Effects of Sand Bedload Sediment on a Brook Trout Population

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EFFECTS OF SAND BEDLOAD SEDIMENT ON A BROOK TROUT POPULATION[1]

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[1] Contribution from Dingell-Johnson Project F-35-R, Michigan.

Abstract

An experimental introduction of sand sediment in Hunt Creek to increase the bedload 4 to 5 fold resulted in a significant reduction of trout and trout habitat. The trout population declined to less than half its normal abundance. The growth rate of individual trout was not affected. Population adjustment to the poorer habitat was via a decrease in the trout survival rates, particularly from the egg to fry and/or the fry to fall fingerling stage of the life cycle.

Habitat for trout and trout food organisms became much poorer judged upon their drastic population reductions. Stream morphometry changed considerably with the channel widening and shallowing. Further, sand deposition aggradated the streambed and eliminated most pools. The channel became a continuous run, rather than a series of pools and riffles. Water velocities increased as did summer water temperatures. Relatively small bedload sediment concentrations of 80 to 100 ppm have a profound effect on trout and trout habitat.

Introduction

Trout streams in the upper midwest of the United States are typically low-gradient, slow to moderate flowing streams. Some of these streams have excessive sand on the streambed. Other streams with somewhat steeper gradient have less sand bed deposits but yet may have considerable sand in transport. Abnormally large amounts of man-induced sediments or sediments associated with catastrophic floods may be detrimental to trout habitat (Cordone and Kelley 1961). However, prior to this study we did not know the affect of low levels of moving sand bedload on trout and trout habitat. In initiating this and other sediment-trout studies in Michigan, we speculated that low concentrations of sand bedload sediments in low-gradient streams have measurable adverse effects on habitat of stream fishes in general and trout in particular.

The presence of sand sediment is deceiving in that it does not produce the turbidity commonly associated with severe stream sedimentation. Even substantial amounts of moving sand bedload are not readily apparent in steep-gradient streams. Only when the gradient is low enough for deposition does the sediment become evident by the presence of sand-filled reaches. Sampling with a hand-held DH-48 suspended sediment sampler (U.S. Interagency Committee on Water Resources 1963) over a natural streambed in low-gradient streams will miss much of the sand bedload sediment. This may lead inexperienced observers to erroneously conclude there is no significant sediment discharge when, in fact, there may be considerable sand moving in the unsampled zone adjacent to the streambed. A modified procedure of sampling with a DH-48 sampler over sills or weirs (Hansen 1974), or with a sampler designed specifically for sampling bedload (Helley and Smith 1971) will assess more realistically the presence of sand bedload.

Sand bedload may decrease food supplies of trout by scouring or burying desirable substrate, destroy cover by aggrading channels and filling pools, and reduce 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 load is often a major objective of fish habitat improvement programs.

This paper reports on a field test on a brook trout stream where sand was added daily for 5 years followed by 5 years without the addition of sand. The effects of this sand on both the stream morphometry and the trout population were measured. The results of this study are compared with those of a companion study we did on another stream where the moving sand bedload was removed with a sediment basin (Hansen et al. 1982).

Study Area

This study was conducted at the Michigan Department of Natural Resources, Hunt Creek Fisheries Research Area, in the north central portion of the Lower Peninsula of Michigan near the village of Lewiston. Hunt Creek is a small 20 cfs trout stream flowing through sandy, glacial-drift country. The deep sand and gravel drift produces little surface runoff, high groundwater, and, consequently, 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 et al. 1960). This stable supply of cold groundwater (47 to 49 F) and low stream 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 predominately brook trout (Salvelinus fontinalis) with a moderate population of sculpins (Cottus bairdi, and C. cognatus). Other fish species were rare.

Methods

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

Fifteen years of brook trout population data were used to determine the response of fish to sediment. The data included 5 pretreatment years, a 5-year sand input-treatment period, and a 5-year posttreatment period with no sand input. Thus, comparisons in fish populations can be made between treated and controlled sections, before, during and after treatment. We will at times refer to the entire 10-year period following initial sand bedload introduction as treatment effect because the impact of sand was evident throughout the 10-year period. Since the entire experimental area was closed to fishing, it is assumed that only natural mortality affected the trout population aside from the controlled sampling of trout in both treated and controlled sections for diet analysis.

A stream gauging station with a water level recorder was established to provide a measure of mean daily flow. In addition, staff gauges were installed at three sediment sampling stations. The stations were located so that the sediment discharge entering and leaving both the control and treated sections was sampled (Fig. 1). Sediment samples were collected over a 10-year period including 1 year before, 5 years during, and 4 years after the sand input period. Sediment samples were collected weekly by sampling with a DH-48 suspended sediment sampler over wooden sills in such a manner that the sampler intake traversed the entire vertical profile of flow (Hansen 1974). Samples collected in this manner provided a measure of the total sediment discharge.

Yearly supplies of sand were stockpiled at the upstream end of the treated section. Samples of bed material and samples from the sand borrow area were analyzed for particle size distribution and compared to insure a similar size distribution. Starting October 1, 1971, sand was added usually once a day to the stream with an endloader. The quantity added was three times the daily sediment discharge. Based on sediment sampling during the one pre-treatment year, a "sediment input table" was developed which gave daily sediment input in cubic yards based on stream discharge. Several times a year the content of the endloader bucket was weighed and converted to volume of sand, based on the sampled bulk density adjusted for moisture and gravel content. This calculated volume provided a check on the equipment operator's estimates of sand input. The sand contained a small amount of gravel which gradually formed a gravel riffle at the input point. These gravel deposits were removed with a backhoe whenever the damming effect became excessive and were replaced with an equal volume of sand added over several days with the normal daily sediment input. The sand bedload was trapped at the lower end of the 1 mile treated section by a 25- x

200-ft sediment basin. The basin was cleaned with a dragline periodically throughout the study. During the first 4 years of the treatment period, the basin was surveyed before and after each cleanout by "leveling" on a 5-ft grid of points. These data permitted calculation of the volume of deposits trapped by the basin thus providing a measure of sediment discharged from the treated section.

Changes in stream morphometry were determined by establishing permanent stream cross sections at 100-foot intervals along the entire 2-mile study section of stream. These cross sections were surveyed annually from 1971 through 1977 and again in 1980. At each cross section a stake was permanently set on each bank. A third stake was buried in the streambed as a benchmark to determine if either of the bank stakes had moved since the initial survey. A steel measuring tape was then stretched at a measured tension between the two bank stakes and distance from the tape to the streambed was measured at all major slope breaks in the channel cross section. The streambed was also subdivided into widths as narrow as 1 ft and classified as to streambed particle size (sand, gravel, cobble), biological materials (vegetation, wood, detritus), or various combinations thereof. These data permitted calculation of changes in channel scour and fill, cross-sectional water area (the static water volume in the channel reach), and streambed composition. A "leveling" survey was also made between selected cross sections along the treated section. From this survey the water surface profile was drawn and then updated with each cross section remeasurement.

A water temperature recorder had been placed at the downstream end of the treated section many years prior to treatment. Maximum-minimum thermometers distributed throughout the study area were read weekly.

Trout population estimates were made from electrofishing data each spring and fall, beginning in the fall of 1967 and extending through the fall of 1981. Estimates, stratified by 1-inch size groups, were calculated by the Petersen mark-and-recapture method. Representative samples of trout scales were used to apportion estimates by length groups to estimates by age groups. Mortality rates were computed from sequential estimates of 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 trout by age group. Estimation of trout production (elaboration of flesh) followed the procedure of Ricker 1975.

Trout were collected by electrofishing for stomach analysis for ten 2-week periods, during the major growing season of trout, beginning with the last Saturday in April. Ten 3- to 4-inch trout, ten 5- to 6-inch trout, and five 7- to 8-inch trout were collected each 2-week period, for an annual sample of 100, 100, and 50 trout, respectively. Stomachs were preserved in 10% formalin until hardened, then the contents were transferred to 80% alcohol for analysis. Both number and volume of food taxa were determined. These collections also served to monitor for possible change in the length-weight relationship of trout. Samples of stream invertebrate benthos were collected monthly from April through September. Samples were taken using a standard Surber sampler. Five samples were taken each month from four stations. Two stations were located in the treatment section and two in the control section. Samples were taken spaced equal distance, across stream transects. Invertebrates were picked using sugar floatation (Anderson, 1964). Both number and volume of benthos per square feet of stream bottom were determined.

We used a ratio analysis technique (Shetter and Alexander 1962; Alexander and Hansen 1982) to test for changes in trout population parameters, food content of trout stomachs, benthic invertebrate communities and water temperatures. These ratios were calculated by dividing the parameter for the treated section by the parameter in the control section for each year. Then the ratios for the pre-treatment years were compared to ratios for the treatment or post-treatment years using analysis of variance or regression analysis.

Hydrology Results

Pre-treatment stream and sediment discharge

Stream discharge at the upstream end of the treated section (sill 2) averaged 20 cfs and ranged from 14 to 50 cfs. Downstream at sill 1, it averaged 25 cfs, or 25% greater. Three small tributaries, totaling about 3 cfs, enter between the two stations, with the balance of the increase originating from groundwater inflow. These sources of additional streamflow do not add much sediment, and sediment concentration actually decreases from 20 ppm at sill 2 to 14 ppm at sill 1 primarily by dilution from inflow of the nearly sediment-free water. Total sediment discharge calculated from measurements was 390 tons per year at sill 2 and 350 tons per year at sill 1. This is a 10% decrease in sediment load between the two stations and is judged to be not significant due to limitations inherent with this type of data. However, a decrease in sediment load is possible if there was a net accumulation on the streambed; in this case an average of about 0.01 ft over the entire channel.

Of the 20 ppm total sediment concentration at sill 2, 5 ppm (25%) was silt and clay. The concentration of these fines did not increase with higher streamflows, but rather stayed at a fairly constant level over the entire range of streamflow (Fig. 2). All of the increased sediment concentration with higher stream discharges was due to increased movement of sand.

Sediment input

Sediment input totaled 4,223 yd^3 over the 5 years or an average of about 2.2 yd^3 per day or 845 yd^3 per year (Table 1). The data in Table 1 include a small fraction of gravel and is not adjusted for the final higher density the sediment acquired when in place on the streambed.

An increase in sediment concentration was noted at sill 1 near the lower end of the treated section in June 1973, 21 months after the start of daily additions of sand nearly 1 mile upstream (Fig. 3). This indicated that sand added to the stream had finally traversed that length of the treatment section, and that essentially all of the sand (1,300 yd^3) added during the first 21 months went into channel deposits.

