caused by it. In fact, perch containing as many as 32 worms were robust and appeared to be in good health. The adult worm was able to migrate to uninfected perch planted in Cassidy Lake from Sugarloaf Lake, but the life cycle of the parasite was not completed and the redworm was not found in Cassidy Lake after the fall of 1965.

During the cold months of several years, in both Cassidy and Jewett lakes, the skin of 4-26% of the perch larger than 5 inches long had a pebbly texture and bluish-white color. Dr. Roland Walker of Rensselaer Polytechnic Institute determined that these perch had a skin condition similar to one he had observed on walleyes from Oneida Lake, New York. The epidermal cells were thickened, but appeared to be healthy in other respects. The skin of an affected specimen returned to normal after it had been warmed to room temperature for 2 weeks.

To test more thoroughly whether the skin condition was lethal, groups of normal and infected perch were collected from Mill Lake on 26 March 1968, given a distinctive fin clip, and placed in a large live crate. When the fish were removed 76 days later, the condition was gone. Survival of the two groups was nearly the same--71% for the normal perch and 67% for the infected perch. Thus there is no reason to believe that this condition was a cause of death in the experimental perch populations.

Food of perch in Cassidy Lake

Food habits of perch in Cassidy Lake are given in Table 8. The data are presented by years only, since no seasonal change in food habits was evident. Also, three size groups of perch--2.0-4.9 inches (small), 5.0-6.9 inches (medium) and 7.0-11.9 inches (large)--were found to be adequate to illustrate differences in food habits among perch of different sizes.

Zooplankton and small-size midges, mayflies and snails were the main food items in the stomachs of small perch. Larger perch ate progressively less plankton, and more of the larger benthos such as Hexagenia and Odonata, and more fish. The same pattern was observed in food studies at Jewett Lake and Mill Lake (Schneider, 1971).

The average size of a given food item also varied among perch of different sizes (Table 9). For example, 3-inch perch ate chironomids about 3 mm long, and 6-inch perch ate chironomids about 9 mm long. A positive correlation between perch size and food size existed for Hexagenia, Caenis and other mayflies, and for Odonata, Mollusca and Trichoptera. Comparison of the average size of benthic organisms in perch stomachs with the average size of benthos taken in dredge samples, showed that small perch were selecting the smaller individuals of a species, and large perch were selecting the larger individuals. The average size of benthos in dredge samples and in stomachs of medium-sized (5-inch) perch was about the same. An unexpected feature of these data are that small perch select the smallest individuals of each food type rather than selecting organisms of a particular size or weight. For example, the weight of an 8.1-mm Hexagenia is much greater than the weight of a 3.3-mm chironomid.

A similar comparison was made between the average size of cladocerans and copepods taken in plankton nets and the average size of these organisms in the stomachs of small perch (Table 9). Here, perch were selecting the largest cladocerans; in fact about half of the cladocerans in stomachs were larger than those taken in nets on the same date. The opposite was true for copepods: the smallest copepods were eaten. These peculiar results were likely due to bias in plankton sampling. Large cladocerans (Daphnia spp.) are known to concentrate near the bottom of shallow lakes during daylight hours. There they are not vulnerable to plankton nets but are available to bottom-feeding perch. Perhaps small copepods also concentrate there and are eaten incidentally.

The data on food habits indicate that cannibalism was infrequent among perch. Those perch which were found in the stomachs of other perch were of small fingerling size; perch fry were not found. However, considerable predation must have occurred on perch fry to cause the weak year classes which I observed. Digestion rate is assumed to be rapid, since in a preliminary laboratory experiment a single fry was digested to an unrecognizable state in only 2 hours. Since predation on fry is a sporadic occurrence, it is difficult to document. I did observe it once at Jewett Lake just as hatching took place. Three of 29 fingerling perch collected on that occasion contained a total of 57 perch fry.

The data in Table 8 also indicate some year-to-year changes in the diet of Cassidy Lake perch, and diet, in turn, affects growth. Perch grew very well in 1965, fairly well in 1966 (except small fish), and poorly in 1967 and 1968; growth was not measured in 1969. Generally, the number of food organisms in perch stomachs was high in the years of good growth and low in the years of poor growth.

The contribution of zooplankton and benthos to the perch diet declined during the study. This was especially true of large invertebrates such as Hexagenia and Odonata which were the principal food of larger perch during the early years of the experiment. The bottom fauna data show similar trends in abundance for these same organisms. The diet became more diverse during the study, and an increase took place in the amount of fish, especially green sunfish. The data for 1969 suggest that the food intake by small perch was increasing once more in response to thinning of the population by natural mortality. Much of this increase was due to a resurgence of the amphipod population.

The stomach contents of perch fry 21-42 days old are summarized in Table 10. Also included in the table are the abundance and size of organisms taken in plankton net samples on the same date, and from the same area of the lake. Food of the fry was entirely plankton.

The fry sampled on 16 May had selected small organisms -- the cladoceran, Bosmina; the protozoan, Urceolus, which were 0.4 mm long; and the smallest Cyclops available, which were 1.1 mm long. Three days later, larger copepods, 1.3 mm long, were selected over smaller Bosmina, 0.4 mm long. Selectivity was even more apparent in the June collection. In that month, Bosmina and Ceriodaphnia outnumbered Cyclops and Epischura in the plankton, but the copepods (which were of larger size) were more prevalent in the diet.

The average size of copepods eaten by perch fry (1.3 mm) was larger than that eaten by perch fingerlings (1.0 mm). Since perch fry were pelagic, whereas perch fingerling were mostly demersal, these data substantiate the hypothesis offered above that small copepods were down near the bottom of the lake and large copepods were up off the bottom.

In Cassidy Lake, plankton of the size that perch fry eat was relatively sparse from late April to mid-May (see below). This information, coupled with the low quantity of food found in fry stomachs in mid-May, suggests that this period (April to May) was crucial to the growth and survival of perch fry. Food was relatively abundant from mid-May to mid-July, and apparently was not a limiting factor. It is likely, then, that the disappearance of the 1966 year class between June and October was due to predation by older perch and not to starvation.

