1
9
4
3

Decline and Recovery of a Brook Trout Stream Following an Experimental Addition of Sand Sediment

Gaylord R. Alexander
and
Edward A. Hansen

Fisheries Research Report No. 1943
July 11, 1988

MICHIGAN DEPARTMENT OF NATURAL RESOURCES
FISHERIES DIVISION

Fisheries Research Report No. 1943
July 11, 1988

DECLINE AND RECOVERY OF A BROOK TROUT STREAM FOLLOWING AN EXPERIMENTAL ADDITION OF SAND SEDIMENT[1]

Gaylord R. Alexander

and

Edward A. Hansen

[1]A contribution from Dingell-Johnson Project F-53-R, Michigan

ABSTRACT

An experimental introduction of sand sediment into Hunt Creek in the northern Lower Peninsula of Michigan that increased the bed load four to five times resulted in a significant reduction of brook trout (*Salvelinus fontinalis*) numbers and loss of habitat. The brook trout population declined to less than half its normal abundance. After the experimental treatment was stopped the stream was allowed to cleanse itself of sand naturally for a 5-year period, followed by another 5-year period when sediment basins were constructed to accelerate sand clean out. The gross channel morphometry, bed type, water velocities, and trout cover recovered in about 6 years. However, to date, some sand is still in deposition along the stream edge and within gravel riffles and still adversely effects trout spawning, nursery habitat, and production of invertebrate trout foods. Little improvement in the numbers of young-of-the-year brook trout has occurred 10 years after experimental sand additions were discontinued. In spite of this reduced recruitment the population of older brook trout has nearly completely recovered. This has come about through increased survival of age-I and older trout, presumably because the habitat has been restored for these larger fish. The growth rate of individual trout showed little change over the course of the study. The decline in habitat quality induced by increased sand bed load caused a decrease in brook trout survival rates which reduced trout numbers. When there was less food, there were fewer fish. Thus, daily ration and growth did not change substantially. When sand bed load was reduced and habitat improved there were increases in trout survival, trout numbers, and food abundance, but little change in trout growth. This study has demonstrated that a relatively small sand bed load concentration of only 80 ppm had a profound negative effect on brook trout and their habitat. Moreover, it demonstrates that reduction of bed load can improve trout populations and trout habitat considerably. However, full recovery from the effects of elevated sand bed load levels will take a longtime in low gradient streams with relatively stable flow regimes.

INTRODUCTION

This paper documents recovery of a stream and its brook trout (*Salvelinus fontinalis*) population following an experimental increase in the sand bed load that caused a significant reduction in trout, their food supply, and desirable habitat in the stream. Results of the degradation phase of the study through 1981 have been reported previously in Alexander and Hansen (1986). Data will be presented in this paper for the entire 20-year study period (1967–1986). We will show the extent and rate of degradation following sand additions and the recovery rate as the sand bed load was reduced.

Many trout streams in midwestern United States have excessive sand on the streambed. They are typically low-gradient streams with slow to moderate velocity. Other streams, with somewhat steeper gradients, have less sand on the streambed but may have substantial amounts of sand in transport. Abnormally large amounts of sediments introduced by human activities or sediments associated with catastrophic floods may be detrimental to trout habitat (Cordone and Kelley 1961). However, prior to this study, the quantitative effects of low levels of moving sand bed load or sand deposits on trout and trout habitat were unknown. On initiating this and other sediment-trout studies in Michigan, we hypothesized that low concentrations of sand bed load in low-gradient streams have measurable adverse effects on the habitat of fishes in general, and trout in particular.

The presence of mobile sand is deceiving because it does not produce the turbidity commonly associated with most severe stream sedimentation. Even substantial amounts of moving sand bed load are not readily apparent in steep-gradient streams. Only when gradient is low enough for deposition to occur does the sediment become evident as it creates sand-filled reaches in streams. A modified procedure of sampling over weirs (Hansen 1974), or a sampler designed specifically for sampling bed load (Helley and Smith 1971), is required to quantify the amount of bed load.

Sand bed load may decrease food supplies of trout by scouring or burying desirable substrate. It destroys cover by aggrading channels and filling pools, and reduces spawning success by covering or plugging gravels. The "finer" suspended sediments also negatively affect some of these same aspects of fish habitat. Consequently, reducing stream sediment loads is often a major objective of fish habitat improvement programs.

Twenty years of brook trout population data were used to determine the response of trout to bed load sediment manipulation. During the first 5 years (1967–1971) pretreatment baseline data were collected. For the next 5 years (1972–1976) sand was added daily to the test reach of stream as we continued to collect biological and physical data. During the next 5 years (1977–1981) no sand was added as the stream was allowed to clean itself at the natural rate. During the final 5 years (1982–1986) no sand was added but "clean out" was accelerated by the use of sediment traps (Hansen 1973). The reason for accelerating the "clean out" was to bring the bed load conditions and stream morphometry back to pretest conditions as quickly as possible. The main question left to be answered after 1981 was: "Once a stream and its trout population has been degraded by large deposits of sand sediment can it recover completely?"

Since the full effect of the added sand on the trout was not apparent until 1976 we termed the years 1972–1975 as the transitional period and 1976–1981 as the treatment-effect years for data analysis purposes. The 1982–1986 period of years was termed posttreatment or recovery years.

STUDY AREA

The study was conducted at the Hunt Creek Fisheries Research Station of the Michigan Department of Natural Resources in the north-central Lower Peninsula of Michigan near the village of Lewiston. Hunt Creek is a small 20-cfs trout stream that flows through sandy, glacial-drift country. The deep sand and gravel drift allows little surface runoff, promotes high groundwater flows, and consequently produces extremely stable stream discharges. For example, records for the Thunder Bay River near Hillman, of which Hunt Creek is a major tributary, show that the stream discharge that is exceeded 2% of the time is only 4.4 times greater than that exceeded 98% of the time (Velz and Gannon 1960). The stable supply of cold groundwater (47–49 °F) and low gradient are typical of trout streams throughout much of the northern part of the Lower Peninsula of Michigan. The sediment concentrations in Hunt Creek were lower than the average of many streams we sampled. The fish population of Hunt Creek was predominantly brook trout with a moderate population of mottled sculpin (*Cottus bairdi*). Other fish species were rare.

METHODS

The stream was divided into two contiguous 1-mile sections. Sand was added to the lower section while the upper section served as a control or reference section (Figure 1). "Treatment" consisted of increasing the stream's total sediment concentration from approximately 20 ppm (primarily sand bed load) to 80–110 ppm to simulate concentrations found in larger trout streams with severe bank erosion (Hansen 1971). Sand was added daily at the upstream end of the treated section for a period of 5 years at a rate that increased the sediment load four to five times over that normally present. The amount added was varied with stream discharge to simulate natural sediment delivery patterns to streams. Although the once-a-day input created a slug effect at the input point, the effect dissipated within a short distance downstream.

Because the entire experimental area was closed to fishing, only natural mortality affected the brook trout population aside from the controlled sampling of fish in both the treated and control sections for diet analysis during part of the study period (1972–1981).

Methods used for measurement of the streams daily flow, sediment discharge, stream morphometry, water temperature, and quantity of sediment added are given in detail in Alexander and Hansen (1986).

Spring and fall brook trout population estimates were made from electrofishing data beginning in the fall of 1967 and extending through the fall of 1986. Estimates were stratified by 1-inch size groups and calculated by the Bailey modification of the Petersen mark-recapture method (Bailey 1951; Ricker 1975). Representative samples of brook trout scales were used to apportion estimates by length group to estimates by age group. Mortality rates were computed from sequential estimates of fish numbers by age groups. The average length by age group was determined following the procedure described by Alexander and Ryckman (1976). Growth rates were computed from sequential estimates of the average size of brook trout by age group.

Samples of benthic invertebrates were collected monthly from April through September with a standard Surber sampler. Five samples were taken monthly at each of four stations. Two stations were located in the treatment section and two in the control section. Samples were taken at sites spaced equal distance across the stream transects. Invertebrates were separated from bottom materials using sugar flotation (Anderson 1959). Both number and volume of benthos per square foot of stream bottom were determined.

We used a ratio analysis technique (Shetter and Alexander 1962; Alexander and Hansen 1982) to test for changes in brook trout population characters and benthic invertebrate communities. Ratios were calculated by dividing the variable for the treated (T) section by that for the control (C) section for each year. The T/C ratios for the pretreatment years then were compared to ratios for the treatment or posttreatment years by analysis of variance or regression analysis.

RESULTS

Sediment Input Effects on Stream

The stream discharge of Hunt Creek at the upstream end of the treated section (sill 2) averaged about 20 cfs and ranged from 14 to 50 cfs. Downstream approximately 1 mile (sill 1) discharge averaged 25 cfs. Three small tributaries and substantial amounts of groundwater enter between the two sills. Detailed results of stream discharge, sediment discharge, sediment concentration, sediment input, channel deposition, and streambed composition changes that occurred from the onset of the study to 1981 can be found in Alexander and Hansen (1986). In this paper we will highlight changes that occurred throughout the study but emphasize changes occurring during the 1982 to 1986 recovery period.

At the onset of the study Hunt Creek had an average total sediment concentration of 20 ppm. About 5 ppm of this was composed of silt and clay size particles and 15 ppm was sand. The concentration of fines did not increase with higher stream flows, but rather stayed at a fairly constant level over the entire range of stream discharge. All of the increased sediment concentration at higher stream flows was due to increased movement of sand.

During the 5-year period involving artificial sand input (1972–1976) a total of 4,233 yards (845 yards/year) of sand were added to the treatment section. The added sand moved slowly downstream, proceeding as a dune front. First it filled the thalwag of the channel, then it gradually spread laterally to form deposits along the stream edge. Elevated sediment concentrations were first noted at sill 1, near the lower end of the treated section in June 1973. Essentially all of the sand added during the first 2 years went into channel deposits. Concentrations of sediment increased steadily at sill 1 from 1973 through 1977 reaching peaks of 250 ppm. The average concentration during this treatment period was round 100 ppm. Following cessation of artificial sand input, sediment concentrations dropped steadily from 1977 to 1986 back to pretreatment levels. A summary of the stream channel geometry changes over the years of study are given in Table 1. The 1971 measurements are considered pretreatment baseline information. The last measurements to assess channel changes were taken in June 1984. Over the entire study period the water surface elevation in the control section decreased 0.12 feet and bed elevation decreased –0.11 feet. Average stream width decreased 0.10 feet. The difference between the change in water elevation and bed elevation is only 0.01 feet which is within the limits of accuracy of our measurement technique. Water volume in the control section decreased about 80 yd^3 or 5% during the study. If we correct for some abnormal channel filling above monitoring weirs and bulkheads the decrease is only about 1%. Therefore, we conclude that the control section changed little, except for downcutting 0.11 feet over the 13-year period or at a rate of about 0.01 foot/year or 1 foot/century.

