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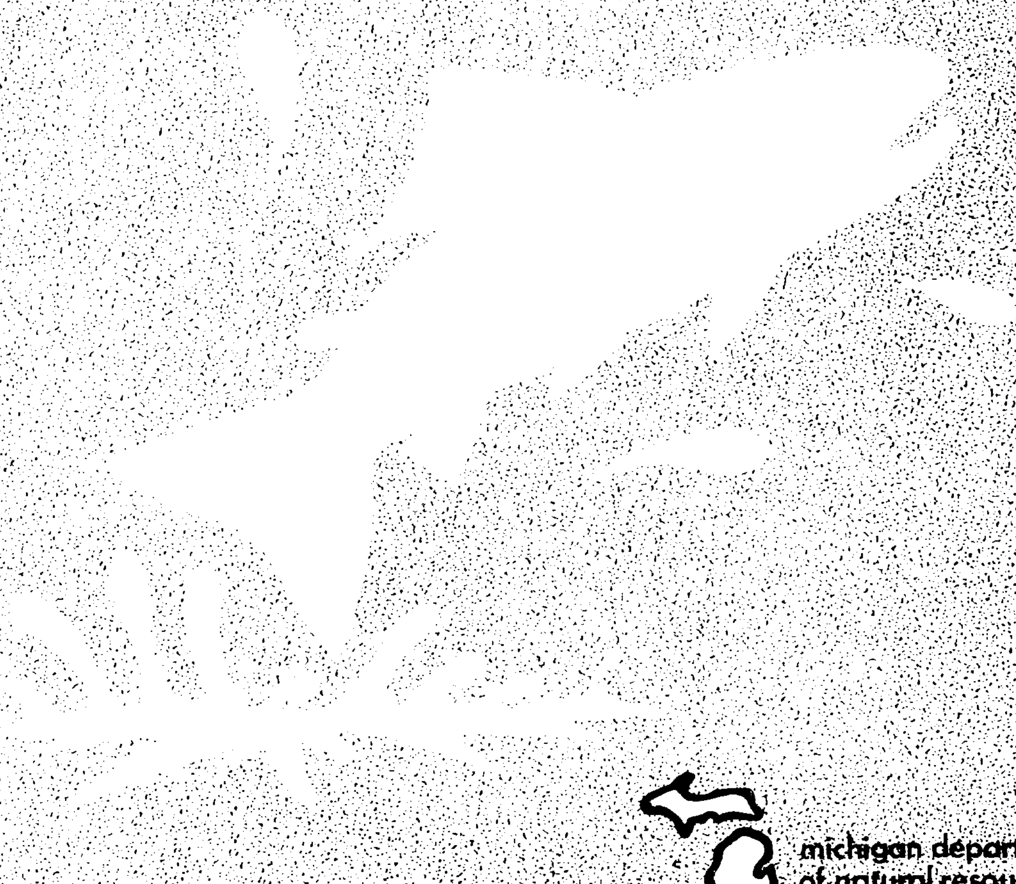

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SOME FACTORS INFLUENCING SIZE OF THE YEAR CLASS OF BLUEGILLS (LEPOMIS MACROCHIRUS) IN PONDS[1]

By W. C. Latta and J. W. Merna

ABSTRACT

At the Saline Fisheries Research Station nine ponds, each about one-half acre in size, were planted in May 1966 and 1968 with matched adult bluegills 5.0-6.9 inches total length. The nine ponds were grouped into blocks of three, and on a random basis each pond of a block received 8, 16 or 32 bluegills. In late September or early October the ponds were drained to determine the number of bluegill fry produced. In both years spawning occurred in June and samples of fry were taken regularly thereafter to determine growth and food habits. Samples of zooplankton were taken each week in 1966 and biweekly in 1968. Benthos was sampled biweekly in 1966 and each month in 1968. A recruitment curve was drawn which shows the relationship between number of eggs and resulting bluegill fry. Survival and growth of fry in the ponds were density dependent. Production of bluegill fry, which is dependent upon growth and survival, reached a peak at about 12 g/m^3 with a level of 120 $eggs/m^3$. The ratio of production to standing crop of bluegill fry had a mean of 1.3. The fry ate zooplankton almost exclusively which resulted in a sharp decline in zooplankton abundance in mid-July in all ponds in both years. Benthic organisms were seldom eaten. The phytoplankton counts made in 1968 increased with the decrease in zooplankton abundance. Primary production measured during the summer by light-and-dark bottle oxygen determinations had a high correlation with phosphate concentrations and standing crop of phytoplankton. A stepwise multiple regression of the effects of number of eggs, primary production, and the square of each of these quantities, on number of bluegill fry indicated that number of eggs and number of eggs squared had the greatest correlation with number of fry (0.89) and accounted for 80% of the variation. However, the addition of primary production and primary production squared increased this correlation to 0.97 and the percentage of variation to 93%.

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

Introduction

The relationship between the number of adults in a fish population and the number of young they produce is poorly understood. In 1954, Ricker published an exceptional analysis of the problem including examples from invertebrate as well as fish populations. He found that "Plotting net production (reproductive potential of the adults obtained) against the density of stock which produced them . . . gives a domed curve whose apex lies above the line representing replacement reproduction." Since then much theoretical consideration has been given to this problem (Larkin, 1973) but empirical observations have not been common. In the present study the relationship between the number of adult bluegills (*Lepomis macrochirus*) and the young they produce was determined experimentally. Food supply of the young, as measured by standing crop of zooplankton and benthos, and by production of phytoplankton, was also considered in an attempt to quantify the relationship among the adults, young and the available food.

Methods

The experiments were done in ponds at the Saline Fisheries Research Station, Saline, Michigan. Of the 18 ponds available, only ponds numbered 5 through 10, and 14 through 16 were used (Fig. 1). The ponds are rather uniform in size, and each slightly larger than a half acre in area. The area, mean depth and volume of each experimental pond are given in Table 1. The ponds were drained each spring and fall--in the spring to remove extraneous fish, and in the fall to count the experimental fish. After filling in the spring, only enough water to balance losses from leakage and evaporation was run into each pond. Total alkalinity of the water in the ponds ranged from 130 to 180 ppm, pH was about 8.2, dissolved oxygen more than sufficient for fish, and summer water temperatures usually in the 70's (F) (Table 2).

Bluegills.--On 20 May 1966, and 21 May 1968, the nine ponds described above were planted with mature bluegills. The fish were selected for size and all were within the group 5.0-6.9 inches total length. The ponds were divided into blocks of three, and on a random basis each pond of a block received 8, 16 or 32 fish. Thus there were three ponds containing 8 fish, three containing 16 fish, and three with 32 fish. The ratio of number of 5-inch to 6-inch fish was 3:5 in each pond. Any fish found dead after planting was replaced. Spawning apparently took place in mid-June in both years. Fry were first collected on 24 June 1966 and 20 June 1968. Collections were continued nearly every week during the summer in 1966 but only every month in 1968. Ten to 25 fry were collected each time for estimates of growth and to determine feeding habits. In late September and early October the ponds were drained, and estimates were obtained of the number of fry in each pond by weighing and counting several samples and multiplying the mean number per unit weight times the total weight of fry in each pond. Adult bluegills were counted, measured, weighed and a sample of scales taken.

