



INFLUENCE OF ORGANIC POLLUTION ON THE DENSITY AND PRODUCTION OF TROUT IN A WISCONSIN STREAM

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ABSTRACT

It took three years following the construction of new sewage treatment facilities for a wild brown trout (*Salmo trutta* Linnaeus) population to recover its former numbers after being nearly destroyed by organic pollution. Four years after pollution abatement wild brown trout exceeded their prepollution stock levels, and both production and numerical density of trout continued to rise until the completion of the study in 1973. The highest annual production and highest biomass of wild brown trout in the study area was 39.6 g/m² and 458 kg/ha (409 lbs/acre), respectively, in a 713-meter section in the center of the former zone of pollution during 1972-73. Before the fish kill in July, 1963, biomass of wild brown trout in April, 1963 was 219 kg/ha (195 lbs/acre) in this section. The highest annual production of wild brown and domesticated brook, brown and rainbow trout combined was 47.2 g/m² during 1961-62 in a 1,513-meter section of the former zone of pollution.

There were significant inverse relationships between numerical density of trout and the average length of wild brown trout in September, 1972. Numerical density of age 0 wild brown trout alone accounted for 77 percent of the variability in the average length of this age group in September, 1972. When the number of older wild brown trout was added, an additional 15 percent of the variability in average length of age 0 wild brown trout was accounted for.

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ON THE DENSITY AND PRODUCTION OF TROUT
IN A WISCONSIN STREAM**

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CONTENTS

| | |
|-----------|--------------------------------------------|
| 2 | INTRODUCTION |
| 3 | METHODS |
| 4 | RESULTS AND DISCUSSION |
| 4 | Trout |
| | Distribution and Density, 4 |
| | Production and Growth, 6 |
| 10 | Water Analyses |
| 14 | SUMMARY AND MANAGEMENT IMPLICATIONS |
| 15 | LITERATURE CITED |

INTRODUCTION

Research on trout and their Black Earth Creek environment began in 1954 and continued, except during 1957 and part of 1958, to 1973. Restoration and protection of non-woody vegetation in the channel and banks, and the removal of a headwaters millpond in 1956 were major efforts which improved Black Earth Creek for trout (Ensign 1955a; Snow and Brynildson 1957; White and Brynildson 1957; and Brynildson 1966). Before 1956, the 8.2 km (5.1 mile) study area contained approximately 80 to 160 spawning brown trout which produced 340 to 390 September young (Brynildson 1955, 1956a, 1956b). By September, 1962 the study area of Black Earth Creek contained a well-balanced population of wild brown trout, with an estimated stock of 522 spawning trout and 1,781 September young.

On 27 July 1963, most of the trout, sculpins (*Cottus bairdi* Girard), and white suckers (*Catostomus commersoni* [Lacepede]) were killed in a 3.4 km (2.1 mile) portion of the creek, as heavy loads of primary domestic effluent plus creamery wastes were

discharged into Black Earth Creek from the sewage plant, depressing dissolved oxygen levels below the tolerance of resident fishes. Fish kills continued during late summer in the zone of pollution until 1968 when the incoming organic wastes received primary and secondary treatment in a new and higher capacity sewage treatment plant. The wild brown trout showed their resiliency in 1969-1972 and responded by producing the largest number of September young ever recorded in the study area of Black Earth Creek.

Our principal objectives were to determine the extent and severity of the trout mortality following dissolved oxygen depletion in Black Earth Creek during summer, and to document the progress made by the wild brown trout to repopulate the former zone of pollution after the new sewage plant began operating.

Black Earth Creek drains 12.0 km² (4.6 mile²) of rich farmland (Fig. 1). Ground water discharge into Black Earth Creek is of the calcium-magnesium bicarbonate type and the carbonate hardness has been measured

at 264 to 368 mg/l (White 1964). During base flow, the volume of water entering the upper limits of the study area, at station 95, is approximately 0.11 cms (5 cfs). At station 15 the volume has increased to 0.34 cms (12 cfs) and below station 16, the flow rises to approximately 0.48 cms (17 cfs) with little increase to the lower station 19 (White 1964). Ground water is discharged at intervals along the 8.2 km study area, holding water temperatures at moderate levels throughout the year. Ice cover is absent or intermittent during winter, while during summer, water temperatures rarely exceed 70°F (21°C).

Nonwoody vegetation is lush on the banks, with water cress (*Nasturtium officinale*) and water buttercup (*Ranunculus longirostris*) the dominant instream plants (Fig. 2). Although more than 19 km (nearly 12 miles) of Black Earth Creek contains wild and stocked trout, only the upper 8.2 km is prime trout water and here the trout populations were regularly and intensively studied.

Lying in the center of this 8.2 km section is the 3.4 km zone that was first polluted by organic waste in the summer of 1963 (Fig. 1). In this report, this zone will be referred to as the "zone of pollution".

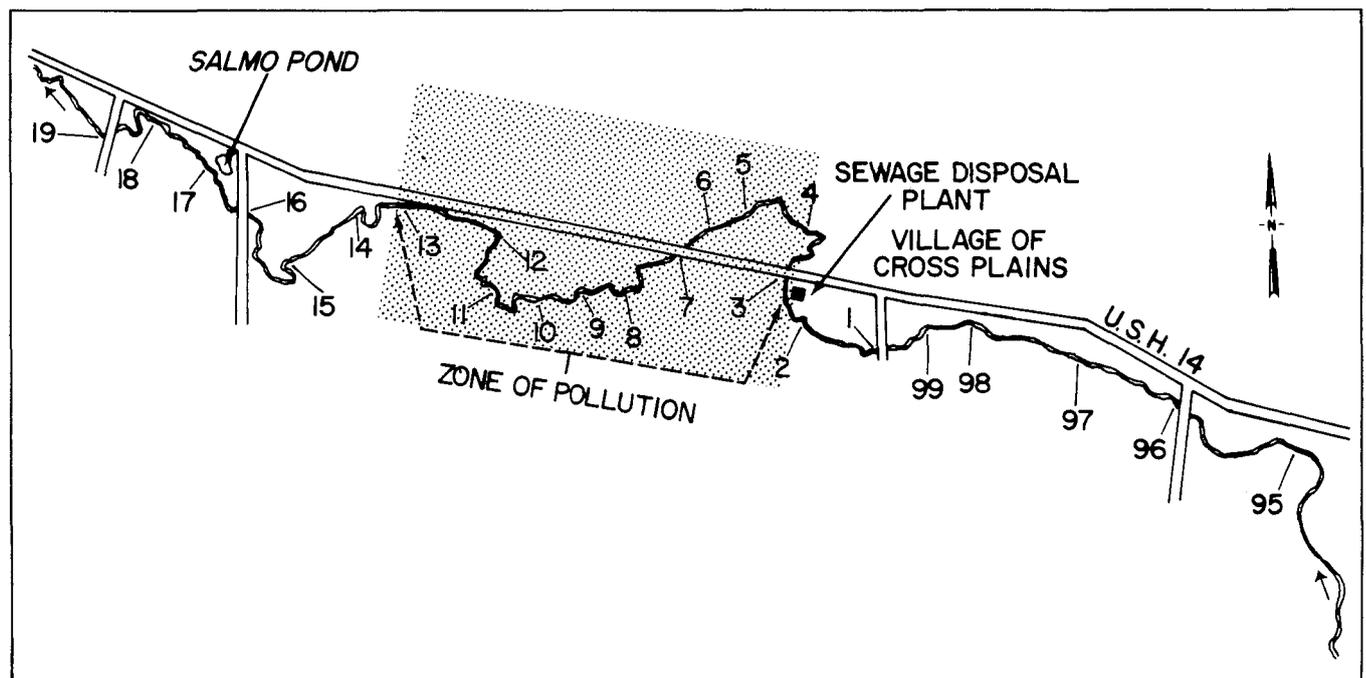


FIGURE 1. The 8.2 kilometers of study area in Black Earth Creek, Stations 19 through 95.



FIGURE 2. Black Earth Creek between Stations 5 and 4 was one of the sections suffering a severe fish-kill in July, 1963. Water cress and water buttercup are the common plants in most of the stream.

METHODS

DETERMINATION OF TROUT DISTRIBUTION AND DENSITY

Estimates of the trout stocks in the 8.2 km study area on upper Black Earth Creek were made in April and September since 1954. The mark and recapture method was employed, making two runs with 230 V dc electric shockers. Details on procedure and efficiency of the electrofishing gear were discussed in McFadden (1961), Hunt et al. (1962) and White (1964). Stations varied in length from 162 to 610 m. Estimates of trout stocks within the study area were made by stations or by combining the electrofishing catch of trout from two or more stations.

Recapture values on trout 15 to 43 cm in total length were 60 to 90

percent of the original numbers captured, marked and released during the first run of the electrofishing units. All trout captured during the first run were measured to the nearest tenth of an inch (0.254 cm) and weighed in grams. On the second run, all trout were measured but only the unmarked trout were weighed. For future identification, selected fins were removed on trout before stocking and on age 0 wild trout in September and age 1 wild trout in April during the two electrofishing runs.

No estimates of the white sucker populations were made since 1962. Two estimates of the sculpin populations were made since 1965 within the zone of pollution, but these estimates were not reliable because the catch of marked sculpins on the second run was inadequate.

DETERMINATION OF TROUT PRODUCTION

Production as used here is defined as the growth in weight by all trout in the population during a period of time, including growth by trout that died during the period. Production was calculated as the product of the average standing stock in weight and the instantaneous rate of growth of the trout. Instantaneous rate of growth is the logarithmic rate of increase in weight of a fish during a period of time.

The number of age 0 wild brown trout at time of emergence from the redds in February was calculated from the estimated egg production by the parent trout as determined for female brown trout in New Zealand (Allen

1951). The average percentage (80%) of fry emerging was based on observed success, over several years, of eggs developing to sac-fry within redds in Black Earth Creek. Average weight of individual fry at emergence (0.1 g) was taken from scatter diagrams of Bagenal (1969). Production of stocked domesticated rainbow trout was calculated from date of stocking to a

given period of time.

