1
9
0
0

Growth Rate of Brown Trout (*Salmo trutta*) in Areas of the Au Sable River, Michigan, Before and After Domestic Sewage Diversion

Glenn S. Merron

Fisheries Research Report No. 1900

January 21, 1982

MICHIGAN DEPARTMENT OF NATURAL RESOURCES
FISHERIES DIVISION

Fisheries Research Report No. 1900

January 21, 1982

GROWTH RATE OF BROWN TROUT (*SALMO TRUTTA*) IN AREAS OF THE AU SABLE RIVER, MICHIGAN, BEFORE AND AFTER DOMESTIC SEWAGE DIVERSION [1]

By Glenn S. Merron

[1] This is a reprint of a thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Fisheries, in the School of Natural Resources, The University of Michigan, 1981.

ACKNOWLEDGMENTS

This research was supported by the Institute for Fisheries Research, Michigan Department of Natural Resources. I am especially indebted to Richard D. Clark, Jr., who suggested this study and gave great assistance during the progress of the study. I would like to express my sincere gratitude to Dr. Karl F. Lagler, for advice during this study and for help in the preparation of the manuscript. Gaylord R. Alexander provided useful information about the wild brown trout of the Au Sable River.

Thanks also go to Margaret S. McClure for typing the final draft of the study and to Alan D. Sutton for drafting the figures.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF APPENDIX TABLES

LIST OF FIGURES

ABSTRACT

Comparisons of growth rates for brown trout (Salmo trutta) were made for two intervals, one during and the other after termination of the discharge of primary treated domestic sewage effluent into parts of the Au Sable River system, Michigan.

The ages of a total of 3,394 brown trout from the mainstream, South Branch, and North Branch Au Sable River were assessed from scale samples. Estimations of length at age and the annual growth increment in length were obtained by conventional back-calculation methods.

The growth rates of brown trout after termination of discharges from sewage treatment plants into the mainstream at Grayling and into the South Branch at Roscommon were found to be significantly slower than during the discharge period. No change in growth rate occurred for the same time intervals on the control, the North Branch, into which no sewage plants have discharged.

The sewage treatment effluents formerly discharged into the Au Sable River stimulated biological production of aquatic plants and invertebrates. Increased trout production resulted through better growth rates.

Following cessation of sewage input, aquatic production declined in the affected river sections. In terms of growth of brown trout, this was apparently due most directly to lowered food production, specifically of the amphipod Gammarus fasciatus and the isopod Asellus militaris.

Back calculation of trout lengths at various ages, made from scale measurements, tended to become progressively longer as older fish were used. This is the reverse of the usual manifestation of Lee's phenomenon of apparent change in the rate of growth. Size selective avian predation of the smallest trout of a cohort is suggested as the principal cause for this reversal.

INTRODUCTION

The section of the mainstream of the Au Sable River from Burton's Landing to Wakeley Bridge in Crawford County, Michigan, is one of the premier trout fishing waters in the Midwest. In the early 1970's many longtime anglers of this river section became concerned that large brown trout were not as numerous as they had been in the 1960's, and trout population samples taken by Fisheries Division personnel of the Michigan Department of Natural Resources confirmed there were fewer large trout. Fall population estimates at sampling stations within the Burton's Landing to Wakeley Bridge section indicated the numbers of brown trout in this area had remained relatively constant, whereas the average size for each age group was significantly smaller in the 1970's than in the 1960's (Alexander et al. 1979). Apparently, the growth of brown trout had declined.

Several hypotheses were presented to explain this decline in growth. First, many anglers blamed the reduction in catch of large trout on increasing angler use of this section. They believed that the river was being overfished. This prompted the Fisheries Division in 1973 to alter the fishing regulation for brown trout from a 254-mm minimum size limit, 5 fish per day, and fly fishing only, to a 304-mm minimum size limit, 3 fish per day, and fly fishing only (Alexander et al. 1979). This new regulation was intended to decrease fishing mortality on 254-mm to 304-mm fish, and allow more fish to survive to an older age and larger size (Clark et al. 1979). Later, when populations of larger trout did not develop, the 304-mm size limit was blamed for slowing growth. It seemed to stockpile too many fish in the 203-mm to 304-mm size range (Clark et al. 1979) which could have slowed growth through increased competition for a limited food source. In support of this idea, White et al. (1975) found that growth of brown trout was poor in the special regulation water from Burton's Landing to Wakeley Bridge when compared with growth both upstream and downstream where trout density was lower. Also, Alexander and Ryckman (1976) found that brown trout had higher densities and slower growth in the sections of the North Branch of the Au Sable being fished under more restrictive fly fishing regulations (228-mm minimum size limit, 5 trout creel limit, artificial flies only) than in sections being fished under normal statewide regulations (177-mm minimum size limit, 10 trout creel limit, any lure permitted).

Another explanatory hypothesis was proposed by Favro, Kuo, and McDonald (1979) who attempted to explain the decline in trout growth through a population genetics model. The model was based on the idea that fishing mortality, when applied to a population under a minimum size limit regulation, would cause the larger fish of a cohort to die faster than the smaller fish. Many of the larger fish would be harvested by anglers as they grew over the minimum size limit, whereas the smaller fish would be protected. Therefore, the smaller fish would have a better chance to survive and reproduce which, presumably, would cause genetic selection for slow growth.

Habitat degradation was suggested as yet another reason for the disappearance of large fish. Biologists of the Fisheries Division pointed out that many of the large holes and submerged log sweepers which served as "hides" for large fish were gone. Also, numerous silt beds that produced food for trout had become less abundant. Many of these changes were attributed to the increasing bedload of sediment, mainly sand particles, from the construction of Interstate 75 in the early 1960's (Coopes 1974). Furthermore, a tremendous number of camping and canoeing related activities could have contributed to the alteration of trout cover.

Finally, it was suggested that a decline in stream fertility was responsible for the decline in growth (Alexander et al. 1979; Clark et al. 1980). This decline in fertility came about when the town of Grayling, Michigan, in 1971, converted from a system that discharged primary treated domestic sewage into the river to a land disposal system (Coopes 1974) and also when the Grayling State Hatchery phased out operations in the mid-sixties and attendant waste discharge ceased (Alexander et al. 1979). It was opined that the organic effluent, although low in volume but high in phosphates and nitrates, may have had a beneficial impact on the trout fishery by increasing the food supply available for fish.

The objective of this study was to test the last hypothesis concerning the impact of sewage discharge. A unique opportunity for such a test presented itself as a matter of coincidence. On three branches of the Au Sable River, the mainstream, the South Branch, and the North Branch, there existed markedly different sewage discharge situations, while at the same time their trout populations were being monitored by the Michigan Department of Natural Resources for evaluation of trout fishing regulations. The South Branch continued to receive sewage effluent until 1974, which was 3 years longer than the 1971 cutoff date for the mainstream. The North Branch received no municipal sewage at all during the period, and therefore, could serve as a control stream.

In view of these events, the trout population data were analyzed to determine if the nature and timing of the decline in growth of brown trout were correlated with organic sewage diversion from the mainstream and the South Branch.

STUDY AREA

The mainstream of the Au Sable River system originates from the confluence of Kolka and Bradford creeks about 24 km north of the town of Grayling, in northern lower Michigan (Fig. 1). The average width of the study section of mainstream from Burton's Landing to Wakeley Bridge, respectively 10.3 and 24.3 km below Grayling, is 28.8 m with a mean discharge rate of 4.95 cm/s (Gowing and Alexander 1980). The average depth is 0.76 m (James Failing, United States Geological Survey, Grayling, Michigan, personal communication).

In November 1971, the town of Grayling, population 2143 in 1970, diverted primary treated domestic sewage effluent from the mainstream to a land disposal system (Coopes 1974). Primary treatment is the physical removal of most of the suspended solids from sewage. When sewage effluent is discharged into a river, the nutrients are processed by natural physical, chemical, and biological means. On the mainstream, increased growth of bacterial, algal, and macrophyte communities occurred below the discharge pipe, and odors of putrification were often present (Coopes 1974). The primary treatment plant was built in 1937, and modernized extensively in 1962 with the addition of facilities for screening, primary sedimentation, and sludge digestion and had an average daily outfall of 1.15 million liters (Michigan Water Resources Commission 1966). Beginning in 1971, at a site 1 mile southeast of Grayling, effluent was passed through three 1-acre aerated lagoons and then to a 7-acre leaching pond where it percolates to the