The sex ratio of the adults in each pond also was determined at the time of draining. In both 1966 and 1968 the adult stock was obtained from Sugarloaf Lake, Washtenaw County, Michigan. Fecundity was determined from 20 females in a sample taken from Sugarloaf Lake in 1966 at the same time as the planted fish were taken. These 20 fish ranged in size from 5.1 to 7.4 inches total length. The number of eggs for each fish was estimated by counting a sample per unit weight of the total ovary. The regression line calculated for number of eggs (y) on total length of fish (x) was $y = -50,154.78 + 10,697.64\,x$. This equation indicated that the average 5.5-inch bluegill female contained 8,682 (± 1,880) eggs; the 6.5-inch female--19,380 (± 2,540) eggs. These estimates were used also in 1968.

In the bluegill, as in other centrarchids, the ovary contains eggs of more than one size. Larimore (1957) recognized seven sizes of eggs in the warmouth (*Lepomis gulosus*); Carbine (1948) recognized three sizes in the bluegill which he called immature, intermediate and mature. He was able to recognize mature eggs in fish only when captured immediately before spawning. Because bluegills will spawn more than once during a season it is difficult to estimate the number of eggs that will be deposited. In this study we counted all eggs macroscopically visible, recognizing that this gave a maximum estimate; undoubtedly a somewhat smaller number would be laid. On the subject of number of eggs versus size of bluegills, information in the literature (Ulrey, Risk and Scott, 1938; Morgan, 1951; Mayhew, 1956) is in reasonable agreement with our counts, considering the problem of succession of egg sizes.

The number of stocked bluegills surviving and the number of females present in each pond were determined in the fall when the ponds were drained (Table 3). From the scale samples, approximate size at stocking was back-calculated for each female. With the known number of 5-inch and 6-inch females in each pond and the estimates of average fecundity, it was possible to calculate the potential egg production for the population in each pond. The percentage survival from potential egg production to fry in the fall is summarized in Tables 4 and 5.

Age of the adult bluegills stocked in the ponds ranged from IV to VIII. Growth of these fish in the ponds was excellent. At time of draining, their size ranged from 7.0 to 9.3 inches total length.

Although an intensive effort was made in both years to keep other fish from the ponds, at the end of the summer all of the ponds contained green sunfish (*Lepomis cyanellus*) and minnows, mostly the fathead *Pimephales promelas*. Seldom did the weight of the extraneous fishes exceed 10% of the weight of the bluegill fry, and there was no obvious detrimental or beneficial influence on the fry by their presence.

On 25-26 June 1968, an unprecedented flood of the Saline River inundated several of the experimental ponds. Fish were mixed among ponds and also fish from outside were brought into the ponds. As a result of the flood, the data from ponds numbered 5, 9, 14 and 15 were not usable.

Following Ricker (1958), production was calculated for the fry in each pond from June through draining in September or October, using exponential growth and mortality. The initial weight of the fry for all calculations was assumed to be 0.002 gram. This was the mean from the total weight of 15 recently hatched fry. The mean weights of the fry collected periodically from each pond were plotted and a line to fit the points was drawn by eye. In general, growth of fry essentially ceased in early to mid-August in most ponds. The exceptions were the ponds where there were few fry. After the initial weight, the next weight used in the production calculation was from the first sample in late June; then weights at monthly intervals were used, until the ponds were drained in late September or October. Empirical weights were used whenever feasible, with the other weights being taken from the drawn line. In most cases each sample for weight contained 25 fry, but the first sample in June contained only 10 while the sample at draining contained 50 or more. Mortality rate of the fry, from estimated number of eggs to fry present in the ponds in the fall (Table 4), was assumed to be proportional to growth. The estimates of standing crop and production are given in Table 6.

Primary production.--In both 1966 and 1968 measurements of gross primary production were made. In 1968 also weekly measurements of nitrates, phosphates and phytoplankton abundance were made.[2] The phytoplankton abundance was determined by cell counts, and the various species were grouped in the following classes: Chlorophyta, Pyrophyta, Euglenophyta, Chrysophyta, and Cyanophyta.

Primary production was measured by the light-and-dark bottle oxygen technique. There are several methods of determining primary production in natural waters based on two conceptually different approaches: (1) measurements performed on isolated samples of natural communities, and (2) measurements performed directly in the natural environment. Both approaches depend on measurable changes in certain metabolic factors, such as oxygen, pH, carbon dioxide or conductivity, that can be quantitatively interpreted in terms of community metabolism. Measurements performed on isolated samples additionally include tracer techniques, with C_{14} being the most common. The relative merits of these various techniques have been reviewed many times in the literature (Ryther, 1956; Vinberg, 1960;

[2] The analyses of chemistry and plankton were done, generously, by personnel of the Great Lakes Laboratory of the U.S. Bureau of Sport Fisheries and Wildlife, now Fish and Wildlife Service.

Vollenweider, 1969). It is hardly necessary to repeat these discussions here, except for a few comments germane to this study.

Measurements on non-isolated communities may represent a truer analysis of natural metabolism but this advantage is probably offset by other complications. There is lack of agreement on the importance of diffusion of oxygen into and out of the body of water being studied. Methods employing isolated samples have been criticized as not representative of the natural environment. This criticism is legitimate if the exposure period exceeds 4 to 6 hours. Long periods of exposure may allow for unknown qualitative and quantitative changes in the enclosed populations. Estimates of production over long periods, such as the 24-hour day, are more realistic if calculated by the summation of a sequence of short exposures.

In very productive waters, even short exposures may lead to super-saturation and loss of oxygen by bubble formation, or a significant change in pH. It is also possible, but rare, to record significantly higher oxygen content in the dark bottles after exposure, compared to clear bottles. This is incongruous, and no conclusive explanation of this anomaly has ever been presented.

Vollenweider (1969) presents a concise summary of the oxygen light-and-dark bottle technique:

> "When an exposure is made with sub-samples of a phytoplankton population in clear (light) and darkened bottles, the initial concentration of dissolved oxygen (C_1) can be expected to fall to a lower value (C_2) in the darkened bottles by respiration, and to be changed to another value (C_3) in the clear bottles according to the difference between photosynthetic production and respiratory consumption. If other processes involving oxygen (e.g., photoxidative consumption) are absent or can be neglected, and if it can be assumed that respiratory consumption is not altered by illumination, then the difference ($C_1 - C_2$) represents the respiratory activity per unit volume over the time interval involved, the difference ($C_3 - C_1$), the net photosynthetic activity, and their sum $(C_3 - C_1) + (C_1 - C_2) = (C_3 - C_2)$, the gross photosynthetic activity. On this basis it is possible to estimate gross photosynthesis directly from the difference in concentration between the clear

> and darkened bottles, but further knowledge of the initial concentration is needed for estimates of respiration and net photosynthesis."