Channel deposits

The volume of sand deposits on the streambed increased throughout the 5-year sand input treatment period (Fig. 4). The trend in channel fill at the survey cross sections is shown in Figure 5. Large differences in fill between cross sections were the result of the initial streambed configuration. Pools acquired deep deposits; stream "run" sections had less deposition.

The accumulation profiles in Figure 5 show the progression of the zone of maximum channel deposition during the treatment period. Deposition during the first year was primarily in the upper 2,200 ft of channel (see 1972 line). Deposition during the last 2 years (from 1974 to 1976) was greatest between about 1,300 and 2,900 ft. By 1980, 4 years after treatment ended, the upstream section of the stream had recovered to near its initial elevation. However, substantial channel fill averaging about 0.25 ft still remained between the 1,700 to 3,000 ft sections.

As the sand wave gradually progressed downstream, the streambed and water surface were both elevated. By the end of the 5-year sand input treatment period, water surface elevation had increased by 0.5-0.75 ft throughout the upper two-thirds of the treated section. As the water surface became higher than its initial datum, the stream width increased. As the channel gradient steepened, the water velocity increased. The greater water velocity, together with pool filling, resulted in reduced cross-sectional water area and therefore reduced static water volume. The streambed was elevated an average of 0.64 ft by the end of the treatment period (see "Bed elevation" in Table 2). Maximum fill of more then 3 ft occurred in some pools which were at those cross sections with maximum deposit thickness shown in Figure 5. Average stream depth decreased 0.31 ft by the end of the treatment period. Almost all of the change in stream depth was due to a reduction in areas deeper then 1.25 ft (Fig. 6). Areas deeper then 2 ft were reduced 86% (from 17 to 2% of the streambed area). There was essentially no change in stream depth in the control section throughout the study period.

Stream width increased 1.3 ft (a conservative figure since the stream was out of its low marshy banks over a considerable distance and most of the very shallow "overbank" width is not included). Static water volume decreased by a maximum of 24% (Table 2). Channel gradient between sill 1 and sill 2 increased from an initial 0.00081 to 0.0099 (from 4.3 to 5.2 ft/mile) and acquired a more uniform slope (Fig. 3).

Streambed composition

As expected, the treatment produced a sizeable increase in sand-covered streambed. Sand areas increased from the initial 40% up to 68% of the area and gravel decreased from 17% down to 5% during the first 4 years of treatment (Table 3). These same bed types showed no trends in the control area during the same period. Areas with wood vegetation, detritus, or various combinations of streambed types showed large fluctuations from year to year but no definite trend. This could be due to both actual changes in their area or to changes in observer bias from year to year. It was observed that many vegetation beds were buried by fairly thick sand deposits. However, vegetation eventually penetrated the deposits and reestablished itself in much of its former area, but beds were less dense.

Stream recovery

After the termination of sediment input, the stream channel gradually reverted towards its initial condition. By 1980 (4 years after the end of sand input) the average streambed elevation had returned to near normal over much of the treated section (Fig. 5). The major remaining section of elevated bed was in the general area of 900 to 2,500 ft. This coincided roughly with the area of elevated water surface between 1,100 and 2,800 ft. Although the streambed elevation is near its original datum in the lower portion of the stream, the water surface elevation is considerably lower than its initial elevation. This lower water surface, due to increased velocity, results from the elimination of vegetation and the covering with sediment of rocks, logs, and other obstacles which cause friction. Consequently, the net reduction in water volume in the treated section is still 13% or just slightly more then half of what it was at the peak of the treatment effect in 1976 (Table 2).

There was some increase in water depths 4 years after the sand input ended. The area of stream with depths between 0.5 to 1.0 ft decreased with a commensurate increase in depths of 1.0 to 1.75 ft (Fig. 6). There was essentially no recovery in depths greater than 1.75 ft. In other words, the deep pools had not scoured out in the 4-year recovery period.

During the first few years of treatment, the sand bedload moved primarily along the main flow line of the stream. Then in a period of over a year it gradually spread laterally, eventually filling in the stream near the banks, until by the end of the sand input period, stream areas deeper than 2 ft lying within 3 ft of the bank had been eliminated (Fig. 7). The process reversed itself after sand input ended. Sand was scoured out from the main flow line of the stream, but little was removed from the stream edges. Although much sand scoured out of the treated section by 1980, there was essentially no recovery of the deeper stream depths near the banks.

Water temperature

Water temperatures in the control section were warmer in the winter but cooler in the summer during the 1972-1981 treatment period as compared to the 1961-1971 period. Water temperatures in the treated section during the 1972-1981 period were likewise warmer in the winter, but in contrast to the control section, were also warmer during the summer. Spring and fall temperatures were relatively unchanged in both sections.

Since water temperature changed in both sections during the study, an analysis of the net change (treated minus control) was done to more clearly show the temperature change in the treated section relative to the control. It showed that temperatures during the treatment period in the treated section averaged 0.3 F warmer during October-February, 1.8 F warmer during March-September, and 2.7 F during June-August. Since the water temperature increased in both sections during October-February, and the average increase in both sections exceeded +1 F for several of the months, the net temperature increase of 0.3 F was not significant. On the other hand, the March-September temperature increase occurred in the treated section despite a concurrent temperature decrease in the control section. We attributed the net average increase of 1.8 F (and 2.7 F, June-August) to the effects of the wider and shallower stream. These increases were statistically significant at the 95% level. The greater surface area and shallower water of the stream apparently resulted in higher water temperatures.

Discussion

A low-gradient stream may take a long time to adjust to an input of sand bed material. Movement rates may be a few hundred feet a month or less. Rates depend upon stream discharge, initial channel gradient, and quantity of added sediment--factors that can vary widely from stream to stream. On Hunt Creek, with an initial slope of 0.0008, the sand wave advanced at a rate of about 0.5 mile per year with the given sediment input rate. It took about 3 years for the 1-mile channel to undergo the major portion of the adjustment. However, significant changes associated with continued deposition continued on through the fourth and fifth year of the treatment.

Many changes occurred in stream morphometry that had a negative effect on fish habitat. The stream became wider and shallower, pools filled, and the stream became a uniform sand bed devoid of cover. These factors would make the trout more vulnerable to predation. A reduction in static water volume, filling of pools, reduction in channel diversity (by changing from "pool-run" situation to essentially one long "run") -- all tended to reduce the carrying capacity of the stream. Although deposition occurred in all areas of the stream, pools filled the most with an 86% reduction in the deeper areas, thus producing a major impact on fish cover.

Moving sand is the least desirable bed type from the standpoint of benthos production. Thus, the increase in this bed type would have an undesirable effect on food production.

The change from a dark silt to a moving sand streambed resulted in a change in albedo. The flat, relatively uniform light colored streambed may have made the trout more vulnerable to predation. The decreased static water volume means higher streamflow velocities, which without a commensurate increase in obstacles to break the flow, may result in a more stressful environment for fish. The impact of bedload sediment is believed to be greatest in low-gradient streams or low-gradient sections of streams, because of the greater deposition (Hansen et al. 1982).

Major changes in channel geometry occurred during the 4 years following the end of treatment. For some characteristics, such as water surface elevation, streambed elevation, and stream width, the stream reverted to near its initial state. For others, such as water depth and static volume, recovery was judged to be about half completed. Of particular importance from the fisheries standpoint is that there was essentially no recovery in terms of pool or channel deepening near banks. Thus, there has been a long-term reduction in fish cover that has shown little recovery in 4 years since the end of adding sand to the stream.

Biology Results

Trout population changes

The trout population remained relatively stable in the control section of stream throughout the experiment. The number of trout present by age group and their survival rate (slope of curve) changed little over the years (Fig. 8).

By contrast, a major change occurred in the trout stock of the treated section of stream (Fig. 9). The greatest change is evident in the survivorship curve for the 1976-1981 period which shows the much smaller population. We believe that this curve best represents the new population status under the higher bedload sediment conditions. The slope of the survivorship curve is only slightly steeper than pre-treatment conditions. The biggest difference is that fewer trout were present at all ages because of less recruitment into the age-0 standing stock. This fact is more significant than the slightly higher death rate of the older trout.

We also show a survivorship curve in Figure 9 that represents the transitional years (1972-1975) of the trout population. Note in this curve that the number of age-0 through age-III trout (particularly age 0 through age II) are lower whereas fish older than age III are of comparable abundance to pre-treatment populations. We hypothesize that this initial drop in the population occurred because of low recruitment to age 0, resulting from poor egg hatch and/or fry survival. Recruitment continued to drop as demonstrated by the difference in the number of young fish between 1972-1975 and 1976-1981. We suspect that this additional drop was caused in part by lower egg deposition from the smaller population of adult trout after about 1975.

Because of the gradual change in the trout population over the study period, we elected to omit the transitional years (1972-1975) from all analysis of variance tests of the population data. This allowed us to best demonstrate the difference in the trout stocks between the pre-treatment and treatment conditions. The average number of trout present in the treated area decreased drastically following the experimental increase in sand bedload (Tables 4 and 5). Trout were only about half as numerous from 1976 to 1981, 5 to 10 years after the initial sediment increase. The 51% decrease in total number of trout was statistically significant (Table 6). The decrease was progressively greater for increasingly larger trout. Trout 2.0-4.9 inches long decreased 49% whereas trout 8 inches long or longer decreased 65%. The spring population also showed a 51% decrease in total stock (Table 7). Again decreases were shown to be greater for larger fish.

Grouping the fish by age rather than size also revealed significant decreases for all age groups of trout in the treated section of stream (Table 8). Decreases were evident in both the spring and fall stocks and were progressively greater for older trout.

Regression analysis of the T/C ratios for total trout for the years 1971 to 1981 (the years during and following sand bedload treatment) showed a statistically significant negative slope indicating a progressive decrease in the T/C ratios over time (Fig. 10). The nearly zero slope of the 1967-1975 regression indicates no change in the T/C ratios for the pre-treatment trout population. Regression tests for the various trout size groupings and age groupings indicate statistically significant decreases in slope occurred for all groupings of trout in the sand treated area. Note in Figure 12 that the trout population decrease was not very evident until after 1975, 4 years after the initial sediment treatment. Also note the slightly improved T/C ratio after 1980, suggesting that the population is possibly beginning to recover. Both of these points were evident in the T/C ratio data sets for all size and age groupings.

Similar analysis of variance and regression tests were run on the weight of trout present (standing biomass) for the various length and age groupings. These tests all showed statistically significant decreases in trout biomass for the treated reach of stream.