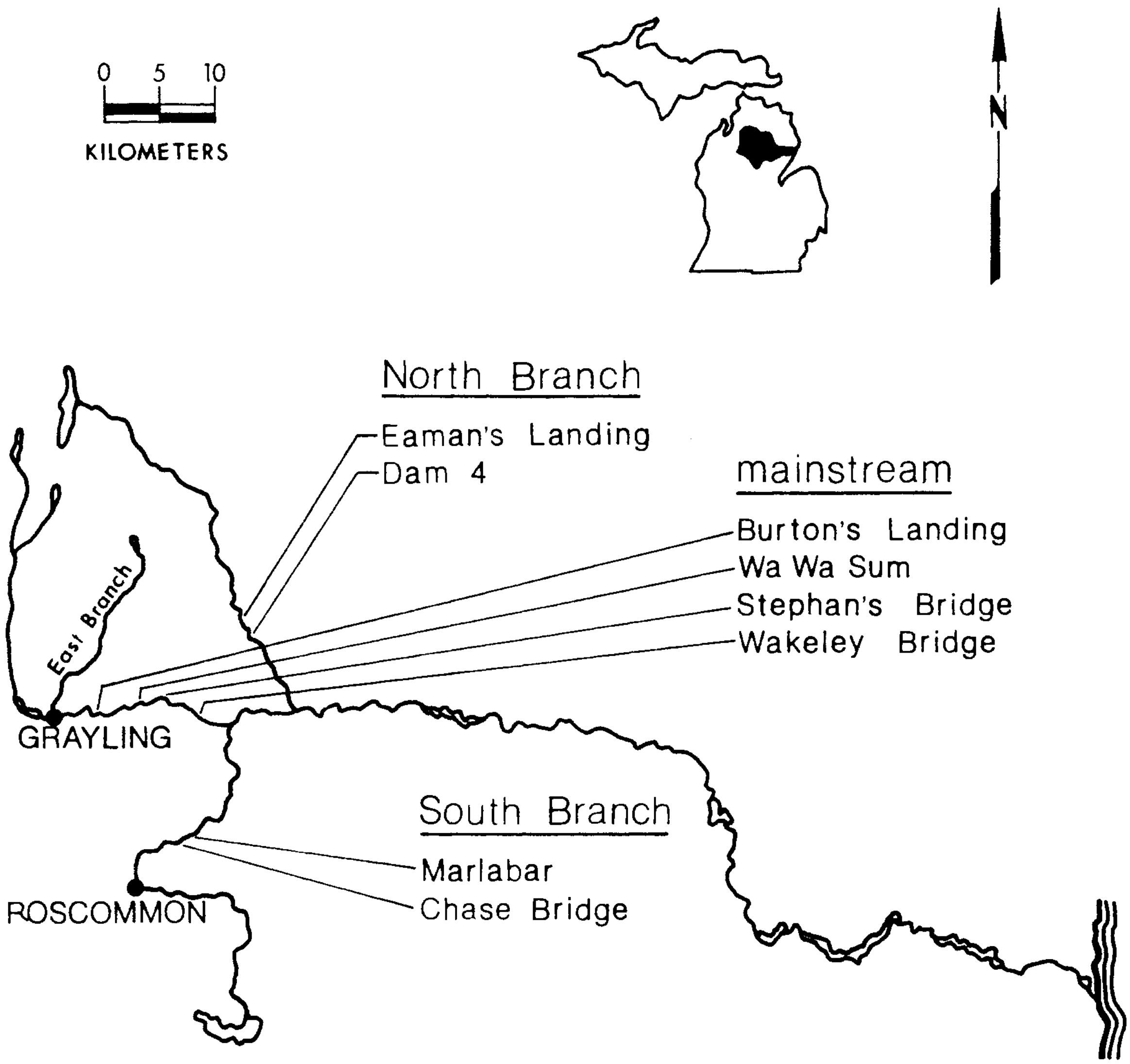

Figure 1.--The Au Sable River system, Michigan, showing the location of the sampling sites.

groundwater (Heckathorn 1977). Until the mid-sixties, the mainstream received additional nutrient loading from the Grayling State Fish Hatchery (Alexander et al. 1979). This hatchery on the northeasterly side of Grayling, used water from the small East Branch of the Au Sable River, and returned it to the branch which entered the mainstream almost immediately.

The South Branch, which originates in Lake St. Helen 63 km above its mouth, passes through Roscommon and joins the mainstream some 27.5 km below Grayling. It is the narrowest of the study streams averaging 23 m wide and with a mean discharge rate of 4.53 cm/s (Gowing and Alexander 1980). The average depth is 0.70 m (James Failing, personal communication). Like the mainstream the South Branch is a habitat that favors aquatic macrophytes. Shelter in the river for trout is abundant and of excellent quality. It consists of many pools, log jams, and good bank cover (Alexander 1974a).

In late 1973, the town of Roscommon, population 810 in 1970 (Coopes 1974), began diversion of primary treated sewage from the river to a land disposal system. Diversion was complete by June 1974 (Ray Moore, Sewage Treatment Plant, Roscommon, Michigan, personal communication). The original primary treatment plant was built in 1957, and included sedimentation, gravity sludge removal, and sludge digestion and had an average daily outfall in August 1966 of 0.568 million liter (Michigan Water Resources Commission 1966). Beginning in 1973-1974, domestic sewage was diverted to a lagoon about 2 miles east of town as part of a spray irrigation disposal system. The new system consists of oxidation lagoons and a large holding pond where the effluent is diffused by spray irrigation to seepage beds (Ray Moore, personal communication). Thus, the mainstream and South Branch differ in two major respects: (1) timing of effluent diversion, and (2) quantity of nutrients received.

The North Branch, which has never received sewage effluent, served as the control. Its headwaters are in Otsego Lake, 53 km above the mouth and joins the mainstream some 10.5 km downstream from the mouth of the South Branch. The average width of the North Branch study section is 33.8 m with a mean discharge rate of 3.25 cm/s (Gowing and Alexander 1974a). The average depth is approximately 0.55 m (James Failing, personal communication).

The total drainage area of the Au Sable watershed, including all branches, is 4662 km^2 (Michigan Water Resources Commission 1966). The area is largely forested, with only a little agriculture (Gislasion 1971). The Au Sable system is highly acclaimed for its excellent trout fishing, canoeing, and other water related activities (Alexander and Shetter 1967). Sport fishermen and outdoor enthusiasts from this and other states place an ever increasing recreational demand upon the basin, and the economy of the area is largely dependent thereon.

The sampling sites for this study were stations used by personnel of the Fisheries Division to obtain fall trout population estimates (Fig. 1). All are located in Crawford County and comprise: (1) two on the mainstream, Wa Wa Sum and Stephan's Bridge, respectively 11.6 and 14.1 km downstream from Grayling; (2) two on the South Branch at Chase Bridge and Marlabar, respectively 8.2 and 11.7 km downstream from Roscommon; and (3) two on the control, the North Branch, Eaman's Landing and Dam 4.

MATERIAL AND METHODS

As this is a comparative growth study, overall conventional and well established methodologies were employed. Scale samples for the brown trout were collected by personnel of the Fisheries Division from fish captured by dc electrofishing gear annually in the period from late September to the end of October. The total length was measured for each individual and a scale sample obtained. In the early 1960's the samples were removed from the left side of the fish above the lateral line and above the anal opening, but during the 1970's, from the left side of the fish above the lateral line and below the anterior edge of the dorsal fin. For age assessment and measurement, a subsample of the scales from each fish was impressed on cellulose acetate slides and examined with a microprojector.

For most years, 10 fish per 25-mm length group could be randomly selected for age and growth analysis; in only a few years were fewer fish available for certain of the specified length groups. The total number of fish analyzed was 3394--1304 from the mainstream, 1111 from the South Branch, and 979 from the North Branch.

At time of analysis, for each fish the following data were recorded: sampling station code, year of capture, and month of capture. Records were made of total scale radius and distance from focus to each annulus along the same anterior radius. The least squares regression analysis was used to obtain the body:scale relationship. The data were then grouped and analyzed according to stream site and time interval for the years 1960-61 and 1973-77. This grouping by time period was required because of the difference in sites of scale removal as described previously. Classically, it is assumed that the body:scale relationship would be different for scales taken from different areas of the body. To test this assumption for the present data, analysis of covariance was used to determine whether or not there were significant differences between the body:scale regressions as derived from the two scale sample locations used in the two time intervals.

A FORTRAN program based on the traditional back-calculation formula was used to calculate the average length at age and annual growth increment in length at age for all fish used in this study. This formula can be expressed in the following form:

$$L_t = S_t \left(\frac{L_c - a}{S_c} \right) + a$$

where:

L_t = total length at age t;

L_c = total length at capture;

S_t = scale measurement to annulus t;

S_c = total scale radius at capture; and

a = intercept of the body:scale regression.

The Student t test was used to detect significant differences in mean length at age and annual growth increment in length at age of brown trout grouped before sewage abatement (1960-61 for the mainstream and 1960-61 plus 1973 for the South Branch) and after sewage discharge abatement (1973-77 for the mainstream and 1974-77 for the South Branch). In the control, the North Branch, time intervals were 1960-61 and 1973-77.

RESULTS

For all stream sections studied the classical linear relationship between body length and scale radius for brown trout was obtained (Table 1). Covariance analysis showed that the body:scale regressions were significantly different ($\alpha = 0.05$) between the two time periods for the same stream section. This difference was most likely due to the change in area of the body from which the scales were removed. As expected, the size of scales was different from different areas of the body. Covariance analysis also revealed differences in the body:scale regressions from one stream section to another within the same time period. However, these differences between stream sections may be due to the slightly different environmental conditions in the streams. In view of these differences, scales from each stream section and time period were back calculated separately using their respective body:scale intercept values (Table 1).

In the mainstream, length at the various ages declined significantly between 1960-61 and 1973-77 (Fig. 2 and Appendix A), in agreement with Alexander et al. (1979), Stauffer (1977), and White (1975). Fish from the South Branch also showed a significant decrease in mean length at various ages between 1960-73 and 1974-77 (Fig. 3 and Appendix A). This is similar to the findings by Stauffer (1977). The mainstream exhibited a greater decrease following effluent cutoff than the South Branch, probably because the mainstream received twice the discharge of domestic sewage as the South Branch. Also, below

Table 1.--Regression statistics for the relationship between body length (y) and scale radius (x) for brown trout from the mainstream, South Branch, and North Branch Au Sable River for years 1960-61 and 1973-77.