Cassidy Lake plankton

The total number of zooplankters was lowest in May and highest in June (Table 11). Cyclops was the most abundant organism in May, Bosmina in June, and Rotifera in July. Diaptomus, Epischura and Ceriodaphnia were less abundant. A few Daphnia spp., Sida, Holopedium, Leptodora and Chaoborus were taken in plankton nets. Evidence was presented in the section on food habits that large Cladocera (probably Daphnia) and small Copepoda were concentrated near the lake bottom and, consequently, were undersampled. Additional data on abundance and size of plankters are given in Tables 9 and 10.

Cassidy Lake benthos

The benthic fauna of Cassidy Lake was diverse but sparse (Table 12). Chironomids were the most abundant group numerically, with at least 13 species present. No one species of midge predominated. Burrowing mayflies (Hexagenia) were common in certain areas of the lake. Other mayflies (Caenis, Ephemera and Ameletus) were sparse.

The benthos declined greatly during the study. In the spring of 1966 there were 27 organisms per sample (one-quarter square foot). By the spring of 1968, there were only 5 organisms per sample, a statistically significant drop. In terms of weight of standing crop, the decline was relatively less, from 78 kg per ha down to 31 kg per ha. An even greater decline would be evident if sampling had been started prior to 1966. In the fall of 1964, large numbers of dragonfly nymphs were seen swimming in the lake at night, a phenomenon which has not been observed since.

Favored perch foods, such as chironomids, mayflies and dragonflies, declined more than did other species. Undoubtedly over-exploitation by perch and other fish was the cause of the demise of these and other benthic organisms. The amphipod Hyallela, on the other hand, suddenly appeared in 1968 (apparently it had been eliminated by the rotenone treatment in 1964) and has become abundant despite fish predation.

Observations on perch eggs

Each year perch spawn was concentrated in an area along the west shore of Cassidy Lake, in water 2 to 4 feet deep. This area was protected from prevailing winds, and was sparsely covered with vegetation (mostly Chara). Spawning began during the fourth week of March in 1966 and 1968, and during the first week of April in 1967. In each year spawning took place over an extended period. In 1967, for example, ripe females were taken 3 weeks after spawning had started. Hatching began about 25 April in 1966, and 19 April in 1967.

Attempts were made to count the number of strings of eggs on the bottom of Cassidy Lake. The counts were 40, 147 and 50 in 1966, 1967 and 1968, respectively. This was far less than the number of mature females known to be present in the lake. The discrepancy between the number of egg strings and the number of mature females cannot be attributed to reabsorption of eggs by females. Of large numbers of perch examined externally during the population estimates in April, and internally during food habit studies, only one fish, 7.6 inches long, was reabsorbing her eggs. The discrepancy could, in part, be due to deposition of eggs in the relatively small, deeper portion of the lake where I could not see them. It is also possible, since almost all of the strings I saw had come from the larger perch in the population, that many small strings were simply overlooked. However, neither explanation seems to be completely satisfactory.

Loss of perch eggs to predation appears to be very small, due no doubt to the gelatinous matrix which forms a protective coating for the eggs. Individual strings were often observed during development and little loss was noted. Sometimes water mites would gather on the strings but no predation on live eggs was seen.

Fertilization of eggs, and survival of eggs were relatively good. The number of developing and unfertilized or dead eggs was counted in samples from six strings of eggs which were only a few days old; 96% of the eggs were developing. Occasionally strings were observed in which the eggs in certain portions, usually at an end, had not been fertilized or had died from unknown causes. Once, all the embryos in a string laid in very shallow water were found dead. Possibly, death was caused by an abrupt drop in temperature the night before. Generally, however, survival appeared to be very high, up until hatching began. Often many embryos died at hatching, but attempts to quantify this were unsuccessful.

Measurements of egg diameter immediately after fertilization, and of fry length and yolk diameter at hatching, were made to explore the possibility that eggs or fry from small adult perch might be less viable than eggs and fry from large adult perch. Perch from Cassidy Lake, 3.8-13.5 inches long, were artificially stripped and fertilized for this experiment. No relationship was found between size of the female parent and egg size, yolk size, fry length or hatching success.

Perch fecundity and maturation

Least square regressions of $\log_{10}$ fecundity on $\log_{10}$ length were highly significant (Table 13). Stepwise multiple regression analyses showed that over 94% of the variability in the data was accounted for by log length, and less than 1% was attributed to log age. Thus perch of the same size had the same number of eggs, regardless of whether they were growing rapidly (as in 1964) or slowly (as in 1967-1969). The regressions differed from each other somewhat and, in two instances (1966 compared to 1968, 1966 compared to all other years) these differences were statistically significant ($p = 0.05$); however most confidence limits overlapped, and since no explanation could be found for the differences, no special importance is attached to them. Consequently the regression derived from all the data is considered to be the most representative of perch.

All male perch larger than 68 mm (2.7 inches) were mature, and all less than this size were immature. Usually males reached this size after one growing season; however, if growth was extremely poor, some did not mature until a year later.

The smallest mature female perch observed was 94 mm (3.7 inches) long, and the largest immature female collected was 181 mm (7.1 inches) long. Almost all females larger than 170 mm (6.7 inches) were mature. Oddly, 57% of the female perch 110 to 129 mm (4.3 to 5.1 inches) long were mature, but only 38% of the females 130-149 mm (5.1 to 5.9 inches) long were mature.

Few females were mature after one growing season and most were mature after four growing seasons. Only 6% of the 1-year-olds, 94 to 182 mm (3.7 to 7.2 inches), were ready to spawn. At ages 2, 3, 4, and older the percentage of mature females increased to 47, 51 and 86, respectively.

Other fish in Cassidy Lake

Green sunfish, mudminnows and killifish survived the rotenone treatments of Cassidy Lake. Only green sunfish became significant contaminants. In 1966, nearly 1 pound per acre of green sunfish was removed in a futile attempt to halt their expansion.

Estimates of the green sunfish population were made in 1967 and 1968. Those estimates in which trapnets were used for both the mark, and the recapture runs were found to be consistently, and appreciably lower than estimates in which both trapnets and electrofishing gear were used. The data presented here were derived from estimates using both kinds of gear.