Primary production determinations for this study were made biweekly between 3 July and 28 August during 1966 and 1968; nutrient analyses and algal counts were between 2 July and 29 August (Table 7). Estimates of gross photosynthesis per day were calculated by summation of three individual 4-hour exposures between 8:00 AM and 8:00 PM. At the beginning of each 4-hour period, three 250-ml BOD bottles were filled with water from a depth of one meter from each of the study ponds. One sample was analyzed immediately to determine the initial oxygen concentration. The other two bottles were suspended in the pond at a depth of one meter during the 4-hour exposure period. One of these bottles was the "light" bottle and the other was covered with heavy-duty aluminum foil to become the "dark" bottle. All oxygen determinations were made by the chemical Winkler method.

Two adjustments were made in the data to compensate for criticisms of the bottle technique. When a pond became supersaturated during the afternoon, and bubble information was possible, the photosynthetic rate from the morning samples was used for the full day, and when the dark bottles contained a higher oxygen content than the light bottles after exposure, the respiration rate was recorded as zero. Both of these situations were rare.

The daily values of primary production were multiplied by 14 to obtain an estimate of total gross production during the 2-week period. The measured photosynthetic rates were assumed to be representative of the rates 1 week prior to, and 1 week following the day of the determinations. The biweekly totals thus determined were further summed to give an estimate of the total production for the period of 3 July to 28 August.

Zooplankton.--Samples of zooplankton were taken each week in 1966 and biweekly in 1968 during the experiments. Four samples were taken from each pond--one from each quarter of the pond. The quarter was also divided into four parts and the part to be sampled was determined by a random choice. A plankton net of No. 10 mesh nylon with a diameter of 31 centimeters, 1 meter in length, was used for each collection. The net was pulled with a constant motion from the bottom to the surface at each collection site. Volumes of zooplankton were determined for each sample. Each sample was centrifuged at a constant rate to assure standard measurements. In 1967, as part of another experiment, zooplankton samples taken during the day were compared with similar samples taken after dark for seven ponds. Samples were taken in late June, early July, early August and late August. In about half of the comparisons, night samples were significantly larger than day samples. In all probability day samples somewhat underestimate the standing crop of zooplankton in the ponds but in the present case they are used only as an index of zooplankton abundance. The mean volume of zooplankton, in milliliters per cubic meter, per pond during the experiments is given in Table 8.

Benthos. --Four bottom samples were collected from each pond biweekly in 1966 and monthly in 1968. Sampling procedure was identical to that used for zooplankton. A random quarter was selected from each quarter of a pond. Preliminary sampling indicated no significant difference in abundance of bottom fauna at different depths or locations in the ponds. Consequently, a stratified sampling design was not used. Samples were taken with a 1/4-square-foot Ekman dredge and were sieved in a screen with 60 meshes per inch. Organisms were "picked" while alive by flotation in sugar solution. The total wet weight of organisms was determined for each sample. Weight in grams per square meter for each pond during the experiments is given in Table 8.

Results

Bluegills. --Survival of bluegill fry in the ponds was density dependent. A recruitment curve was constructed by plotting the number of fry per cubic meter at time of draining in the fall against the estimated number of eggs per cubic meter for each pond (Table 8, Fig. 2). It appears that 120 to 130 eggs per cubic meter result in an optimum level of about 41.5 fry per cubic meter. After this optimum point is reached, an increase in eggs results in an apparent decrease in fry. Judging from the point of origin of the curve, something greater than 10 to 20 eggs per cubic meter is needed to guarantee some survival of fry.

Growth of the fry was also related to density. In ponds with high density of fry, growth was slow. It was obvious at the time of draining in the fall that the ponds with the most fry contained the smaller fry. The average total length and estimated weight of 50 or more fry from each pond at time of draining are given in Table 9. Plotting total length against the number of fry per cubic meter for each pond illustrates the density-dependent relationship (Fig. 3). With an increase in density of bluegill fry per cubic meter, there is a decrease in the mean total length of fry. There is a rapid increase in length of fish at densities less than 15 fry per cubic meter.

A plot of fry production for each pond against number of eggs has the same form as the recruitment curve (Fig. 4). It appears that 120 to 135 eggs per cubic meter, which results in optimum growth and survival, also results in the optimum production of about 12 grams per cubic meter. Any increase in number of eggs does not lead to greater production, because of a decrease in growth and an increase in mortality. An increase in number of eggs apparently results in a decrease in productivity.

The ratio of production to standing crop of bluegill fry for the ponds was quite consistent (Table 6). With the exception of pond 9 in 1966, which had a ratio of 2.9, the others in both years varied only from 1.1 to 1.7 and had a mean of 1.3. There is no obvious explanation for the high value in pond 9, except that survival of fry was very low (0.5%) and growth was very good (70.3 mm) (Tables 4 and 9). However, in pond 6, similar conditions existed and the ratio was not high as in pond 9.

Stomachs of bluegills sampled each month during the experiments were examined to identify food eaten. In 1966, samples taken 24 June, 18, 19 July, 15, 16 August and 6, 7 September were examined. In 1968 the dates were 20 June, 7 July, 6 August and 4 September. The bluegills ate zooplankton almost entirely. Only occasionally would chironomid larvae appear in the stomachs. The genera of copepods found in the stomachs were *Cyclops* and *Diaptomus*; the cladocerans found were *Bosmina*, *Chydorus*, *Simocephalus*, *Scapholeberis*, *Diaphanosoma*, *Macrothrix*, *Leydigia*, *Daphnia*, *Pleuroxus*, *Ceriodaphnia* and *Alona*. Rotifers and ostracods were rare in the stomachs. In both years the fry had a major impact on abundance of zooplankton. Shortly after the fry appeared in the ponds in late June, the zooplankton started to decline and by mid-July it was mostly gone.

Primary production.--Average values of phosphorus (PO_4) and nitrogen (NO_3), numbers of algal organisms per milliliter, and total primary production during the period of 2 July to 29 August for 1968, and for primary production only in 1966, are given in Table 7.

Vinberg (1960) summarized productivity information available for ponds of various levels of productivity. He concluded that ponds of low productivity have a gross phytoplankton production of less than 1 g (0.7-0.8) oxygen per square meter per day. In the most productive ponds studied, the values were in the range of 3 to 4, and he was aware of ponds with daily production of 6 to 7 g oxygen per square meter per day or higher in isolated cases. He concluded that in ponds of varying productivity, the average values for the entire growing season (100-120 days) usually fall within the range of 0.5 to 5.0 g oxygen per square meter per day.