River branch	Number of fish	y-intercept	Slope	R^2 value
Mainstream				
1960-61	432	12.631	2.218	0.89
1973-77	872	5.409	2.364	0.90
South Branch				
1960-61	293	18.162	2.185	0.92
1973-77	686	16.683	2.328	0.90
North Branch				
1960-61	324	8.149	2.091	0.91
1973-77	787	14.935	2.379	0.88

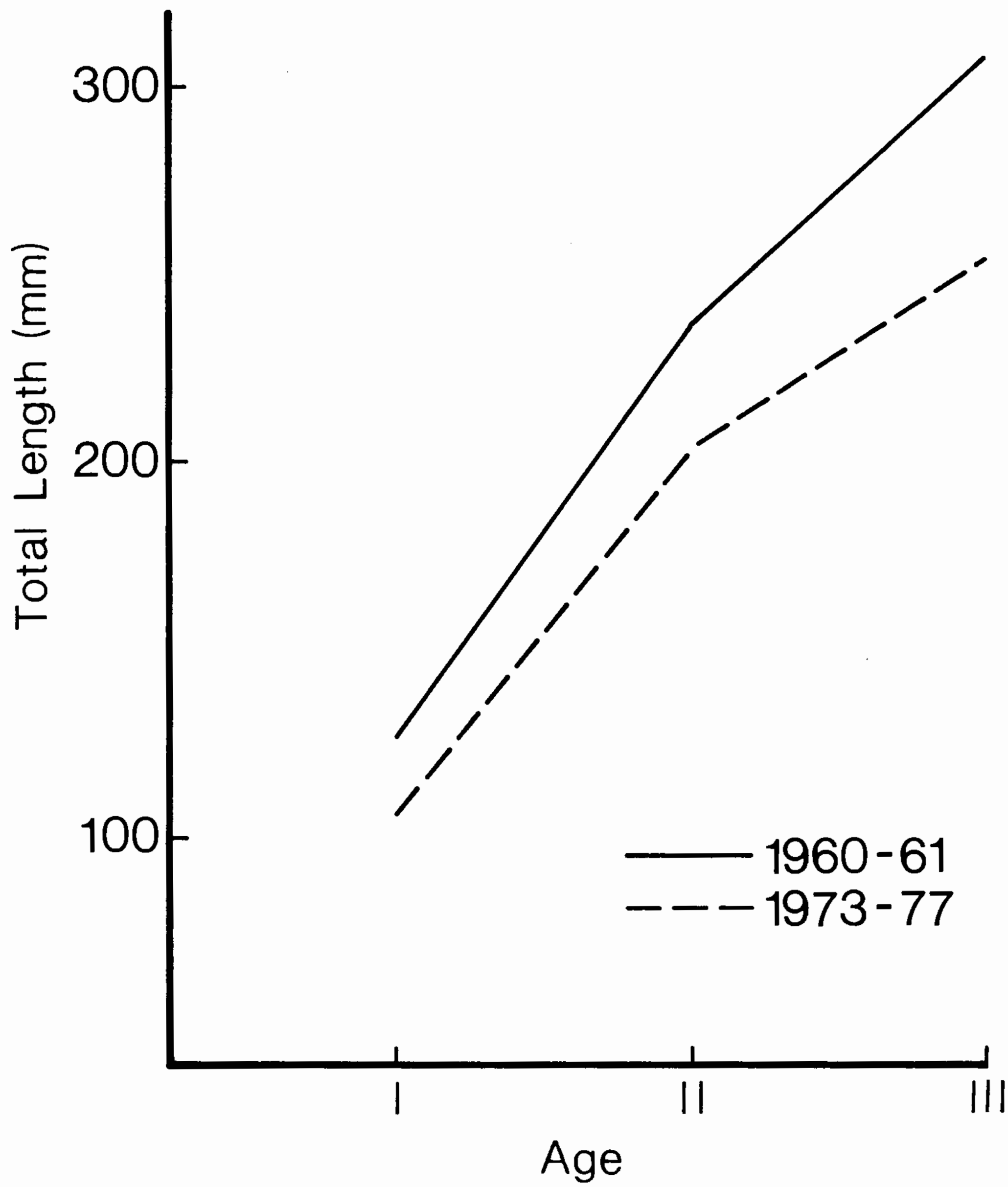

Figure 2.--Average total length at age for brown trout from the mainstream Au Sable River for years 1960-61 and 1973-77.

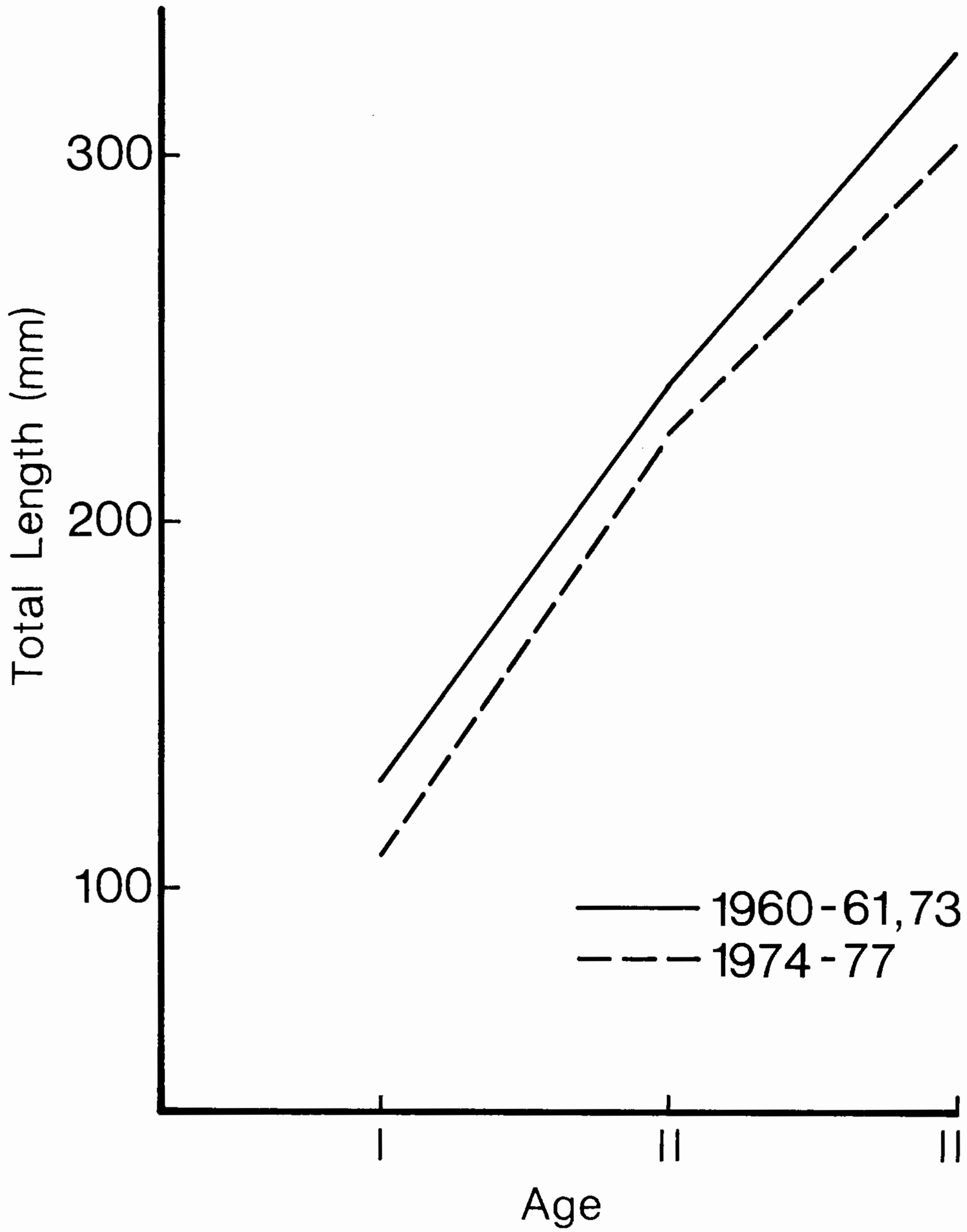

Figure 3.--Average total length at age for brown trout from the South Branch Au Sable River for years 1960-61 plus 1973 and 1974-77.

Grayling the mainstream picked up additional nutrient loading from the operations of the State Fish Hatchery in the early years.

Average lengths for the successive age groups of brown trout in the North Branch from 1960-61 to 1973-77 remained relatively constant except that age-II fish were somewhat longer in the latter interval (Fig. 4 and Appendix A). These results agree with the findings of Alexander et al. (1979) who suggested that the North Branch may be experiencing a progressively increasing nutrient load by seepage from numerous dwellings that have been built along the river since the 1960's.

The average growth increment in length at various ages was calculated for years before and after effluent diversion for the various streams (Appendix B, C, and D). The results showed growth declined abruptly on both the mainstream and South Branch after organic effluent was terminated (Figs. 5 and 6). The growth increments were significantly lower for all age groups of trout in the mainstream (Appendix E), and also significantly lower for all on the South Branch, except for age II (Appendix E).

On the North Branch the growth increment for brown trout remained nearly constant over time (Fig. 7 and Appendix E). Growth of trout in the North Branch was as good or better between the two time periods.