Trout growth changes

We found a slight increase of 2.7% in the average length of trout age 0 and older during the treatment (Table 9). Age-0 trout were 0.1 inch longer and age-V trout were 0.3 inch longer. Even though these slight increases in average size proved to be statistically significant, we judge them nonsignificant from a practical point of view. Further, even though trout were slightly larger, at age 0 and older, their rate of growth did not change after age 0. The only change in rate of growth occurred in the first summer of life which resulted in the slightly larger age-0 trout.

We found no significant change in the length-weight relationship (or condition factor "C") of trout during this study.

The production of trout flesh (Ricker 1975) was significantly lower during the period of higher sand bedload. The decreased production was due to decreased numbers of trout being present rather than a change in trout growth.

Benthos standing crop

Pre-treatment levels of benthos were based upon 1972 samples (sand bedload did not reach our benthic sampling stations until 1973) and data collected in 1954 by Curry (unpublished). Based upon the T/C ratios after 1972, benthic populations dropped to less than half their pre-treatment level (Figs. 11 and 12).

Reduction in benthic invertebrates by taxa showed that the insect orders of Ephemeroptera, Diptera, and Coleoptera showed the most dramatic declines. Lesser reductions occurred for Trichoptera and Plecoptera. No consistent reductions in Odonata, Megaloptera, or Hemiptera were evident.

Invertebrates belonging to the taxa Annelida, Amphipoda, and Hydrocarina showed no reduced trends in their abundance related to increased bedload sediment. Note that numbers of benthic organisms were reduced somewhat more than volumes of organisms present per square feet of stream bottom (Figs. 11 and 12) which suggests smaller benthic invertebrates were affected more than larger ones.

Food per trout stomach

Analysis of the average volume of food present per trout stomach showed highly variable T/C ratios and no consistent change over the study period. Based upon the fact that trout growth rate, and their condition factor did not change much during the study, it follows that the daily ration of the trout did not change either. Apparently less food being available for trout, based upon the benthos sampling, was offset by fewer fish to eat it, thus the amount of food eaten per fish did not change significantly, nor did their growth.

Discussion

The significant reduction of brook trout of all sizes and age groups in Hunt Creek has been shown to be related to increased sand bedload. The most devastating impact on trout appears to be reduced survival of the early life stages. We hypothesize that fry production was reduced because of degradation of micro-habitat caused by sand embeddedness of the substrate (Sandine 1974). Sand deposition on the stream bottom filled, plugged, and buried most of the rough substrate and resulted in a much smoother stream bottom.

Bedload deposition also caused substantial pool filling, which eliminated most of the deeper water, undercut banks and larger cover obstacles such as logs, branches, and cobble. This transformed the stream channel into a uniform sand-bottomed canal. The end result was a stream that had a more uniform gradient, greater water velocity, more laminar flow, and less cover. As a consequence, trout had poorer habitat, particularly for resting, but possibly also for feeding.

Small trout were believed to be particularly affected because of reduced cover and increased competition for available niches. The smoother bottom probably increased visual contact and interaction between trout thus increased territorial competition and stress. Stuart 1953, Kalleberg 1958, and LeCren 1973, all suggest that competition for territories limit the population. The loss of diverse water velocities adjacent to the stream bottom is believed to reduce for fry the habitat needed for resting and energy conservation. Bjornn et al. (1977) speculated that sediment embeddedness reduced protective cover for juvenile salmonids. Kalleberg 1958 made observations of brown trout and Atlantic salmon in a experimental stream and observed that increased water velocity "pressed fish toward the stream bottom" and increased their aggressiveness which caused formation of new territories. Aggressiveness was also observed to be greatest in bottom-oriented fish. This probably indicates that the bottom niches are the preferred habitat, at least for brown trout young and salmon. The trout preferred resting station was always in close proximity with a solid surface. Observations also indicated that brown trout and salmon fry always selected sites where they could be in direct contact with the bottom substrate while resting. Larger fish also preferred contact with the streambed but apparently subdominate fish were excluded from it. Based upon the literature it would seem that the ever changing stream bottom composed of moving sand bedload would preclude trout from establishing permanent territories.

Older trout were also forced to live in poorer habitat. Shallower water with few pools, less cover, and higher sustained velocities forced trout to reside where they probably suffered greater mortality from predation. Trout age 0 and older in Michigan streams have been shown to suffer high losses to predacious birds, reptiles, and mammals (Alexander 1977 and 1979).

To summarize, we believe that sand bedload sediment deposition destroyed many of the niches for trout, particularly for small trout, thus the "carrying capacity" of the stream was reduced. Trout territorialism which causes spatial segregation limits the population to a size that is compatible with the lower "carrying capacity" resulting from increased bedload sediment.

The population of brook trout in Hunt Creek showed little change during the initial sand deposition in the thread of the stream but declined more quickly when the sand began depositing near the stream edge. Brook trout fry, in contrast to brown or rainbow trout fry, appear to be more oriented to the stream edge and water surface. It is conceivable the water flow characteristics, and thus habitat niches, attractive to fry for feeding and resting were reduced.

The canal type channel morphometry created by greater bedload, causing more laminar flow (less turbulence), may have resulted in drifting foods being concentrated more than normal, in the center of the channel, farther away from fry habitat. This could be detrimental to fry foraging.

Observations of both fry behavior and stomach analysis indicate that fry feed on drift up in the water column in contrast to foraging off the substrate. Hunt Creek fry eat mostly early instars of aquatic Diptera, Ephemeroptera, Trichoptera, and Plecoptera which dominate the drift.

It has been shown that higher velocities result in trout inhabiting areas closer to the stream bottom where velocities are lower. Fish take up stations in lower velocity areas which are mostly near the bottom or stream edge. Any condition reducing turbulence and diversity of water velocity within the stream cross section, we hypothesize will force trout to concentrate more for feeding, particularly for drift foods. These poorer water flow patterns may restrict the areas that trout efficiently forage for drift.

Further, drift foods would travel through the stream reach much faster than normal because of higher average water velocities, and the reduction in pools and quiet water pockets along the stream edge in which to settle. These factors, in addition to less benthic production, thus reduced the food supply available to trout.

A related observation made during our bedload sediment studies is that bedload particles and organic detrital particles being transported are not mixed homogeneously throughout the water column, but rather are concentrated in narrow bands in straight sections of the stream channel (Hansen 1974). We suggest that drift organisms, which we believe to be subdominate, weak, or injured members of the benthic community, settle out on the streambed like sediments. Thus, small trout may be forced to concentrate their feeding for drift in these bands more distant from resting areas than previously. If so, they would be subject to greater competition with their cohorts and other fish requiring the niche. Nilsson (1967) noted that spatial segregation changed with food abundance. However, greater food density may not entirely compensate for loss of space. Also, many of the drifting invertebrates may be deposited on the streambed and buried in the moving sand sediment.

Another probable factor causing reduced fry production was the poorer bottom substrate for egg incubation. More sandy substrate with less permeability may have resulted in a lower hatch of deposited eggs (Cooper 1965). Further, it has been shown that sand bedload can bury trout redds and trap fry even though they have developed normally up to emergence time (Harshbarger and Porter 1979, 1982). All of these factors could reduce fry and fingerling production.

As pointed out earlier, the major adjustment of the population to bedload took place as reduced survival rates of eggs or fry trout. Survival rates of the older trout changed less. However, we hypothesize that if the population adjustment had not taken place in the very young, it would have ultimately occurred in the older trout. We think survival or possibly growth of older trout would have been reduced significantly. The purpose of speculation here is that if one was to mitigate the adverse effects of bedload by stocking age-0 trout, this may not succeed because the bedload also destroyed the carrying capacity of the stream for the older, larger trout.

Growth rates of trout changed little during this study. It again appears that the trout population was brought into a new equilibrium state under a lower "carrying capacity" due to higher bedload, via mainly a decrease in survival of the very young.

Benthic invertebrate populations, presumably the food supply for trout, were reduced about half by increased bedload. Sand substrate, particularly moving sand bedload, is considered the poorest substrate for habitation and production of benthic food organisms (Pennak and Van Gerpen 1947, Usinger 1968, Hynes 1970). Trout growth rate, condition factor, length-weight relationship, and average volume of food per trout stomach did not change much with increased bedload. However, less food being present did not have an adverse impact on the daily ration of trout because only half as many trout were present to utilize it.

The increase in summer water temperature demonstrated in this study, related to increased bedload, probably had little impact on trout in Hunt Creek because this stream has very favorable water temperatures for trout. However, water temperature increases due to bedload sedimentation could have major adverse effects on trout streams with marginal water temperatures.

Findings and conclusions drawn from the Hunt Creek study are similar and consistent with findings determined from another bedload sediment manipulation study on Poplar Creek, Michigan (Hansen et al. 1982; Alexander and Hansen 1982). In the Poplar Creek study the sand bedload was reduced, using a sediment basin, and the trout stock, which was composed of brown trout and rainbow trout, increased significantly. Vital statistics on the trout response were comparable with those noted for the Hunt Creek brook trout.

From our sand bedload studies on Hunt and Poplar creeks we can make a rough estimate suggesting the relationship between the concentration of sand bedload sediment and the fall trout standing crop per acre. Our predictive lines showing these relationships are shown in Figure 13. Note that the slope indicating the relationship between sediment concentration to trout standing crop are similar for Hunt and Poplar creeks. An increase in bedload sediment of about 17 ppm will result in a 10-pound decrease in standing crop of trout.

Acknowledgements

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We appreciate the efforts of our colleagues, Howard Gowing and W. C. Latta, in many aspects of the study and in reviewing the manuscript.

Table 1. Annual sediment input into Hunt Creek.

Water year (began Oct. 1)	Volume (yd^3)
1972	870
1973	824
1974	754
1975	770
1976	1,005
Total	4,223

Table 2. 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		Bed elevation	
	Control (ft)	Treated (ft)	Control (ft)	Treated (ft)
1971	0.00	0.00	0.000	0.00
1972	-0.01	0.02	-0.002	0.15
1973	-0.05	0.12	0.002	0.31
1974	---	---	0.002	0.45
1975	-0.05	0.24	-0.040	0.47
1976	-0.07	0.33	-0.020	0.64
1980	-0.13	-0.03	-0 090	0.13

Year	Stream width		Water volume			
			Control		Treated	
	Control (ft)	Treated (ft)	(yd^3)	(percent)	(yd^3)	(percent)
1971	13.4	19.4	1,665	100	4,662	100
1972	0.2	0.3	36	+2	-467	-10
1973	0.2	0.9	---	---	---	---
1974	0.2	1.5	---	---	---	---
1975	0.3	1.4	64	+4	-883	-19
1976	0.0	1.3	12	+0.7	-1,136	-24
1980	0.1	-0.3	-41	-3.1	-606	-13

Table 3. Streambed composition as percent of area, Hunt Creek.