Production values reported per unit of surface area are determined by multiplying the measured quantity of oxygen production in milligrams per liter (g/m^3) times the average depth. Since the Saline ponds have an average depth of only 1.14 m (Table 1) our gross production values reported in milligrams oxygen per liter are nearly synonymous with grams oxygen per square meter. Division of the primary production values in Table 7 by 57, gives a range of daily production values of 1.1 to 11.2 g oxygen per square meter (mean 4.1) during the study period, which indicates that the productivity of our ponds is within the range of the most productive ponds. Bails and Ball (1966) also recorded primary production values comparable to ours in small ponds at Lake City, Michigan.

Phosphate concentrations were quite uniform throughout the summer. The values for Pond 16 were lower than for the others, with an average of 26 $\mu g/l$. Pond 10 was high in phosphates, with an average of 64 $\mu g/l$. The other three ponds were intermediate between these extremes, and fluctuated little during the 9-week study period.

Nitrate values fluctuated widely within ponds and between ponds. Most concentrations were high in June, but fell to near zero during July and August. For this reason the average of nine weekly samples is probably not very meaningful with respect to the seasonal productivity of a pond. Exceptionally high values early in the season influence the average, even though nitrate values may have been near zero in July and August.

Phytoplankton populations were low (less than 1,000 organisms per ml) in all ponds until 16 July. They then increased rapidly, and remained at a high level throughout July and August. Cell counts were fairly uniform within ponds. Rarely did the number of organisms change by more than a factor of two between weekly samples. The increase in number of cells occurred with the decrease in zooplankton (Hrbacek, Dvorakova, Korinek and Prochazkova, 1961).

The estimates of total primary production suggest that productivity was higher in 1966 than in 1968. Not only were most ponds higher in production in 1966, but the ponds changed in order of rank of productivity.

Even though there can be no doubt that algae production is dependent on availability of essential nutrients, it is often difficult to demonstrate this dependence by correlations of nutrient levels. In fact, Margalef (1968) is of the opinion that there is no reason to foresee a correlation between phosphate concentration and phytoplankton density, since a low phosphate level may indicate depletion by plants. He believes that the rate of increase of phytoplankton is more apt to be correlated with the rate of depletion of phosphate. This is probably true in a laboratory culture where an algal population starts at a low level of abundance with a large store of available nutrients. However, these conditions are seldom met in nature, where plant biomass is more likely to be in a state of equilibrium with the available nutrients.

The data indicate a high level of correlation between phosphate levels and both production and standing crop of phytoplankton. An analysis of the regression of total primary production during the summer of 1968, as a function of average phosphate levels, has a correlation coefficient of 0.91, and the log of the average phytoplankton cell counts has a correlation of 0.96 with the phosphate levels. The slopes of these two regressions are significant at the 95 and 99% levels, respectively. The log of the algal cell counts has a correlation of 0.77 with primary production. This regression is significant at the 80% level. These values not only demonstrate the relationship of phosphates to primary production, but also support the validity of using the technique of summation of several short light-and-dark bottle oxygen production estimates to calculate total phytoplankton production over an extended period of time.

The correlation between the oxygen production estimates and nitrate levels was very low (-0.38). In fact the negative correlation, if significant, would indicate that high rates of production were responsible for depletion of nitrates. The nitrate values in the ponds were almost always reduced to nearly zero when the phytoplankton abundance exceeded 2,000 cells per milliliter.

Zooplankton.--The common genera of zooplankters found in the ponds were the same as those in the stomachs of the bluegill fry. As indicated above, the fry drastically cropped the zooplankton. A plot of the mean standing crop (volume) of zooplankton for each pond (Table 8) against number of eggs present in each pond demonstrates this relationship between density of fry and abundance of zooplankton in the ponds (Fig. 5). Those ponds (e.g., 6, 9 and 16 in 1966) which had few or no fry present had much higher standing crops of zooplankton. Plots of the weekly or biweekly samples demonstrated that in those ponds with abundant fry, the zooplankters virtually disappeared by mid-July, whereas in those ponds with few or no fry the zooplankton abundance stayed high throughout the experiment.

Benthos.--All of the ponds experienced a peak in benthos abundance in June or early July. In the month following the peak, the biomass was rapidly depleted by emergence and remained low for the remainder of the summer.

The benthic community was made up almost entirely of Chironomidae and Oligochaeta with rare occurrences of *Caenis*, *Chaoborus*, Ceratopodonidae and Zygoptera. Almost the entire biomass of Chironomidae consisted of *Chironomus* sp.; however numerically *Procladius*, *Cryptochironomus*, *Tanytarsus* and *Polypedilum* were often significant. There was no evidence that the bluegill fry exerted any influence on the benthic population. As indicated earlier, only occasionally was a chironomid larva found in their stomachs.

Discussion

Hall, Cooper and Werner (1970) experimentally manipulated nutrients and predators for 3 years in a series of twenty 0.07-ha ponds at Cornell University. In 1967, the last year of the study, they introduced bluegills into nine of the ponds in April and May. The size structure of bluegills stocked simulated a natural population. In each pond 10 fish were stocked which had an average total length of 8.1 inches, 100 fish with an average length of 3.4 inches, 150 at 1.8 inches, and 1,000 at 1.0 inch. Although the 3.4-inch group had the potential for some spawning during the season, undoubtedly the 8.1-inch group contributed the bulk of the eggs. The ponds were grouped into three blocks of six ponds each for the addition of fertilizer and bluegills. Thus one block of ponds was designated high nutrient (HN), one medium (MN) and the third low nutrient (LN). Three ponds of each block were stocked with bluegills.

When they checked the fish populations in September, Hall et al. (1970) found 33 fry/m^3 of water in the LN ponds, 49 fry/m^3 in the MN ponds and 39 fry/m^3 in the HN ponds. The counts were not statistically significant from each other. Their mean value of 40 fry/m^3 is almost identical with our optimum level in the Saline ponds of 41.5 fry/m^3. Our recruitment curve (Fig. 2) indicates that a potential of 120 eggs/m^3 from adult stock is sufficient to produce the 41.5 fry/m^3, and additional eggs do not result in an increase in fry. In the ponds of Hall et al. (1970) the ten largest bluegills had the potential of 281 eggs/m^3 according to our calculations.