WATER ANALYSES

Dissolved oxygen was determined during the summer of 1963-67 at various locations above and below the sewage outfall. The Winkler method and a Weston and Stack dissolved oxygen analyzer were employed.

Because maximum sag in dissolved oxygen occurred at station 7 during the monitoring in 1963-67, a Weston and Stack dissolved oxygen analyzer with a strip chart recorder was installed at that station during 1968-70 to record dissolved oxygen levels. Water for chemical analyses was collected each season of the year at stations 13, 3 and 96 during 1967-71.

RESULTS AND DISCUSSION

TROUT

Distribution and Density

As a result of removing the millpond at station 97 in 1956 and protecting the streambank from livestock, lush nonwoody plants flourished on the banks and in the stream, narrowing the stream's channel and increasing water velocity. This resulted in a scouring of the silt off the gravel to expand spawning grounds below, into and above the old millpond. The trout responded well to the habitat alteration and by September, 1962 the stock of wild brown trout of all ages was well distributed in the 8.2 km study area (Fig. 3). Relative number of trout in each age group was also better balanced in 1962 when compared with the two preceding Septembers in 1959 and 1960. By April, 1963 there were approximately 2,800 creelable wild brown trout age I and older in the study area a month before the trout fishing season in May. Important to the burgeoning stock of wild brown trout in Black Earth Creek was the increasing numbers of trout over one year of age (mature) in the future zone of pollution. These trout would have spawned in November, 1963 had they not been killed by organic pollution in July, 1963.

In mid-September, 1963 the number of mature wild brown trout between stations 12 and 5 was reduced drastically from the number present in April, 1963, after dissolved oxygen levels in July, 1963 dropped as low as 1 ppm (Fig. 11 Append.). By September, 1967 and April and September, 1968, after successive but less drastic

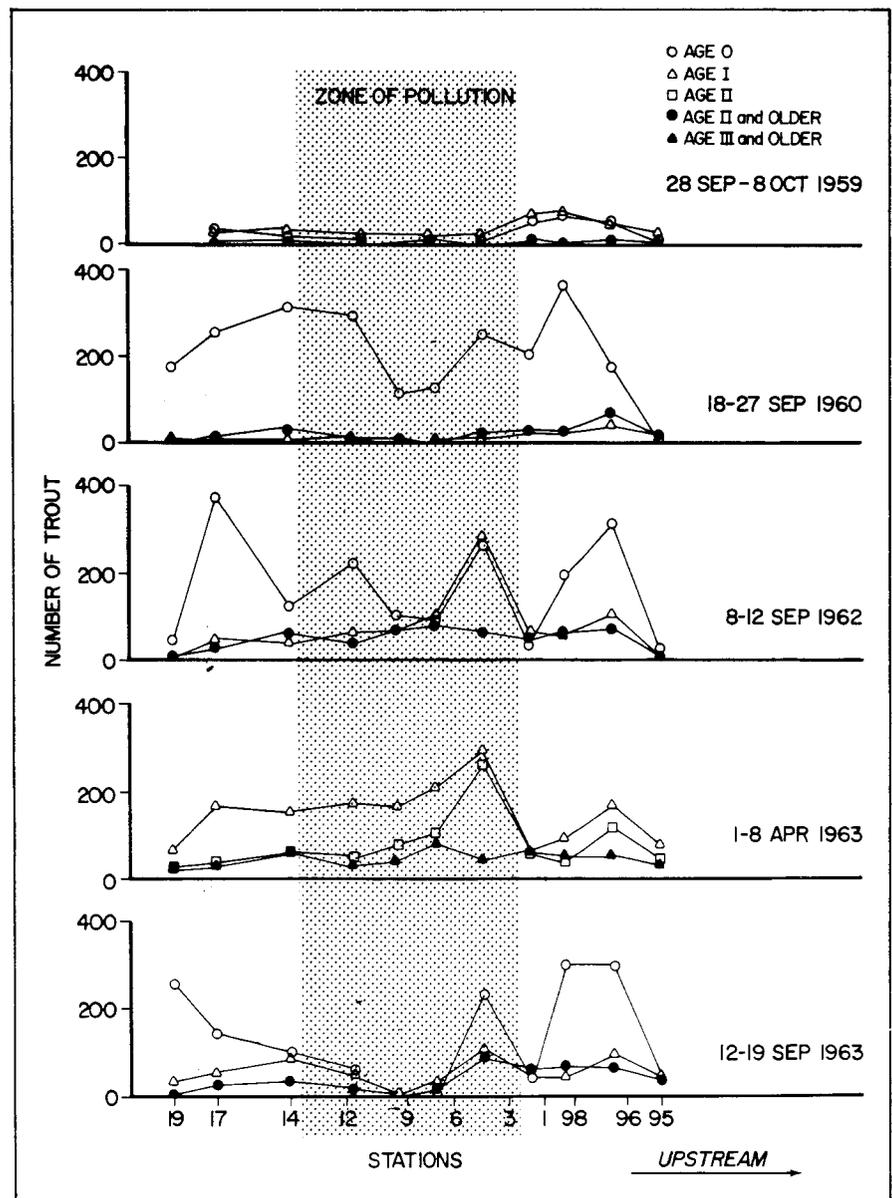


FIGURE 3. Distribution of wild brown trout in 8.2 km of upper Black Earth Creek during selected periods.

summer fish kills, the population of wild brown trout was further reduced in the zone of pollution from station 12 up to station 3 (Fig. 4). During mid-April, 1969 wild brown trout age I and older (age 0 trout were too small to catch consistently by electrofishing) were present in higher numbers than at any period of electrofishing since September, 1963. By late September, 1969 there were nearly as many wild brown trout of age I in the former zone of pollution as there were in April, 1969, indicating a high survival rate. Moreover, wild brown trout age 0 (7 months) were present in the former zone of pollution in relatively large numbers during September, 1969 in contrast to September, 1968 when age

0 trout were scarce in that section of stream (Fig. 4).

Since 1969 the population of wild brown trout in the former zone of pollution and in the rest of the study area increased (Fig. 5). Even the relatively low number of wild breeders (174 age II and older) in September, 1969 produced a large year class, of which 3,001 were estimated to be in the 8.2 km study area (with a good representation in the former zone of pollution) during September, 1970. The brood stock had increased to 366 by September, 1970 and produced 3,168 September young in 1971, many of which, along with older trout, were resident in the former zone of pollution. Moreover, most of the 1971 year class (now age I) and older trout

present in the former zone of pollution in September, 1971 were still there during the latter part of April, 1972 (Fig. 5). By that time, the population of wild brown trout in the study area was well represented in age groups, as it was in September, 1962 and April, 1963, (Fig. 3) shortly before the fish kill in July, 1963. The wild brown trout stock increased in the former zone of pollution from approximately 1,700 creelable (TL 152 cm [6 inches]) trout in April, 1963 to 2,100 in April, 1972.

Among those creelable trout in April, 1972 were brood fish from a potential spawning stock of 567 which were present in the study area September, 1971. This stock produced a record-breaking crop of September young of 4,239 in 1972, many of which were resident in the former zone of pollution. The potential spawning stock (age II and older) of wild brown trout was estimated to be 1,122 fish after the trout fishing season closed in mid-September, 1972. The highest number present in the study area (approximately 600 were in the former zone of pollution) since the trout population studies began in 1954. A small number of trout in the spawning stock were migrants from below the study area, trout that never were fin-clipped in the past as trout in the study area were during electrofishing operations.

Because the best spawning grounds and the most redds were above station 99, many trout age 0 that were resident in the former zone of pollution in September, 1969-72, may have hatched above station 99, but due to high densities of young trout above station 99, moved downstream into more sparsely occupied areas. In November, 1955 stations 6-1 (Fig. 1) contained only 1 redd, whereas 9 redds were present above station 99, and yet the density of age 0 wild brown trout in stations 6-1 was nearly double the density above station 99 in September, 1956.

The added stress caused by the release of large stocks of age I domesticated brown trout above station 99 in April, 1956 may have triggered the downstream migration of the young wild brown trout (Brynildson 1957b). However, migration downstream by young wild brown trout must generally occur before mid-July. Of 196 age 0 wild brown trout marked 13 July 1962 in stations 98-96, only 2 of these trout were found in September, 1962 below stations 98-96 (1.6 and