Date	Control		Treated	
	Sand	Gravel	Sand	Gravel
6/71	16	63	40	17
6/72	16	57	52	12
6/73	9	58	50	9
6/74	20	61	59	7
6/75	14	59	68	5

Table 4. Number of trout by length group in fall for treated and control areas of Hunt Creek; pre-treatment years 1967-1971, transitional 1972-1975, and treatment 1976-1981.

Year	Length group (inches)			Total
	2.0-4.9	5.0-7.9	8.0+	
Treatment area				
1967	3,821	739	287	4,847
1968	4,151	750	179	5,080
1969	5,192	1,342	393	6,927
1970	3,294	917	293	4,504
1971	4,079	1,133	367	5,579
1972	2,680	743	367	3,790
1973	3,668	597	212	4,477
1974	2,278	381	116	2,775
1975	2,065	428	83	2,576
1976	1,957	326	81	2,364
1977	2,596	223	34	2,853
1978	1,407	464	111	1,982
1979	1,716	428	170	2,314
1980	2,686	307	95	3,088
1981	2,314	464	55	2,833
Pre-treatment average (1967-71)	4,107	976	304	5,387
Transitional average (1972-75)	2,673	537	194	3,404
Treatment average (1976-81)	2,113	369	91	2,573

Table 4. Continued.

Year	Length group (inches)			Total
	2.0-4.9	5.0-7.9	8.0+	
Control area				
1967	2,561	680	157	3,398
1968	3,123	865	169	4,157
1969	3,458	900	179	4,537
1970	3,024	814	146	3,984
1971	3,022	818	134	3,974
1972	2,691	692	134	3,517
1973	2,081	631	127	2,839
1974	1,784	586	122	2,492
1975	1,947	538	103	2,588
1976	2,220	733	150	3,103
1977	3,479	482	130	4,091
1978	2,823	812	165	3,800
1979	3,388	827	144	4,359
1980	3,036	662	100	3,798
1981	3,941	776	103	4,820
Pre-treatment average (1967-71)	3,038	815	157	4,010
Transitional average (1972-75)	2,126	612	122	2,860
Treatment average (1976-81)	3,148	715	132	3,995

Table 5. Number of trout by length group in the spring for treated and control areas of Hunt Creek; pre-treatment years 1968-1971, transitional 1972-1975, and treatment 1976-1981.

Year	Length group (inches)			Total
	2.0-4.9	5.0-7.9	8.0+	
Treatment area				
1968	1,276	424	139	1,839
1969	1,258	641	145	2,044
1970	1,538	663	236	2,437
1971	1,096	617	190	1,903
1972	880	485	286	1,651
1973	1,184	487	307	1,978
1974	701	220	132	1,053
1975	784	183	56	1,023
1976	551	228	58	837
1977	731	160	37	928
1978	721	139	25	885
1979	480	220	31	731
1980	320	157	86	563
1981	921	265	83	1,269
Pre-treatment average (1968-71)	1,292	586	178	2,056
Transitional average (1972-75)	887	344	195	1,426
Treatment average (1976-81)	621	195	53	869

Table 5. Continued.

Year	Length group (inches)			Total
	2.0-4.9	5.0-7.9	8.0+	
Control area				
1968	1,141	527	115	1,783
1969	1,021	612	88	1,721
1970	1,000	628	107	1,735
1971	1,122	580	101	1,803
1972	1,152	474	114	1,740
1973	1,084	518	86	1,688
1974	873	463	105	1,441
1975	423	239	75	737
1976	727	352	69	1,148
1977	774	229	77	1,080
1978	963	265	69	1,297
1979	1,099	511	126	1,736
1980	1,599	523	130	2,252
1981	1,391	572	105	2,068
Pre-treatment average (1968-71)	1,071	587	103	1,761
Transitional average (1972-75)	883	424	95	1,402
Treatment average (1976-81)	1,092	409	96	1,597

Table 6. Ratio of treated-to-control area (T/C) for number of trout present in the fall before and during treatment. Ratio listed by length group with 95% confidence limits. Changes in trout numbers between the pre-treatment (1967-1971) and treatment (1976-1981) periods are shown as percent.

Year	Length group (inches)			Total
	2.0-4.9	5.0-7.9	8.0+	
Pre-treatment 1967-1971	1.35 ±0.01	1.19 ±0.01	1.97 ±0.01	1.34 ±0.10
Treatment 1976-1981	0.68 ±0.07	0.51 ±0.07	0.69 ±0.07	0.65 ±0.10
Percent change	-49 ±8	-57 ±10	-65 ±6	-51 ±11

Table 7. Ratio of treated-to-control area (T/C) for number of trout present in the spring before and during treatment. Ratio listed by length group with 95% confidence limits. Changes in trout numbers between the pre-treatment (1968-1971) and treatment (1976-1981) periods are shown in percent.

Year	Length group (inches)			Total
	2.0-4.9	5.0-7.9	8.0+	
Pre-treatment 1968-1971	1.22 ±0.09	0.99 ±0.09	1.74 ±0.09	1.17 ±0.12
Treatment 1976-1981	0.62 ±0.07	0.51 ±0.07	0.56 ±0.07	0.59 ±0.09
Percent change	-49 ±9	-49 ±15	-68 ±7	-49 ±13

Table 8. Ratio of treated-to-control area (T/C) for number of trout by age group for populations present in the fall and spring. Changes in trout numbers between the pre-treatment (1967-1971) and treatment (1976-1981) periods are shown in percent with 95% confidence limits.

Year	Age group			
	0	I	II	III
Fall populations				
Pre-treatment 1967-1971	1.46 ±0.07	1.03 ±0.07	1.31 ±0.07	1.80 ±0.07
Treatment 1976-1981	0.72 ±0.07	0.50 ±0.07	0.47 ±0.07	0.54 ±0.07
Percent change	-51 ±11	-51 ±16	-64 ±17	-70 ±11

Year	Age group			
	I*	II*	III*	IV*
Spring populations				
Pre-treatment 1968-1971	1.23 ±0.08	1.02 ±0.08	1.19 ±0.08	1.39 ±0.08
Treatment 1976-1981	0.68 ±0.07	0.48 ±0.07	0.36 ±0.07	0.44 ±0.07
Percent change	-45 ±12	-52 ±16	-69 ±16	-69 ±14

Table 9. Ratio of treated-to-control area (T/C) of trout length by age group with 95% confidence limits.

Age group[a]	Pre-treatment (1967-1971)		Treatment 1976-1981)		Percent change[b]	
0	1.04	±0.01	1.07	±0.01	+2.4	±1.5*
I^{s}	1.00	±0.01	1.05	±0.01	+4.5	±1.8*
I	1.05	±0.01	1.04	±0.01	-0.3	±1.5
II^{s}	1.01	±0.01	1.08	±0.01	+6.9	±1.8*
II	1.05	±0.01	1.05	±0.01	+0.3	±1.5
III^{s}	1.03	±0.01	1.06	±0.01	+3.4	±1.5*
III	1.06	±0.01	0.99	±0.01	-6.3	±1.5*
IV^{s}	1.04	±0.01	1.04	±0.01	+0.5	±1.5
IV	1.06	±0.01	1.10	±0.01	+3.3	±1.4*
V^{s}	1.08	±0.01	1.22	±0.01	+12.6	±1.6*

[a] s indicates sample taken in the spring before annulus was formed.

[b] Asterisk denotes a significant difference at the 95% level.

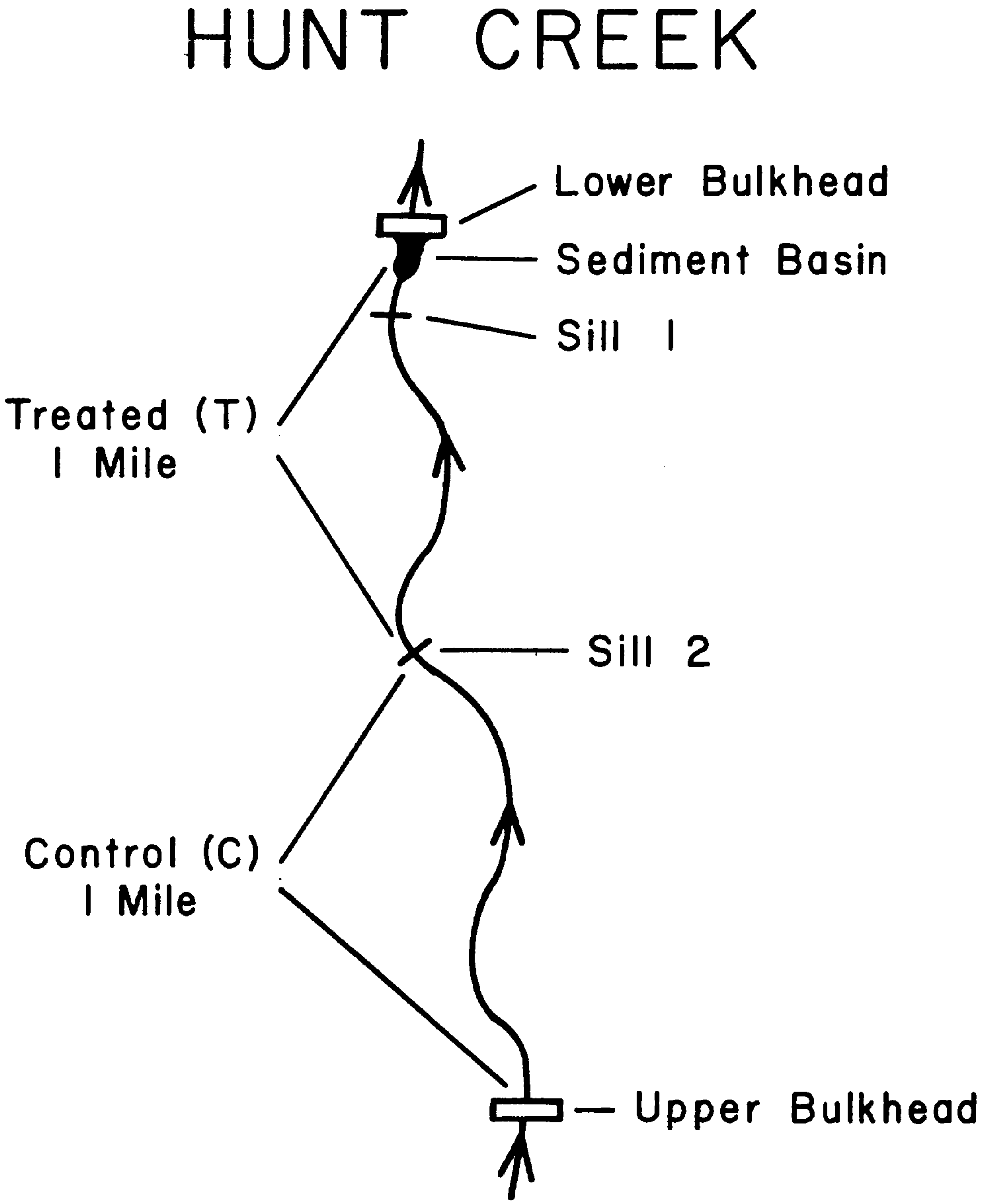

Figure 1.--Diagrammatic presentation of Hunt Creek study area.

