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THE IMPACT OF MANAGED STREAMSIDE TIMBER REMOVAL ON CUTTHROAT TROUT AND THE STREAM ECOSYSTEM

PART I — A SUMMARY

by

Douglas J. Martin,
Ernest O. Salo, Steven T. White, Jeffrey A. June,
William J. Foris and Gino L. Lucchetti

FINAL REPORT — PART I OF PHASE I AND II

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Approved: Robert L Burgner
Robert L. Burgner, Director

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ABSTRACT

The habitat, including food supply, of fish living in a woodland stream environment is closely linked to riparian vegetation. The removal of streamside timber causes significant changes in the aquatic-terrestrial linkages, often resulting in detrimental effects on fisheries resources. Managers recognizing that the riparian zone requires special management considerations have implemented the "streamside management zone" (SMZ) concept as a compromising method of harvesting timber yet providing protection for fisheries resources. The effects of current SMZ practices have not been assessed; therefore the functional relationship between riparian vegetation management and fish production was studied.

In this study, the components of the stream ecosystem influenced by removal of riparian vegetation were isolated from physical disturbances associated with road building and log yarding by postponing the removal of the fallen timber in the SMZ and by delaying the logging of the watershed. Physical and biological parameters associated with cutthroat trout production were investigated for two years (Phase I, 1977-78) in designated treatment and control zones. Then commercially valuable timber was carefully removed from the treatment zone in a manner so that understory vegetation and stream bank integrity were maintained. Key environmental parameters in the post-treatment period (Phase II, 1979-80) were compared to the pre-treatment phase (Phase I).

A reduction in canopy density causes changes in the quantity and quality of fixed energy inputs entering the stream and stimulates an increase in the density and biomass of the fish food supply. Salmonid biomass can be governed by the availability of the fish food supply;

therefore, canopy density is functionally related to fish production through a food regulatory mechanism. Large organic debris from the riparian zone and the physical integrity of riparian vegetation controls channel morphology and stability, thus regulating habitat quantity and quality that determines salmonid density and age structure. Consequently, riparian management is functionally related to fish population density and age structure through the development and maintenance of fish habitat. Although the density of riparian vegetation may be a limiting factor in fish production, the physical structure of the within-stream ecosystem is more important in maintaining populations of salmonids.

The SMZ concept, when properly implemented, is a satisfactory management practice for protecting fisheries resources and yet optimizing for timber production. However, the implementation requires: a site-specific management plan; design input from an interdisciplinary team; and skilled loggers using modern technology to minimize physical impacts in the environment of the SMZ.

PREFACE

This report is a summary of the streamside timber removal study conducted at Bear Creek. Most of the research was conducted by graduate students as partial fulfillment of the requirements for a graduate degree. Three graduate theses are in preparation and will be considered as parts II, III and IV of this study. The theses are more detailed investigations concerning: cutthroat trout life history and habitat utilization, taxonomic composition and phenology of the aquatic insect family Chironomidae in relation to stream canopy removal, and the relationship between riparian vegetation management and production of cutthroat trout. The theses will be available to the sponsors on request and to others through the regular procedures of the Fisheries Research Institute.

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We wish to thank Mr. C. Jeffrey Cederholm (Washington Department of Natural Resources, formerly with the Fisheries Research Institute) who helped coordinate this project with the Department of Natural Resources and generously provided field assistance and research equipment, and offered many helpful suggestions.

We are indebted to personnel from the Olympic National Forest, particularly Messrs. Glen Beckman and Rich Larsen from the Soleduc District, for their cooperation and assistance whenever needed. Thanks are also due Mr. Richard Beaubien, forest supervisor, and staff in the supervisor's office for their interest and cooperation in planning the study. We also wish to acknowledge the cooperation and interest of the Washington Department of Ecology personnel, Messrs. Rollie Geppert (now with Ecosystems Inc.), Tom Halbach and Ms. Dru Hobbs.

The actual field work at Bear Creek could not have been completed without the efforts of our competent technicians Messrs. James Jorgenson, Joel Hubble and Thomas Schadt. Thanks are also due the many graduate and undergraduate students, from the University of Washington College of Fisheries, who provided help during the course of the study.

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INTRODUCTION

The need for an interdisciplinary streamside-management plan for forest and fisheries resources in the Pacific Northwest has been recognized for a long time. However, the development of a mutually acceptable plan has moved slowly because forestry and fisheries managers had differences of opinion on the degree of streamside protection required to maintain water quality. The literature cites some cases of detrimental effects of logging, yet the results of many more studies are confusing and inconclusive (Gibbons and Salo 1973). More recent studies have emphasized the ecological relationships between streamside timber and the stream environment. The riparian vegetation zone is a critical component of the aquatic ecosystem because it provides the physical and biological structure around which the stream ecosystem has developed.