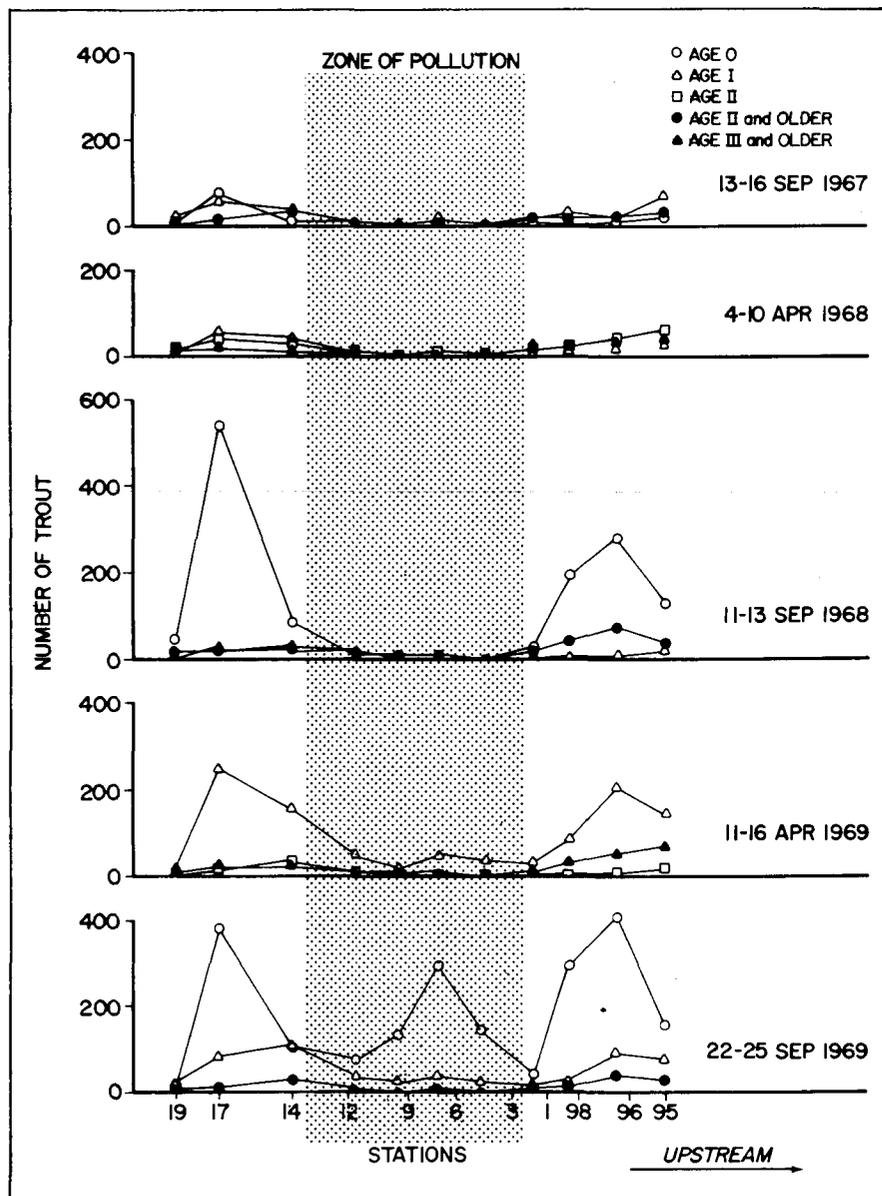


FIGURE 4. Distribution of wild brown trout in 8.2 km of upper Black Earth Creek during selected periods.

6.4 km below) while 79 percent were still resident in stations 98-96 (Brynilson 1963). During the intermittent pollution of Black Earth Creek from stations 3-14 during 1964-67, migrant young wild brown trout were probably killed or failed to establish residence in the zone of pollution (Fig. 4) because of low dissolved oxygen levels during early mid-summer mornings throughout that zone. In 1968, the migrant young wild brown trout probably could not tolerate the high chlorine levels (2 to 3 times recommended levels) in the effluent from the new sewage plant during April, 1968. Moreover, the stock levels of age 0 and older wild brown trout were all low in stations 12-3 in September, 1968 when dissolved oxygen levels were relatively high during early August (Figs. 13 and 14, Append.).

In addition to pollution, trout in Black Earth Creek were periodically subjected to the ravages of late winter floods that scoured the streambed and wrought havoc with the trout eggs and sac-fry nestled in the gravel (Brynilson 1956b, 1957a; White 1961, 1964). Flood damage to trout redds have been reported by other investigators (Allen 1951; McFadden and Cooper 1962; Elwood and Waters 1969; Seegrist and Gard 1972). In Black Earth Creek, the 1959 and 1967 year classes of wild brown trout were drastically reduced (Figs. 3 and 4) in numbers by late winter floods. The near loss of the 1967 year class to late winter floods did not, however, dampen the upsurge of the year classes in 1969-72 (Figs. 4 and 5) because there were adequate numbers of potential brood trout hatched in 1966 and 1968 to produce strong year classes up to 1972.

An example of how a strong year class can emerge, even with a small number of brood trout, occurred in 1960. In September, 1959 only 61 wild brown trout (42 females and 29 males) age II and older were present in the 8.2-km study area (Fig. 3). In November, 1959 these brood trout, and possibly a few additional from below the study area, constructed 25 redds, the third lowest (18) recorded up to that period (White 1961). From the 25 redds, 2,307 September young were in the study area in 1960, nearly six times more than ever recorded since the studies began in 1954. Increased ground water discharge in 1959-60 is probably the main factor in the high survival of the 1960 year class

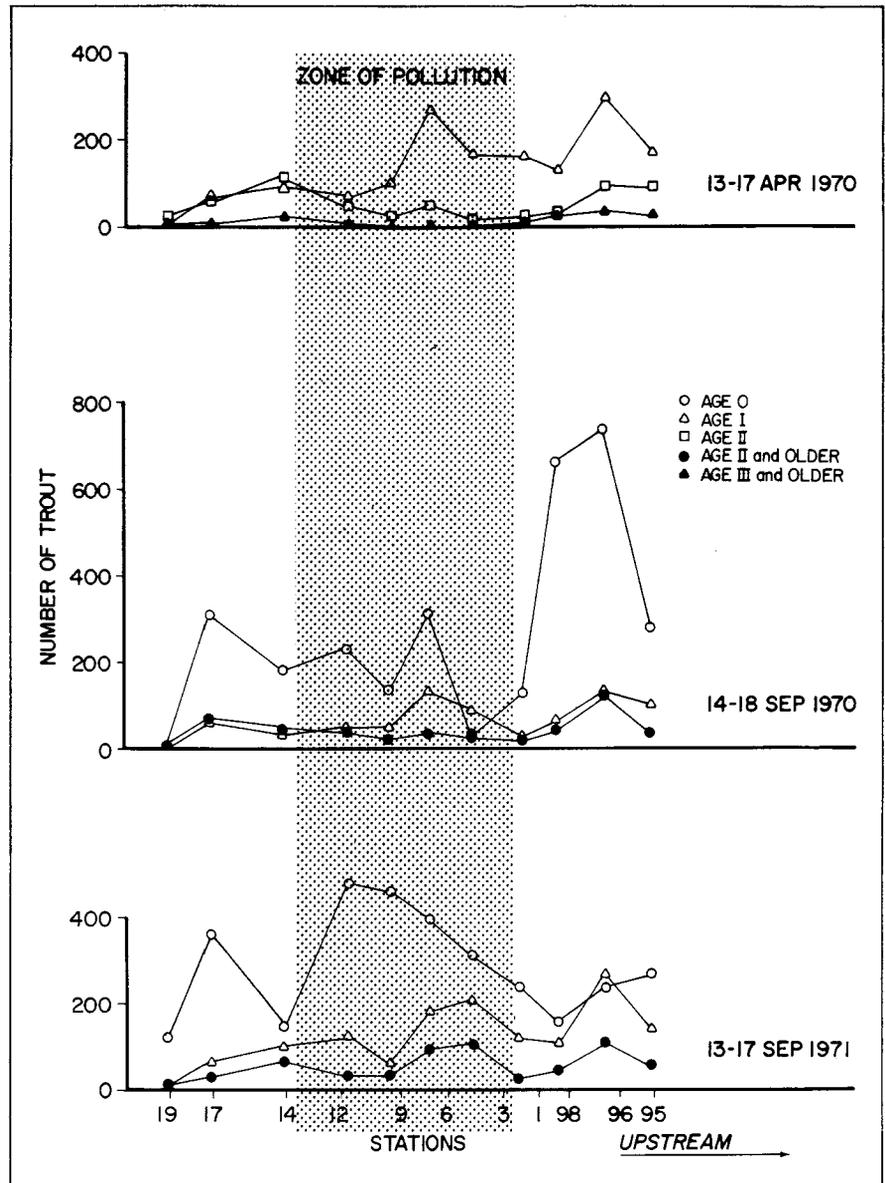


FIGURE 5. Distribution of wild brown trout in 8.2 km

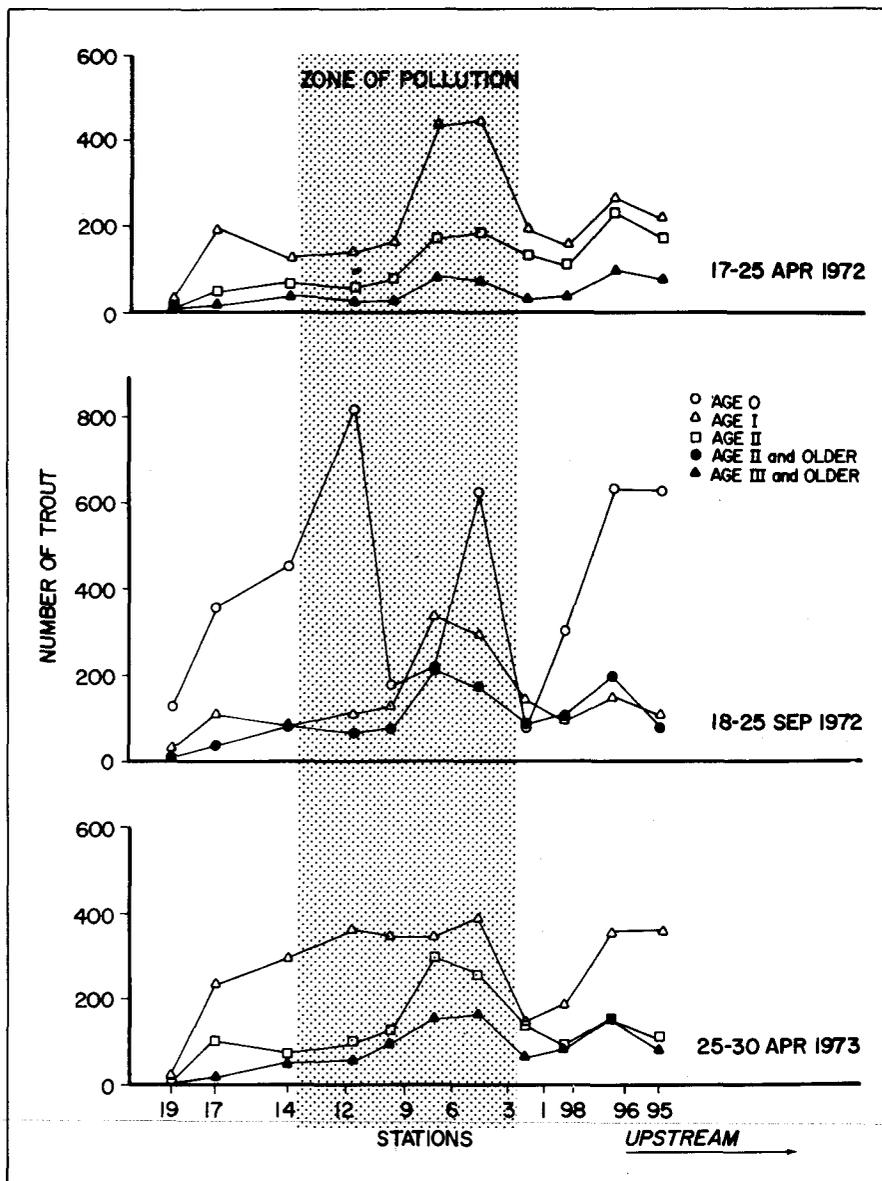
of wild brown trout (Brynilson 1960; White 1964; Dunst 1970).