The population of green sunfish 3.0 inches, and larger, increased from 145 fish per acre (5 pounds) in 1967, to 819 fish per acre (29 pounds) in 1968. The 1963 and 1964 year classes, survivors of the rotenone treatment, were small; the 1965-1968 year classes were large. Unlike the perch there was no evidence of diminishing year class strength. Only two rough estimates of natural mortality can be made, due to inconsistencies in the data. From spring to fall 1968, natural mortality for age-2 and age-3 green sunfish was 37% and 54% respectively.

The effect which green sunfish, killifish and mudminnows had on the course of the perch population is of major concern. They were eaten by perch to a limited extent and, therefore, they buffered predation by large perch on small perch somewhat. Killifish and mudminnows were not abundant enough to have other effects. Green sunfish, on the other hand, were abundant, and a food study showed that they were both predacious and competitive.

The diet of the green sunfish was very similar to the diet of the perch, in terms of both food type and food size (Table 14). Small green sunfish fed primarily on zooplankton, medium-sized green sunfish ate mostly benthos, and large specimens ate larger benthos, small perch and other green sunfish. Slightly greater amounts of terrestrial and adult insects were found in green sunfish as compared with perch. This suggests that the sunfish fed more on the surface of the lake than did the perch.

Only one perch fry, 19 mm long, was found in the stomach of a green sunfish. However, it is likely that green sunfish predation, as well as perch predation, was far more prevalent than indicated by this study, and that green sunfish may, in part, be responsible for the weak year classes of perch in 1967 and 1968. It is also likely that the expansion of the green sunfish population was partially at the expense of the perch population. The standing crop of perch declined from 58 pounds per acre in the fall of 1966 to 16 pounds per acre in the fall of 1968, whereas green sunfish expanded from a few pounds per acre to 29 pounds per acre. (Prior to this experiment the lake supported 3 pounds per acre of green sunfish, among 166 pounds per acre of all species.) Considering the scarcity of food supplies during these years, the predation pressure by perch on green sunfish, and the head start enjoyed by the perch, the green sunfish demonstrated a superior competitive ability. It is also likely that they exploited food resources not used by the perch.

Discussion

The perch populations in Cassidy and Jewett lakes developed along similar lines. In both experiments a large year class, established the first year, dominated the populations. Growth of the strong class was satisfactory the first year but extremely slow thereafter. As a result, few perch reached a size useful to anglers.

The dominant year class greatly inhibited survival of succeeding year classes for a period of 3 or more years. It is likely that many generations would pass before recruitment, and consequently the structure of the population, would have reached a fairly steady state. For the longer-lived European perch, Alm (1952) found that a strong year class may suppress recruitment for as long as 15 years. It is also possible that stochastic fluctuations in the environment may have kept the system oscillating indefinitely, for unstable recruitment is characteristic of both the yellow and the European perch in both single-species and multi-species populations (Forney, 1971; Schneider, 1971; Buck and Thoits, 1970; LeCren, 1965; El-Zarka, 1959; Alm, 1952). Even if a reasonably steady state would have been achieved in Cassidy and Jewett lakes, it is likely that the population would have been slow growing and few would have reached a useful size (Buck and Thoits, 1970; Alm, 1946; Eschmeyer, 1938).

It is especially difficult to establish stable populations of perch, or other species of fish, in lakes which have been treated chemically. On one hand, production of food organisms may be stimulated by cessation of fish predation and by the release of nutrients from decomposing fish; on the other hand, certain fish foods, especially the crustacea, may be poisoned also and some may require several years to recover. The net effect would seem to favor the establishment of a large year class of fish at the earliest opportunity and result in a depression of the carrying capacity of the lake for several years. Formation of a dominant year class may be avoided if the lake could be stocked at its carrying capacity, but the large number of fish required makes this impractical. Stocking Jewett and Cassidy lakes at 26% and 3% of their carrying capacity did not hinder formation of overwhelming broods.

The food habit data indicated that there were progressive changes in the diet of perch as they grew. Although there were no abrupt changes in diet, there appear to be three major size groups of perch with sufficiently different food preferences so that competition occurs mainly within a group and not among groups. Approximate size range of these groups is 0-3 inches, 3.0-6.5 inches, and larger than 6.5 inches. The small perch feed mainly on zooplankton, the medium-sized perch on small-sized benthos, and the larger-sized perch on large-sized benthos and fish.

Data on growth provide supporting evidence for these groupings. In Cassidy Lake, for example, the 1966-1968 year classes grew at an average rate during their first summer of life (reaching a length of 3.0-3.4 inches by fall) irrespective of the dominant 1965 year class which was only slightly larger (3.4-4.4 inches long). Buck and Thoits (1970), Pycha and Smith (1954) and Alm (1946) have concluded that growth of young-of-the-year is essentially independent of the density of older perch also.

Supporting evidence that 3.0- to 6.5-inch and 6.5-inch and larger perch occupy different niches is not as strong. In Cassidy Lake, growth of the relatively less abundant large perch continued after growth of the relatively more abundant medium-sized perch had stopped. In Jewett Lake, the large perch were relatively more abundant (due to a higher planting rate) and they stopped growing before the relatively less abundant medium-sized perch had stopped. In Jewett Lake, the large perch were relatively more abundant (due to a higher planting rate) and they stopped growing before the relatively less abundant medium-sized perch. Thus the growth patterns of 3.0- to 6.5-inch and 6.5-inch-plus perch appear to be independent of each other. Alm (1946) concluded that the European perch experiences a similar change in diet and growth. He estimated that the change took place at a length of about 5.5 inches.

Within the 0.0- to 3.0-, 3.0- to 6.5-, and 6.5-inch and larger size groups there is evidence that growth is density related. Comparing the strong year class in Jewett Lake to the strong year class in Cassidy Lake after one growing season, the Jewett Lake perch were much more abundant (5,328 per acre compared to 2,471 per acre) and grew much slower (2.6 versus 3.2 inches, mean length). The standing crops which resulted in the fall were similar, 34 and 30 pounds per acre, respectively. The other size groups of perch also grew much faster when their density was low (during the early years of the study) than when their density had reached its maximum.

The biomass of perch which the lakes could support differed for the three size groups of perch. The lakes could produce, by fall, 3,000 young of the year per acre, 3.2 inches long, weighing 30 pounds. For growth to continue the next year, however, the population had to be reduced to about 15 pounds per acre by spring. When the perch reached about 6.5 inches long, growth would continue only at densities of about 10 pounds per acre.