By contrast these parameters changed considerably over the study period in the treated section (Table 1). Measurements in 1984 showed that the water surface elevation decreased 0.09 feet while the bed elevation decreased 0.18 feet. Stream width increased 0.10 feet, a negligible amount. Thus, the difference between the water surface elevation and the bed elevation is 0.09 feet, which results in the 173 yd^3 (4%) increase in water volume. We speculate that this lowering of the bed elevation below the original datum is due in part to natural downcutting as seen in the control section. But we might expect somewhat less downcutting in the treated section because it has a flatter gradient. However, it downcut even more than the control did. This is most likely due to the sediment traps that were installed in 1982. Given the type of flow regime in the treated section, one would expect lower streambed elevations to induce slower stream velocities and higher water surface elevation. This is what, in fact, happened. The water surface dropped less in the treated compared with the control section, even though the bed elevation decreased more.

In conclusion, the morphometry of the control section remained constant over the 20-year-study period except for some natural downcutting. The treated section has been generally restored to its pretreatment morphometry as of 1984, except that we removed a little more sediment with sediment traps than would have scoured out normally.

Although the general channel morphometry (good pools, log cover, gravel riffles, and rougher bottom topography) has been restored, there is still abnormal sand deposition near the stream edge and sand embedded gravels. Further, the small bank undercuts, backwater pockets, and ragged stream edge that serve as good nursery habitat for brook trout are still not completely restored. It may take many more years or a major flood event to wash out the deposits of sand along the stream's edge.

Even though the gross channel morphometry is restored now, during the treatment phase of the study the channel was changed radically (Table 1). As stated in Alexander and Hansen (1986) the greater sand bed load increased the water surface elevation, the bed elevation, and the average stream width. The static water volume (living space for trout) decreased substantially. The moving sand filled pools, smoothed the bottom topography, smoothed the stream edges, eliminated most bank undercuts, buried cover, and embedded gravel riffles. The added sand bed load had the effect of smoothing the channel, transforming it into a sand-bottomed canal, resulting in increased velocity and more laminar flow.

Brook Trout Population Changes

The total brook trout population fluctuated normally in the control section of Hunt Creek throughout the 20-year study. Only minor changes in abundance occurred for size groups of fish over the years. For example, somewhat more 5.0- to 7.9-inch trout but fewer 8.0-inch and larger fish were present during the 1982–1986 period compared to the 1976–1981 period of years (Table 2). These normal variations, which are unrelated to our bed load sediment manipulations, are taken into account when using the treated-to-control stream section ratio method of analysis to determine bed load sediment effects. The number of brook trout present by age group and their survival rate (slope of curve) change little over the years in the control section (Figure 2). By contrast, major changes occurred in the brook trout population in the treated section of stream (Table 3). The greatest change occurred between the pretreatment years and the treatment years. As a result of treatment the population dropped to about half its normal abundance. Trout populations have rebounded during the posttreatment years but have not yet attained pretreatment population levels as of 1986. These changes are also evident in the survival curves (Figure 3). The greatest change can be seen by comparing the 1967–1971 pretreatment curve to the 1976–1981 treatment curve which reflects the much smaller brook trout population. The survival curve for the posttreatment period shows a much improved population although it is still not back to pretreatment levels. Based upon changes in the slope of the survival curves it appears that sand bed load adversely affected the survival rate of the younger trout. We believe, the best way to judge the effect of changes in sand bed load on brook trout in this study is to use the treated/control stream-section ratio analysis technique. We used an analysis of variance to test for changes in the ratio T/C for the pretreatment (1967–1971), transitional (1972–1975), treatment (1976–1981), and posttreatment (1982–1986) period of years. The results of this analysis are summarized in Table 4 and shown graphically in Figures 4, 5, 6, and 7 for various size groupings of trout in the spring, fall, and seasons combined. Test results were similar for spring, fall, or combined season data. It is evident that the total brook trout population declined significantly during the treatment (1976–1981) period due to the elevated levels of sand bed load. The total stock improved some during the posttreatment (1982–1986) period but does not show statistically significant improvement to date (Figure 4). This is because stocks of 2.0- to 4.9-inch trout have not increased to pretreatment levels (Figure 5). These small fish numerically dominate the total trout stock.

Note, however, that the abundance of 5.0- to 7.9-inch trout also dropped significantly during the sand treatment, but in contrast to the smaller trout or total trout, their population has essentially recovered during the posttreatment period (Figure 6). The population of 8.0-inch and larger trout has also increased significantly during the posttreatment period, but recovery is still not complete (Figure 7). This size group is judged to be about 70% recovered to date.

When trout are grouped by age rather than size, results, and conclusions on population changes are similar. Significant decreases in abundance of all ages of brook trout were noted during the treatment period (Table 5). The recovery status of the various age groups of brook trout during the posttreatment years has varied. Populations of young trout, ages 0 and I* (asterisk indicates spring population) have not shown much improvement. However, the number of age I, II*, and II have improved significantly and are presently not significantly different from their pretreatment population levels. In general, the populations of trout age III* and older have shown considerable improvement, but their numbers are judged to be only about 70% recovered to date. Note that trout of age V* and older are fewer but the number of these old fish is small to begin with and sample sizes are too small for statistical analysis.

A smoothed two-degree polynomial curve fitted to the T/C ratios for total brook trout over the 20 years of study shows clearly the adverse effect of sand bed load on trout abundance (Figure 8). This figure also demonstrates the gradual nature of the population changes that occurred. Sediment treatment began in October 1971. From 1971 to 1981 it can be seen that the trout population in the treated section dropped significantly relative to the control population. It is also evident that improvement, has occurred with the reduced sand bed load, from 1982 to 1986, but recovery is not complete to date. Polynomial curves plotted for the various trout size groups (2.0–4.9, 5.0–7.9, and 8.0+) showed reductions and improvement similar to those shown in Figures 5, 6, and 7.

Changes in Trout Growth

As reported in Alexander and Hansen (1986) there was a slight increase of about 3% in the average length of brook trout age-0 and older in the treated section during the sand treatment period compared to the pretreatment period. This amounted to only 0.1 inch greater length for age-0 fish up to 0.7 inch greater length for age-V fish (Figure 9). Even though the slight changes noted were statistically significant for some age classes of trout they are insignificant from a practical fish management point of view. During the posttreatment period growth decreased for age-I and older trout and they are presently of similar length at age as found during the pretreatment period. However, age-0 trout are presently larger than at any time during the study, probably because their numbers are still down. Little change in growth was observed in the control section between the pretreatment and posttreatment periods. There was a slight decrease in average size at age in the control during the posttreatment period (Figure 10).

Changes in Benthos Standing Crop

Pretreatment levels of benthos were based upon 1972 samples (the introduced sand bed load did not reach our benthic sampling stations until 1973) and data collected in 1954 by Curry (doctoral thesis, unpublished). Based upon the T/C ratios after 1972, benthic populations dropped to less than half their pretreatment level (Figure 11). Benthic populations have shown slow but steady improvement since sand treatment ceased in 1976. By 1985, benthos recovered about 50% by number and 80% by volume of pretreatment populations levels. Changes in benthic invertebrate populations by taxa showed that the insect orders of Ephemeroptera, Diptera, and Coleoptera declined most dramatically during the sand bed load treatment. These orders have also shown the greatest improvement since sand treatment ceased. The orders Trichoptera and Plecoptera have shown smaller increases. Other orders showed no consistent change during the study. Invertebrates belonging to the taxa Annelida, Amphipoda, and Hydrocarina showed no reductions in abundance during the study period.

DISCUSSION

The channel of a low-gradient stream may take a long time to adjust to an input of sand-bed material. Movement rate may be only a few hundred feet a month or less (Alexander and Hansen 1986). Information from the later phase of this study demonstrates that the streams' natural cleanout or recovery rate is also slow after sand input is reduced. The rate of adjustment to a new channel equilibrium state, under a particular sand loading, depends upon stream discharge, channel gradient, and the quantity of added or subtracted sediment. These factors can vary widely from stream to stream. On Hunt Creek it took about 3 years for a 1-mile channel reach to undergo the major portion of adjustment to an increased loading rate that increased sand bed load concentration from 20 to about 80 ppm. It took about 6 years for this same 1-mile reach of stream to make the major adjustment back to pre-loading conditions. Following the major adjustment it may take many more years to remove the remaining sand deposits in slow velocity areas along the stream edge. This is particularly true of streams like Hunt Creek, and other good trout streams of the Midwest which have relatively stable streamflow. Flood events would speed up the clean out process considerably. The amount of sand discharged annually from a stream reach following elimination of sediment input decreases progressively over time, following a typical decay curve providing other factors such as stream discharge remain relatively constant.

Hunt Creek at this writing has had its pools and riffles reestablished essentially where they existed prior to the experimental sand loading. The stream again has a stair step in gradient at riffles, rather than the uniform drop in gradient observed under elevated bed load: in angler's terms, pools and riffles rather than a continuous run.

As the channel morphometry reverted to pretreatment conditions the original stream bed composition and cover types improved. Extensive areas of sand deposits were removed uncovering gravels or gravel-sand mixtures. Buried tree limbs, logs, boulders, and man-made debris reappeared to serve as trout cover. Aquatic plant growth became more extensive and luxuriant. Many bank undercuts, particularly the small ones were reestablished. The edge of the stream became more scalloped creating small areas of quiet backwater believed to be important for trout nursery areas. All of these factors which create roughness within the channel tend to produce more drag for the water, thereby slowing velocity. This creates a greater average stream cross-section resulting in a greater total static water volume (living space for fish).