In the back calculation of growth a reverse "Lee's phenomenon" (Lee 1912) was discovered (Appendix B, C, and D). The older the age group of fish used for back calculation the greater was the growth for the early years of life. Most often, Lee's phenomenon of apparent change in the rate of growth shows the opposite effect and has been attributed, among other things, to size selective mortality of larger fish brought about by angler cropping. For example, selective catching by

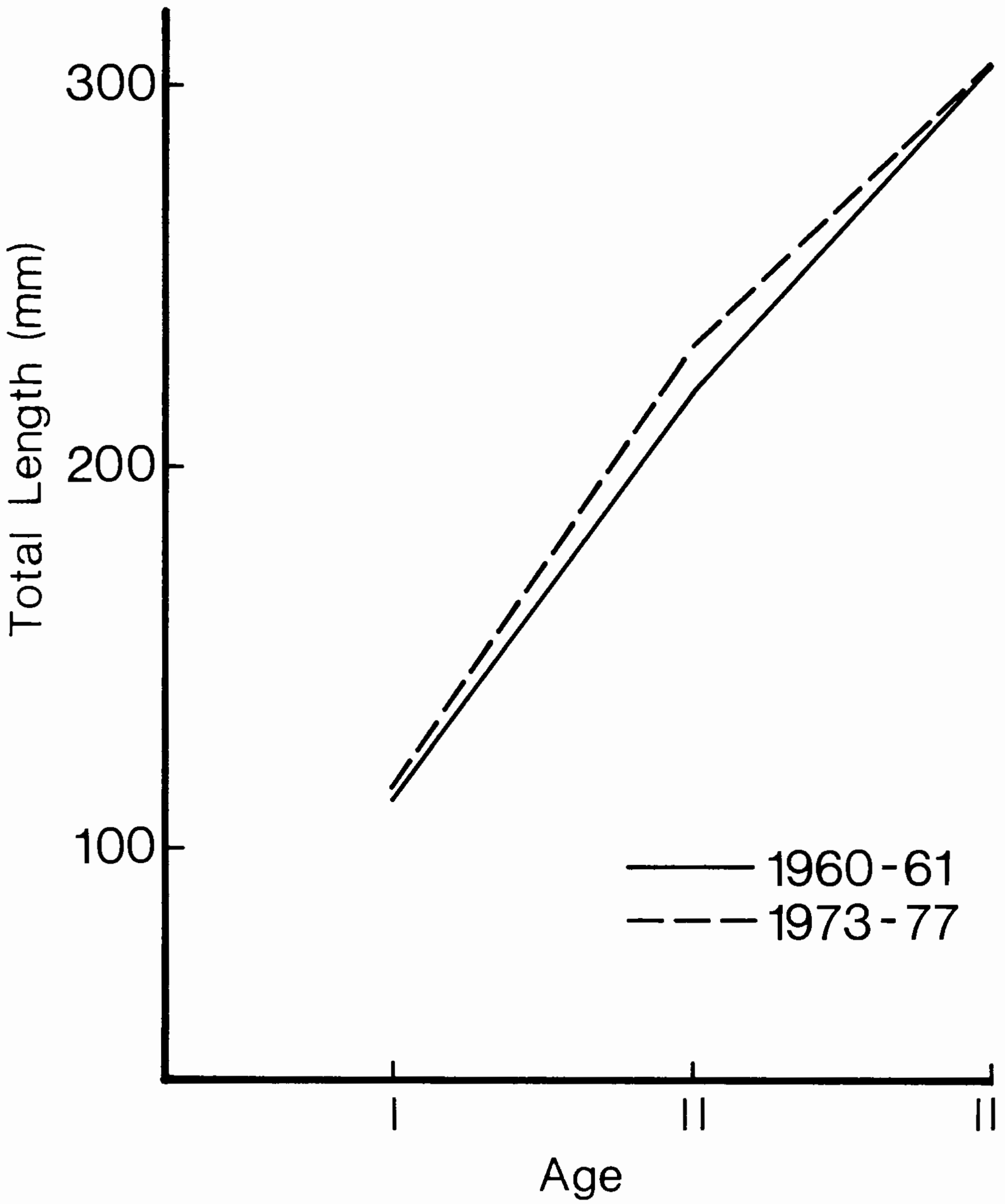

Figure 4.--Average total length at age for brown trout from the North Branch Au Sable River for years 1960-61 and 1973-77.

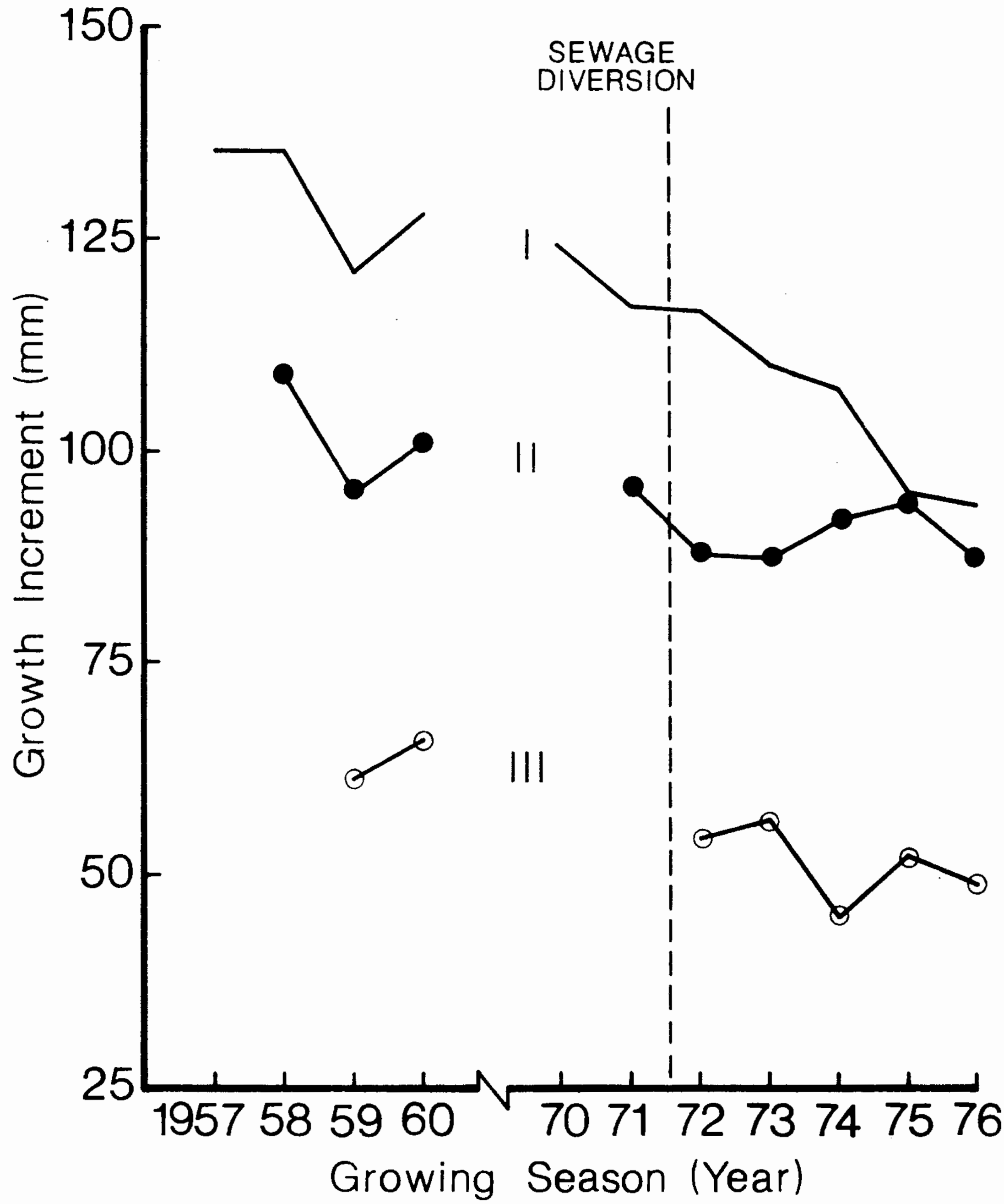

Figure 5.--Average back-calculated increment of growth in length of various age groups of brown trout from the mainstream Au Sable River.