Some of the wild brown trout now resident in the former zone of pollution probably hatched there. As evidence that trout are utilizing the section between stations 6-4 as a spawning area, 25 active redds (as many as found in the entire 8.2 km study area in 1959) were counted in that stretch of stream 6 November 1972. However, none were found from stations 3 to 1. The highest previous number recorded in this section of stream was 14 in November, 1960 (White 1964). With an increase in brood trout in the former zone of pollution, spawning in that zone should expand even though most of the former zone of pollution has a bottom of rubble and silt with

only small, isolated gravel beds for spawning.

Production and Growth

Production of trout per square meter of stream surface in relation to number of trout per 100 square meters (0.01 ha [0.025 acre]) of stream surface is presented in Figures 6 and 7. Production of wild brown trout in the 8.2 km study area increased with an increase in numerical density of trout. Numerical density had a greater influence on production of wild brook trout in Lawrence Creek than did variation in growth rates in different sections (Hunt 1966). Chapman (1965) concluded that variations in survivorship of coho salmon in streams



of upper Black Earth Creek during selected periods.

has a strong impact on production. These observations are supported by the similar production:biomass (P:B) ratios in the fertile stations 8-3 and the less fertile station 95 of Black Earth Creek (Table 1). Although the average instantaneous growth rate of wild brown trout from April, 1972 to April, 1973 was 1.14 and 1.02 in stations 8-3 and 95, respectively, the relatively higher numerical density of wild trout in station 95 (Table 1) sustained the uniform P:B ratios found in stations 8 to 3.

Generally, the wild brown trout in the study area of Black Earth Creek older than age II weighed less on an average in April than they did the previous September. However, weight lost would be more than regained by

the next September. Thus, a significant amount of production was tied up in gain and loss of sexual products during late summer and late fall, respectively.

Production of wild brown and domesticated (domestic) rainbow trout in 1961 and 1962 (before the fish kill in July, 1963) was high in the upper zone of pollution (stations 8-3) where numerical density of trout was high (Fig. 6 and Table 1). This indicates that limited amounts of domestic sewage effluent, low in BOD, could have a beneficial influence on trout growth, especially in infertile trout streams of northern Wisconsin where numerical density of trout are often relatively high. For example, a group of 10,000 rainbow trout (5-8 cm)

stocked in mid-June, 1961 at 4 months of age (Brynildson et al. 1966) and before being exposed to angling, produced 25.1 g/m² of trout flesh in stations 8-6 from date of stocking to mid-April, 1962. Production (13.5 g/m²) by these rainbow trout during the colder months from mid-September, 1961 to mid-April, 1962 was also high (Table 1), and rivaled annual production of trout in most areas of the world.

As the wild brown trout stock recovered and gained in numbers in the former zone of pollution during 1970-72 (Fig. 5) so did the trout production. The annual production of wild brown trout in 1971-72 (Fig. 7), however, was higher in the former zone of pollution than in 1961-62 (Fig. 6) before the fish kill occurred in July, 1963.

The annual production of wild brown trout in the heart of the former zone of pollution (stations 8-6) reached 39.6 g/m² during the period April, 1972-73 (Fig. 7 and Table 1), boosting the weight of the wild brown trout stock to 357 and 458 kg/ha (318 and 409 lbs/acre) in September, 1972 and April, 1973, respectively. The highest previous biomass of wild brown trout before the July, 1963 fish kill through stations 8-6 was 217 kg/ha (194 lbs/acre) in April, 1963.

The annual production of wild brown trout (39.6 g/m²) in stations 8-6 was higher than the highest annual production of 25.8 g/m² and 32 g/m² recorded for wild brook trout in any section of Lawrence Creek and Maxwell Springs, Wisconsin, respectively, (Robert Hunt and Robert Carline, pers. comm.) or the 7-year range of 12.0-14.0 g/m² published for Lawrence Creek (Hunt 1966, 1971), the 30.0 g/m² in Big Spring Creek, Pennsylvania (Cooper and Scherer 1967), and 6.2 g/m² in Valley Creek, Minnesota (Elwood and Waters 1969) and 2-12 g/m² of brown trout in small streams in England (LeCren, 1969). However, a combination of stocked domesticated brook, brown and rainbow trout plus wild brown trout had the highest annual production calculated to date in Black Earth Creek when 47.2 g/m² of trout flesh were produced in stations 8-3 during the period from April 1962 to April 1963 (Table 1). Even these high trout production figures fall short of the annual average production of 54 g/m² in the Horokiwi of New Zealand (Allen 1951).

TABLE 1. Numerical density, biomass and production of domesticated and wild trout in selected sections of Black Earth Creek

| Stations Along Stream | Trout Groups | Periods of Production | Avg. No. Trout Per 100m ² | Production (grams per m ²) | Average Biomass (grams per m ²) | P:B ¹ |
|-----------------------|--------------|-----------------------|--------------------------------------|----------------------------------------|---------------------------------------------|------------------|
| 8-6 (713m) | Brown* | | | | | |
| | Rainbow* | Sep 1961-Sep 1962 | 14.0 | 28.0 | 12.2 | 2.3:1 |
| 8-6 (713m) | Brown | Sep 1961-Apr 1962 | 7.8 | 4.1 | 11.1 | 0.4:1 |
| | | Sep 1961-Sep 1962 | 7.4 | 12.8 | 11.4 | 1.1:1 |
| 8-6 (713m) | Rainbow** | Jun 1961-Apr 1962 | 26.9 | 25.1 | 8.7 | 2.9:1 |
| | | Sep 1961-Apr 1962 | 17.0 | 13.5 | 8.5 | 1.6:1 |
| 8-6 (713m) | Brown | Sep 1971-Apr 1972 | 15.4 | 11.1 | 19.4 | 0.6:1 |
| | | Sep 1971-Sep 1972 | 16.1 | 31.9 | 24.7 | 1.3:1 |
| | Brown | Apr 1972-Apr 1973 | 17.1 | 39.5 | 35.3 | 1.1:1 |
| | | Sep 1972-Apr 1973 | 17.9 | 19.0 | 40.8 | 0.5:1 |
| 8-3 (1,513m) | Brown | | | | | |
| | Brown* | | | | | |
| | Brook* | | | | | |
| | Rainbow* | Apr 1962-Apr 1963 | 40.2 | 47.2 | 38.0 | 1.2:1 |
| 5-3 (800m) | Brown | Sep 1961-Sep 1962 | 10.9 | 16.8 | 12.6 | 1.3:1 |
| | Brown | Sep 1971-Sep 1972 | 13.9 | 29.3 | 19.7 | 1.5:1 |
| | Brown | Apr 1972-Apr 1973 | 14.7 | 33.3 | 27.3 | 1.2:1 |
| | | Sep 1972-Apr 1973 | 16.1 | 12.1 | 31.2 | 0.4:1 |
| 95 (499m) | Brown | Sep 1961-Sep 1962 | 2.0 | 2.3 | 3.9 | 0.6:1 |
| | Brown | Sep 1971-Apr 1972 | 17.3 | 8.3 | 18.2 | 0.4:1 |
| | | Sep 1971-Sep 1972 | 21.6 | 25.0 | 17.8 | 1.4:1 |
| | Brown | Apr 1972-Apr 1973 | 22.9 | 25.6 | 21.6 | 1.2:1 |
| | | Sep 1972-Apr 1973 | 25.8 | 8.9 | 19.6 | 0.4:1 |

*Stocked domesticated trout.

**Domesticated winter-hatched rainbow trout (5 to 8 cm) stocked 12 June 1961 at age 0.

¹Production:biomass.

It appears that numerical density of wild brown trout in Black Earth Creek has not reached a high where further increase in numbers of wild brown trout would slow production of trout flesh. LeCren (1972) reported that increased population density increases trout production to a point until a maximum is reached which is then maintained regardless of further increase in numerical density.

Even though the stock of wild brown trout by 1971-72 had increased in the study area above the level of April, 1963, the average total lengths of the year classes were similar at different stations of the study area in April, 1963 and 1972 (Fig. 8, Append.). However, competition from the large stocks of age 0 domesticated brown and rainbow trout released (10,000 stocked) in the study area in June (Brynildson et al. 1966) apparently slowed the growth in length of the 1962 year class of wild brown trout during the summer between stations 14 and 6 (Fig. 9, Append.). This decrease in average length of the 1962 year class was apparent by April, 1963 when compared with the average length of age 1 wild brown trout in April, 1972 from station 12 upstream to station 95 (Fig.