Even though average velocity is reduced, the diversity of velocities within the channel is greater. There are relatively high velocity areas near resistant obstructions to flow such as logs, limbs, boulders, deflectors, and outside banks at stream bends. These obstructions cause turbulence resulting in back-eddie areas of low velocity. All of these factors along with good pools and riffles, appear to be favorable to trout in contrast to a sand-bottomed canal having little turbulence, laminar flow, and low diversity. The impact of bed load is believed to be greatest in low-gradient streams or low-gradient sections of streams because of the greater deposition that occurs (Hansen et al. 1982).

Sand substrate is considered the poorest substrate for habitation and production of benthic food organisms (Pennak and Van Gerpen 1947; Usinger 1968; Hynes 1970). We believe that a sand bottom that is moving as bed load is even worse. This study demonstrated that increased bed load can reduce benthic invertebrate populations in low-gradient streams. Further, reduction in bed load can enhance benthos. We are not sure of the mechanisms causing changes in benthos. It could be in part that unstable sand substrate is simply a poor holdfast for many benthic creatures. It could be the relatively small pore size or interstices within sand substrate compared to that of gravels. Many benthic invertebrates live well below the substrate surface. The abrasive effect on organisms may also be a factor. However, since our benthic sampling index stations were located on gravel riffles and the bed type remained mostly gravel throughout the study period, we believe that plugging or sand embeddedness (Sandine 1974) of gravels and possibly, the abrasion factor were the main reasons benthic populations were reduced. Benthos has not improved as much as gross channel morphometry and populations of trout larger than 5 inches. We think that gravels are still greatly embedded with sand compared to pretest conditions. This embeddedness may still be a problem for some benthos taxa and trout reproduction because the numbers of young trout also have not recovered to date.

A significant reduction of brook trout of all size and age groups in Hunt Creek was shown to be related to increased sand bed load (Alexander and Hansen 1986). We concluded that the most devastating impact on the brook trout was the reduced survival of the early life stages. We hypothesized that fry production in Hunt Creek was reduced because of degradation of microhabitat caused by sand substrate. A number of authors have shown adverse effects of salmonids when sand and other fines become embedded in gravels (Cooper 1965, Sandine 1974, Phillips et al. 1975, Hausle and Cable 1976, Bjornn et al. 1977, Hillman et al. 1987). Sand-plugged gravels not only reduce the chances for normal development of eggs and fry in the redds, but also can prevent emergence of fry from the redd due to entrapment (Harshberger and Porter 1979; 1982). Further, fry survival may have been reduced because of poorer nursery habitat along the stream edges due to the sand deposition. Changes in channel morphometry, bed composition, and cover undoubtedly affected the vulnerability of trout to predation. The change from relatively dark to light streambed results in a change in albedo. Further, the flat, shallow, relatively uniform light-colored sand streambed, devoid of cover, may have made trout more vulnerable to predation. Trout age-0 and older in Michigan streams have been shown to suffer high losses to predacious birds, reptiles, and mammals (Alexander 1977; 1979).

Populations of small brook trout in Hunt Creek have not returned to normal to date. Thus trout recruitment is still not up to pretreatment levels. However, in spite of this lower level of recruitment, the population of 5.0- to 7.9-inch trout has completely recovered and the 8-inch and larger sized groups have nearly recovered. This improvement has undoubtedly been possible because good habitat (pools and cover) for these large fish has been restored. Survival of fall fingerling brook trout (age-0) and older appears to have greatly increased in the posttreatment period. However, part of the apparent increased survival may be due to immigration of surplus young from the control section. These trout may have taken up residence upon finding open niches created by the improving habitat. Under normal recruitment levels in the treated stream segment territorial interactions would cause migrating trout to keep moving or displace a resident trout thus maintaining the population in equilibrium with the available habitat. The works of Stuart (1953), Kalleberg (1958), and Le Cren (1973) suggest that territorial competition and stress limits the trout population to available habitat, thus a relatively stable population equilibrium state is maintained.

It is now evident that the level of recruitment of brook trout in Hunt Creek in the past (pretreatment) was in excess of that needed to maintain good populations of older fish, at least in the 1-mile test section of stream. However, these excess recruits may be desirable and in fact essential to generate drift (emigration) of young brook trout to downstream reaches of stream in the drainage, where local reproduction might be inadequate or nonexistent. Further, excessive recruitments could be a safe guard resulting in a more stable population of age-I and older trout.

In our 1986 paper, we speculated that if recruitment failure had not operated first to reduce the trout population in Hunt Creek the adjustment would have taken place anyway in older fish, via poor survival, because their habitat was destroyed by sand deposition. It appears that we were correct in our assessment.

In view of the above, we can now say that sand bed load impacts on habitat for both recruits and older-and-larger fish. Sand bed load in low gradient streams appears to impact adversely on all size and age categories of brook trout. This is consistent with the findings from our Popular Creek study (Hansen et al. 1982; Alexander and Hansen 1982) where sand bed load was reduced using sediment traps. In Popular Creek populations of young brown trout (*Salmo trutta*) and rainbow trout (*Salmo gairdneri*) increased in stream areas that had less sand bed load. However, populations of older and larger brown and rainbow trout increased mainly in areas where the reduction of sand bed load resulted in creation of pools and exposure of logs and other debris for cover.

There were not major changes in growth of brook trout during this study. All age groups grew a little faster (0.1 inch for age-0 to 0.7 inch for age V) during the sand treatment phase of the study. Growth reverted to the pretreatment status for trout age-I and older during the posttreatment phase. However, growth of young-of-the-year (age-0) trout is now better than during either the treatment or pretreatment period. This suggests a density-dependent growth adjustment. The posttreatment period has improved benthos (trout food) but caused lower-than-normal stocks of young fish. This may be allowing young fish to obtain larger daily food rations resulting in better growth. This development suggests that young trout intentionally eat somewhat different foods (either size or kind) or they are spatially segregated compared to the older trout. Nilsson (1967) noted that spatial segregation changes with food abundance. Young brook trout in Hunt Creek and the Au Sable River are known to frequent mostly shallow water along the stream margins and small early instar forms of aquatic invertebrates are their predominate food (Alexander and Gowing 1976).

In general, however, we conclude that brook trout and benthic invertebrates are adversely affected to a proportional degree by sand bed load. When there is less food due to sand bed load there are fewer trout to eat it and when there is more food with lower bed load there are more trout to eat it. This result in a relatively constant daily food ration and growth rate which remains relatively constant over a wide range of sand bed load conditions. This also shows that growth rate of trout in streams is not necessarily a good indicator of food production and productivity unless you take into account the population density of trout and other fish.

The growth rate of stream trout in most Michigan streams varies little from year to year. By contrast, trout population density varies considerably. We hypothesize that this comes about because the environmental factors affecting trout abundance are also affecting trout food production in a similar proportion. Factors such as bed load, climate and floods probably always affect both trout density and food production similarly. By contrast when a factor such as nutrient loading is altered by elimination of sewage effluent, as was the case in the Au Sable River, Michigan (Alexander et al. 1979), trout growth decreased because food production decreased. Trout recruitment and numerical density was not altered by the decreased nutrients.

This study has demonstrated significant negative effect of sand bed load on low-to-moderate gradient trout streams. Further, the concentrations of moving bed load sediment doing damage are not perceived by most people as being excessive. Most lay observers of streams, including experienced trout fishermen, do not observe the relatively inconspicuous sand bed load as it slowly tumbles down the stream. This moving sand does not appear very menacing to most, probably because it does not create turbidity. Turbid water on the other hand, even at low concentrations of suspended sediment, is readily noticed by stream observers and it disturbs them greatly although it may have little negative impact on stream biota.

Even though to date the Hunt Creek brook trout population and benthos has not completely recovered, we believe it will given time to rid itself of the sand deposits along the stream margins and within interstices of gravel beds. As demonstrated, much time is required to reclaim even 1 mile of stream by letting the stream cleanse itself naturally. The process can be speeded by installing sediment basins (Hansen 1973; Hansen et al. 1983; Alexander and Hansen 1983). Even if we stop sand input to a stream completely and let it cleanse itself naturally, the load of sand, moving out of the first upstream mile, must then move through the second mile, and so on downstream until it reaches the streams mouth or an impoundment. Thus, it could take 60 years or longer to clean out 10 miles of stream at the rate measured in Hunt Creek. If we want to shorten this clean-out time we must use sediment basins. In larger river systems like the Manistee, Au Sable, Jordan, Fox, Tahquamenon, and many others which are 50 to 100 miles long it could take centuries for them to clean out, naturally. We are still suffering in the Midwest from excessive erosion created by mans' land developments and logging operations, particularly log drives in the late 1800's.

ACKNOWLEDGMENTS

This study was made possible by the assistance of many people from the Region II staff of the Michigan Department of Natural Resources and the staff of the U. S. Forest Service, North Central Forest Experiment Station. During the later years of the study, Jack Rodgers, Otis Williams, and Yvonne Rolandson of the Hunt Creek Fisheries Research Station staff did much of the field work, lab analysis, data summarization, and draft typing. James Ryckman, Biometrician, Institute for Fisheries Research, did most of the statistical analysis of the data. Grace Zurek of the Institute did the final typing. We appreciate the efforts of our colleagues, Howard Gowing, Andrew Nuhfer, Richard Clark, and W. Carl Latta, in many aspects of the study and in reviewing the manuscript.