The fertility of the Cornell ponds was only slightly less than our ponds, judging from the total phosphorus levels. In our ponds, phosphorus varied from 26 to 64 μg/l, with a mean of 44 (Table 7); at Cornell the LN ponds had an average value of 17 μg/l; MN 30, and HN 64, for a mean of 37 μg/l. Although the HN ponds had a high phosphorus value for the season, the zooplankton did not respond to the increased nutrients until August. During June and July, when most of the fry were hatching, zooplankton levels were no higher in the HN ponds than in the LN and MN ponds. With the exception of the large increase starting in late July and extending through August, the Cornell ponds and our ponds had similar mean standing crops of zooplankton of about 2 to 4 ml/m^3 (conversion of dry weight to wet weight from Ravera, 1969). Undoubtedly the zooplankton level influences fry abundance. The Saline ponds were stocked with only the adult bluegills, whereas the Cornell ponds contained 1,250 yearling and larger bluegills as well as the adults; but judging from the relative abundance of fry in both sets of ponds, these yearlings and other fish had little effect on fry numbers in the Cornell ponds.

The relationship between bluegill fry and number of eggs is illustrated in Figure 2. A plot of bluegill fry density against primary production indicates a similar relationship (Fig. 6). An increase in primary production to about 350 g/m^3 results in a curvilinear increase in number of fry per cubic meter. The peak is reached at about 41.5 fry/m^3, and any increase in the primary production beyond 350 g/m^3 does not lead to an increase in number of fry.

A stepwise multiple regression was utilized to analyze the relative effects of number of eggs and primary production on number of bluegill fry. In an effort to calculate a line to fit the data, the values for primary production and number of eggs were squared and entered as independent variables. The number of eggs had the greatest correlation with the number of fry; R equaled 0.74 (Table 10). The stepwise additions of number of eggs squared, of primary production, and of primary production squared, lead to an R of 0.97 and a coefficient of determination (R^2) of 0.93. This suggests that 93% of variation is accounted for in this multiple regression, with 2% and 11% attributable to primary production. However, the experiments were designed for a limit on number of eggs. In nature it is probably seldom that there is a scarcity of eggs for bluegill reproduction. Under these conditions it would seem probable that primary production would be the real limiting factor for number of fry present. The number of fry per cubic meter can be predicted with the following equation:

$$\text{Fry/m}^3 = -11.221 + 0.127\ \text{Production} + 0.559\ \text{Eggs} - 0.000178\ \text{Production}^2 - 0.00206\ \text{Eggs}^2$$

With an increase in primary production it seems reasonable to assume an increase in benthos production and zooplankton production. Production estimates were not made for these segments of the pond system. However, the benthos standing crop (which was not cropped by the bluegill fry) has a correlation of 0.63 with the primary production. The zooplankton standing crops were influenced significantly by the number of bluegill fry (Fig. 5) and there is no correlation (0.23) for a plot of primary production against zooplankton standing crops for both years combined, for the ponds with large numbers of fry. However, 1966 data, considered alone, had a correlation coefficient of 0.86.

An increase in primary production leads to an increase in zooplankton production which results in more bluegill fry within the limitations found. However, many of the details of the mechanisms from primary production to fry need yet to be elucidated.

Table 1.--Area, mean depth, and volume of experimental ponds at the Saline Fisheries Research Station

Pond number	Area		Mean depth[1]	Volume
	Acres	m^2	(m)	m^3
5	0.74	3,004	1.3	3,536
6	0.70	2,826	1.2	2,848
7	0.65	2,620	1.2	2,534
8	0.62	2,506	1.2	2,599
9	0.66	2,664	1.3	2,880
10	0.62	2,502	1.1	2,473
14	0.53	2,130	1.0	1,930
15	0.71	2,863	1.0	2,544
16	0.59	2,397	1.0	2,301

[1] Mean depth excludes the sloping bank of each pond.

Table 2.--Monthly mean (M) of maximum and minimum water temperatures with standard deviations (SD) for Pond 6 at Saline, May-September, 1966 and 1968

(N = number of observations)

Month	1966					1968				
	Max		Min			Max		Min		
	M	SD	M	SD	N	M	SD	M	SD	N
May	--	-	--	-	--	62	4	59	2	8
June	77	6	70	7	22	76	6	70	5	19
July	83	3	75	3	20	82	4	75	4	22
August	78	7	70	3	23	82	4	74	4	21
September	75	5	66	4	10(9)	76	3	66	3	8

Table 3.--Number of mature bluegills stocked, number recovered, and number of females recovered in ponds at Saline, 1966 and 1968

Pond number	1966 Stocked	1966 Recovered	1966 Females	1968 Stocked	1968 Recovered	1968 Females
5	16	15	10	8	6	5
6	8	6	3	16	15	5
7	32	31	23	32	18	9
8	16	16	9	16	13	8
9	8	7	2	8	6	2
10	32	30	22	32	28	18
14	32	30	22	16	13	6
15	16	16	9	32	32	13
16	8	7	2	8	8	6

Table 4.--Survival of bluegill fry in ponds at Saline, summer 1966

Pond number	Number of eggs	Number of fry	Percent survival
8 spawners per pond			
6	47,442 ± 15%	3,364 ± 6%	7.1
9	28,062 ± 16%	140 -	0.5
16	38,760 ± 13%	0 -	0.0
16 spawners per pond			
5	129,616 ± 17%	98,991 ± 21%	76.4
8	142,326 ± 15%	96,668 ± 13%	67.9
15	142,326 ± 15%	66,513 ± 15%	46.7
32 spawners per pond			
7	360,156 ± 15%	115,332 ± 5%	32.0
10	340,776 ± 15%	98,853 ± 44%	29.0
14	351,474 ± 15%	65,450 ± 11%	18.6

Table 5.--Survival of bluegill fry in ponds at Saline, summer 1968

Pond number	Number of eggs	Number of fry	Percent survival
8 spawners per pond			
16	84,186 ± 16%	35,680 ± 4%	42.4
16 spawners per pond			
6	86,202 ± 14%	51,922 ± 4%	60.2
8	112,248 ± 16%	47,076 ± 4%	41.9
32 spawners per pond			
7	142,326 ± 15%	72,440 ± 17%	50.9
10	263,256 ± 15%	98,617 ± 2%	37.5

Table 6.--Standing crop and production of bluegill fry in ponds at Saline, 1966 and 1968

Year, pond number	Standing crop		Production		Ratio production: standing crop
	g/m^3	lb/acre	g/m^3	lb/acre	
1966					
5	8.73	91.6	11.73	123.0	1.3
6	2.87	25.8	4.41	39.5	1.5
7	5.71	49.3	7.78	67.1	1.4
8	6.34	58.6	7.23	66.9	1.1
9	0.24	2.3	0.69	6.7	2.9
10	6.28	55.3	10.52	92.7	1.7
14	12.66	102.3	14.81	119.8	1.2
15	6.85	54.3	7.80	61.8	1.1
1968					
6	7.68	69.1	8.38	75.4	1.1
7	4.50	38.8	7.81	67.4	1.7
8	7.63	70.6	9.90	91.6	1.3
10	8.15	71.8	10.06	88.4	1.2
16	6.87	58.8	7.96	68.2	1.2

Table 7.--Primary production, phosphates, nitrates and algal organisms in the ponds at Saline during 2 July to 29 August, 1966 and 1968

Pond number	Primary production mg O_2/liter/57 days		PO_4 μg/liter	NO_3 μg/liter	Algal organisms[1] per ml
	1966	1968	1968	1968	1968
5	177.0	---	--	--	---
6	198.5	184.9	48	16	3,700
7	153.9	161.0	44	5	3,500
8	404.1	99.7	39	2	4,200
9	149.6	---	--	--	---
10	581.4	193.4	64	9	21,450
14	126.0	---	--	--	---
15	139.3	---	--	--	---
16	210.3	63.1	26	27	900

[1] To the nearest 50.