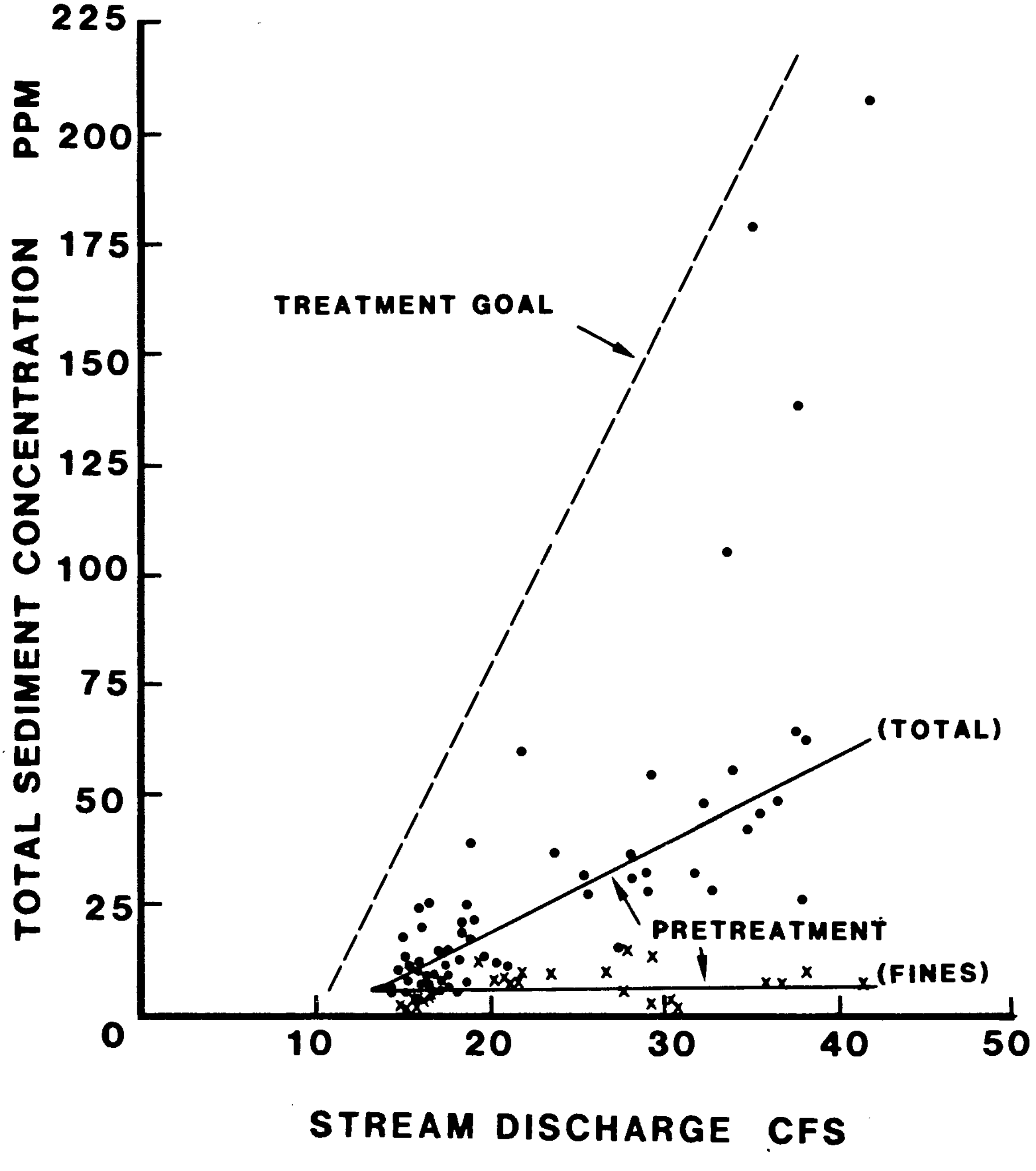

Figure 2.--Relationship of the pretreatment total sediment concentration to stream discharge in Hunt Creek treated section.

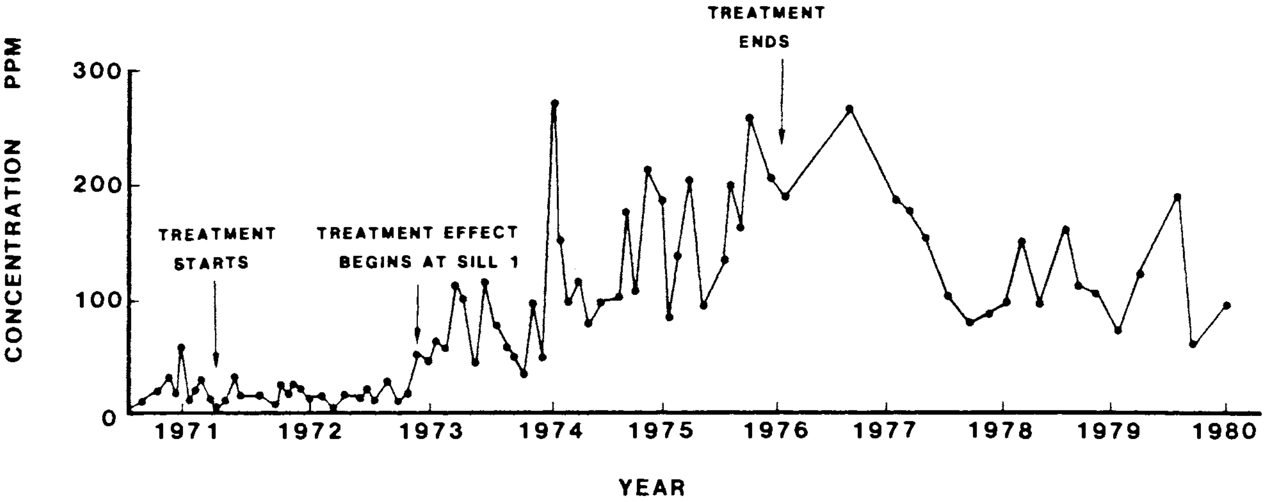

Figure 3.--Sediment concentration at sill 1. Points for 1971-1976 are means of 5 samples collected at approximately weekly intervals; points for 1977-1980 are means of 2 samples collected at monthly intervals.

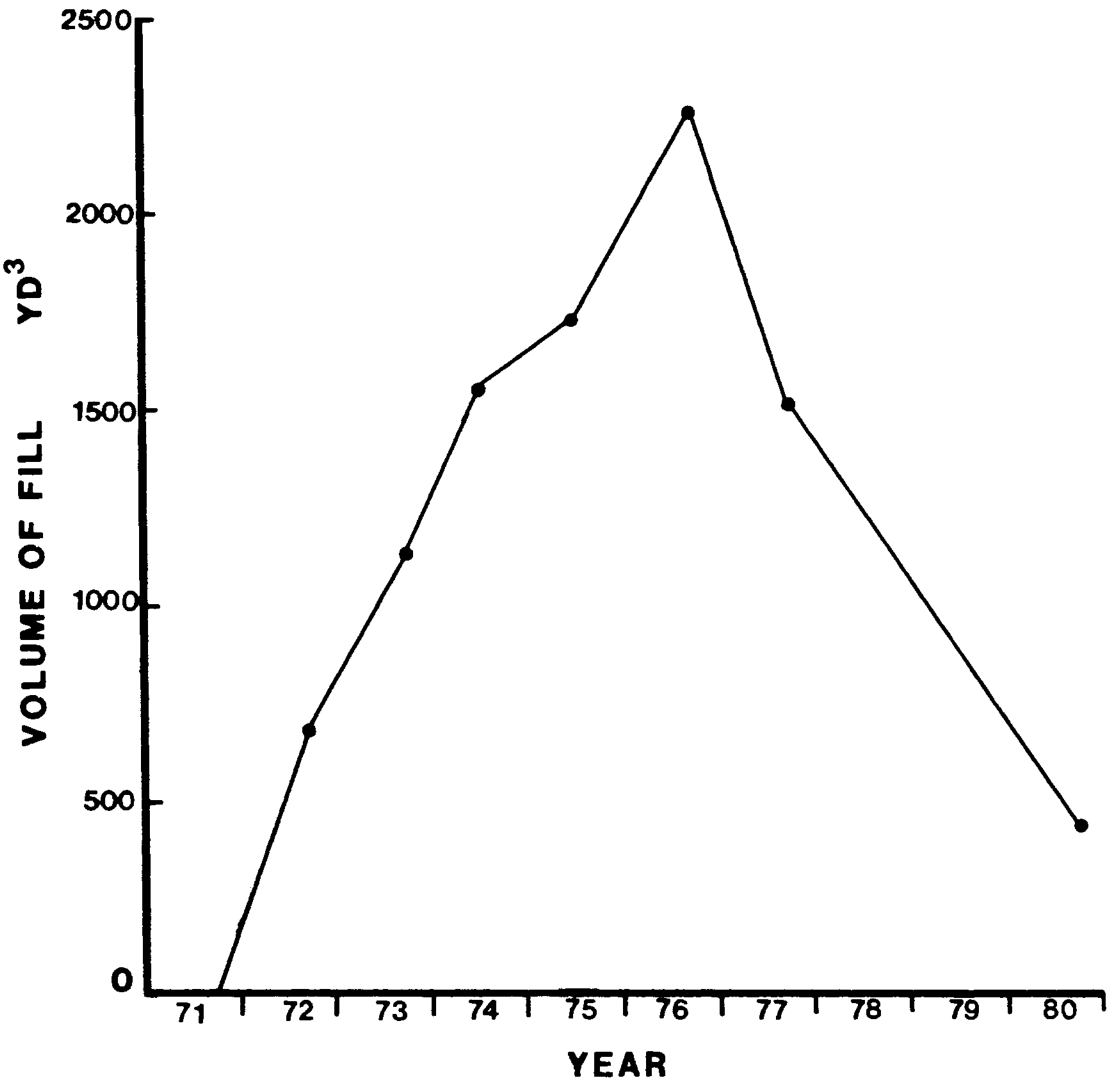

Figure 4.--Cumulative channel fill with sand as calculated from change in streambed elevation.