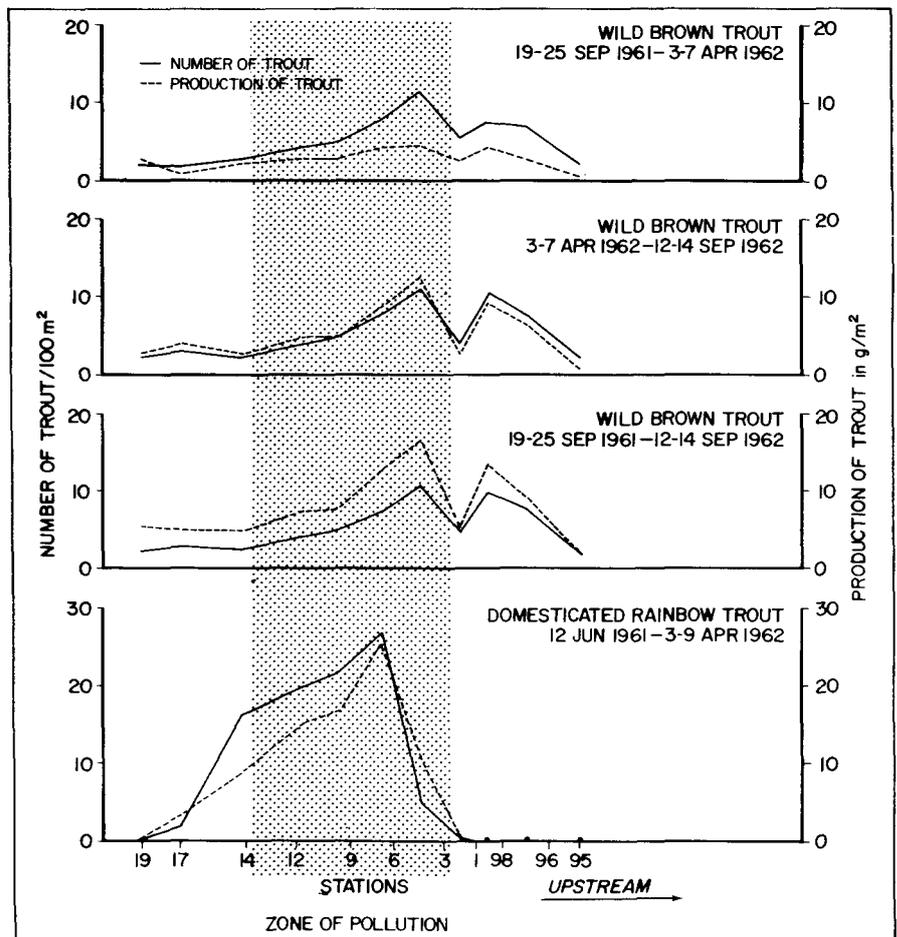


FIGURE 6. Production of wild brown and domesticated rainbow trout in 8.2 km of upper Black Earth Creek during selected periods.

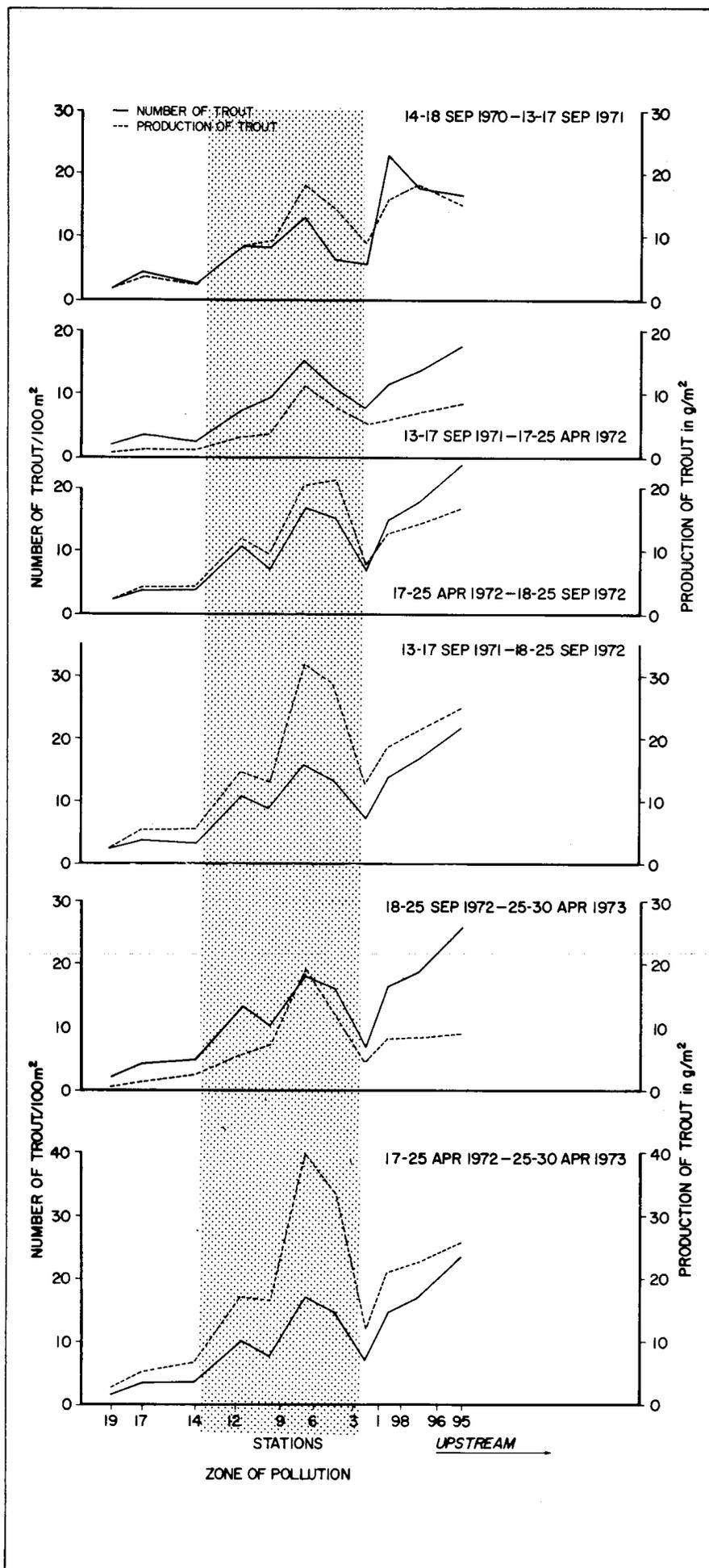


FIGURE 7. Production of wild brown trout in 8.2 km of upper Black Earth Creek during selected periods.

8, Append.) where an additional 3,000 domesticated brook trout age 0 were stocked in September, 1962 (Mason et al. 1967). Also evident was the inverse relationship of numerical density of age 0 wild brown trout and their average length between stations 98 and 95 in both September, 1963 and 1972 (Fig. 9, Append.). Experiments with fry or brown trout (LeCren 1962; Backiel and LeCren 1967), rainbow trout and coho salmon (Fraser 1969) showed that growth was negatively correlated with numerical density of fry.

There were negative correlations between numerical density of various groups of trout and the average length of age 0 and I wild brown trout in the study area of Black Earth Creek (Figs. 10-11 and Table 2, Append.). The highest correlation coefficient ($r = -0.956$), significant at the 0.01 level, was between density of wild brown trout of all ages and average length of age 0 wild brown trout (Fig. 10, Append.). The lowest correlation coefficient ($r = -0.660$), not significant at the 0.05 level, was between density of wild brown trout of all ages plus domestic brook, brown and rainbow trout age I, and the average length of age I wild brown trout (Table 2).

Numerical density of age 0 wild brown trout alone accounted for 77 percent of the variability in the average length of age 0 wild brown trout in September, 1972. When the density of age I and older wild brown trout in September, 1972 was added, an additional 15 percent of the variability in average length of age 0 wild brown trout in September, 1972 was accounted for. However, correlation between numerical density of domestic brook, brown and rainbow trout plus wild brown trout age I, and average length of wild brown trout age I in April, 1963 was not significant at the 0.05 probability level (Table 2) when growth vs. density in the entire study area was examined. This may be due to the inherent differences in growth of trout in different sections of Black Earth Creek.

The greatest biomass of domesticated trout in April, 1963 was 259 kg/ha (231 lbs/acre) within stations 8-6. In numbers, there were 17.1 domesticated trout per 100 m² competing with wild brown trout at a density of 9.6 per 100 m² a total of 26.7 trout per 100 m² (1,080/acre). In contrast, the density of domesticated and wild trout in stations 8-6 during

April, 1972 was 0.4 and 15.6 per 100 m², respectively. Because of suspected competition with the younger wild brown trout for food and survival, domesticated trout are no longer stocked in Black Earth Creek above station 18.

WATER ANALYSES

Concentrations of dissolved oxygen in the water were variable at different stations of the study area, especially before the new sewage plant began operations in 1968 (Fig. 12, Append.). After 1967 the dissolved oxygen was relatively stable and adequate for trout within the study area. These dissolved oxygen determinations were made from approximately midnight to dawn, during a time when dissolved oxygen generally sags to its lowest level during the 24-hour day.

At station 7, dissolved oxygen levels dropped to as low as 1.4 ppm during the early hours of 30 July 1963 (Fig. 14, Append.), the lowest recorded in the study area. This reading was obtained three days after the heavy fish kill 27 July 1963. The early morning dissolved oxygen levels did not improve at station 7 (1.2 km [0.9 miles] below the sewage outfall) during summer until after the new sewage plant began operating in 1968, after which dissolved oxygen levels during the summer did not sag below 4 ppm up to 30 June, 1971 (Fig. 13, Append.).

Up to the time the new sewage plant began operating, the range of ammonia nitrogen and organic nitrogen at station 3 was 0.2-2.6 ppm and 0.0-2.9 ppm, respectively. After the new plant was in operation these ranges were 0.1-0.4 ppm ammonia nitrogen and 0.2-4.0 ppm organic nitrogen. The range of nitrate nitrogen at station 3 was (0.14 km [450 ft] below the sewage outfall) ranged from 0.5-2.8 ppm, before the new plant began operating and 0.7-2.4 ppm after the new plant began operating. At station 96 above the sewage outfall, the range of ammonia, and organic nitrogen was 0.0-0.1 ppm and 0.1-0.3 ppm, respectively, and these ranges have held through 1971 as has the range of the nitrate nitrogen from 0.3 to 2.4 ppm.