In so-called "stunted" perch lakes, such as Cassidy and Jewett, cessation of growth begins at a length of about 3 inches when the diet changes from plankton to benthos. In these lakes, and many others as well, the productivity of plankton is high relative to the productivity of benthos, and consequently, many more young perch survive the first year than the environment can support the second year.

The number of young perch recruited to the population in the fall is a function of the number of eggs produced by the parental stock and the survival rate of their progeny. Because of the high fecundity of the perch, more eggs and young are usually produced than the environment can support. Consequently, there is no correlation between size of the parental stock and the size of the resulting year class in typical perch populations (LeCren, 1961; El-Zarka, 1959). In my experimental lakes, the dominant year class of Jewett Lake was twice as numerous as the dominant year class in Cassidy Lake, apparently because the adult stock in Jewett Lake had produced four times as many eggs; however subsequent year classes, which originated from egg complements many times larger, failed completely, or nearly so, presumably because of predation by fingerling perch. Alm (1952) and Buck and Thoits (1970) also have concluded that predation by fingerling perch is a major factor in the formation of year classes. Other factors which reportedly influence year class size in the yellow or European perch are climate (LeCren, 1965), cannibalism among fry when zooplankton is scarce (Smyly, 1952), and predation by walleyes when perch are in the demersal stage (Forney, 1971).

Natural mortality of older perch did not appear to be density related. Buck and Thoits (1970) reached the same conclusion in their pond studies. Typical annual natural mortality rates in Cassidy and Jewett lakes were 25% during the second year of life and 41% during the third year of life and beyond. An important exception was that mortality of fingerling perch, stocked at very low densities after the native fish had been eliminated, was very low (4-5%).

At Mill Lake (Schneider, 1971), I also found a constant rate of mortality among older perch but it was 70%, much higher than in these lakes. Perhaps in Mill Lake this was due to predation by northern pike. At Cub Lake (Clady, 1970), which contained only perch and bass, perch mortality was similar to that found in my perch-only lakes. For the

European perch, natural mortality plus fishing mortality was about 47% for males and 30% for females (McCormack, 1965; LeCren, 1961).

Since perch populations produce a large surplus of eggs, and mortality of fry is density dependent, the recruitment of fall fingerlings cannot be reduced effectively by controlling reproduction. After the first year of life mortality is not sensitive to density and, consequently, an over-abundant, slow-growing year class of fingerling perch will not adjust itself so that more than a few of its members will grow to a useful size. The perch population or the environment needs to be modified by extrinsic forces to reduce (1) the amount of production ending up in young perch (as through competition or greatly reduced reproduction) or (2) the survival of fingerling perch (as through predation). Predation on young should be concentrated late in the first year of life so that growth of young will not compensate. Since a high degree of control is required to reduce a potential fall crop of 30 pounds per acre of young to 15 pounds per acre of yearlings, both mechanisms may be required.

If we wish to optimize the numbers of perch larger than 7.0 inches long for an intensively managed fishery, the data gathered in this study may be used to predict the optimal rate of recruitment and the structure of the resulting population. By a trial and error process I have determined that recruitment to age 1 should be about 100 fingerling perch per acre (average length of 3.3 inches) (Table 15). About 85 of these would survive to age 2 and grow to 5.8 inches. By age 3 the population would have been reduced to 50 fish (one-half of the age-1 recruits) averaging 7 inches long. Harvest would begin at this time, and if fairly extensive, roughly 15 perch, 8 inches long, would survive to the beginning of the next year.

While constructing this model it became apparent that the greatest constraint on the production of usable perch occurred when they reached a length of 6.5 inches. In my experimental lakes, perch grew to a larger size only if there were less than about 10 pounds per acre of large perch. Consequently, the model was constructed so that there would be 10 pounds of large perch per acre. The poundage of medium-sized perch was then back calculated to be 6.5 plus 1.4, or 7.9 pounds per acre, which is only about one-half the amount the environment could easily support. As a result, perch would grow rapidly during age 1 and part of age 2 when their density is relatively low, and slowly during the latter half of age 2, and beyond, when their density is relatively high.

There are three major implications of these data and computations. First, a fishery for perch is limited by the food resources used by the larger-sized perch. In the experimental lakes, these foods were large-sized benthic invertebrates such as burrowing mayflies, dragonflies and crayfish. In other lakes, fish, large midges and large zooplankters are also choice foods (Laarman and Schneider, 1972). Second, harvest of perch should be intensive for it stimulates the growth of medium-sized perch. Also, with these growth and mortality rates, 7 inches is the optimum size to harvest because it is the point in the life history of a cohort of perch when its biomass is at a maximum. Third, the food resources used by small- and medium-sized perch are usually not constraining. Consequently, the numbers of perch reaching 6.5 inches must be restricted by some other means. Several ways of managing perch populations to increase yield are discussed below.

A straightforward way of controlling recruitment would be to establish a population of sterile perch and maintain them by the addition of 100 sterile fingerlings per acre each year. Unfortunately a technique to sterilize large numbers of fish is not available at this time. An attempt to sterilize bluegills by means of gamma radiation was not promising (Ulrikson, 1969).

Another way of controlling recruitment would be to annually stock 100 3-inch fingerling perch of only one sex. The sex of fingerling perch may be readily determined in the spring when they become 1 year old. At that time, all males will be mature and nearly all females will be immature. Females tend to grow faster than males and, hence, are preferred for stocking purposes. Males, on the other hand, are often more easily obtained than females when seining the shorelines of shallow lakes. Large quantities of fingerlings could be cultured in ponds for stocking purposes also.

If fingerling perch of both sexes are accidentally, or intentionally, introduced into the same lake, at a rate not to exceed one perch of the opposite sex per acre, it is likely that small year classes will occur 1 and 2 years after the planting and that a large year class will be produced the third year after planting. The large year class will eventually disrupt recruitment, however the older perch present at this time will sustain the fishery for another 3 years or so. Under this management scheme, harvest could begin 2 years after the initial plant and it could continue at a high level until about the sixth year after the initial planting. By that time retreatment of the lake would be necessary to eliminate the slow-growing year class of perch. It is likely that other species of fish will have contaminated the lake by then also.