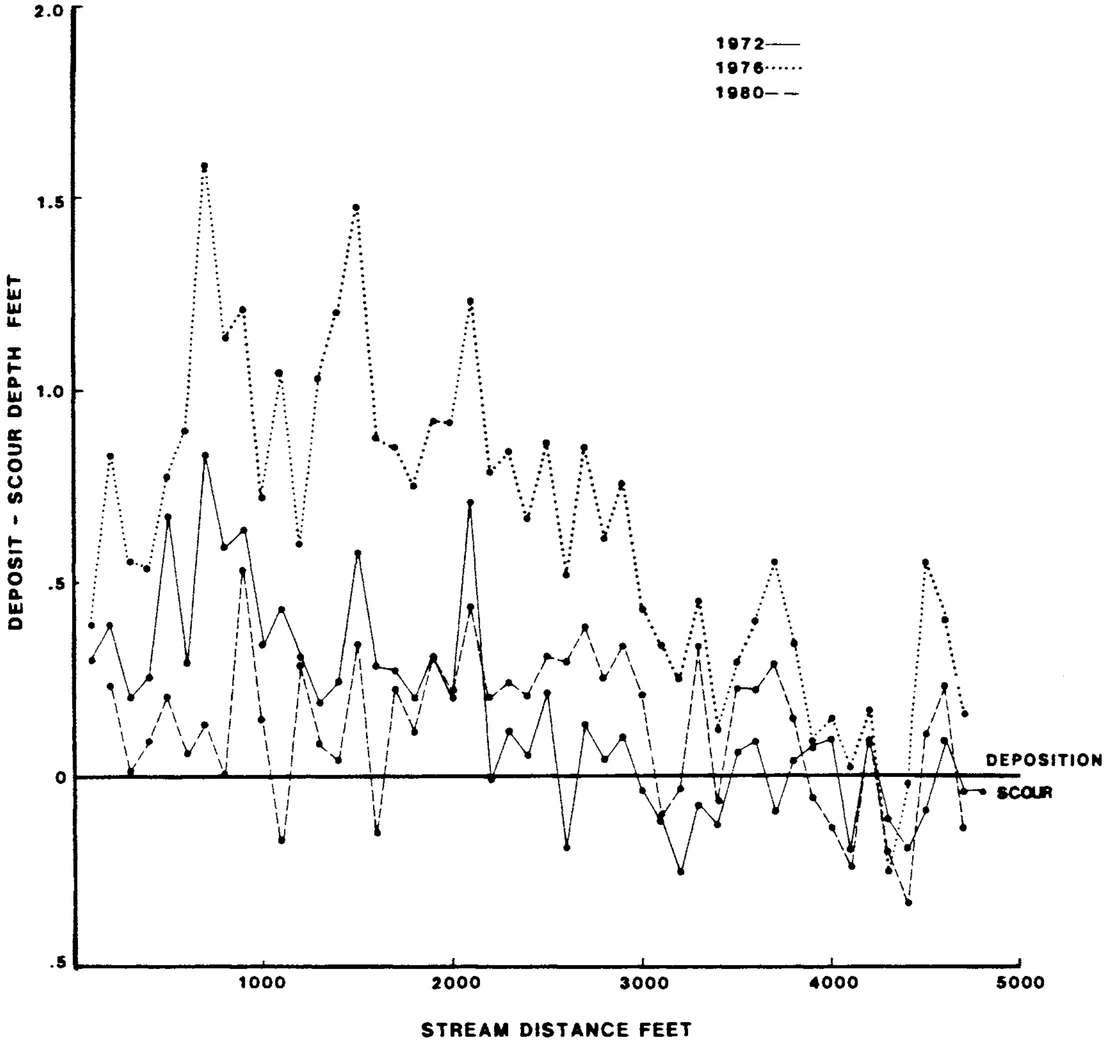

Figure 5.--Trends in channel sand deposition or scour from 1971 baseline survey data taken at 100-ft intervals along the treated section of stream for selected years. Depths are averages for each stream cross section.

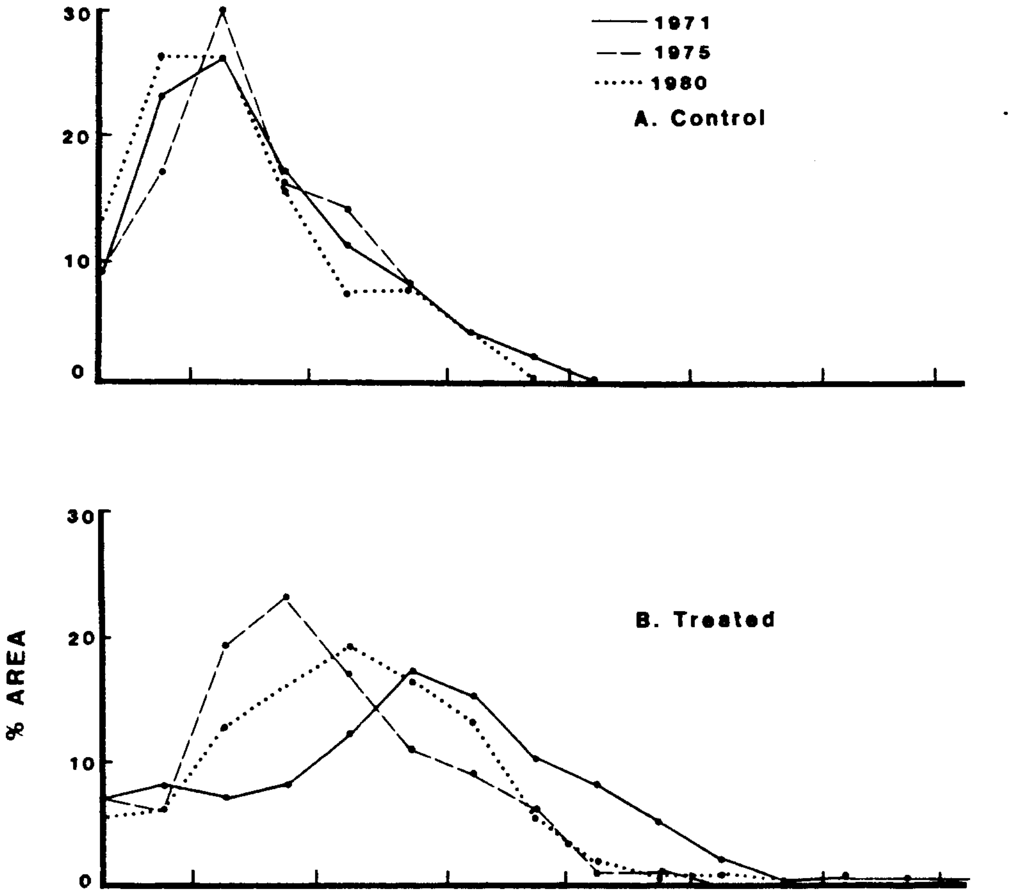

Figure 6.--Distribution of water depths for entire stream.

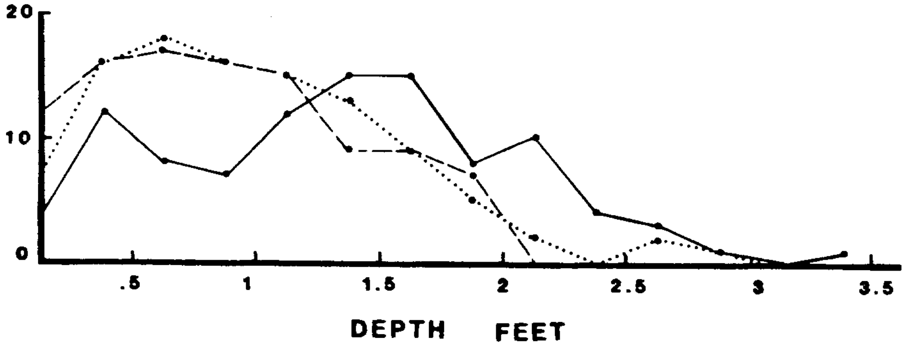

Figure 7.--Distribution of water depths within 3 ft of the bank in the treated section.