Table 8.--Estimates of primary production, mean standing crop of zooplankton and benthos, number of bluegill fry at draining, and number of eggs planted in the ponds at Saline, 1966 and 1968

Year, pond number	Primary production g/m^3/ 57 days	Zoo-plankton ml/m^3	Benthos g/m^2	Bluegill fry Number per m^3	Eggs Number per m^3
1966					
5	177.0	1.8	9.5	28.0	36.7
6	198.5	23.9	20.7	1.2	16.7
7	153.9	1.6	9.0	45.5	142.1
8	404.1	4.3	12.1	37.2	54.8
9	149.6	22.8	16.8	tr[1]	9.7
10	581.4	5.0	22.0	40.0	137.8
14	126.0	1.8	4.3	33.9	182.1
15	139.3	3.5	3.9	26.2	55.9
16	210.3	16.7	3.0	0.0	16.8
1968					
6	184.9	10.3	8.2	18.2	30.3
7	161.0	1.8	9.1	28.6	56.2
8	99.7	2.5	2.2	18.1	43.2
10	193.4	4.6	5.9	39.9	106.5
16	63.1	4.5	4.3	15.5	36.6

[1] tr = trace, indicates value of 0.05 or less.

Table 9.--Mean total length and estimated weight of bluegill fry at draining, in ponds at Saline, September or October, 1966 and 1968

(Sample size was 50 or more)

Year, and pond number	Total length (mm)	Weight (g)
1966		
5	29.2	0.40
6	58.0	2.33
7	22.9	0.13
8	25.8	0.18
9	70.3	4.83
10	24.6	0.20
14	30.4	0.30
15	26.1	0.26
1968		
6	32.5	0.42
7	24.3	0.24
8	31.9	0.47
10	25.2	0.20
16	29.5	0.44

Table 10.--Results of multiple correlation analysis of the relationship of number of eggs and primary production to density of bluegill fry in ponds at Saline, 1966 and 1968

Independent variables entered	Multiple correlation coefficient (R)	Coefficient of determination (R^2)	Increase in R^2
Number of eggs	0.74	0.54	0.54
Number of eggs squared	0.89	0.80	0.26
Primary production	0.90	0.82	0.02
Primary production squared	0.97	0.93	0.11

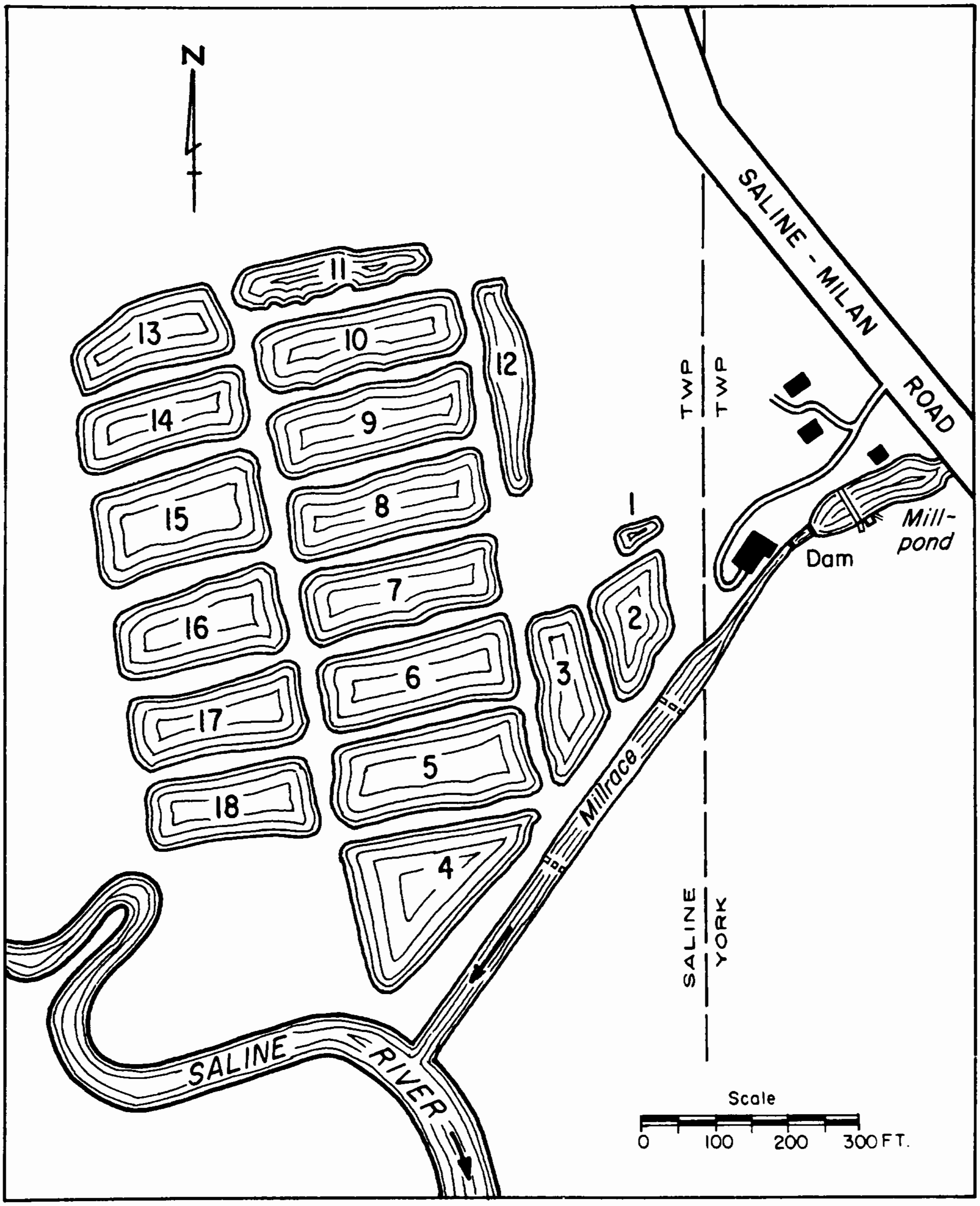

Figure 1. --Experimental ponds at the Saline Fisheries Research Station, Saline, Michigan.