Since it is the food resources of the lake which are limiting the abundance of large perch and, hence, the size of the fishery, management techniques which will improve the supply of food for large perch would benefit the fishery directly. One possible technique is to establish a population of planktivorous minnows, such as the fathead. Theoretically, the minnows would transform some of the lakes' primary production into a form which can be directly utilized by large perch. Minnows may also reduce recruitment of young-of-the-year perch by acting as competitors. This system, perch plus minnows, was tested experimentally at Jewett Lake after the perch-only experiment was concluded.

To initiate the perch-minnow experiment, Jewett Lake was dosed with rotenone in October 1969. Fathead minnows, blackchin shiners and redbelly dace were stocked in the lake in May 1970. Only the fatheads reproduced successfully and, by fall, they had established a large population. Perch were planted in the fall of 1970. The number and size distribution of the planted perch duplicated the population which began the perch-only experiment in the spring of 1968. Due to a mortality over winter, however, the population beginning the perch-minnow experiment was fewer in number (127 instead of 249 per acre), of less biomass (12.2 instead of 16.9 pounds per acre) and of larger average size (5.2 instead of 4.8 inches). The first-year results were used to compare the perch-only experiment to the perch-minnow experiment.

In the perch-only experiment, the number of perch larger than 7 inches long increased slightly from 78 per acre (weighing 14.3 pounds) in the spring to 81 per acre (weighing 15.3 pounds) in the fall. In the perch-minnow experiment, the number of perch larger than 7 inches long increased much more, from 38 per acre (weighing 9.1 pounds) in the spring to 55 per acre (weighing 13.9 pounds) in the fall. Because of the difference in the perch populations initially, these results cannot be compared directly; however it seems safe to conclude that minnows did not greatly increase the production of large perch.

Minnows appeared to affect recruitment and growth of young-of-the-year perch. In the perch-only situation, over 5,300 young survived to fall. In the perch-minnow experiment, only 1,900 survived to fall. Furthermore, young grown with minnows were much smaller in size, 2.1 inches long compared to 2.7 inches long. It is likely that the smaller young were more heavily preyed upon by large, adult perch during the following winter and, consequently, their abundance was reduced further. Even so, more young survived until spring than Jewett Lake could have supported at a satisfactory growth rate. A more voracious predator, such as bass or walleye, is needed to reduce survival of small perch even further. An additional, perhaps even larger, benefit would result from the conversion of small perch to a more useful form (larger fish). I reached a similar conclusion after studying the perch population of Mill Lake, a lake which contained a typical assemblage of warmwater fish species (Schneider, 1971). An experimental fathead-perch-walleye population is being established at this time (Dingell-Johnson Project F-29-R-7, XV-3) to determine the feasibility of using small perch as prey for planted walleye fingerlings.

The data presented above indicate that yellow perch are not amenable to single-species management except under rather special, short-term conditions. Predators, and perhaps also competitors appear to be necessary to improve the fishery. Even so, the yield of perch will be relatively small due to the low carrying capacity of many lakes for large perch. Yield is also restricted by the relatively high rate of natural mortality of large perch and the shunting of large amounts of productivity into excessive numbers of eggs which are wasted, from man's point of view.

Perch feed extensively during the fall and winter months and, although little growth in length takes place, females increase greatly in weight due to growth of their ovaries. For the European perch, LeCren (1951) estimated that females lose 17% of their weight at spawning and that males lose 6%. LeCren (1962) calculated that the production of eggs and milt by adults nearly equaled the production of all other tissues.

The yellow perch devotes similar, or even larger, amounts of energy to reproduction. Ovaries made up as much as 31% of the weight of female perch in Cassidy Lake. Using the above data of LeCren, and the production figures of Shaffer (1968), I calculated that sex products made up 2.7% of the total yellow perch production in Cassidy Lake. For adult perch age 3 and older, production of sex products equaled or exceeded production of other tissues in years of poor growth.

Since it is the food supply of large perch which limits the yield of a fishery, yield could be nearly doubled if food devoted to reproduction went into muscle. Development of a sterilization technique, or selective breeding for strains of perch with greatly reduced fecundity or later maturity would, consequently, not only aid in the control of recruitment, but would also have a large effect on yield of large perch. If growth and survival characteristics of perch could be improved concurrently, intensive management of perch would be much more feasible.

Table 1.--Estimated number of perch per acre present in Jewett Lake in the spring and fall of 1968 and 1969

Size group (inches)	1968 Spring	1968 Fall	1969 Spring	1969 Fall
2.0- 3.9	101[a]	5,318	4,524	3,909
4.0- 6.9	67	126	155	258
7.0-12.9	78	81	89	55

[a] A prediction based on 100% survival of perch stocked the preceding fall.

Table 2.--Estimated number and biomass (per acre) of perch in Jewett Lake belonging to the 1969, 1968, 1967 and older year classes

Year class	1968 Spring	1968 Fall	1969 Spring	1969 Fall
Number of perch				
1967 and older	249	203	-	146
1968	85[a]	5,328	4,528	4,076
1969	-	-	233[a]	0
Biomass in pounds				
1967 and older	16.9	23.2	-	19.3
1968	-	34.0	-	48.5
1969	-	-	-	0.0

[a] Estimated number of eggs (in thousands per acre) produced by the adult stock.

Table 3.--Food of 71 small, 11 medium, and 11 large-sized perch collected from Jewett Lake in September 1968, and October 1969

tr = trace = less than 0.05

Food item	Perch size group (inches)					
	2.0-4.9		5.0-6.9		7.0-10.5	
	Number per fish	Size (mm)	Number per fish	Size (mm)	Number per fish	Size (mm)
Cladocera	102.9	0.2-2.0	0.0	-	0.0	-
Copepoda	9.2	0.5-1.0	0.0	-	0.0	-
Chironomidae	5.4	2.0-10.0	8.4	3.0-10.0	0.2	-
Caenis	tr	-	0.0	-	0.0	-
Amphipoda	4.9	1.0-4.0	7.4	2.0-3.0	0.0	-
Odonata	0.1	5.0-22.0	0.3	15.0-20.0	0.1	-
Mollusca	0.2	-	2.2	2.0-3.0	0.0	-
Trichoptera	0.0	-	0.0	-	0.1	-
Perch	0.0	-	0.1	-	0.1	-
Other	0.1	-	0.4	10.0-28.0	0.4	25.0
Total	122.8	-	18.8	-	0.9	-