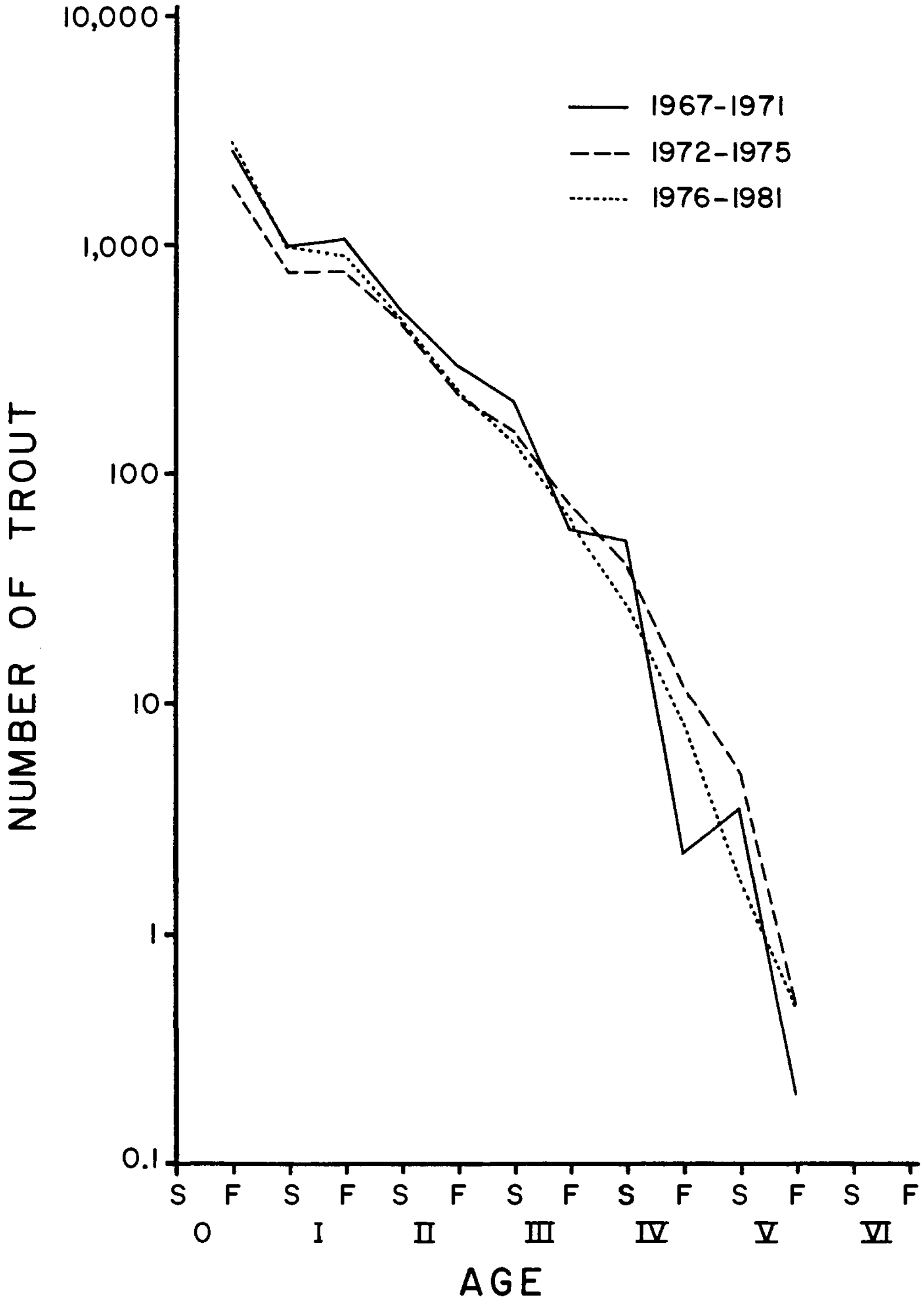

Figure 8.--Survivorship curves for brook trout in the control section of Hunt Creek, spring (S) and fall (F).

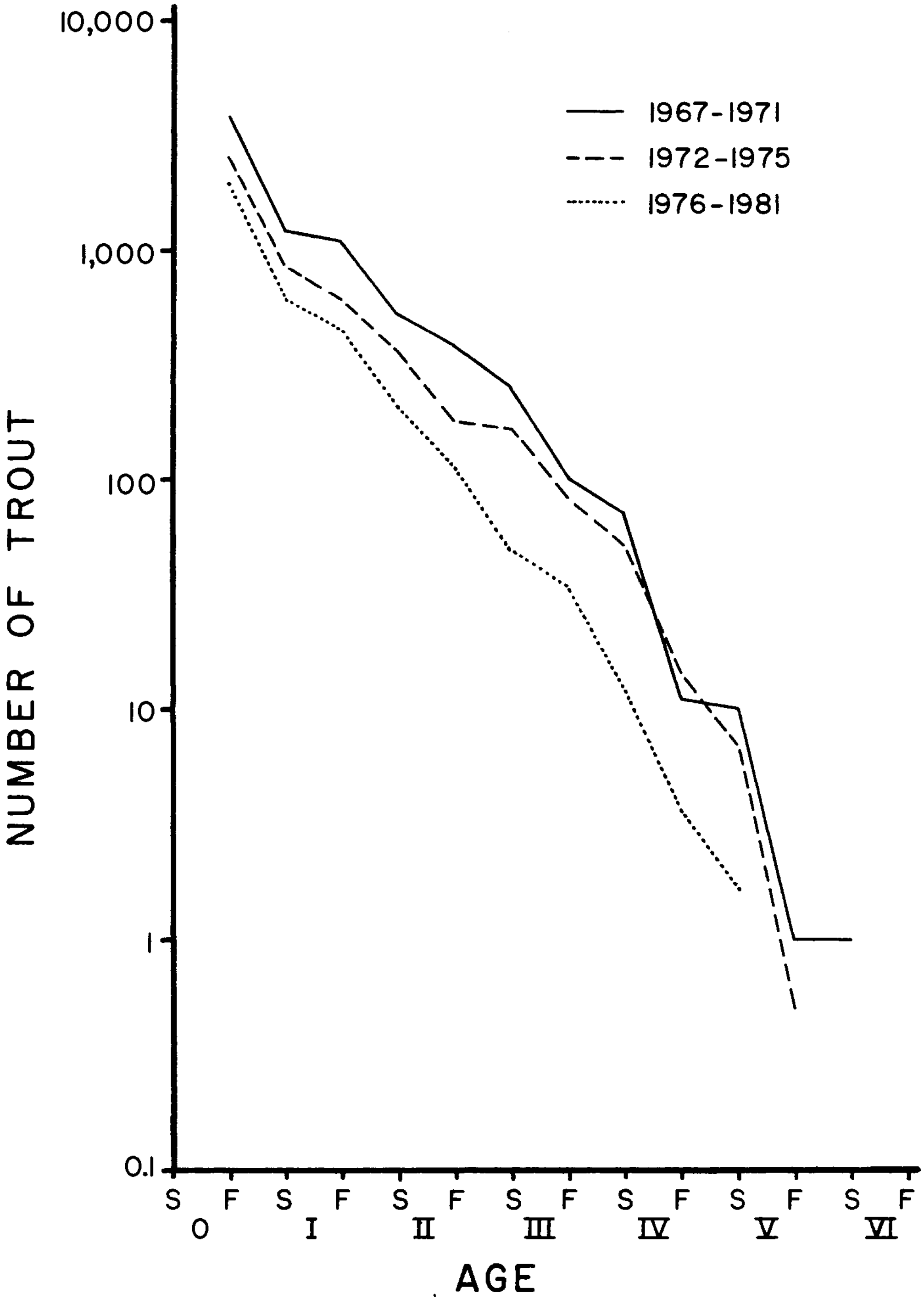

Figure 9.--Survivorship curves for brook trout in the treated section of Hunt Creek, spring (S) and fall (F).

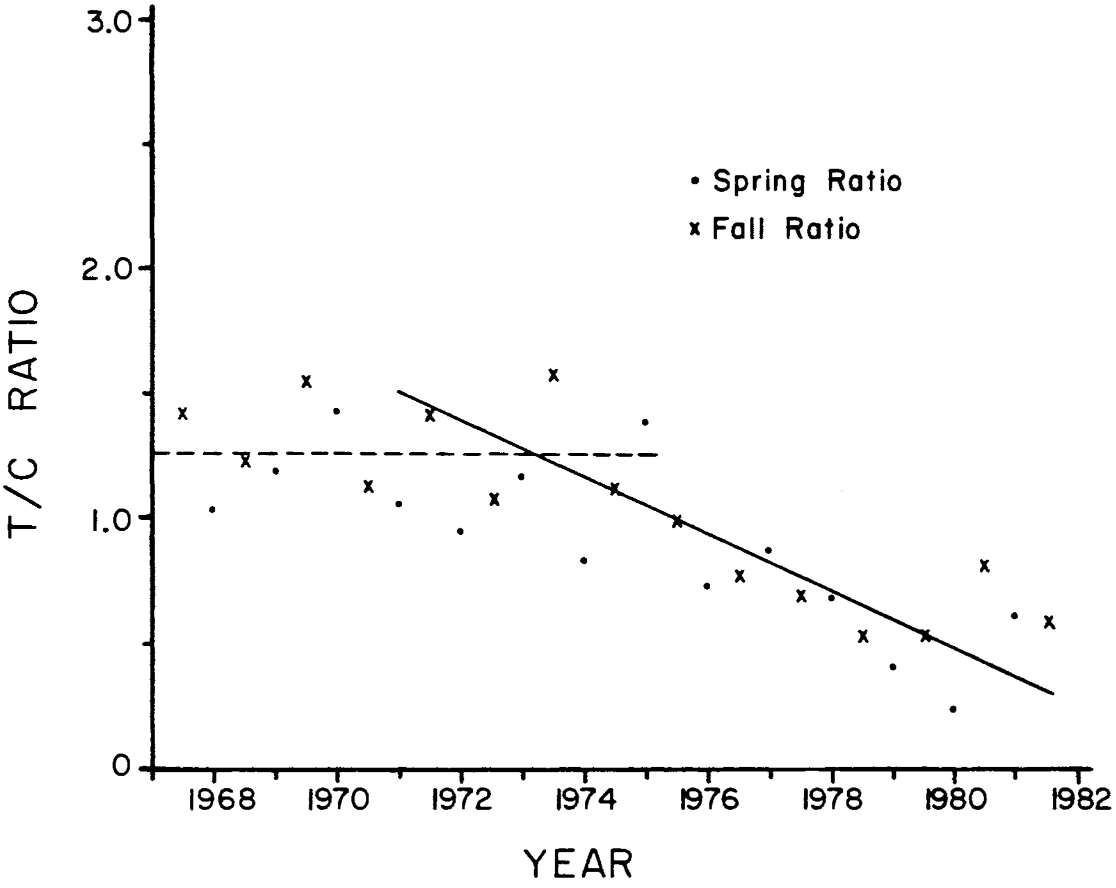

Figure 10.--Ratio of the total number of trout present in the treated area, divided by the total number of trout present in the control area, for each spring and fall. Dashed regression line is for pre-treatment ratios of T/C whereas solid line is for treatment ratios of T/C.