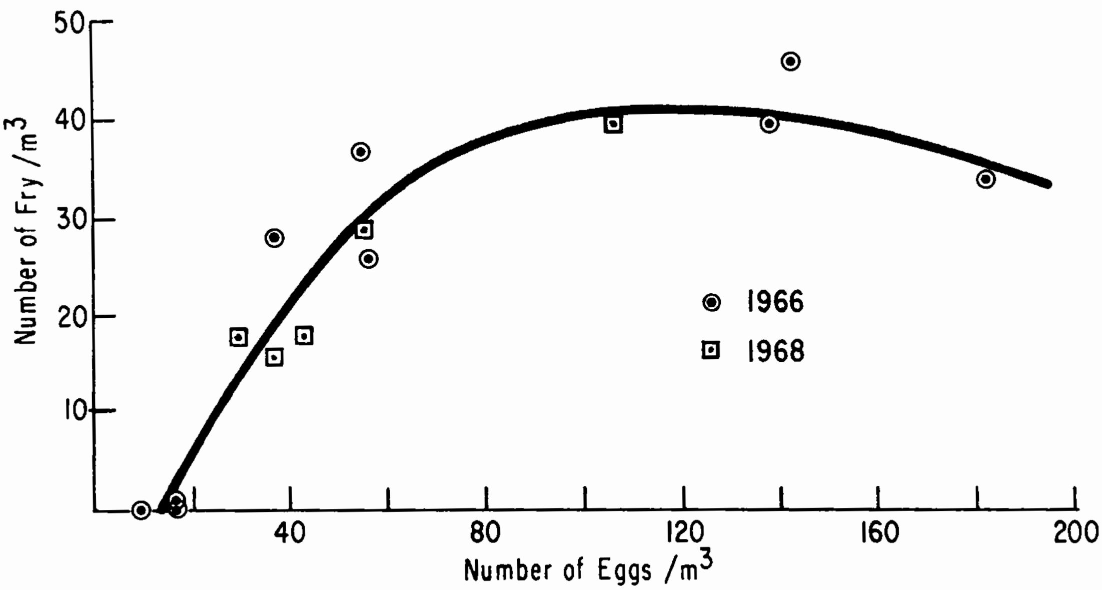

Figure 2. --Recruitment curve for bluegill fry in ponds, Saline Fisheries Research Station, 1966 and 1968.

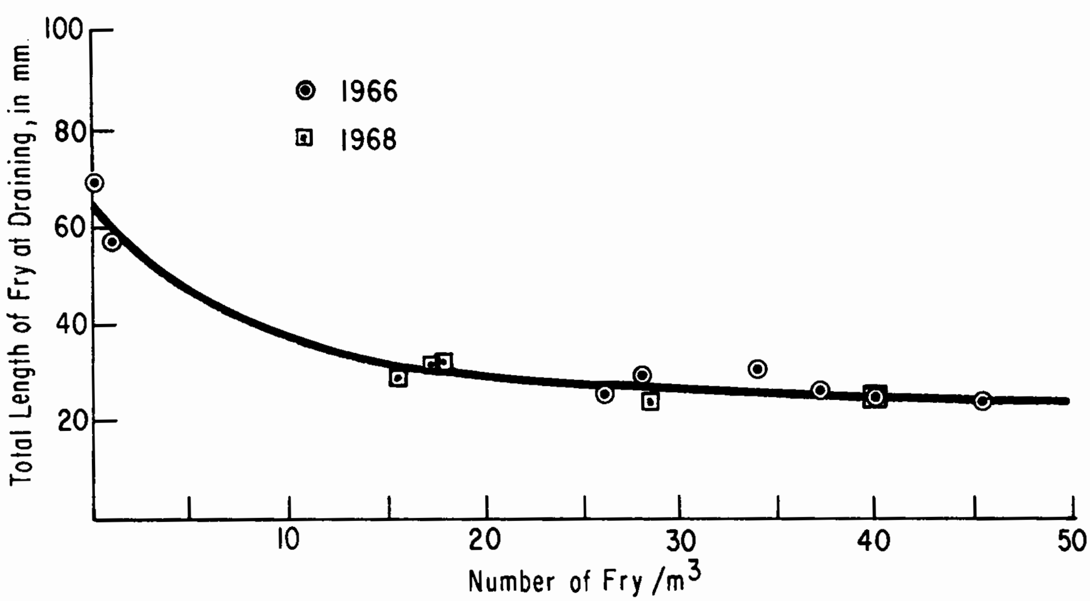

Figure 3. --Relationship between total length at time of draining and density of bluegill fry in ponds, Saline Fisheries Research Station, 1966 and 1968.

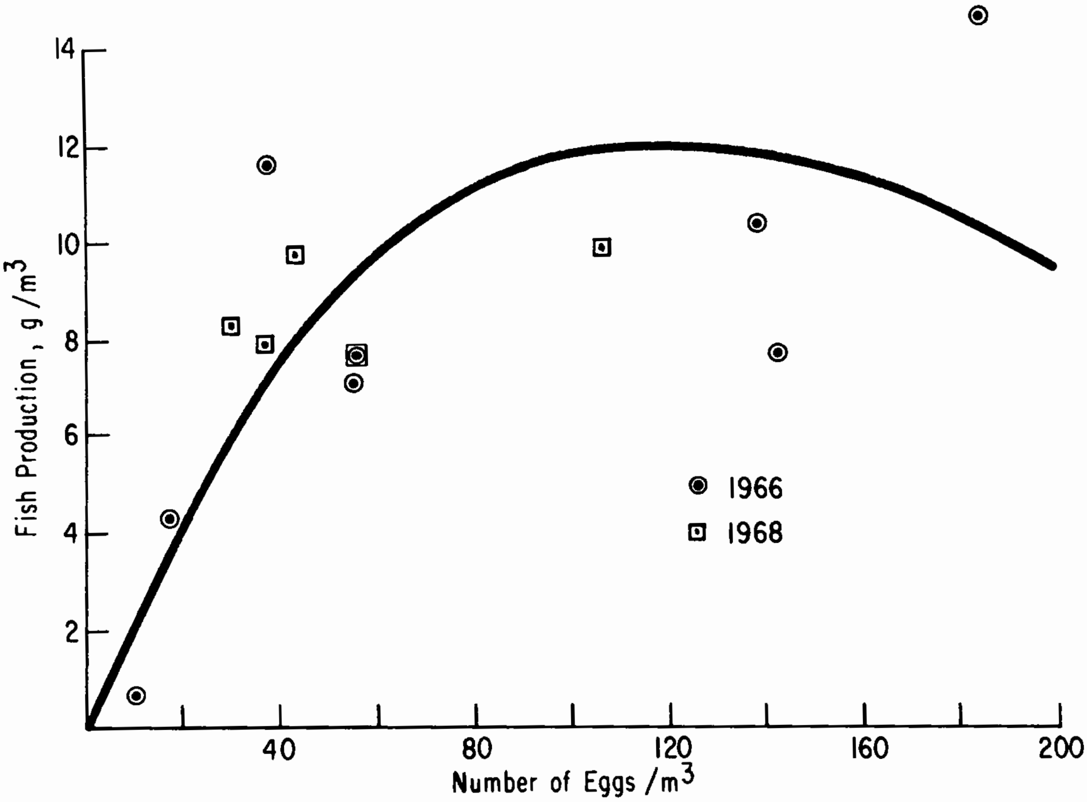

Figure 4. --Relationship between production of bluegill fry and number of eggs in ponds, Saline Fisheries Research Station, 1966 and 1968.