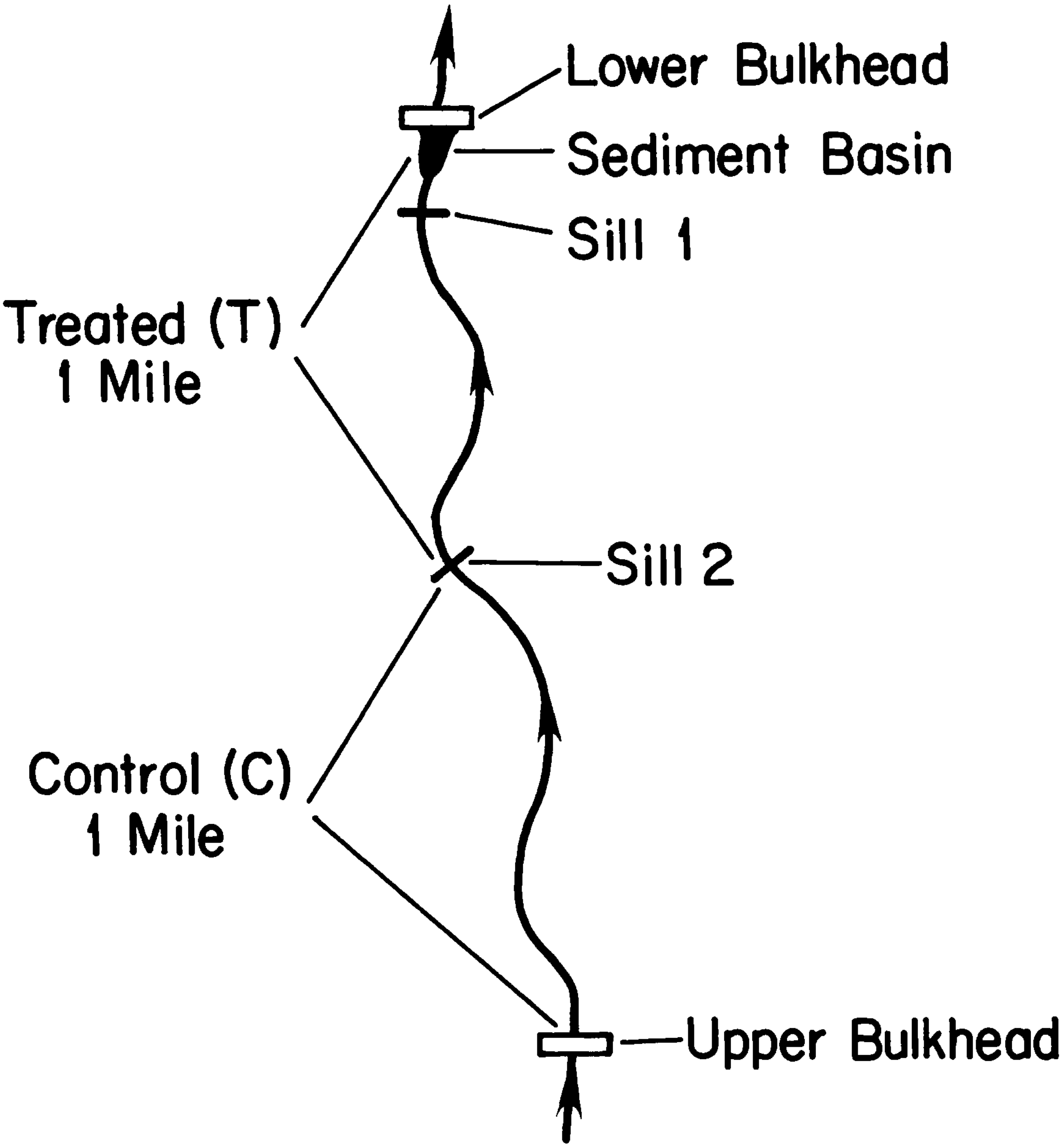

Figure 1. Diagrammatic presentation of Hunt Creek study area.

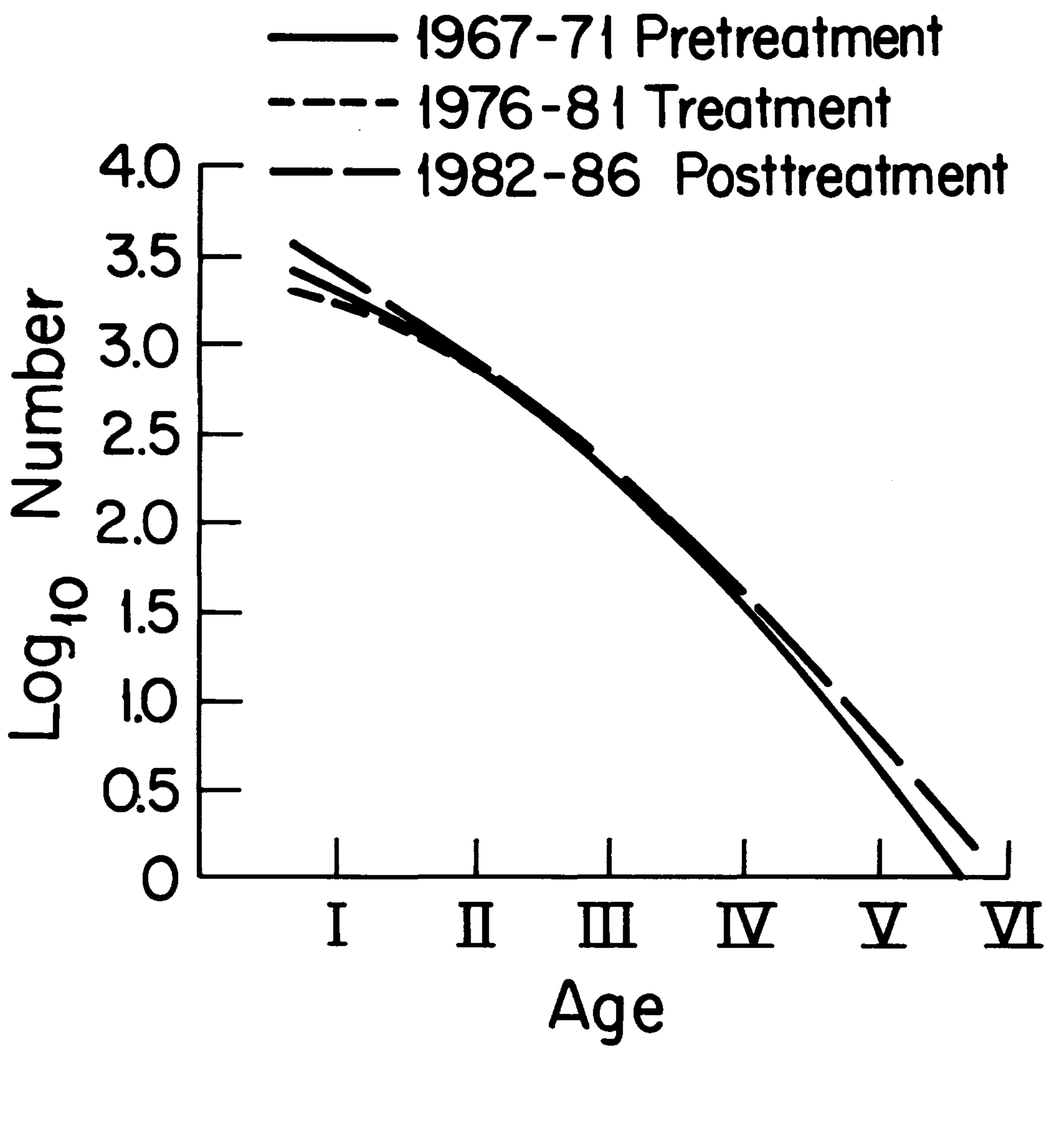

Figure 2. Brook trout number by age group in the control section of Hunt Creek. Curve slope represents survival rate.

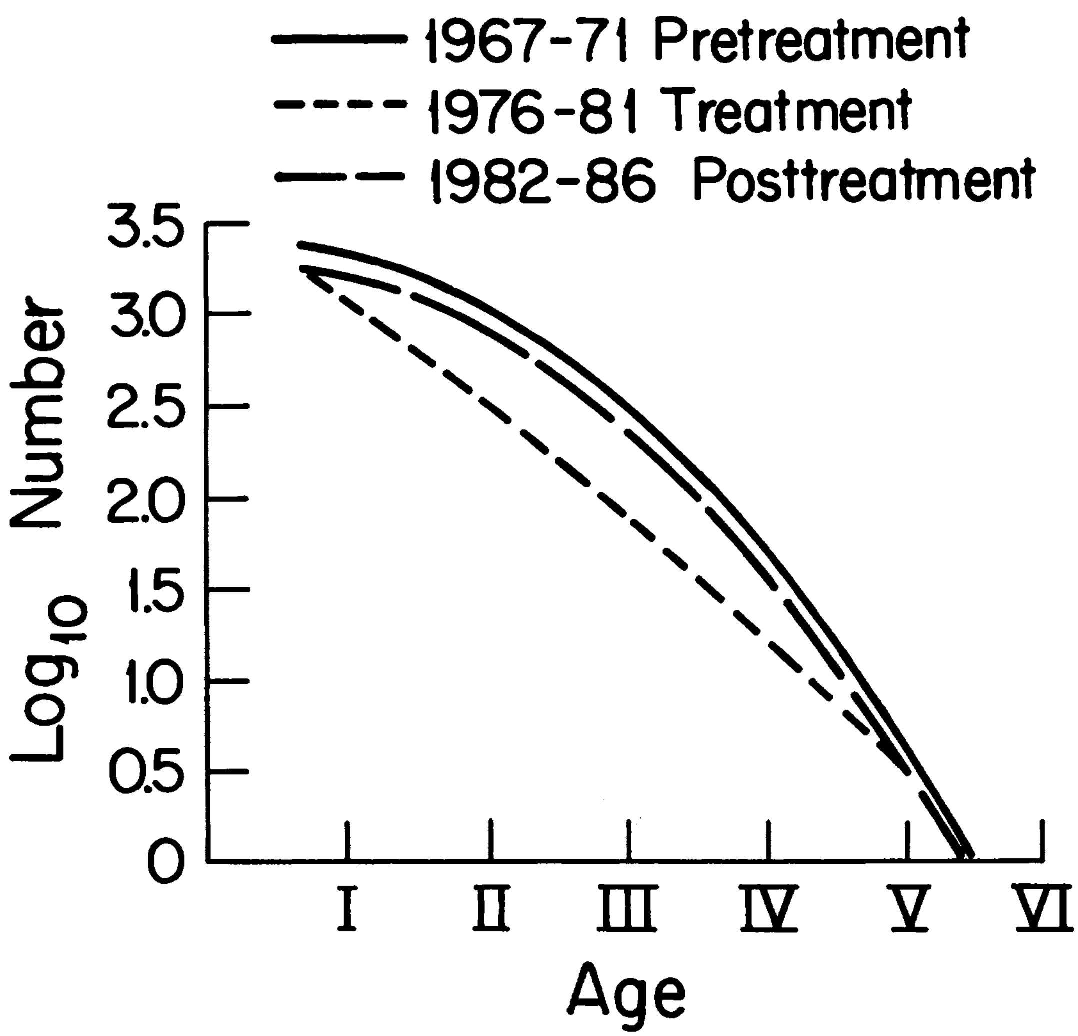

Figure 3. Brook trout number by age group in the treated section of Hunt Creek. Curve slope represents survival rate.