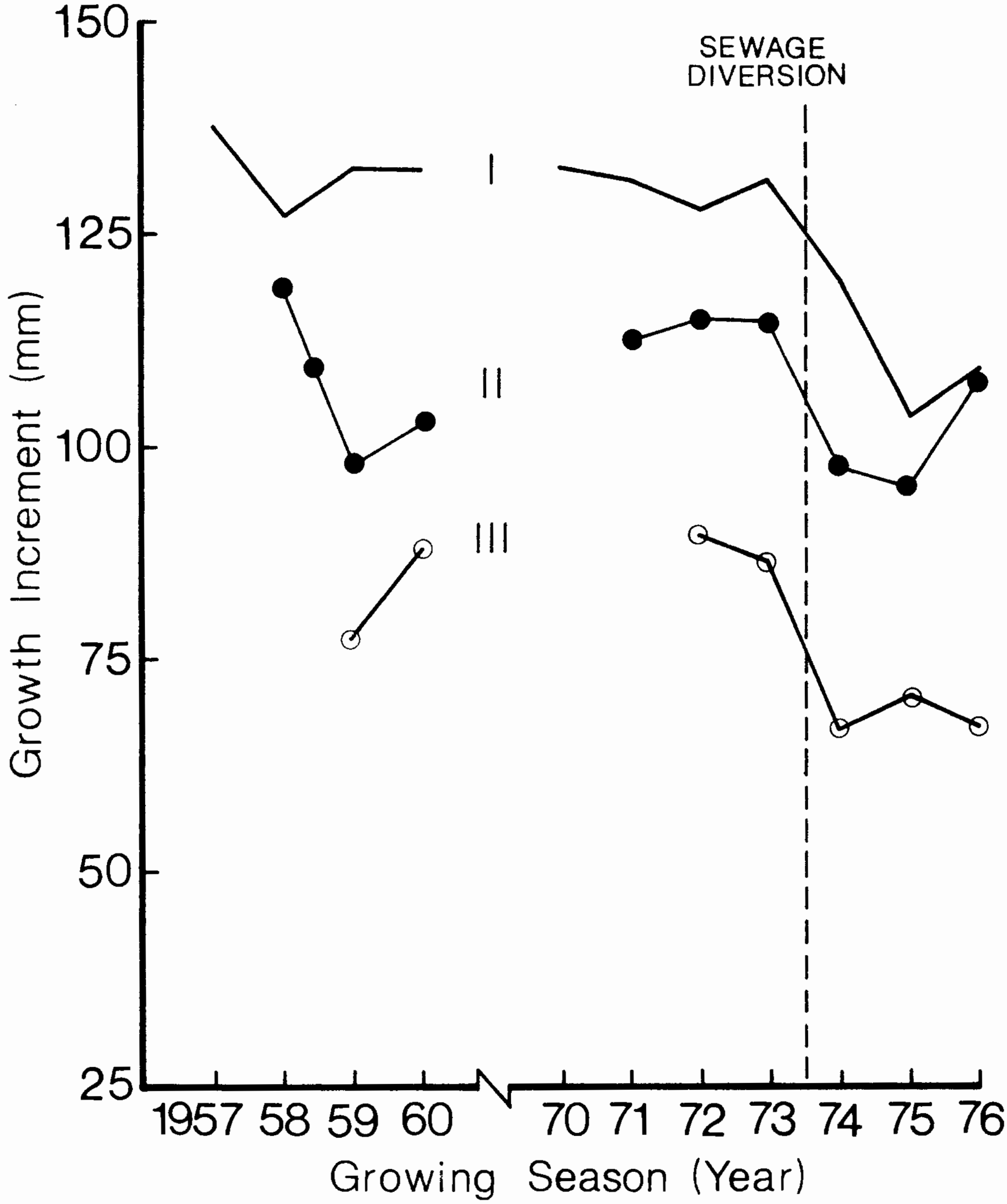

Figure 6.--Average back-calculated increment of growth in length of various age groups of brown trout from the South Branch Au Sable River.

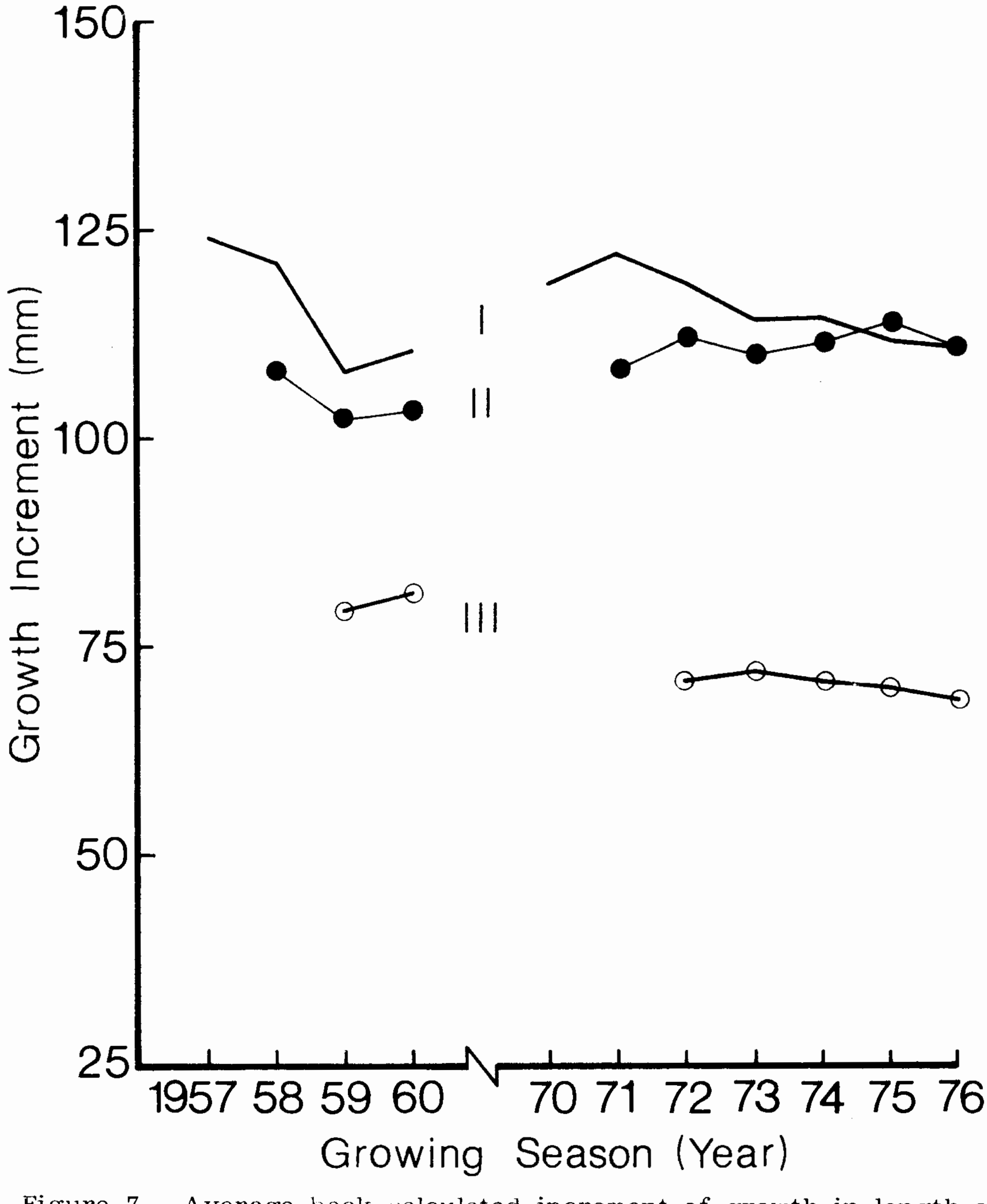

Figure 7.--Average back-calculated increment of growth in length of various age groups of brown trout from the North Branch Au Sable River.

anglers of fast growing fish of a cohort has been documented for the brook trout (Salvelinus fontinalis) in the Pigeon River, Michigan (Cooper 1951). However, Cooper's data also show a pattern of reverse Lee's phenomenon for brown trout from age I-III. Of the fish used in my study, approximately 90% were smaller than the minimum size limit on the respective stream section, so fishing had little impact on my results. Thus, some form of size selective mortality, possibly predation, bearing most heavily on the slowest growing fish of a cohort, must be acting on these populations.

Several studies indicate that the Common Merganser (Mergus merganser) and the Great Blue Heron (Ardea herodeas) are very effective predators upon several species of fish, especially the brown trout (e.g., Salyer and Lagler 1940; Alexander 1974, 1976). Food studies of the merganser in captivity (Latta and Sharkey 1964) suggest that the birds tend to select those fish which are from 102 to 229 mm in length. Alexander (Hunt Creek Trout Research Station, Lewiston, Michigan, personal communication) has suggested that because the slow growing fish are in the preferred size range for two growing seasons, they might suffer greatest losses to avian predation. Thus, more of the fast growing fish in this size range would survive.

The reverse Lee's phenomenon could have introduced a bias when calculating the average growth increment of an age group based on fish from different year classes. For example, in Fig. 5 the average age-I increment in 1958 is based on the back-calculated history of age-III fish, whereas for 1977, the average age-I increment is based on only age-I fish. Therefore, a difference in the back-calculated mean length would exist between the years as a result of reverse Lee's phenomenon which is independent of any effect of sewage. In an effort to overcome this bias when determining growth changes related to sewage effluent, the data were plotted by age group for each year class of fish (Figs. 8, 9, and 10). The results still support the hypothesis that a decrease in brown trout growth coincided with the termination of domestic sewage discharge into the river.