Table 4.--Average number of benthic animals per one-quarter square foot of Jewett Lake

tr = trace = less than 0.05

Organism	1966	1967			1968			1969
	Fall	Spring	Sum-mer	Fall	Spring	Sum-mer	Fall	Spring
Amphipoda	14.2	11.9	11.6	21.6	9.5	22.3	14.7	1.5
Chironomidae	0.7	0.3	3.3	6.4	1.5	5.9	3.4	7.6
Gastropoda	0.1	4.2	tr	1.5	0.1	2.3	0.1	3.0
Trichoptera	tr	tr	0.0	0.1	tr	0.0	tr	0.0
Ephemeroptera	0.1	0.0	tr	0.1	0.0	tr	0.0	0.0
Odonata	tr	tr	0.0	1.1	0.4	0.2	tr	tr
Annelida	0.8	2.2	7.9	0.5	0.1	0.7	0.3	0.1
Other	0.1	0.1	0.1	0.1	0.0	0.3	0.8	1.0
Total	16.0	18.7	22.9	33.4	11.6	31.7	19.2	13.2

Table 5.--Estimated number of perch per acre present in Cassidy Lake from spring 1965, to fall 1968

tr = trace = less than 0.05

Size group (inches)	1965		1966		1967		1968	
	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
2.0- 4.9	39	2,483	2,192	2,422	1,636	1,082	984	520
5.0- 6.9	7	29	25	55	83	75	86	38
7.0- 9.9	3	14	16	17	17	14	14	19
10.0-12.9	tr	tr	1	2	2	2	3	3

Table 6.--Number and pounds (per acre) and the average length (inches) of several year classes of perch in Cassidy Lake, 1965-1968

tr = trace = less than 0.05

Year class	1965		1966		1967		1968	
	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
1963 and older								
Number	17.8	11.1	9.2	7.3	5.6	2.0	3.7	1.6
Pounds	1.9	2.5	1.9	2.0	1.5	0.7	1.4	0.6
Length	6.4	8.1	8.1	9.1	9.1	9.7	9.9	9.8
1964								
Number	31.1	30.6	30.1	23.0	23.2	13.1	10.8	6.2
Pounds	0.2	3.0	3.0	2.8	3.1	2.3	2.0	1.1
Length	3.0	6.3	6.5	7.1	7.3	7.8	7.8	8.1
1965								
Number	20[a]	2,471	2,181	2,451	1,700	1,148	1,062	466
Pounds	-	29.9	25.0	52.7	36.5	24.3	29.9	12.6
Length	-	3.2	3.4	4.1	4.1	4.1	4.2	4.4
1966								
Number	-	-	154[a]	1.9	-	1.5	-	61.1
Pounds	-	-	-	tr	-	tr	-	1.5
Length	-	-	-	3.2	-	3.7	-	4.3
1967								
Number	-	-	-	-	870[a]	1.5	-	28.2
Pounds	-	-	-	-	-	tr	-	0.4
Length	-	-	-	-	-	3.0	3.5	3.7
1968								
Number	-	-	-	-	-	-	907[a]	14.1
Pounds	-	-	-	-	-	-	-	tr
Length	-	-	-	-	-	-	-	3.4

[a] Estimated number of eggs (thousands) produced by the adult population.

Table 7.--Annual mortality rates (a) of three year classes of Cassidy Lake perch from the spring of 1965 to the spring of 1968 based on the survival curve in Figure 1

Year class	1965-1966	1966-1967	1967-1968
1963 and older	0.488	0.366	0.461
1964	0.047	0.314	0.521
1965	0.881[a]	0.264	0.531

[a] Based on the estimated number of eggs carried by the adult population in the spring of 1965 and the number of survivors in the spring of 1966.

Table 8.--Average number of food organisms in the stomachs of small, medium and large perch from Cassidy Lake, 1965-1969

tr = trace = less than 0.05

Size group and food item	1965	1966	1967	1968	1969
2.0-4.9 inch group					
Sample size	16	204	200	151	28
Percentage empty	38	14	12	34	32
Cladocera	30.0[c]	32.4	6.7	4.7	5.8
Copepoda	0.1	10.6	4.5	2.2	0.7
Chironomidae	0.2	8.5	1.2	0.2	14.5
Caenis[a]	-	4.9	0.6	0.3	0.3
Hexagenia[b]	0.2	0.3	0.5	tr	tr
Odonata	0.8	1.4	0.2	0.2	0.6
Mollusca	0.1	0.3	0.7	0.6	0.4
Trichoptera	-	1.0	0.6	0.5	0.2
Perch	-	-	tr	-	-
Green sunfish	-	-	tr	tr	-
Killifish	-	-	tr	tr	-
Unknown fish	-	tr	tr	tr	-
Other	0.1	0.3	0.7	0.2	8.7[d]
Total	31.6	60.0	15.8	9.0	31.2
5.0-6.9 inch group					
Sample size	16	60	37	33	11
Percentage empty	6	8	24	45	55
Cladocera	-	tr	-	-	1.1
Copepoda	-	tr	0.1	-	-
Chironomidae	0.2	2.5	0.4	-	1.5
Caenis[a]	1.1	6.7	tr	-	0.1
Hexagenia[b]	1.4	1.7	0.4	0.1	-
Odonata	2.4	1.0	0.3	0.1	-
Mollusca	-	0.4	0.3	-	-
Trichoptera	-	-	0.3	-	0.2
Perch	-	-	-	-	-
Green sunfish	-	-	0.2	0.4	-
Killifish	-	tr	tr	0.1	0.1
Unknown fish	-	tr	0.1	0.2	0.2
Other	-	tr	-	0.1	4.6[d]
Total	5.1	12.4	2.2	1.0	7.8

(continued next page)

Table 8.--concluded

Size group and food item	1965	1966	1967	1968	1969
7.0-11.9 inch group					
Sample size	41	75	19	42	0
Percentage empty	17	5	21	36	-
Cladocera	-	tr	-	-	-
Copepoda	-	-	-	-	-
Chironomidae	-	8.9	0.2	-	-
Caenis[a]	-	0.9	-	-	-
Hexagenia[b]	3.4	4.3	0.1	tr	-
Odonata	2.1	1.2	0.2	0.1	-
Mollusca	0.1	0.2	-	-	-
Trichoptera	-	0.1	0.9	-	-
Perch	tr	0.2	0.1	0.1	-
Green sunfish	-	tr	0.6	0.1	-
Killifish	-	tr	0.1	0.1	-
Unknown fish	tr	tr	0.4	0.1	-
Other	tr	0.1	-	0.1	-
Total	5.7	16.0	2.6	0.6	0

[a] Includes other small mayflies.