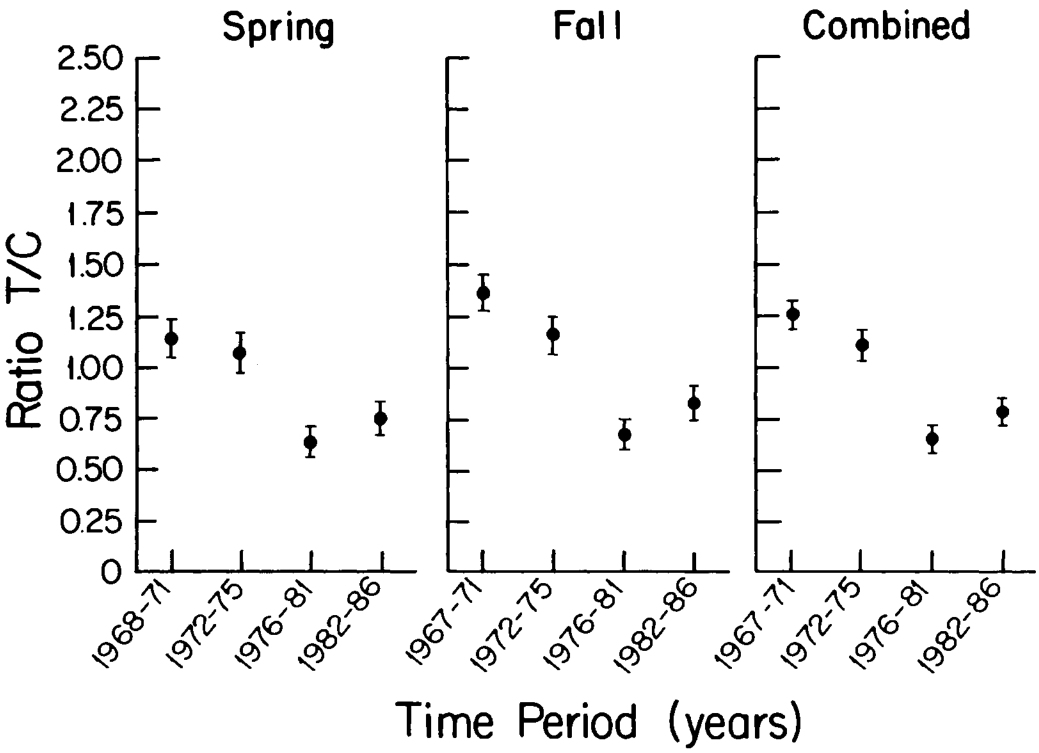

Figure 4. Average ratios (±95% confidence limits) of treated-to-control areas (T/C) for numbers of brook trout of all sizes present in the fall, spring, and combined seasons, for various time periods.

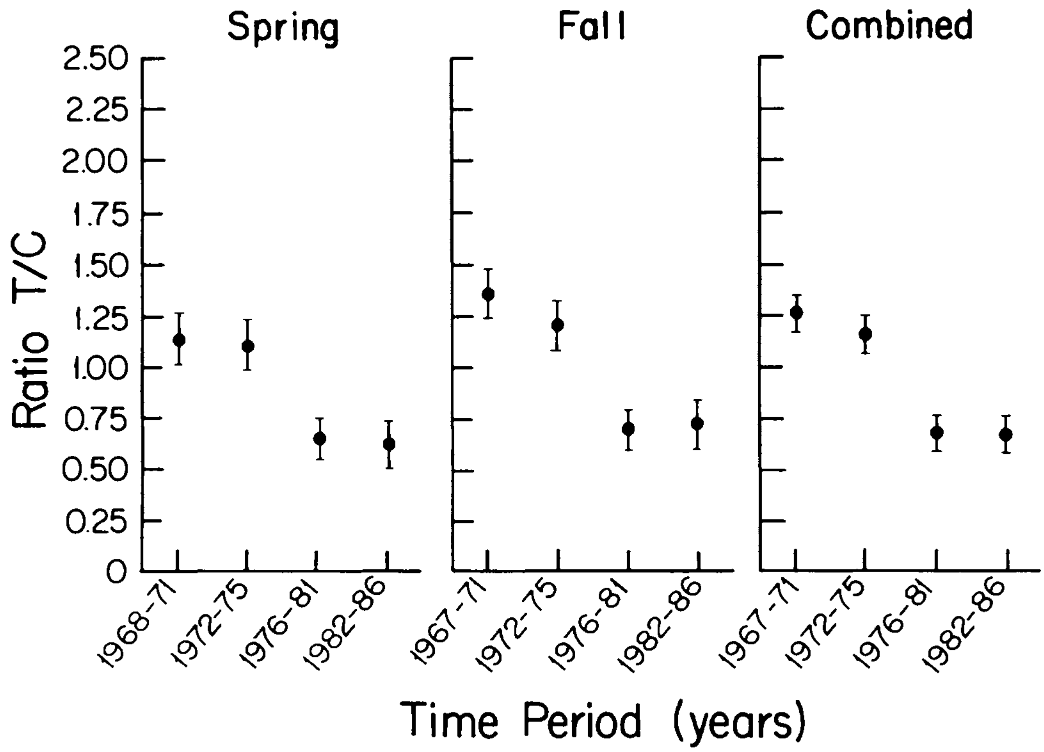

Figure 5. Average ratios (±95% confidence limits) of treated-to-control areas (T/C) for numbers of 2.0- to 4.9-inch brook trout present in the fall, spring, and combined seasons, for various time periods.

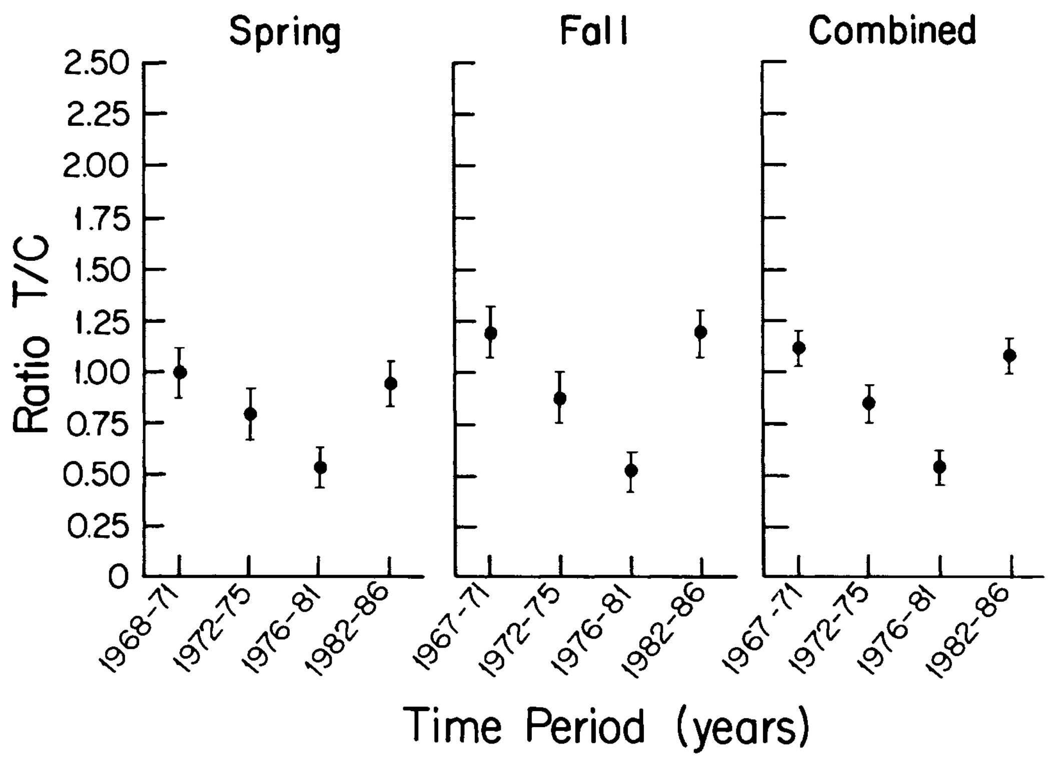

Figure 6. Average ratios (±95% confidence limits) of treated-to-control areas (T/C) for numbers of 5.0- to 7.9-inch brook trout present in the fall, spring, and combined seasons, for various time periods.

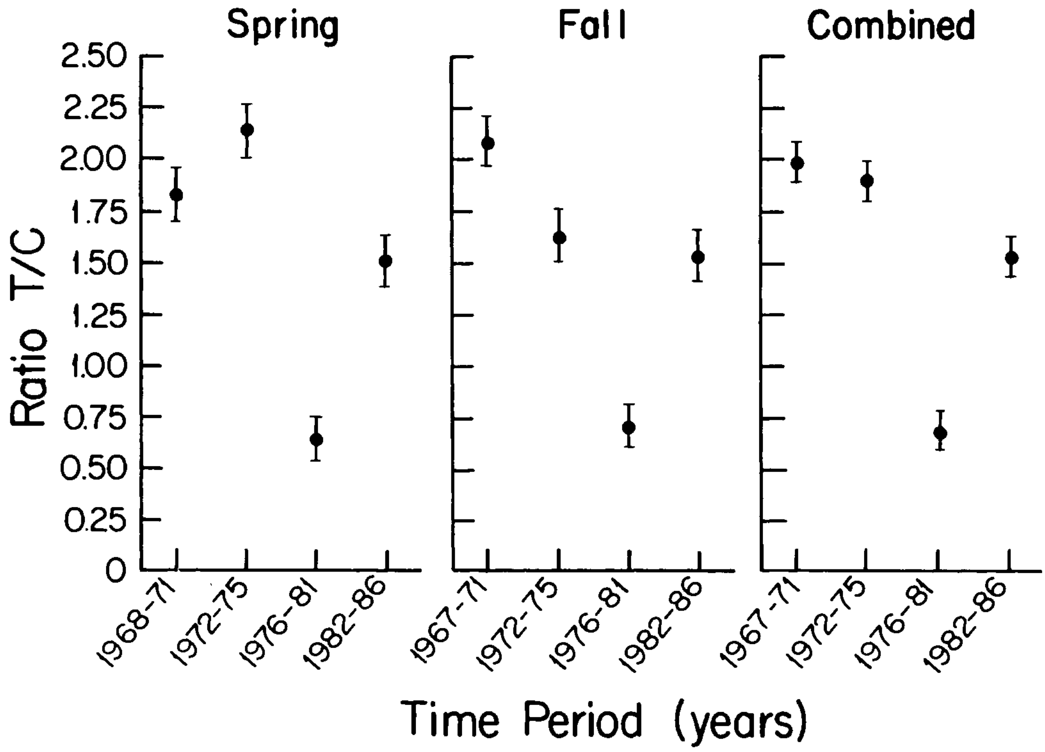

Figure 7. Average ratios (±95% confidence limits) of treated-to-control areas (T/C) for number of 8.0 inch plus brook trout present in the fall, spring, and combined seasons, for various time periods.