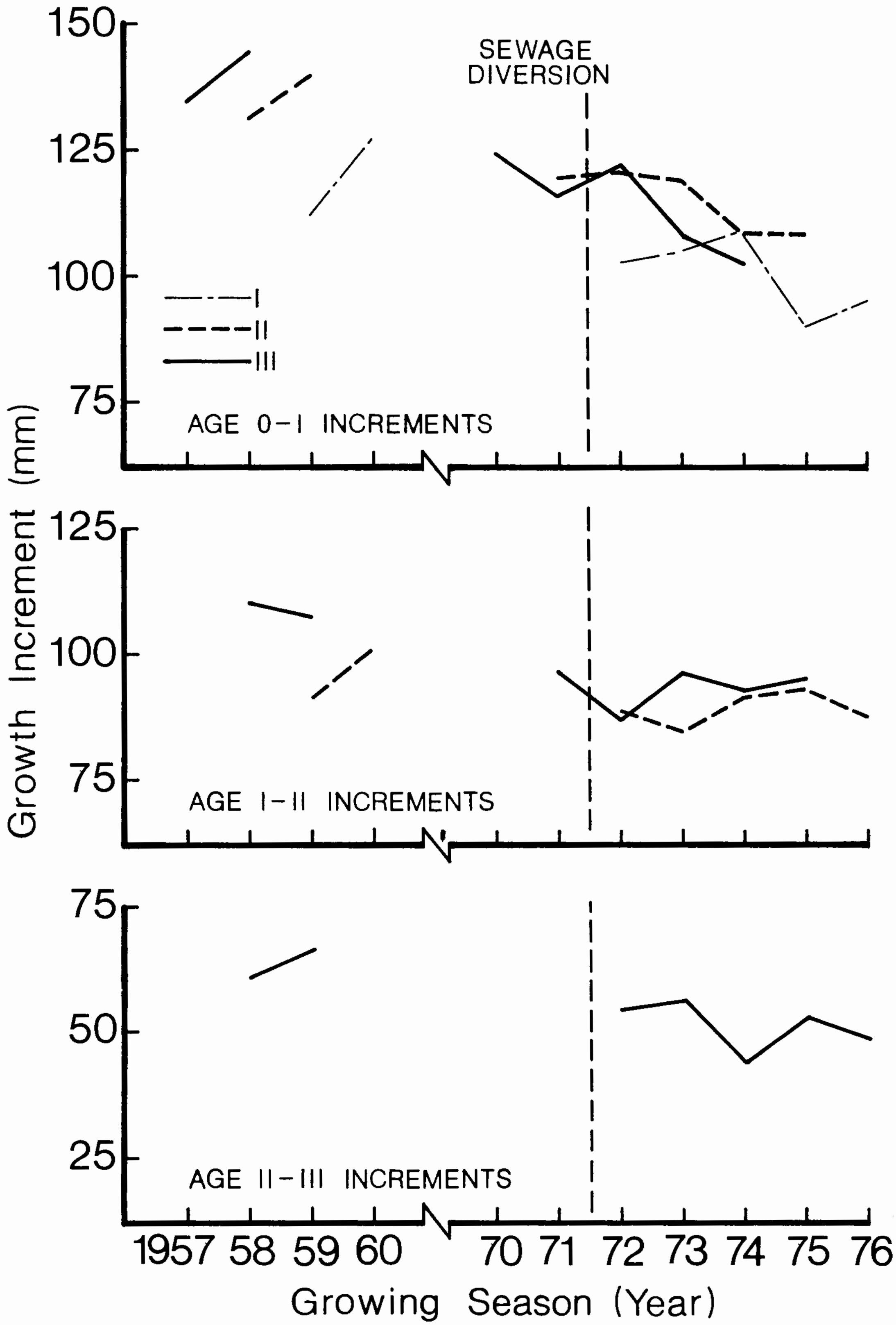

Figure 8.--Average increment of growth in length per year as calculated by fish of different age groups from the mainstream Au Sable River.

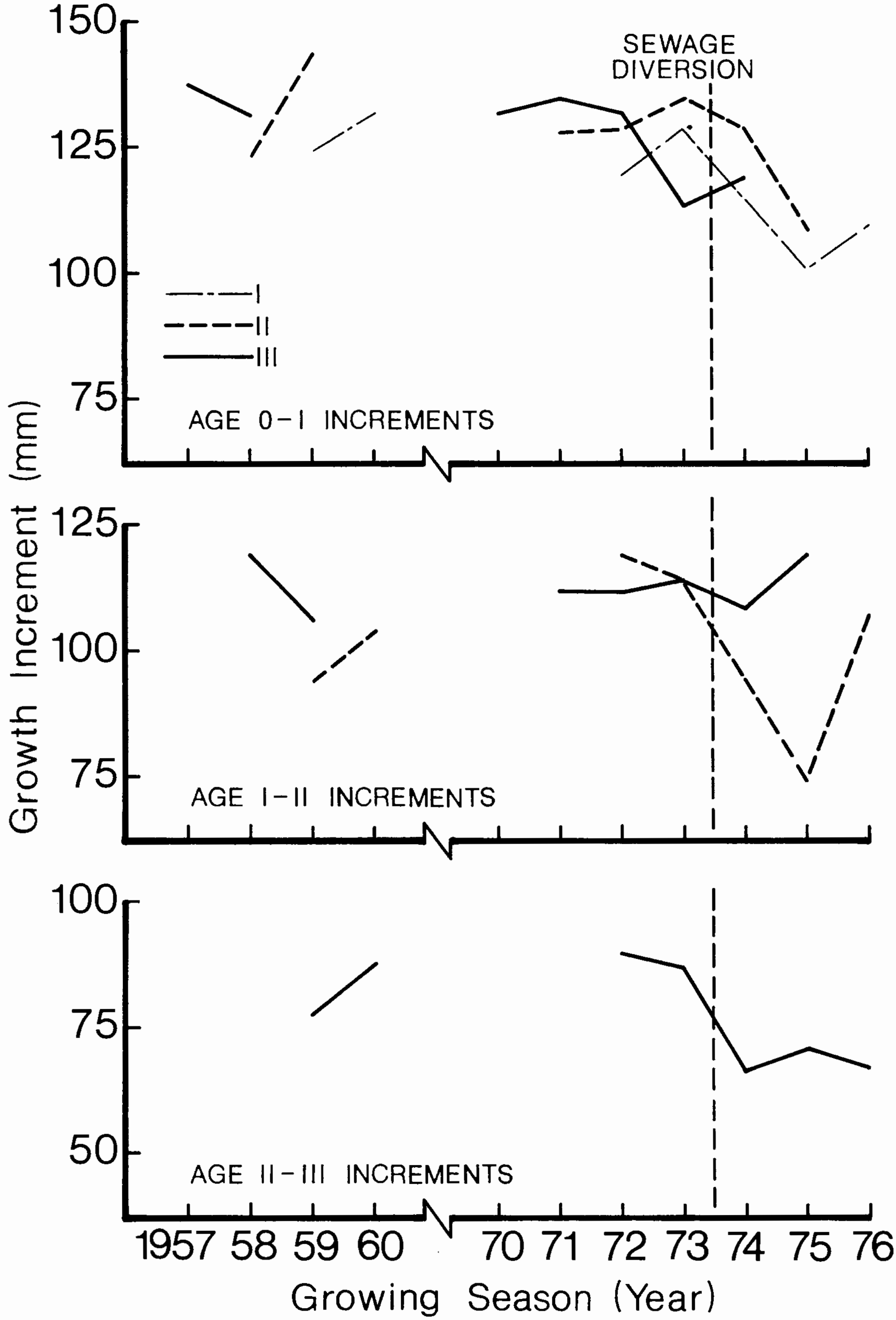

Figure 9.--Average increment of growth in length per year as calculated by fish of different age groups from the South Branch Au Sable River.

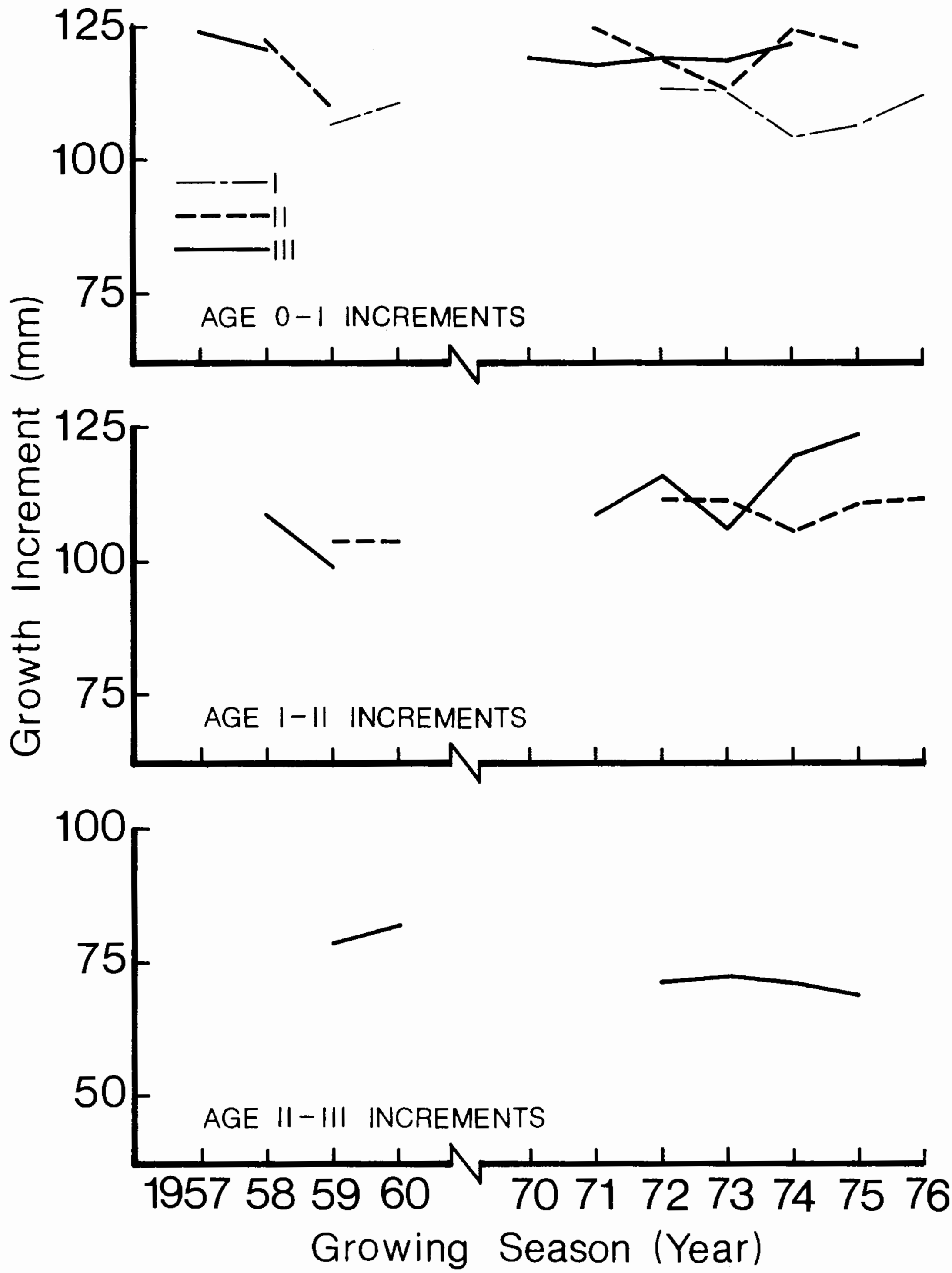

Figure 10.--Average increment of growth in length per year as calculated by fish of different age groups from the North Branch Au Sable River.