Factors controlling the habitat, food supply and growth of fish living in a woodland stream are closely linked to the terrestrial riparian environment. Aquatic insect production is largely dependent upon input of small organic litter from riparian vegetation for its energy supply (Nelson and Scott 1962, Triska 1970, Fisher and Likens 1972, Cummins et al. 1973) and input of large organic debris for its habitat (Sedell and Triska 1977). Fish food supply from the terrestrial insect community is also dependent upon the riparian vegetation complex for food and habitat. Large organic debris from windfalls forms log jams stabilizing the stream bed, creating riffles and pools that provide spawning and rearing habitat for salmonids (reviews by Giger 1973, Hall and Baker 1975, and Reiser and Bjornn 1979). The root mats of streamside vegetation increase stream bank stability

(Keller and Swanson 1979) contributing to undercut bank formations that provide cover for fish. Shade from streamside vegetation is the primary factor controlling water temperature (Brown 1971) and hence the metabolic rate of aquatic organisms. In summary, salmonid production in a woodland stream is regulated by an ecological connection with the terrestrial environment and with streamside vegetation in particular.

The physical and biological structure of the stream ecosystem can be maintained during timber harvest if undisturbed buffer strips are retained (Moring 1975). However, forest managers are often opposed to implementing buffer strip management either by decree or by formula for all streams because of economic considerations. Also, buffer strips are frequently prone to blowdown, sometimes causing blockage to fish passage and resulting in a timber loss for the forest industry. Managers recognize that the riparian zone requires special management consideration for both forestry and fisheries interests. Therefore, the "streamside management zone" (SMZ) concept was developed as a compromise to protect both timber values and water quality interests (Wash. Dept. of Ecology, in press). The SMZ is defined as: "A specified area alongside natural waters where specific attention must be given to the measures that can be taken to protect water quality". (Washington Forest Practice Board 1976).

The SMZ regulations have been in effect since 1976, yet the effect of riparian vegetation management on fishery resources has not been investigated. Therefore, the present study was initiated to: 1) determine the functional relationship between riparian vegetation management and fish production, and 2) determine if the careful removal of streamside timber will maintain the physical and biological structure of the stream ecosystem within limits suitable for salmonid production.

In this study, stream ecosystem components influenced by riparian vegetation removal are isolated from physical disturbances associated with road construction and log yarding by separating the timing of logging operations. The study is divided into three phases: Phase I, documentation of background conditions; Phase II, documentation of effects of clearcutting with a SMZ along the stream but without timber yarding and without roads; and in Phase III, documentation of road construction and timber yarding effects combined with effects from streamside timber removal.

The results presented in this report are from Phases I and II. Phase III is scheduled for 1981-82.

DESCRIPTION OF STUDY AREA

The upper reaches of Bear Creek, a fourth-order tributary to the Bogachiel River, near Forks, Washington (Fig. 1) were chosen for this study. The study watershed is in a remote part of the Olympic National Forest, has no roads and has never been logged. The study reach is 1.2 km long, has an average gradient of 2.1 percent and discharge ranging 0.02 m^3/s to 5.66 m^3/s.

Climate of the Bear Creek vicinity is oceanic with heavy winter precipitation and relatively dry summers (average annual precipitation = 300 cm). In fall, precipitation increases, reaches a peak in December, and then decreases in the spring. Precipitation occurs mostly as rain at elevations below 600 m (Phillips 1965).

Bedrock of the area consists of cretaceous sedimentaty rock known as the Soleduck formation and is the oldest known rock in the Olympic Mountains. The rocks are profoundly folded and consist of course textured, thickly bedded graywacke interbedded with fine textured, thinly bedded mudstone, siltstone and argillite. (Snyder et al. 1972).

A dense climax forest covers the Bear Creek watershed and consists of western hemlock (*Tsuga heterophylla*), western red cedar (*Thuja plicata*), and Sitka spruce (*Picea sitchensis*). Along the stream banks, red alder (*Alnus rubra*) occurs in small clumps usually in association with unstable toeslopes. Woody vegetation along the stream includes: vine maple (*Acer circinatum*), salmonberry (*Rubus spectabilis*), Devil's club (*Oplopanax horridus*), salal (*Gaultheria shallon*), tall blue huckleberry (*Vaccinium ovalifolium*), and red huckleberry (*V. parvifolium*).