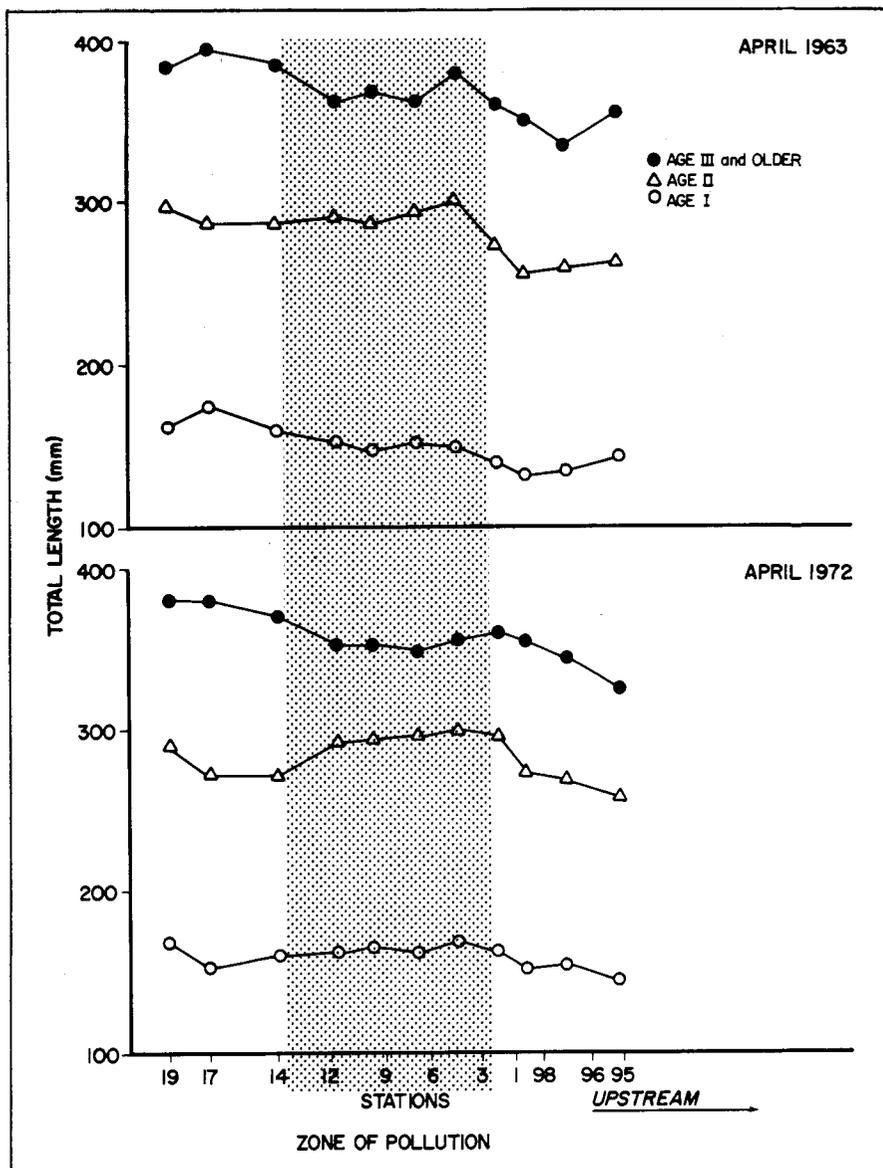


FIGURE 8. Average length of wild brown trout in various sections of the upper 8.2 km of Black Earth Creek, April 1963 and 1972.

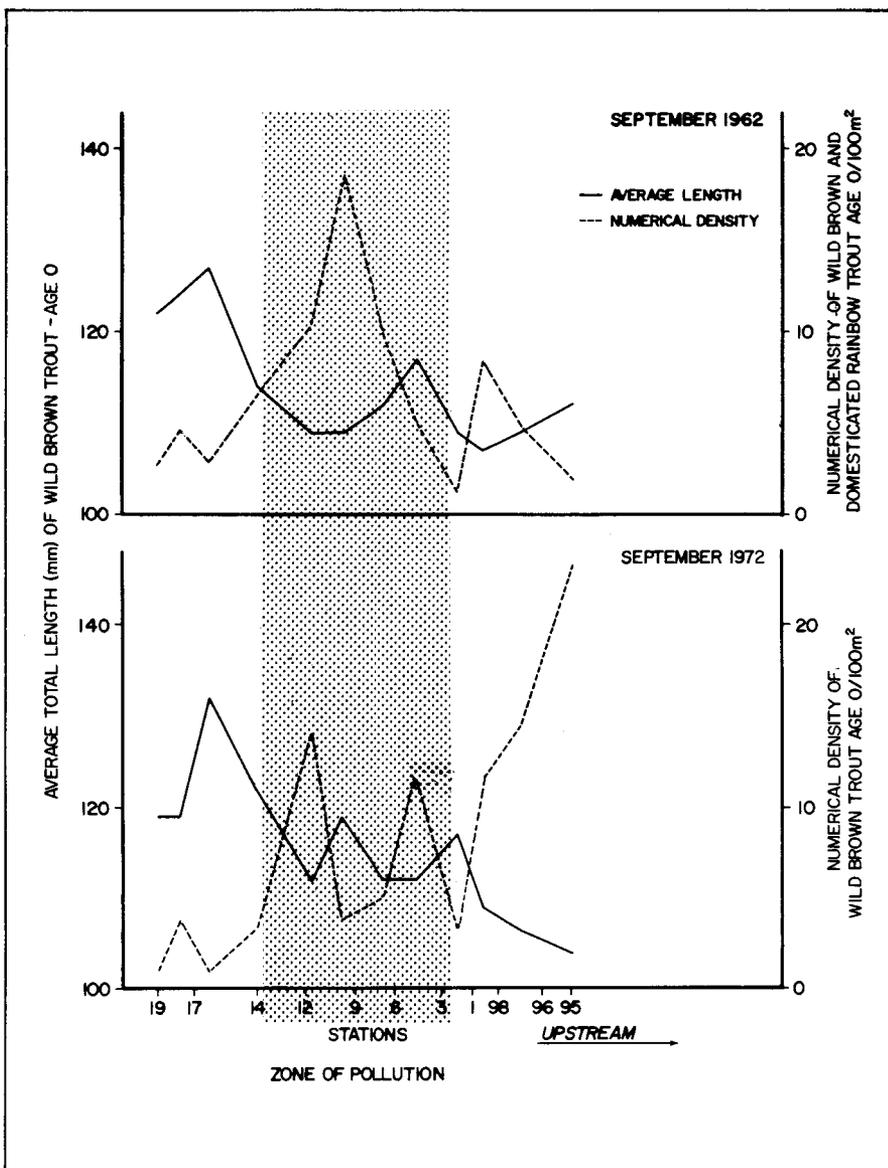


FIGURE 9. Average total length of wild brown trout age 0 and the numerical density of wild brown and domesticated rainbow trout age 0 in 8.2 km of upper Black Earth Creek in September, 1962 and 1972.

TABLE 2. Correlations between numerical density of various groups of trout and the average length of wild brown trout age 0 and I in Black Earth Creek

| Date | Average Length of Age 0 vs. Densities of: | Degrees of Freedom | Coefficient of Correlation (r) |
|-------------------------------------------|-----------------------------------------------------------------------|--------------------|--------------------------------|
| Sep 72 | Wild brown (age 0) | 11 | -0.879** |
| Sep 72 | Wild brown (all ages) | 11 | -0.956** |
| Sep 62 | Wild brown and domestic rainbow (age 0) | 6 | -0.832* |
| Sep 62 | Domestic rainbow (age 0) | 6 | -0.757* |
| Sep 62 | Wild brown of all ages plus domestic rainbow (age 0) | 6 | -0.835** |
| Average Length of Age I vs. Densities of: | | | |
| Apr 63 | Wild brown and domestic brook, brown and rainbow (age I) | 6 | -0.698 |
| Apr 63 | Wild brown of all ages plus domestic brook, brown and rainbow (age I) | 6 | -0.660 |

*Significant at 0.05 level.
 **Significant at 0.01 level.

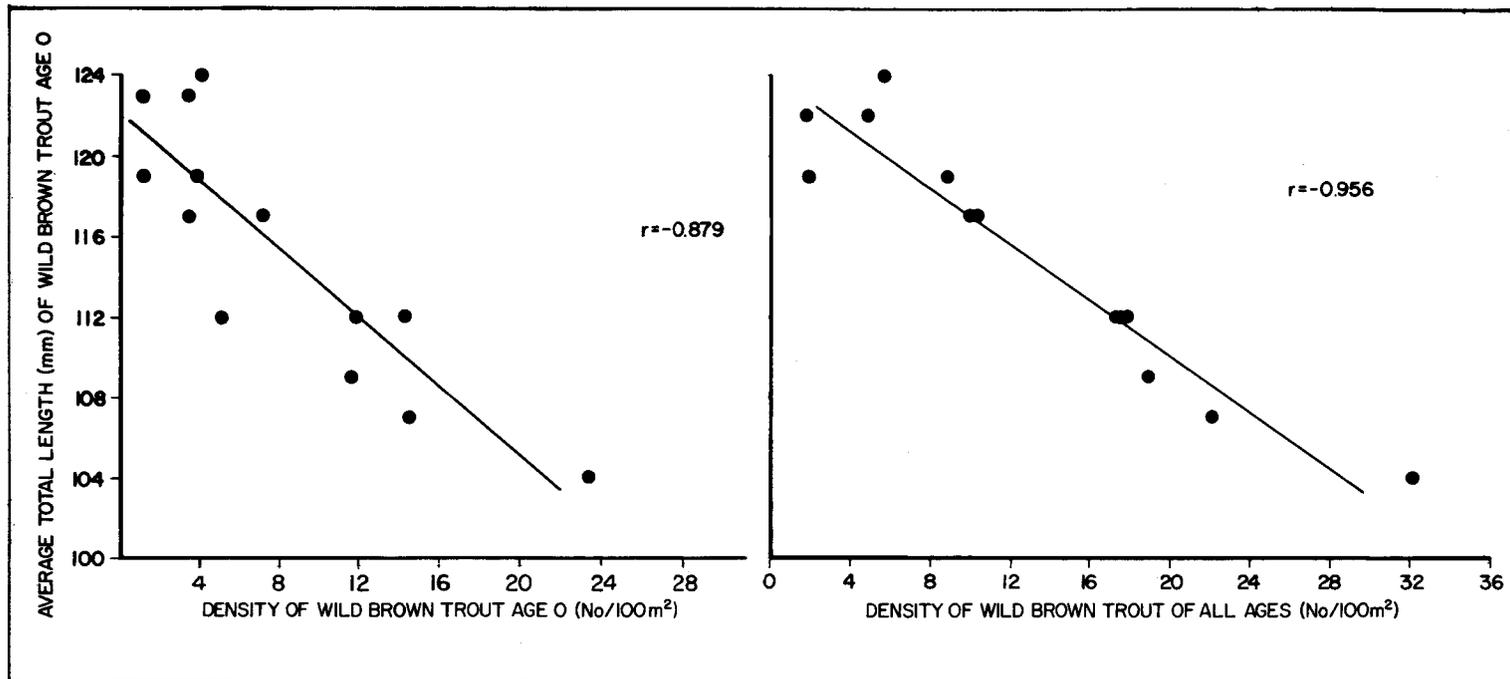


FIGURE 10. The relationship of numerical density of wild brown trout to average length of age 0 wild brown trout in 8.2 km of upper Black Earth Creek, 18-25 September 1971.