[b] Includes another large mayfly, *Ephemera*.

[c] Estimated number.

[d] All Amphipoda.

Table 9.--Average size, or range in size (mm), of planktonic and benthic invertebrates in stomachs of perch of various sizes and in plankton net and Eckman dredge samples from Cassidy Lake in 1966

Organism	Method of capture							
	Net	Dredge	Perch (inch group)					
			3.0	4.0	5.0	6.0	7.0	8.0-10.0
Collected 15-29 April								
Cladocera	0.2-0.9[a]	-	0.9	1.5	-	-	-	-
Copepoda	0.8-1.9	-	0.9	0.9	-	-	-	-
Chironomidae	-	6.5	3.3	4.5	-	9.3	9.3	8.9
Hexagenia[1]	-	13.4	8.1	10.0	6.8	12.6	12.6	21.4
Caenis[2]	-	3.6	3.3	3.2	3.4	4.2	5.0	10.0
Odonata	-	6.4	6.1	9.7	-	7.9	8.4	18.5
Mollusca	-	6.6	1.5	-	-	9.0	7.0	9.0
Trichoptera	-	5.6	2.0	4.5	-	-	-	18.3

	Method of capture					
	Net	Dredge	Perch (inch group)			
			3.0	4.0	5.0	6.0-9.0
Collected 20-29 June						
Cladocera	0.4-0.9[a]	-	1.0	-	-	-
Copepoda	0.7-1.6	-	1.0	1.0	-	-
Chironomidae	-	5.1	2.7	-	5.0	-
Hexagenia[1]	-	16.3	-	14.5	-	17.0
Caenis[2]	-	3.9	2.4	3.0	3.0	-
Odonata	-	8.4	6.5	8.7	11.2	19.3
Mollusca	-	2.7	1.7	-	-	7.5
Trichoptera	-	3.4	2.4	-	-	-

[1] Includes a few Ephemera also.

[2] Includes a few Ameletus also.

[a] Occasionally a few Cladocera (Daphnia) as large as 2.2 mm were taken in plankton netting.

Table 10.--Abundance (number per fish) and size (average in mm) of zooplankters in the stomachs of Cassidy Lake perch fry, and abundance (number per cubic meter) and size (range in mm) of zooplankters taken in plankton nets, 16 May to 6 June 1966

tr = trace = less than 0.05

Organism	16 May		19 May		6 June	
	Net[1]	Perch	Net	Perch	Net	Perch
Number of zooplankters						
Cyclops	3,100	1.0	6,640	23.6	27,180	18.6
Epischura	20	-	20	1.1	1,784	2.1
Bosmina	1,690	1.0	1,700	0.4	43,350	0.4
Ceriodaphnia	54	-	830	tr	1,320	0.1
Other[2]	-	1.5	-	-	-	-
Length of zooplankters						
Cyclops	1.1-1.5	1.1	0.9-1.4	1.3	1.1-1.6	1.3
Epischura	1.3-1.6	-	1.4-1.7	1.5	1.3-1.8	1.5
Bosmina	0.4-0.6	0.4	0.4-0.6	0.4	0.4-0.6	0.5
Ceriodaphnia	0.7-0.9	-	0.7-0.9	0.8	0.7-0.9	0.8
Other[2]	-	0.3	-	-	-	-

[1] The plankton sample was taken on 17 May.

[2] Other includes *Urceolus*, *Ceratium* and Arachnida.

Table 11.--Mean number per cubic meter, and range in size of Cassidy Lake zooplankton during 1966

	Mean number per cubic meter			Size (mm)
	May[1]	June	July[2]	
Diaptomus sp.	124	1,624	450	0.7-1.2
Cyclops vernalis	11,931	12,829	3,126	0.9-1.9
Epischura lacustris	157	2,600	4,810	1.2-1.9
Bosmina coregoni	2,506	69,852	22,787	0.7-1.2
Ceriodaphnia lacustris	155	5,044	16,948	0.7-0.9
Rotatoria	-	-	-	-
Nauplii	4,091	2,325	1,438	-
Adult[3]	5,261	33,001	25,001	0.04-0.3

[1] Includes collection of 29 April.

[2] 1-15 July only.

[3] Identified as *Trichocera* and *Testudinella*.

Table 12.--Average number of benthic organisms per one-quarter square foot of Cassidy Lake

tr = trace = less than 0.05

	1966			1967		1968
	Spring	Summer	Fall	Spring	Summer	Spring
Amphipoda	tr	0.0	tr	0.0	0.0	2.0
Chironomidae	17.7	12.2	7.8	1.5	0.9	1.6
Hexagenia and Ephemera	2.2	0.6	1.2	0.8	tr	0.3
Other mayfly	4.5	0.7	0.8	0.2	0.1	0.0
Odonata	2.4	0.5	0.2	0.1	0.2	tr
Mollusca	0.1	0.5	0.0	0.1	0.1	0.8
Trichoptera	0.2	0.3	0.1	1.1	0.0	0.5
Annelida	0.0	0.0	tr	0.1	0.0	0.1
Other[1]	0.3	0.3	1.5	0.6	0.4	0.2
Total	27.4	15.1	11.7	4.5	1.7	5.5

[1] Includes Chaoborus, Anthromyiidae, Sialis, and Hydracarinae.