DISCUSSION

Each of several different hypotheses, which attempted to explain the decline in growth of brown trout in the mainstream of the Au Sable River, can be reassessed in light of the present study. First, the hypothesis that increasing angler use and/or fishing regulations were responsible seems unlikely. Actual fishing pressure in the Burton's Landing to Wakeley Bridge section was down 29% from 1960 to 1976 (Alexander et al. 1979). Moreover, the growth rate of brown trout seems to have declined before the 305-mm limit was implemented. Also, the growth rate diminished on the South Branch where fishing regulations were not changed.

Second, the population genetics model of Favro et al. (1979) did not appear to fit my results. If angling cropped the fastest growing individuals, those fish genetically superior with respect to growth, then presumably, a gradual decline in the average increment should have been expected, not an abrupt one as occurred. It is now apparent from the data that growth dropped rather abruptly at the time of sewage diversion on both the mainstream and South Branch. Also, if the genetic theory was true it probably should be spread over many streams. However, the bulk of the empirical data available for trout streams do not appear to support this theory. In fact, several studies have shown that the growth rate of trout in streams has remained relatively constant over long periods of time, even in heavily fished populations (e.g., Clark et al. 1980).

The timing of the growth decline seemed to rule out the hypothesis of habitat degradation in the form of loss of cover and concomitant decline in fish food production. Extensive stream improvement efforts to increase food production and create holes and "hides" for large trout in the Burton's Landing to Wakeley Bridge section of the mainstream have not demonstrated any improvement in either trout stocks or fishing (Alexander et al. 1979).

Finally, however, the sewage diversion hypothesis definitely coincides with the decline in growth. The nature of the decline in growth, based on scale reading, was found to correlate with the timing of sewage diversion. The mainstream exhibited a greater decrease in growth following effluent cutoff than the South Branch. This may have been so because the South Branch received less sewage effluent than the mainstream and thus the brown trout were not benefiting to the same degree as fish on the mainstream. Gislasion (1971) has demonstrated for the mainstream that the abundance of pollution-tolerant benthic invertebrates, especially the amphipod <u>Gammarus fasciatus</u> and the isopod <u>Asellus militaris</u> increased as the level of organic enrichment increased.

Other chemical and biological data also support this hypothesis. Records show a 70% decrease in nitrogen and a 10% decrease in phosphorus in the mainstream after 1971 (Heckathorn 1977, Coopes 1974). The fall population estimates of fishes made by Fisheries Division personnel at the Wa Wa Sum station confirm that the total weight of trout decreased substantially after 1971 (Fig. 11). On the South Branch similar decrease in nitrogen and phosphorus levels occurred between 1973-74 (Ray Moore, personal communication). Benthic macroinvertebrates collected by Reger (1973) on the mainstream above and below the Grayling sewage treatment

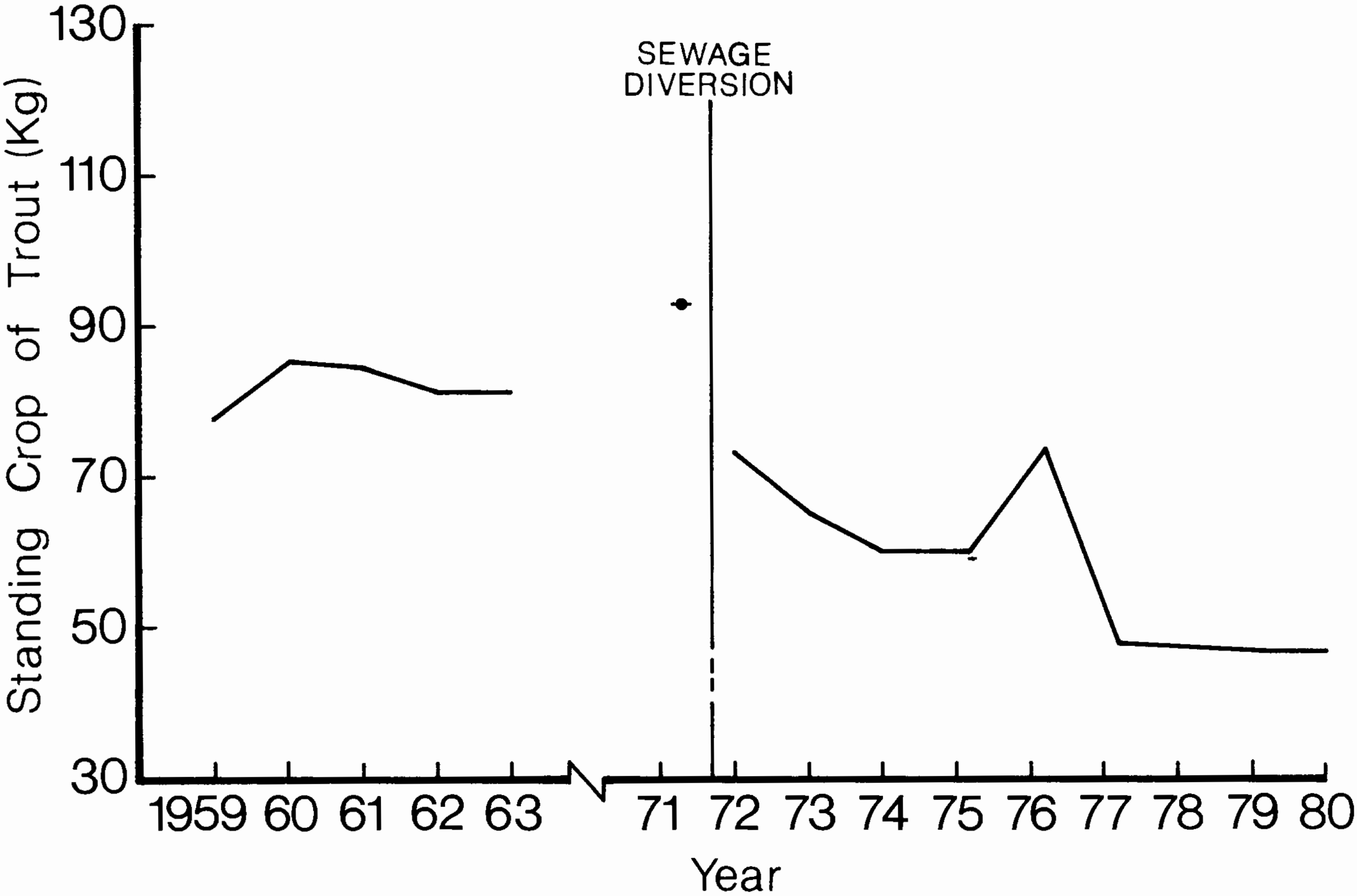

Figure 11.--Total weight of trout from the Wa Wa Sum station, mainstream Au Sable River, for the years 1959-63 and 1971-80.

plant exhibited a greater number of aquatic invertebrates and a larger biomass downstream from the plant. A significant contribution to the increased standing crop came from the isopod Asellus militaris.

In Wisconsin, Brynildson and Mason (1975) found that production of both brown and rainbow trout below a sewage plant effluent was elevated where numerical density of trout was high. They suggested that limited amounts of domestic sewage outfall could benefit trout growth. A study conducted by Ellis and Gowing (1956) on Houghton Creek, Michigan, demonstrated a significantly higher coefficient of condition (K) for brown trout below than above a domestic sewage treatment plant. They collected benthic macroinvertebrates and showed that two important brown trout food organisms, the isopod Asellus militaris and the amphipod Gammarus fasciatus, which are both pollution-tolerant species, were greatest in abundance below the sewage treatment plant. They concluded that the importance of these crustaceans as brown trout food organisms was greatest in the latter part of the summer when important aquatic insects like the Trichoptera and Ephemeroptera were often in low supply due to seasonal oscillations in their populations. However, throughout this time of year population levels of both the crustaceans remained relatively high.

The Bow River of Alberta, Canada, has experienced an increase in trout growth and numbers through enrichment (Martin Paetz, Fish and Wildlife Division, Edmonton, Alberta, personal communication). At Calgary, where the Bow receives a highly concentrated phosphate and nitrate effluent, per kilometer harvest of trout, mainly the rainbow (Salmo gairdneri), above the city averages only 90 whereas below Calgary it is 433.

Phosphorus, especially orthophosphorus, is often a significant limiting factor in aquatic production. The growth of algae in both natural and laboratory cultures exhibits a dependency on the amount of available phosphorus (Wetzel 1975). Southworth (1974) found that the standing crop of benthos increased following the addition of phosphate fertilizer into the Pigeon River, Michigan, with algal production being chiefly augmented. Coopes (1974) and the Michigan Water Resources Commission (1966) have both shown that enrichment of the Au Sable system below the communities of Grayling and Roscommon stimulated growth of algae and aquatic macrophytes.

Increased diurnal dissolved oxygen fluctuations from heightened levels of primary production possibly could affect the energy requirements of trout. Brown trout under such a stress would have to shunt more energy into body maintenance and less into growth processes. However, there is no evidence of record that fish in the study sites ever experienced oxygen deficiency as a result of increased primary production or of the biochemical oxygen demand of the sewage plant effluent. This is most directly the result of a uniform streamflow throughout the year due to a remarkably constant groundwater recharge (Coopes 1974). Also, the numerous riffle areas would also serve to compensate for oxygen sags, by affecting physical reaeration of oxygen depleted waters.

Levels of insect diversity and sensitive aquatic invertebrates have increased on the mainstream, especially in the former zone of pollution immediately downstream of the sewage treatment plant, and are believed to be due to the elimination of effluent that formerly entered the river at Grayling (Michael Quigley, National Oceanic and Atmospheric Institute, Ann Arbor, Michigan, personal communication).

Heckathorn (1977) sampling below Grayling in 1975, found densities of aquatic weed growth minimal when compared with densities prior to 1971.