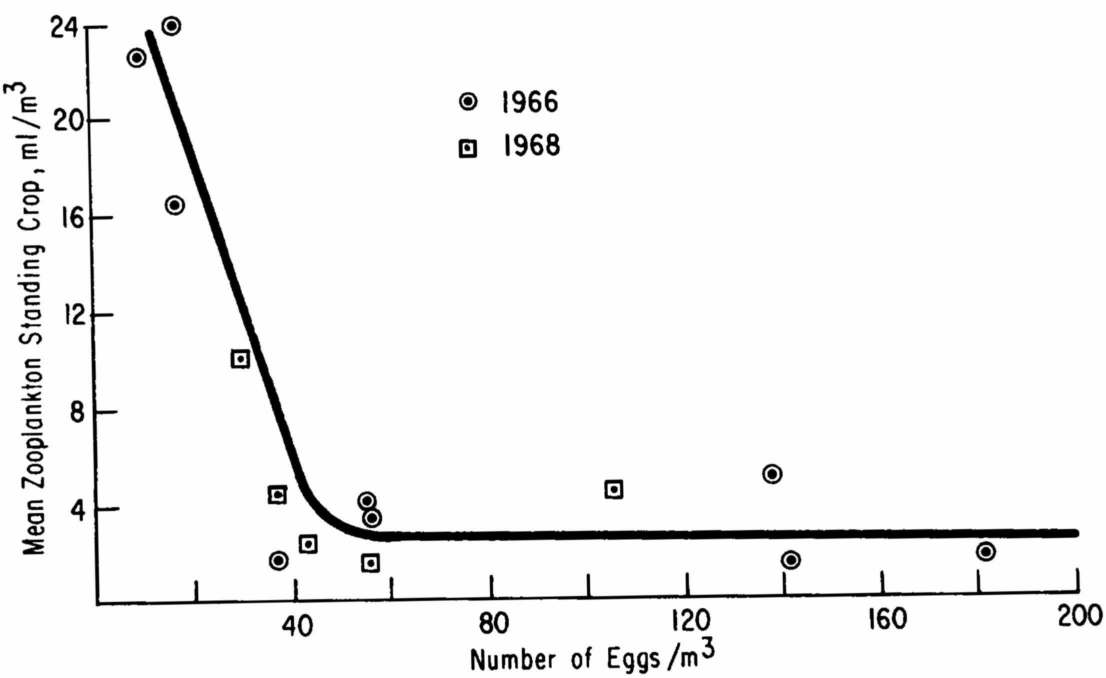

Figure 5. --Relationship between mean zooplankton standing crop and number of eggs in ponds, Saline Fisheries Research Station, 1966 and 1968.

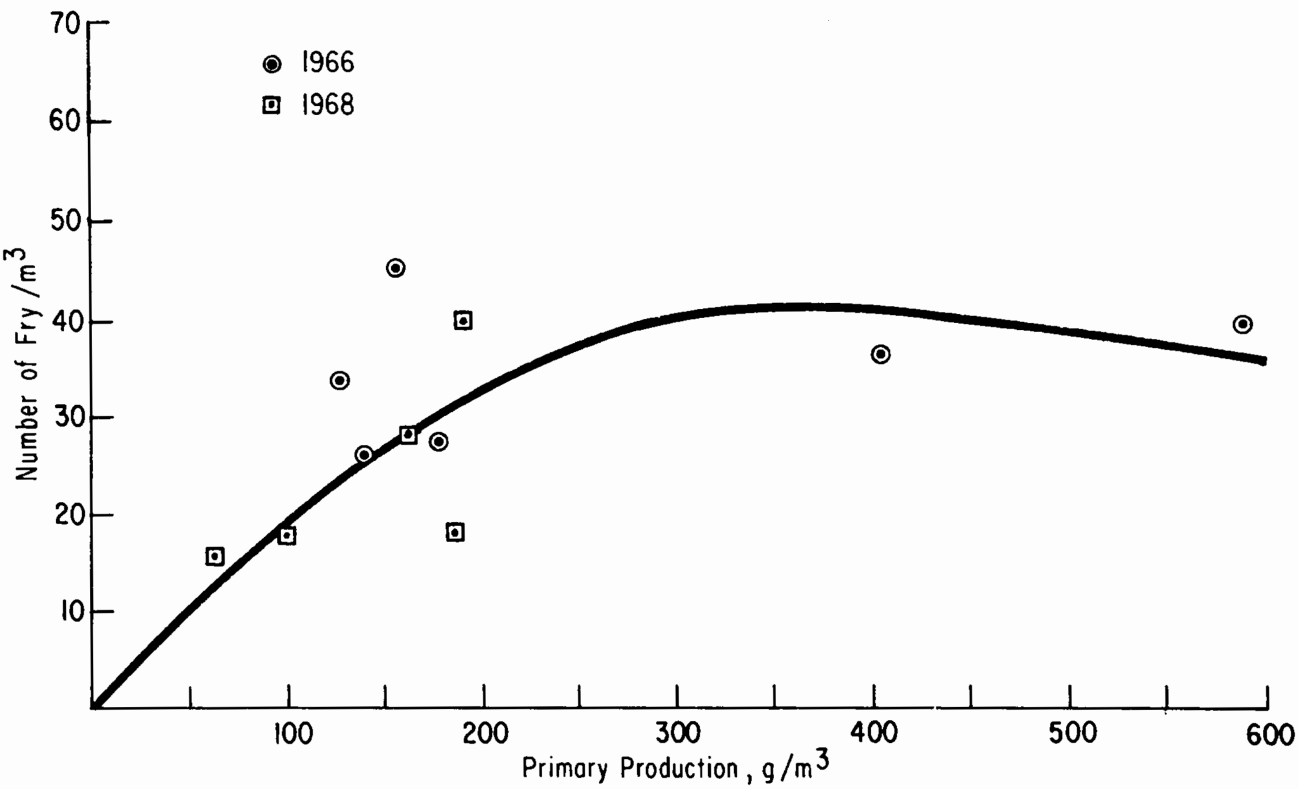

Figure 6. --Relationship between density of bluegill fry and primary production in ponds, Saline Fisheries Research Station, 1966 and 1968.

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