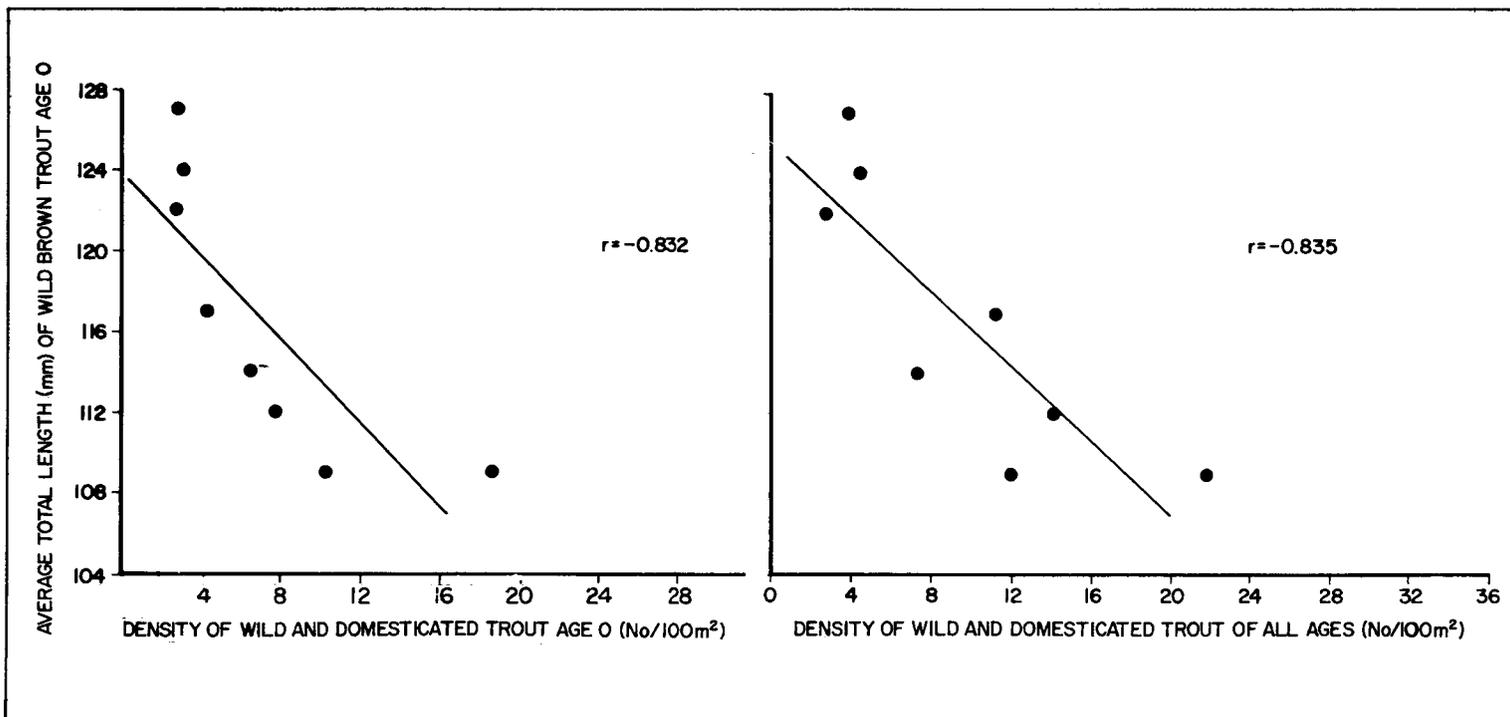


FIGURE 11. The relationship of numerical density of wild brown plus domesticated brown and rainbow trout to average length of age 0 wild brown trout in 5.6 km of upper Black Earth Creek, 8-12 September 1962.

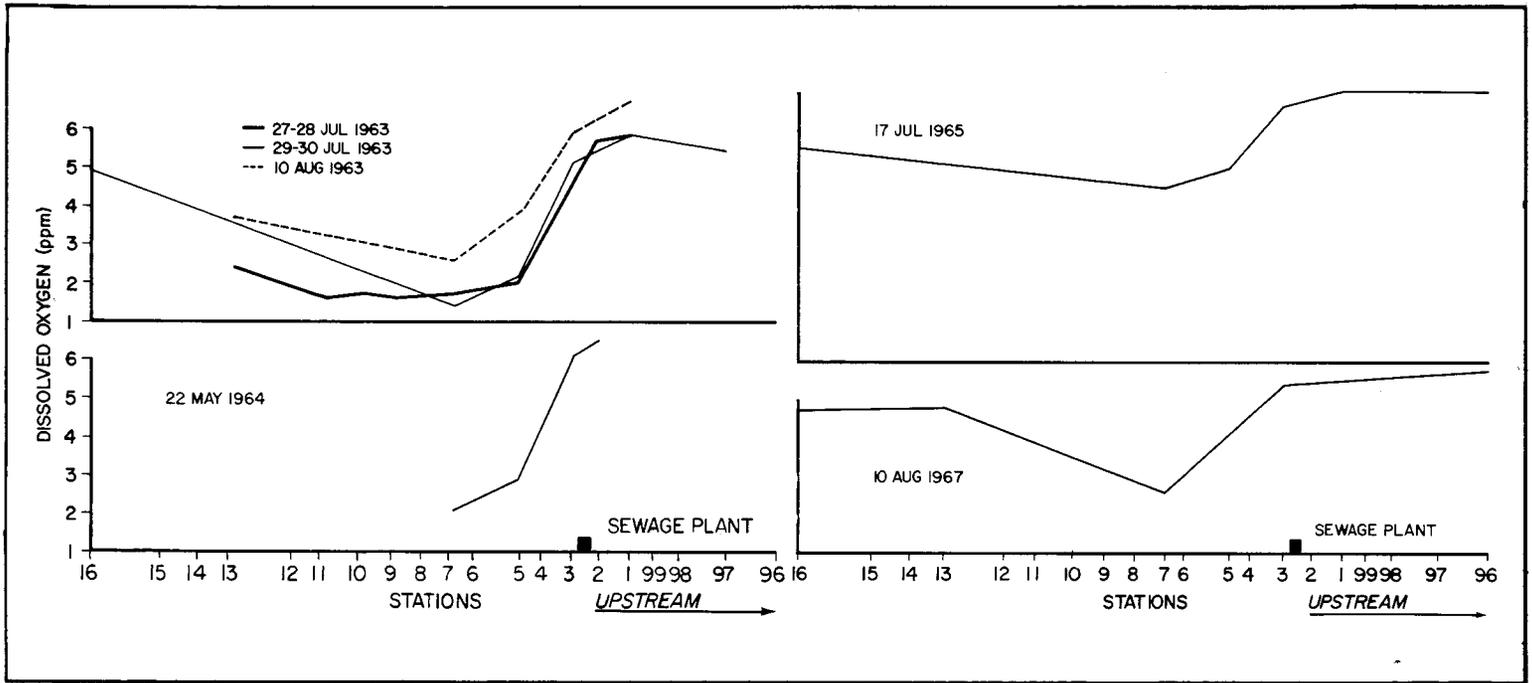


FIGURE 12. Concentration of dissolved oxygen at various stations on Black Earth Creek from 2330 to 0300 hours on given dates before a new sewage plant was installed.