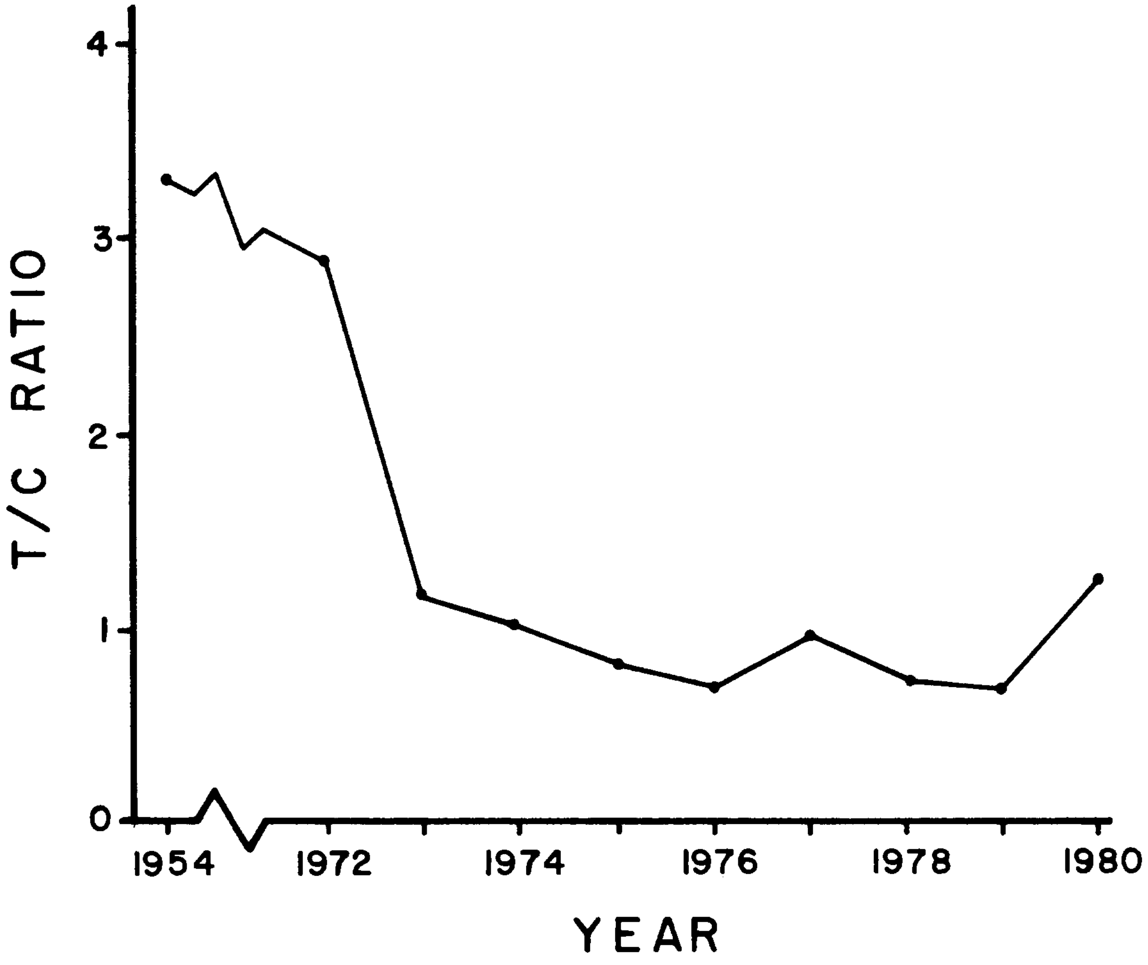

Figure 11.--Ratio T/C of number of invertebrates per square foot of stream bottom.

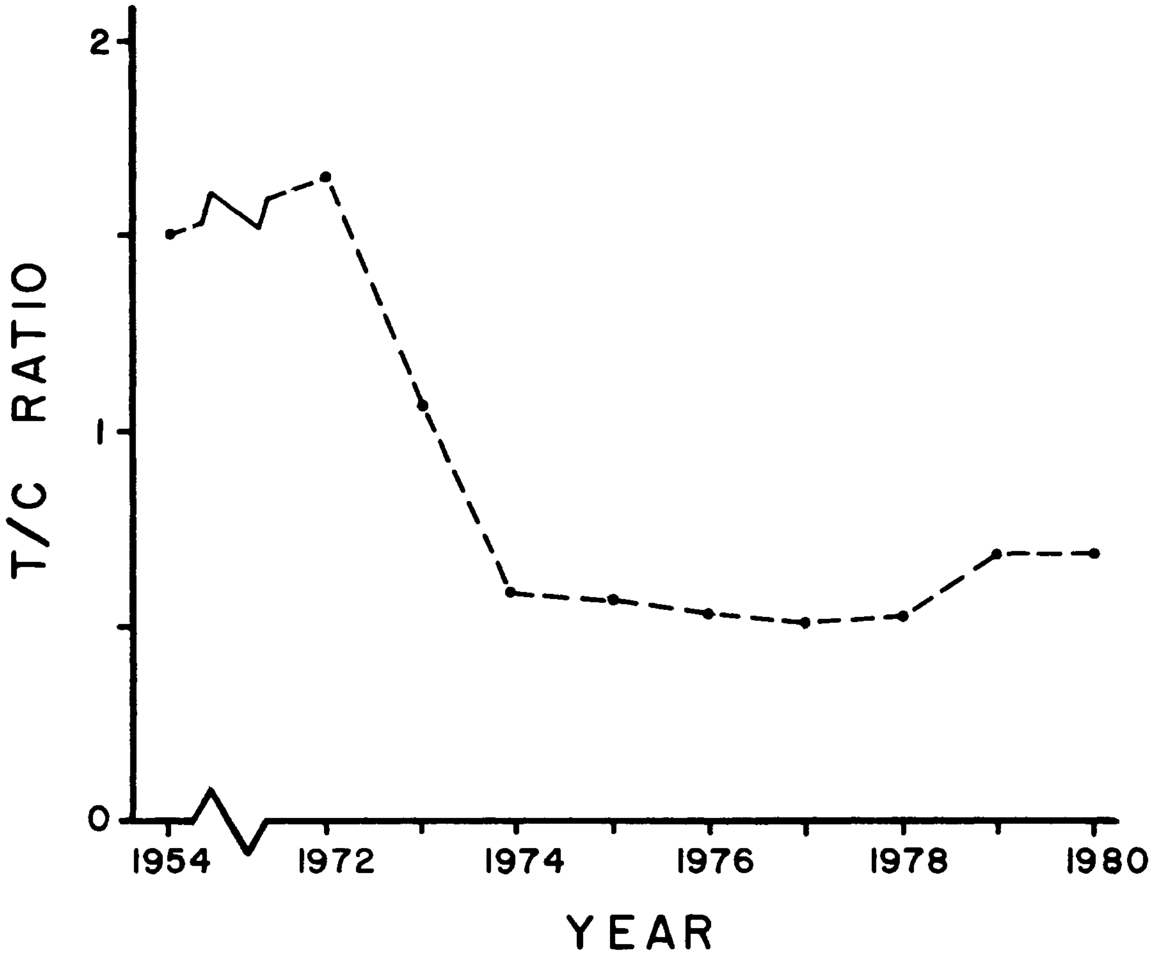

Figure 12.--Ratio T/C of milliliters of invertebrates per square foot of stream bottom.

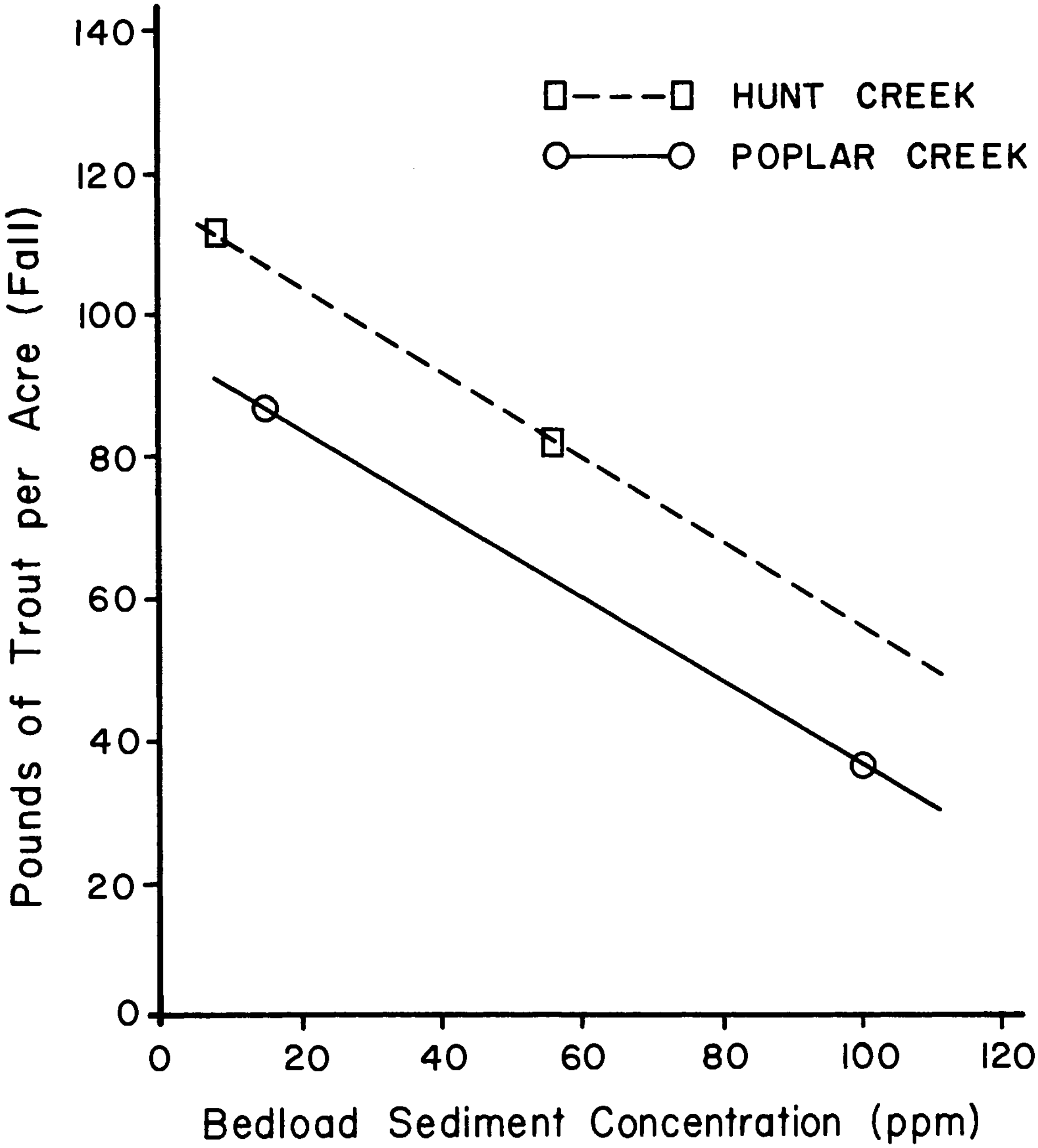

Figure 13.--Relationship of the trout standing crop (pounds/acre) to sand bedload concentration (ppm).

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