In conclusion, the data presented in this study support the view that the apparent decrease in brown trout growth in the mainstream and South Branch of the Au Sable River is correlated with sewage diversion to a land disposal system. The explanation appears to lie in the reversion of the composition and level of the brown trout food supply to its natural level after being inflated artificially by nutrients of sewage origin. Food has long been recognized as a major limiting factor in the numbers of large fish.

LITERATURE CITED

Alexander, G. R. 1974a. Results of fishing and angler questionnaire on the South Branch Au Sable River, Mason Tract, Crawford County, Michigan, during the burrowing mayfly hatch, 1973. Michigan Dep. Nat. Resources, Fish. Res. Rep. 1808. 24 p.

Alexander, G. R. 1974b. The consumption of trout by bird and mammal predators on the North Branch Au Sable River. Michigan Dep. Nat. Resources, Fish. Res. Rep. 1855. 26 p.

Alexander, G. R. 1976. Diet of vertebrate predators on trout waters in north central lower Michigan. Michigan Dep. Nat. Resources, Fish. Res. Rep. 1839. 18 p.

Alexander, G. R., W. J. Buc, and G. T. Schnicke. 1979. Trends in angling and trout populations in the main Au Sable and North Branch Au Sable rivers from 1959-76. Michigan Dep. Nat. Resources, Fish. Res. Rep. 1865. 59 p.

Alexander, G. R., and H. Gowing. 1976. Relationships between diet and growth in rainbow trout (Salmo gairdneri), brook trout (Salvelinus fontinalis), and brown trout (Salmo trutta). Michigan Dep. Nat. Resources, Fish. Res. Rep. 1841. 41 p.

Alexander, G. R., and J. R. Ryckman. 1976. Trout production and catch under normal and special angling regulations in the North Branch of the Au Sable River, Michigan. Michigan Dep. Nat. Resources, Fish. Res. Rep. 1840. 14 p.

Alexander, G. R., and D. S. Shetter. 1967. Fishing and boating on portions of the Au Sable River in Michigan, 1960-63. Trans. Am. Fish. Soc. 96(3):257-267.

Brynildson, O. M., and J. W. Mason. 1975. Influence of organic pollution on the density and production of trout in a Wisconsin stream. Wisconsin Dep. Nat. Resources, Tech. Bull. 81. 15 p.

Clark, R. D., G. R. Alexander, and H. Gowing. 1980. Mathematical description of trout-stream fisheries. Trans. Am. Fish. Soc. 109:587-602.

Clark, R. D., G. R. Alexander, G. T. Schnicke, and W. J. Buc. 1980. Fly fishing on the Au Sable River mainstream. Michigan Dep. Nat. Resources, Fish. Div. Pamphlet. 14 p.

Cooper, E. L. 1952. Growth of brook trout (Salvelinus fontinalis) and brown trout (Salmo trutta) in the Pigeon River, Otsego County, Michigan. Pap. Mich. Acad. Sci., Arts, Lett. 37: 151-162.

Coopes, G. F. 1974. Au Sable River watershed project biological report (1971-73). Michigan Dep. Nat. Resources, Fish. Manage. Rep. 7. 296 p.

Ellis, R. J., and H. Gowing. 1957. Relationship between food supply and condition of wild brown trout in a Michigan stream. Limnol. Oceanogr. 2(4):299-308.

Favro, L. D., P. K. Kuo, and J. F. McDonald. 1979. Population-genetic study of the effects of selective fishing on the growth rate of trout. J. Fish. Res. Board Can. 36:552-561.

Gislasion, J. C. 1971. Species diversity of benthic macroinvertebrates in three Michigan streams. MS thesis, Michigan State University, East Lansing. 53 p.

Gowing, H., and G. R. Alexander. 1980. Population dynamics of trout in some streams of the northern lower peninsula of Michigan. Michigan Dep. Nat. Resources, Fish. Res. Rep. 1877. 45 p.

Heckathorn, C. 1977. Au Sable River study, July 21-22, 1975. Michigan Dep. Nat. Resources, Env. Protection Bur., Publ. 4833-5135. 65 p.

Klein, L. 1966. River pollution and control. Butterworth and Company, London, England. 484 p.

Latta, W. C., and R. F. Sharkey. 1964. Feeding behavior of the Common Merganser in captivity. Michigan Dep. Conserv., Res. Develop. Rep. 20. 17 p.

Lee, R. M. 1912. An investigation into the methods of growth determination in fishes. Conseil Permanent International pour l'Exploration de la Mer, Publ. de circonstance, No. 63.

Reger, S. J. 1973. Benthic macroinvertebrate diversity in three differentially perturbed Michigan streams. MS thesis, Michigan State University, East Lansing. 60 p.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Fish. Res. Board Can. Bull. 191. 382 p.

Salyer, J. C. II, and K. F. Lagler. 1940. The food and habits of the American Merganser during winter in Michigan, considered in relation to fish management. J. Wildl. Manage. 4(2):186-219.

Southworth, G. R. 1974. The effects of low level enrichment with inorganic phosphate on the composition and structure of the benthic invertebrate community of a trout stream. MS thesis, University of Michigan, Ann Arbor. 67 p.

Wetzel, R. G. 1975. Limnology. W. B. Saunders Company, Philadelphia, Pennsylvania. 743 p.

Report approved by W. C. Latta

Typed by M. S. McClure

Appendix A.--Average back-calculated length (mm) of trout by age group (sample size in parentheses) with 95% confidence limits and attained significance of *t* test (α = 0.05) for brown trout grouped before and after sewage diversion from the mainstream, South Branch, and North Branch Au Sable River.

Location	Age	Before	95% confidence limits	After	95% confidence limits	Attained significance (α = 0.05)
		1960-61		1973-77		
Mainstream	I	127 (401)	124,129	106 (524)	103,108	0.0000
	II	236 (178)	231,240	203 (323)	200,206	0.0000
	III	308 (64)	301,315	254 (102)	249,260	0.0000
		1960-61+73		1974-77		
South Branch	I	129 (494)	127,131	109 (168)	106,112	0.0000
	II	237 (211)	233,241	224 (132)	219,230	0.0004
	III	328 (47)	320,336	303 (60)	294,311	0.0002
		1960-61		1973-77		
North Branch	I	113 (269)	111,116	114 (532)	112,116	0.5961
	II	221 (128)	216,226	232 (256)	228,235	0.0003
	III	305 (29)	295,315	305 (64)	297,313	0.9980

Appendix B.--Average back-calculated increment of growth in length (mm) of various age groups of brown trout from the mainstream Au Sable River.

Year class	Age at capture	Number of fish	Increment		
			0-I	I-II	II-III
1957	III	46	135	109	61
1958	II	62	132	92	
	III	18	144	107	65
1959	I	82	112		
	II	44	139	101	
1960	I	95	128		
1970	III	8	124	96	54
1971	II	38	117	88	
	III	8	115	86	56
1972	I	29	102		
	II	51	122	84	
	III	17	123	95	45
1973	I	46	104		
	II	45	118	91	
	III	42	108	92	52
1974	I	54	109		
	II	63	108	92	
	III	27	102	94	49
1975	I	70	89		
	II	32	108	87	
1976	I	48	93		

Appendix C.--Average back-calculated increment of growth in length (mm) of various age groups of brown trout from the South Branch Au Sable River.

Year class	Age at capture	Number of fish	Increment		
			0-I	I-II	II-III
1957	III	9	137	118	77
1958	II	49	123	94	
	III	24	131	106	87
1959	I	35	124		
	II	25	144	103	
1960	I	59	132		
1970	III	7	132	111	89
1971	II	12	127	117	
	III	7	135	110	86
1972	I	26	118		
	II	47	128	113	
	III	31	132	113	65
1973	I	79	129		
	II	68	134	95	
	III	16	113	108	69
1974	I	36	114		
	II	14	128	74	
	III	13	117	118	66
1975	I	41	100		
	II	21	108	107	
1976	I	43	109		

Appendix D.--Average back-calculated increment of growth in length (mm) of various age groups of brown trout from the North Branch Au Sable River.

Year class	Age at capture	Number of fish	Increment		
			0-I	I-II	II-III
1957	III	9	124	108	79
1958	II	63	122	103	
	III	20	120	99	82
1959	I	74	107		
	II	36	109	103	
1960	I	67	110		
1970	III	2	118	108	71
1971	II	12	125	111	
	III	4	115	115	72
1972	I	10	113		
	II	36	119	111	
	III	12	117	106	71
1973	I	59	113		
	II	31	113	105	
	III	24	117	118	70
1974	I	68	104		
	II	58	124	110	
	III	22	122	123	68
1975	I	72	106		
	II	55	121	111	
1976	I	67	111		

Appendix E.--Average back-calculated increment of growth in length (mm) of trout by age group (sample size in parentheses) with 95% confidence limits and attained significance of the t test (α = 0.05) for brown trout grouped before and after sewage diversion from the mainstream, South Branch, and North Branch Au Sable River.

Location	Age	Before	95% confidence limits	After	95% confidence limits	Attained significance (α = 0.05)
		1960-61		1973-77		
Mainstream	I	127 (401)	124,129	106 (524)	103,108	0.0000
	II	100 (178)	97,103	91 (277)	88, 93	0.0000
	III	62 (64)	58, 66	51 (94)	47, 54	0.0001
		1960-61+73		1974-77		
South Branch	I	129 (494)	127,131	109 (168)	106,112	0.0000
	II	107 (211)	104,110	105 (48)	99,110	0.5252
	III	85 (47)	79, 92	68 (29)	61, 74	0.0003
		1960-61		1973-77		
North Branch	I	113 (269)	111,116	114 (532)	112,116	0.5961
	II	103 (128)	99,106	112 (256)	109,114	0.0000
	III	82 (29)	73, 90	70 (64)	66, 74	0.0062