Table 13.--Summary of data used in fecundity studies of perch and coefficients determined for the regressions:

$$\log_{10} \text{eggs} = \log a + b \log_{10} \text{length}$$

Collection	Lake	Number of fish	Size range (inches)	Regression coefficients	
				log a	b
1964	Cassidy	7	4.2-10.3	1.0695	3.4147
1965	Sugarloaf	5	4.5- 6.7	1.0278	3.3702
1966	Sugarloaf	24	4.1-11.3	0.5818	3.7742
1967	Cassidy	19	3.8-11.1	0.8913	3.5436
1968	Cassidy	22	3.8-11.7	1.1244	3.3206
1969	Cassidy	9	3.8-10.6	0.9073	3.4197
1964-69	Cassidy	57	3.8-11.7	1.0019	3.4247
1964-69	Both	86	3.8-11.7	0.9415	3.4556

Table 14.--Food of 37 small, 42 medium and 92 large green sunfish from Cassidy Lake between October 1966, and February 1969

tr = trace = less than 0.05

Food item	Size group of green sunfish (inches) 0.8-2.9 Number per fish	0.8-2.9 Size (mm)	3.0-3.9 Number per fish	3.0-3.9 Size (mm)	4.0-6.0 Number per fish	4.0-6.0 Size (mm)
Cladocera	19.9	0.3-0.8	1.0	0.1-1.0	-	-
Copepoda	33.4	0.4-1.0	0.5	-	-	-
Chironomidae	0.3	1.0-3.0	0.4	2.0-4.0	0.1	2.5
Caenis[a]	-	-	-	-	tr	-
Hexagenia[b]	tr	-	0.1	18.0	0.2	5.0-30.0
Odonata	-	-	0.1	12.0	tr	13.0-26.0
Mollusca	1.0	1.0-2.5	0.5	1.0-3.0	0.8	2.0-2.5
Trichoptera	tr	-	1.8	4.0-5.0	-	-
Perch	-	-	-	-	tr	19.0-89.0
Green sunfish	-	-	-	-	tr	20.0
Killifish	-	-	-	-	tr	-
Unknown fish	-	-	-	-	-	-
Other	0.9	-	2.0	2.5-15.0	0.9	1.0-35.0
Total	55.5	-	6.4	-	2.1	-

[a] Includes other small mayflies. [b] Includes another large mayfly, Ephemera.

Table 15.--Structure of a hypothetical perch population from which the harvest of perch larger than 7.0 inches would be optimal

Age	Natural mortality	Perch per acre Number	Perch per acre Pounds	Average length (inches)
1		100	1.4	3.3
	0.15			
2		85	6.5	5.8
	0.41			
3		50	6.9	7.0
	0.41			
4		15[a]	3.0[a]	8.0

[a] The predicted perch population if fishing mortality is 0.5.

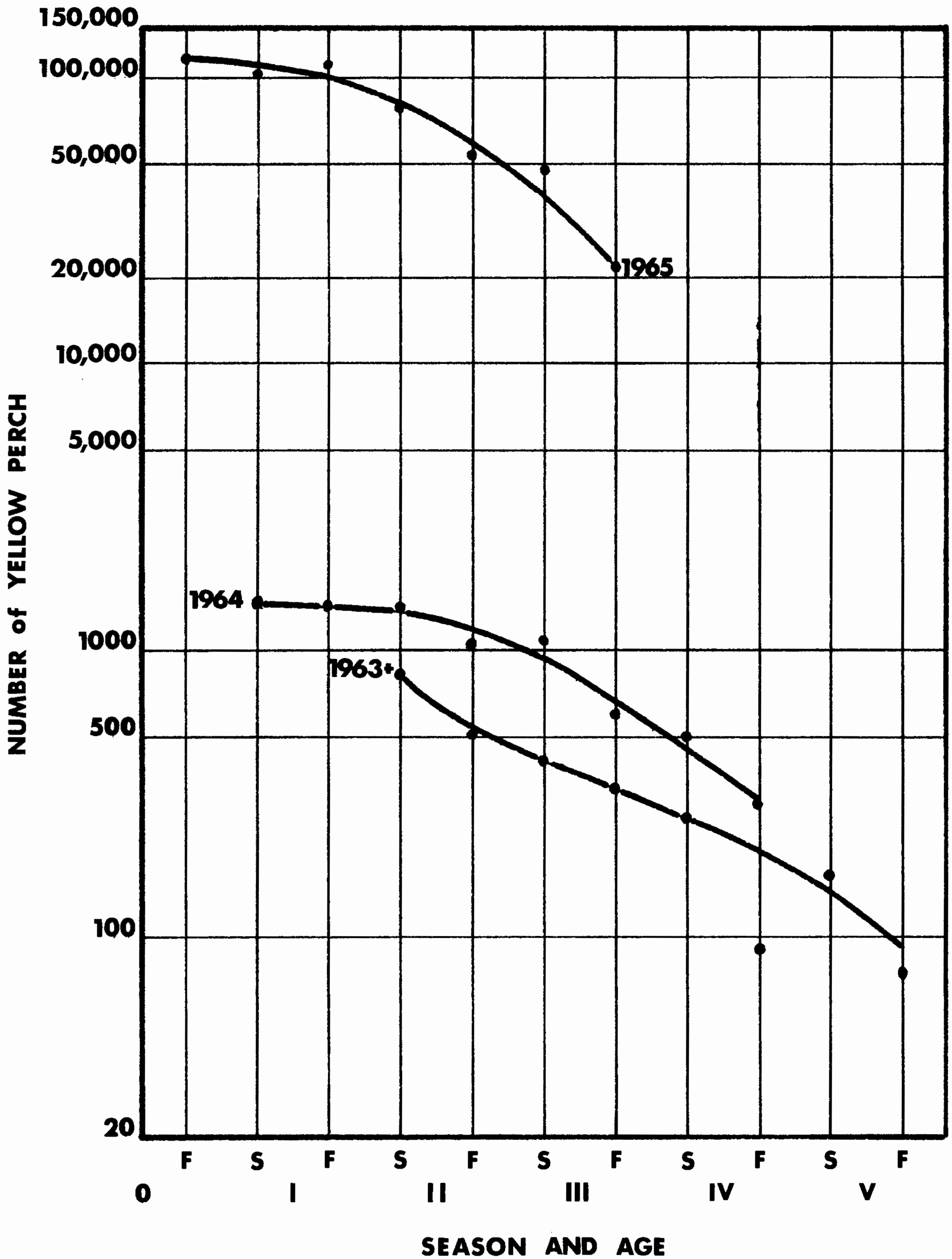

Figure 1.--Survival curves for the 1963 and older, 1964, and 1965 year classes of perch in Cassidy Lake. (F = Fall estimate; S = Spring estimate)

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