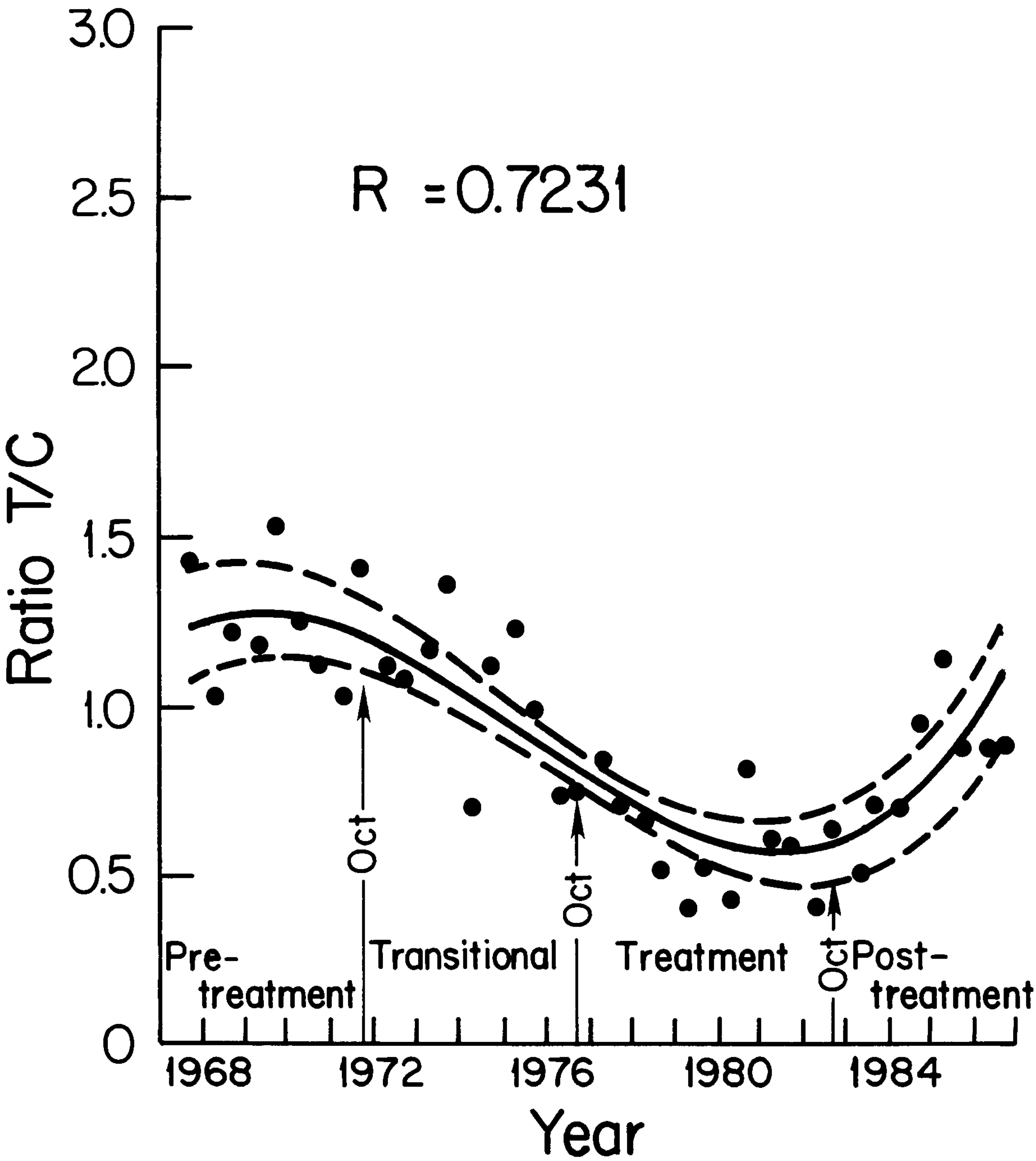

Figure 8. Ratios of the total number of brook trout present in the treated area (T) divided by the control area (C) each spring and fall. Solid line is best fit of polynomial regression and dashed lines represent 95% confidence limits.

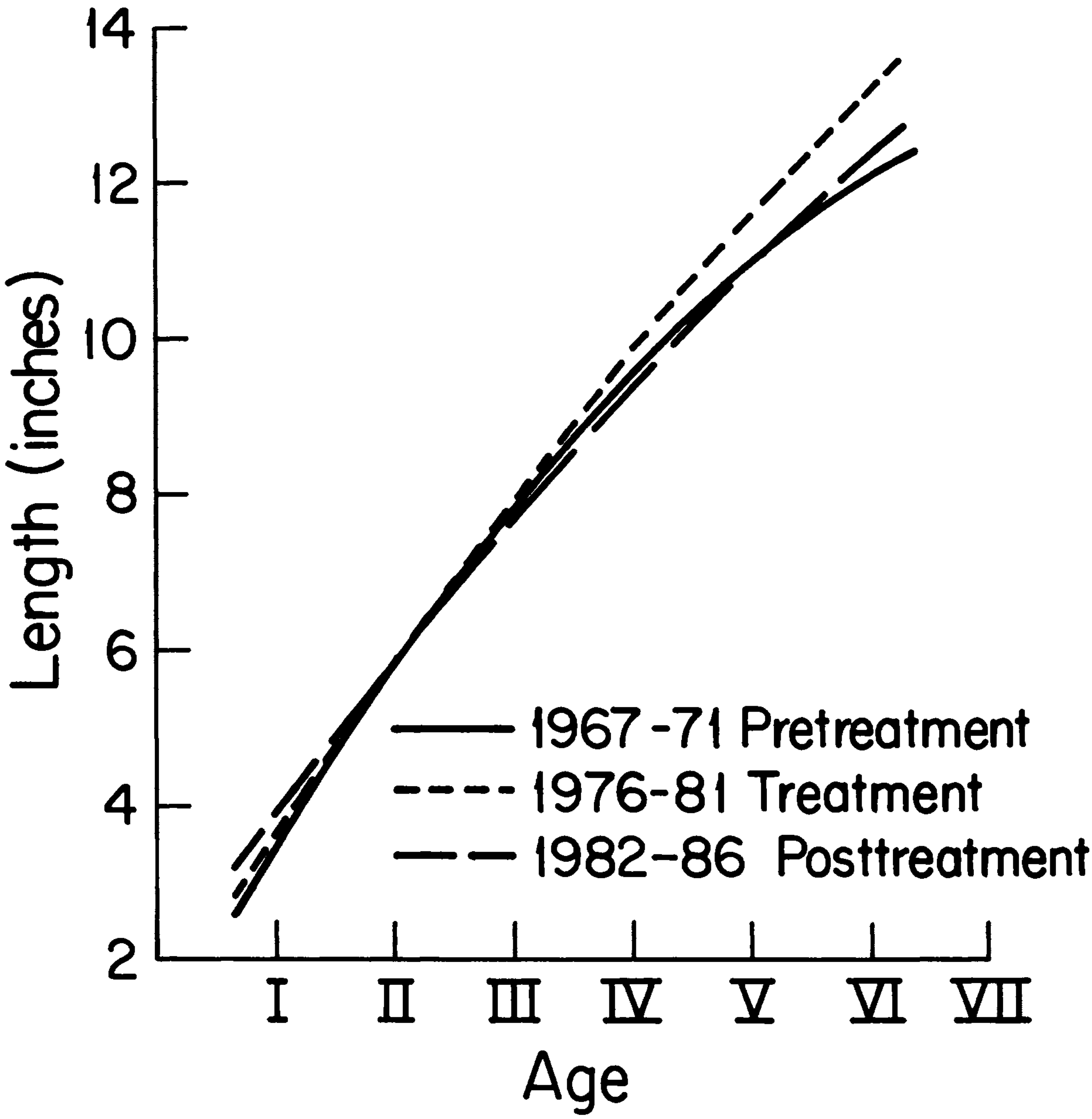

Figure 9. Average brook trout length at age for the treated section of Hunt Creek for various time periods.