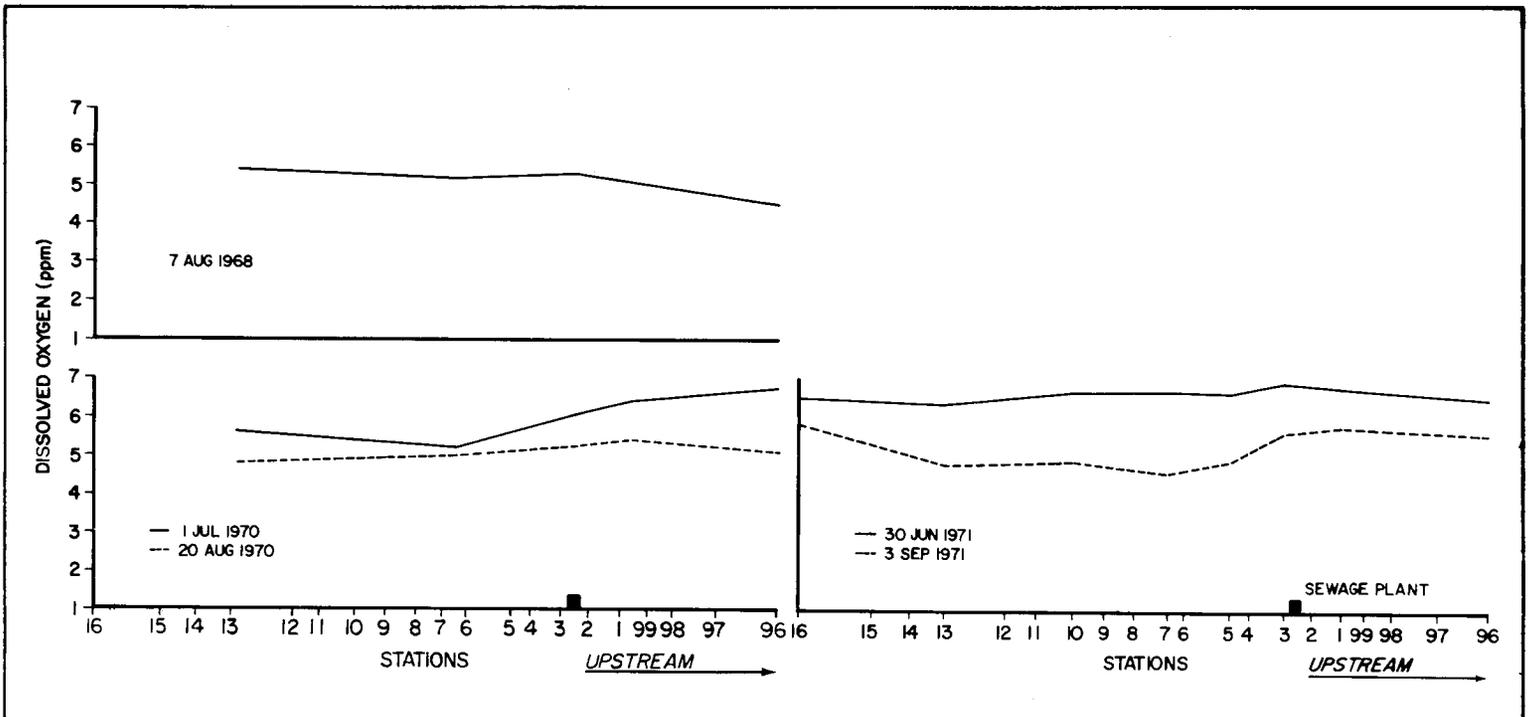


FIGURE 13. Concentration of dissolved oxygen at various stations on Black Earth Creek from 0200 to 0530 hours on given dates after a new sewage plant began operating.

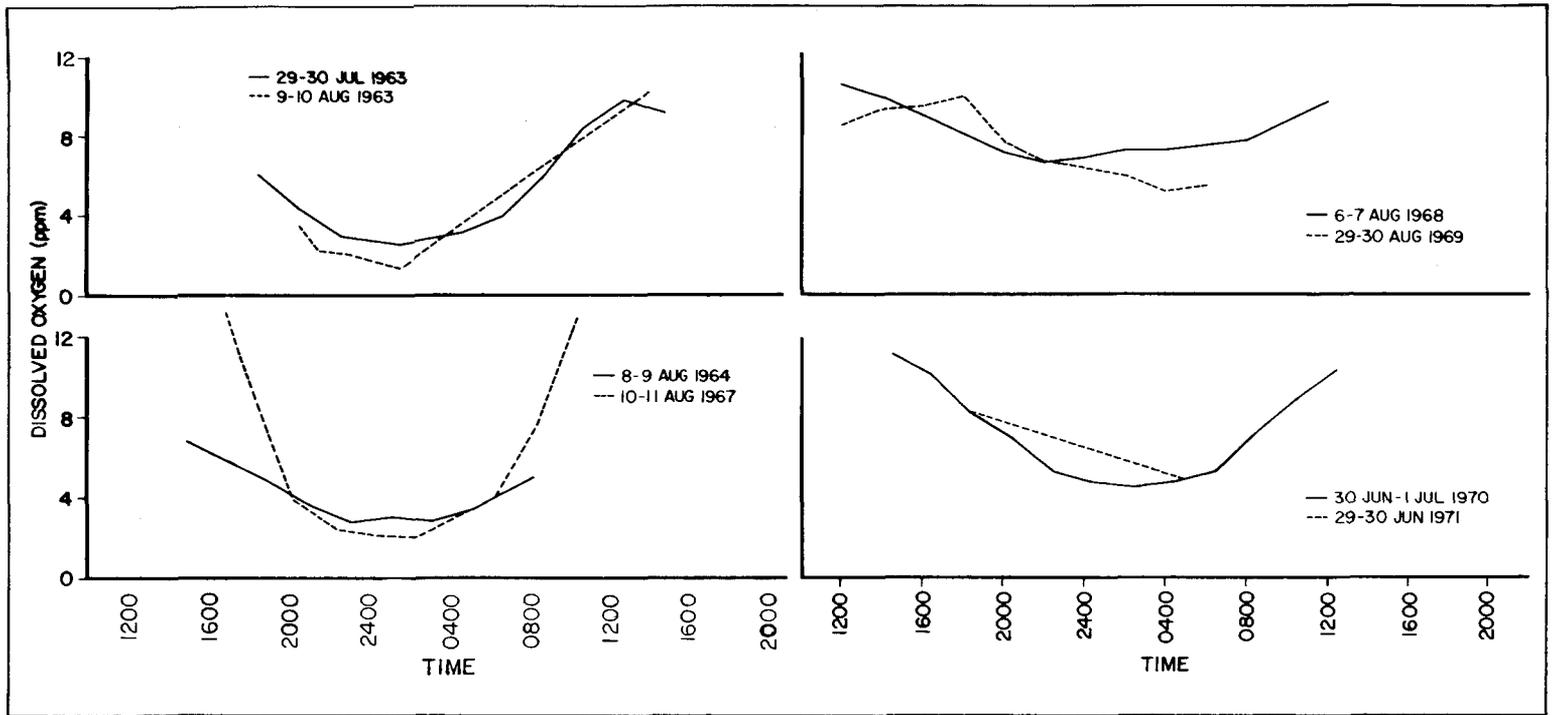


FIGURE 14. Concentration of dissolved oxygen at Station 7 in Black Earth Creek during different periods of the day before (1963-67) and after (1968-71) installation of a new sewage plant.

SUMMARY AND MANAGEMENT IMPLICATIONS

A wild brown trout population in Black Earth Creek that suffered high mortality because of organic pollution in 1963, regained its original density three years after a new sewage plant began operating in April, 1968. After four years the wild brown trout had increased in numbers and weight above the levels of 1963 before the trout kill.

The relatively low levels of fertility from the effluent sustained higher trout production in the former zone of

pollution than above the sewage out-fall. Such diluted effluent when stripped of high biochemical demand could increase fertility of the water and, hence, increase production of trout in infertile sand bottom streams of Wisconsin.

Production of wild brown trout in the former zone of pollution has not as yet reached its potential, and continued increase in the wild brown trout stock in that zone should be

followed by expanded trout production. The domesticated trout formerly released in the former zone of pollution are currently being replaced by wild brown trout. The domesticated trout not only competed for food with wild trout, causing slower growth in the young wild trout, but probably displaced the young wild trout resulting in lower survival of the wild young.

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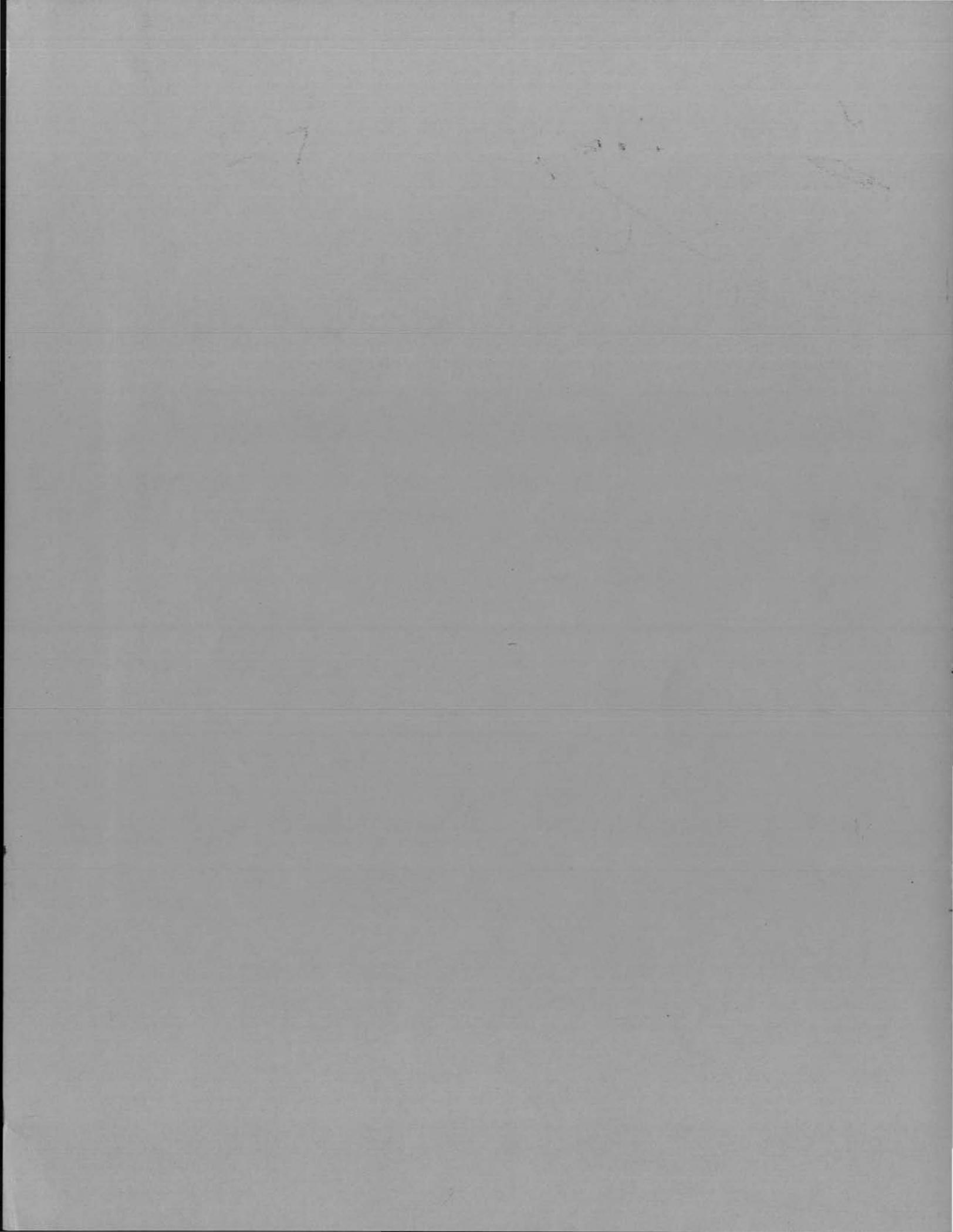
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