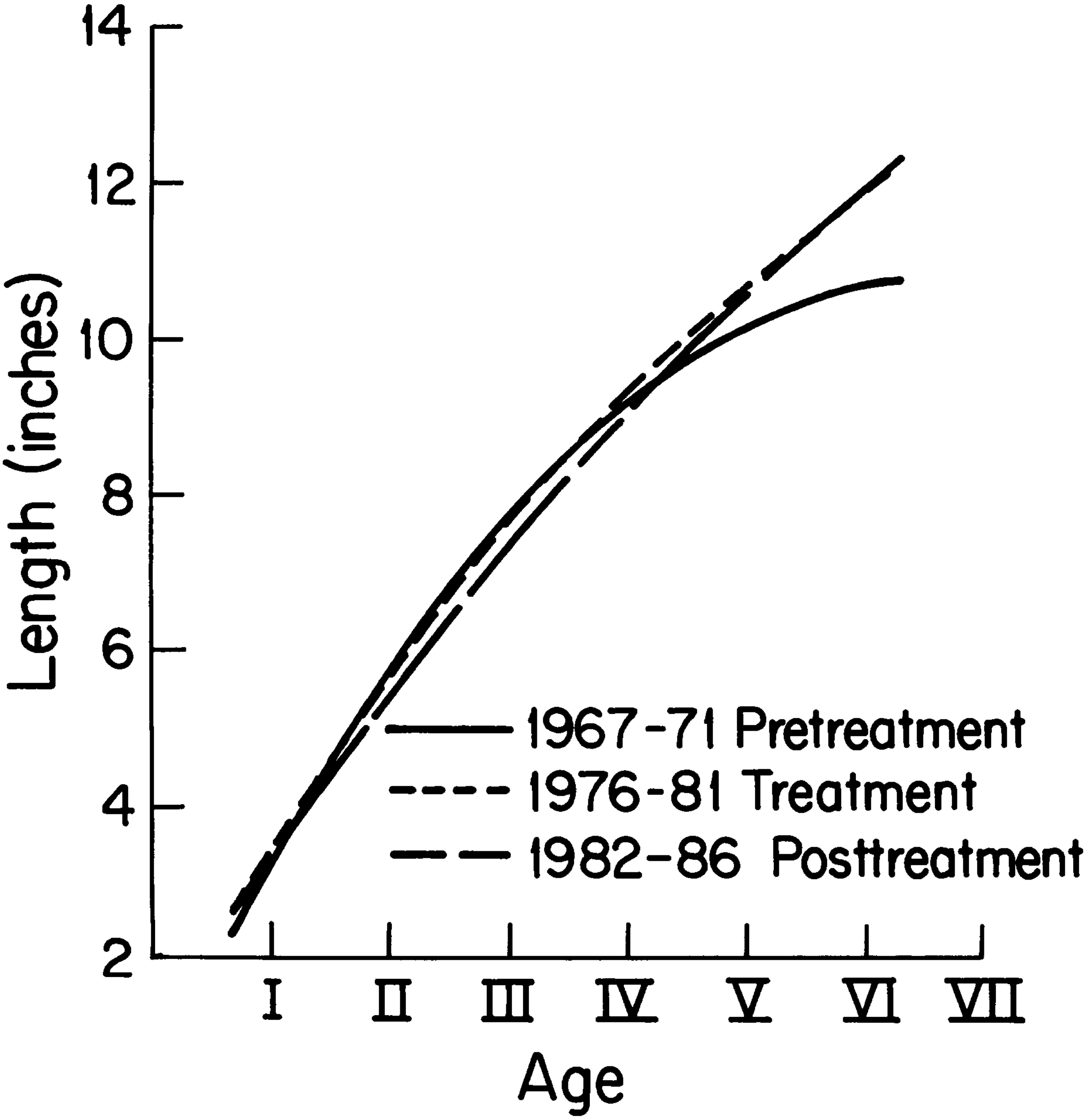

Figure 10. Average brook trout length at age for the control section of Hunt Creek for the various time periods.

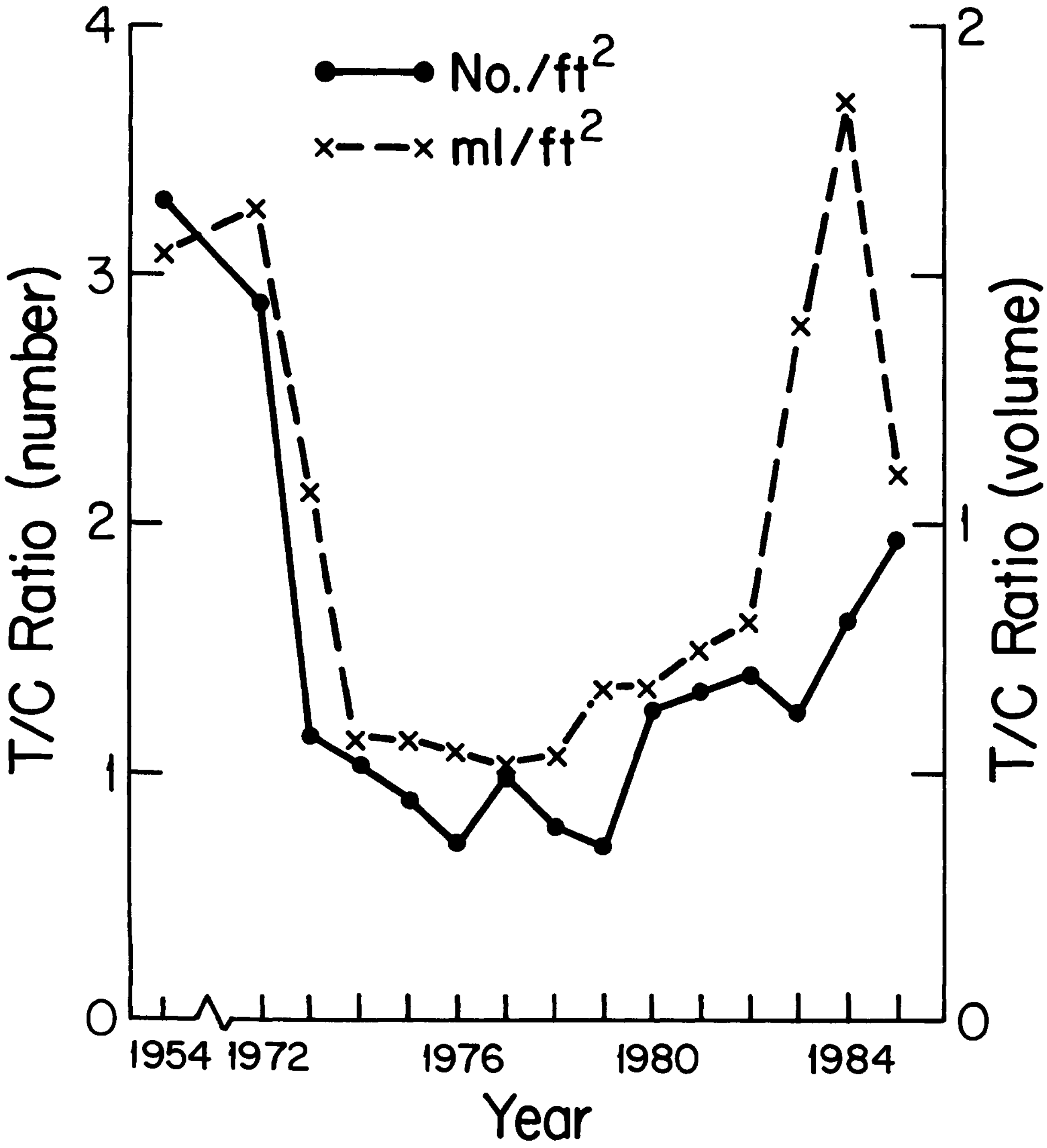

Figure 11. Treated/control (T/C) ratios of numbers and volumes of invertebrates per square foot of Hunt Creek bottom.

Table 1. Channel geometry changes relative to June 1971 base period. The initial stream widths and water volumes are given to provide a comparison for subsequent changes.

Year	Water elevation: Control (feet)	Water elevation: Treated (feet)	Bed elevation: Control (feet)	Bed elevation: Treated (feet)
1971	0.00	0.00	0.000	0.000
1972	–0.01	0.02	–0.002	0.150
1973	–0.05	0.12	0.002	0.310
1974	—	—	0.002	0.450
1975	–0.05	0.24	–0.040	0.470
1976	–0.07	0.33	–0.020	0.640
1980	–0.13	–0.03	–0.090	0.130
1982	—	–0.06	—	–0.150
1984	–0.12	–0.09	–0.110	–0.180

Year	Stream width: Control (feet)	Stream width: Treated (feet)	Water volume: Control (yard^3)	Water volume: Control (percent)	Water volume: Treated (yard^3)	Water volume: Treated (percent)
1971	13.4	19.4	1,665	100.0	4,662	100.0
1972	0.2	0.3	36	2.0	–467	–10.0
1973	0.2	0.9	—	—	—	—
1974	0.2	1.5	—	—	—	—
1975	0.3	1.4	64	4.0	–883	–19.0
1976	0.0	1.3	12	0.7	–1,136	–24.0
1980	0.1	–0.3	–41	–3.1	–606	–13.0
1982	—	0.1	—	—	79	2.0
1984	–0.1	0.1	–80	–5.0	173	4.0

Table 2. Estimated numbers of brook trout, by length group, in the fall (1967–1986) and in the spring (1968–1986) in the control area of Hunt Creek.

Year	Length group (inches)			Total
	2.0–4.9	5.0–7.9	8.0+	
Fall				
1967	2,553	678	156	3,387
1968	3,113	864	168	4,145
1969	3,446	899	179	4,524
1970	3,017	814	145	3,976
1971	3,014	818	130	3,962
1972	2,687	688	133	3,508
1973	2,080	630	126	2,836
1974	1,777	583	120	2,480
1975	1,942	537	102	2,581
1976	2,212	727	149	3,088
1977	3,442	480	128	4,050
1978	2,821	810	163	3,794
1979	3,393	826	144	4,363
1980	3,018	660	99	3,777
1981	3,901	776	103	4,780
1982	3,301	774	90	4,165
1983	3,982	966	93	5,041
1984	3,666	880	76	4,622
1985	3,460	705	85	4,250
1986	3,918	849	87	4,854
Pretreatment average (1967–1971)	3,029	815	156	3,999
Transitional average (1972–1975)	2,122	610	120	2,851
Treatment average (1976–1981)	3,131	713	131	3,975
Posttreatment average (1982–1986)	3,665	835	86	4,586

Table 2. Continued:

Year	Length group (inches)			Total
	2.0–4.9	5.0–7.9	8.0+	
Spring				
1968	1,133	525	112	1,770
1969	1,009	610	87	1,706
1970	1,193	627	105	1,925
1971	1,112	576	99	1,787
1972	873	471	113	1,457
1973	1,074	515	83	1,672
1974	864	460	104	1,428
1975	447	237	74	758
1976	666	350	68	1,084
1977	759	226	76	1,061
1978	931	263	66	1,260
1979	1,092	508	125	1,725
1980	1,587	522	130	2,239
1981	1,386	571	106	2,063
1982	1,589	661	82	2,332
1983	1,830	808	61	2,699
1984	1,736	783	80	2,599
1985	1,427	732	77	2,236
1986	1,706	622	70	2,398
Pretreatment average (1968–1971)	1,112	584	101	1,797
Transitional average (1972–1975)	814	421	94	1,329
Treatment average (1976–1981)	1,070	407	95	1,572
Posttreatment average (1982–1986)	1,658	721	74	2,453

Table 3. Estimated numbers of brook trout, by length group, in the fall (1967–1986) and in the spring (1968–1986) in the treated area of Hunt Creek.

Year	Length group (inches)			Total
	2.0–4.9	5.0–7.9	8.0+	
Fall				
1967	3,812	737	287	4,836
1968	4,140	747	177	5,064
1969	5,181	1,340	392	6,913
1970	3,284	916	291	4,491
1971	4,073	1,132	367	5,572
1972	2,671	741	365	3,777
1973	3,043	596	211	3,850
1974	2,272	380	116	2,768
1975	2,045	423	81	2,549
1976	1,947	324	73	2,344
1977	2,583	221	33	2,837
1978	1,393	458	106	1,957
1979	1,709	427	166	2,302
1980	2,680	305	90	3,075
1981	2,312	464	54	2,830
1982	1,886	686	74	2,646
1983	2,501	948	154	3,603
1984	3,164	1,130	119	4,413
1985	2,552	1,044	130	3,726
1986	2,980	1,134	145	4,259
Pretreatment average (1967–1971)	4,098	974	303	5,375
Transitional average (1972–1975)	2,508	535	193	3,236
Treatment average (1976–1981)	2,104	366	87	2,558
Posttreatment average (1982–1986)	2,617	988	124	3,729

Table 3. Continued:

Year	Length group (inches)			Total
	2.0–4.9	5.0–7.9	8.0+	
Spring				
1968	1,263	422	138	1,823
1969	1,236	635	144	2,015
1970	1,522	668	231	2,421
1971	1,046	609	186	1,841
1972	865	483	285	1,633
1973	1,160	484	304	1,948
1974	654	217	130	1,001
1975	712	169	54	935
1976	524	226	57	807
1977	693	157	37	887
1978	673	136	23	832
1979	459	218	28	705
1980	594	231	130	955
1981	915	263	82	1,260
1982	652	275	37	964
1983	581	693	89	1,363
1984	977	714	150	1,841
1985	1,539	883	119	2,541
1986	1,177	811	129	2,117
Pretreatment average (1968–1971)	1,267	584	175	2,025
Transitional average (1972–1975)	848	338	193	1,379
Treatment average (1976–1981)	643	205	60	908
Posttreatment average (1982–1986)	985	675	105	1,765

Table 4. Ratios (±95% confidence limits) of treated-to-control areas (T/C) for numbers of brook trout present in the fall and spring, before and during various sedimentation periods, by length group.

Length group (inches) and season	Year			
	1967–1971	1972–1975	1976–1981	1982–1986
2.0–4.9				
Spring	1.14±0.13	1.10±0.13	0.64±0.10	0.61±0.12
Fall	1.35±0.12	1.20±0.13	0.68±0.10	0.71±0.12
Combined	1.26±0.09	1.15±0.10	0.66±0.09	0.66±0.09
5.0–7.9				
Spring	0.99±0.13	0.79±0.13	0.53±0.10	0.94±0.12
Fall	1.19±0.12	0.87±0.13	0.51±0.10	1.19±0.12
Combined	1.10±0.09	0.83±0.10	0.52±0.09	1.07±0.09
8.0+				
Spring	1.74±0.13	2.04±0.13	0.61±0.10	1.44±0.12
Fall	1.98±0.12	1.54±0.13	0.66±0.10	1.45±0.12
Combined	1.88±0.09	1.79±0.10	0.64±0.09	1.44±0.09
All sizes				
Spring	1.12±0.09	1.06±0.10	0.62±0.08	0.73±0.09
Fall	1.34±0.09	1.14±0.10	0.65±0.08	0.81±0.09
Combined	1.25±0.07	1.10±0.07	0.63±0.07	0.77±0.07

Table 5. Ratios (±95% confidence limits) of treated-to-control areas (T/C) for numbers of brook trout, by age group, for populations present in the fall and spring.

	Year			
Age	1967–1971	1972–1975	1976–1981	1982–1986
0	1.46±0.17	1.34±0.20	0.72±0.16	0.74±0.17
I*	1.15±0.20	1.27±0.20	0.70±0.16	0.65±0.17
I	1.03±0.17	0.80±0.20	0.50±0.16	0.91±0.17
II*	1.01±0.20	0.77±0.20	0.51±0.16	0.86±0.17
II	1.29±0.17	0.78±0.20	0.47±0.16	1.21±0.17
III*	1.20±0.20	0.99±0.20	0.40±0.16	0.74±0.17
III	1.92±0.17	1.05±0.20	0.52±0.16	1.08±0.17
IV*	1.44±0.20	1.16±0.20	0.47±0.16	1.25±0.17
IV	11.25±0.78	1.06±0.20	0.54±0.16	2.42±0.17
V*	2.65±0.20	0.95±0.20	1.29±0.20	0.63±0.17
V	—	0.00±0.78	0.00±0.78	0.10±0.17
Total of all ages				
Spring	1.12±0.09	1.05±0.09	0.61±0.07	0.73±0.08
Fall	1.31±0.08	1.13±0.09	0.65±0.07	0.81±0.08
Combined	1.23±0.07	1.09±0.07	0.63±0.06	0.77±0.07

*Asterisk denotes spring populations.

LITERATURE CITED

Alexander, G. R. 1977. Food of vertebrate predators on trout waters in north central lower Michigan. Michigan Academy of Sciences, Arts, and Letters 10:181–195.

Alexander, G. R. 1979. Predators of fish in coldwater streams. Pages 153–170 *in* H. Clepper, editor. Predator-prey systems in fisheries management. Sports Fishing Institute, Washington, D. C.

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 1959–1976. Michigan Department of Natural Resources, Fisheries Research Report 1865, Ann Arbor.

Alexander, G. R., and H. Gowing. 1976. Relationship between diet and growth in rainbow trout (*Salmo gairdneri*), brook trout (*Salvelinus fontinalis*), and brown trout (*Salmo trutta*). Michigan Department of Natural Resources, Fisheries Research Report 1841, Ann Arbor.

Alexander, G. R., and E. A Hansen. 1983. Sand sediments in a Michigan trout stream. Part II. Effects of reducing sand bedload on a trout population. North American Journal of Fisheries Management 3:365–372.

Alexander, G. R., and E. A. Hansen. 1986. Sand bed load in a brook trout stream. North American Journal of Fisheries Management 6:9–23.

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 Department of Natural Resources, Fisheries Research Report 1840, Ann Arbor.

Anderson, R. O. 1959. A modified flotation technique for sorting bottom fauna samples. Limnology and Oceanography 4:223–225.

Bailey, N. J. 1951. On estimating the size of mobile populations from recapture data. Biometrika 38:293–306.

Bjornn, T. C., and six coauthors. 1977. Transport of granitic sediment in streams and its effects on insect and fish. University of Idaho, Cooperative Fisheries Research Unit, Completion Report, Project B-036-IDA, Bulletin 17. Moscow.

Cooper, A. C. 1956. The effects of transported stream sediment on the survival of sockeye and pink salmon eggs and alevins. International Pacific Salmon Fisheries Commission Bulletin 18.

Cordone, A. J., and D. E. Kelly. 1961. The influence of inorganic sediment on the aquatic life of streams. California Fish and Game 47:189–228.

Hansen, E. A. 1971. Sediment in a Michigan trout stream, its source movement, and some effects on fish habitat. U. S. Forest Service, Research Paper NC-59.

Hansen, E. A. 1973. In-channel sedimentation basins—a possible tool for trout habitat management. The Progressive Fish-Culturist 85:138–142.

Hansen, E. A. 1974. Total sediment discharge sampling over sills. Water Resources Research 10:989–994.

Hansen, E. A., G. R. Alexander, and W. H. Dunn. 1983. Sand sediments in a Michigan trout stream. Part I. In-stream sediment basins: a technique for removing sand bedload from streams. North American Journal of Fisheries Management 3:355–364.

Harshbarger, T. J., and P. E. Porter. 1979. Survival of brown trout eggs: two planting techniques compared. The Progressive Fish-Culturist 41:206–209.

Harshbarger, T. J., and P. E. Porter. 1982. Embryo survival and emergence from two methods of planting brown trout eggs. North American Journal of Fisheries Management 2:84–89.

Hausle, D. A., and D. W. Cable. 1976. Influence of sand in redds on survival and emergence of brook trout. Transactions of the American Fisheries Society 105:57–63.

Helley, E. J., and W. Smith. 1971. Development and calibration of a pressure-difference bedload sampler. U. S. Geological Survey, Open-file report, Menlo Park, California.

Hillman, T. W., J. S. Griffith, and W. S. Platts. 1987. Summer and winter habitat selections by juvenile chinook salmon in a highly sedimented Idaho stream. Transactions of the American Fisheries Society 116:185–195.

Hynes, H. B. N. 1970. Ecology of running waters. University of Toronto Press, Toronto.

Kalleberg, H. 1958. Observations in a stream tank of territoriality and competition in juvenile salmon and trout (*Salmo salar* L. and *Salmo trutta* L.). Institute of Freshwater Research Drottningholm Report 39:55–98.

Le Cren, E. D. 1973. The population dynamics of young trout (*Salmo trutta*) in relation to density and territorial behavior. Rapports et Proces-Verbaux reunions, Conseil International pour l'Exploration de la Mer 164:186–198.

Nilsson, N. A. 1967. Interactive segregation between fish species. Pages 295–330 *in* S. D. Gerking, editor. The biological basis of freshwater fish production. Blackwell Scientific Publications, Oxford.

Pennak, R. W., and E. D. Van Gerpen. 1947. Bottom fauna production and physical nature of the substrate in a northern Colorado trout stream. Ecology 28:42–48.

Phillips, R. W., R. L. Lantz, E. W. Claire, and J. R. Moring. 1975. Some effects of gravel mixtures on emergence of coho salmon and steelhead trout fry. Transactions of the American Fisheries Society 104:461–466.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Fisheries Research Board of Canada Bulletin 191.

Sandine, M. F. 1974. Natural and simulated inert-substrate relationships in Idaho batholith streams. Master's thesis. University of Idaho, Moscow.

Shetter, D. S., and G. R. Alexander. 1962. Effects of a flies-only restriction on angling and on fall trout populations in Hunt Creek, Montmorency County, Michigan. Transactions of the American Fisheries Society 91:295–302.

Stuart, T. A. 1953. Spawning migrations, reproduction and young stages of loch trout, *Salmo trutta* L. Scottish Home Department, Freshwater and Salmon Fisheries Research 5:1–39.

Usinger, R. L., editor. 1968. Aquatic insects of California. University of California Press, Berkeley.

Velz, C. J., and J. Gannon. 1960. Drought flow characteristics of Michigan streams. The University of Michigan, Department of Environmental Health, School of Public Health, Ann Arbor.

Report approved by W. C. Latta

Typed by G. M. Zurek