The study stream contains a native fish community composed of the

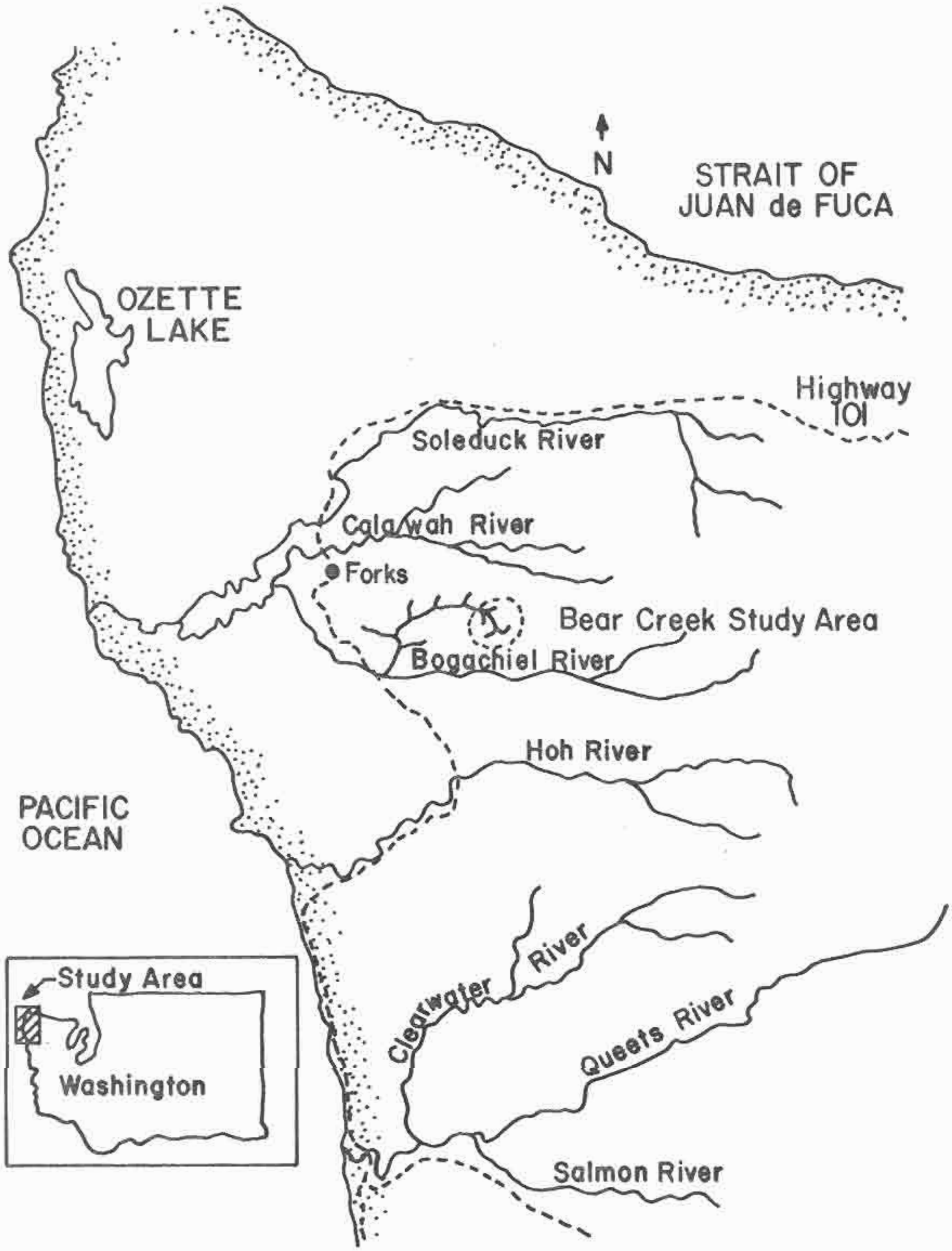

Fig. 1. Western Olympic Peninsula with location of Bear Creek study area.

prickly sculpin (*Cottus asper*), cutthroat trout (*Salmo clarki*), and steelhead rainbow trout (*Salmo gairdneri*). The steelhead trout population is very small relative to the other species because the escapement of spawning adults is limited by a waterfall and log jam downstream from the study area (Fig. 2). The barrier is sieve-like, allowing upstream migration of smaller adult cutthroat but restricting the coho salmon (*Oncorhynchus kisutch*) and steelhead trout. Steelhead trout redds were observed above the barrier but below the study area once during the 4-year study period.

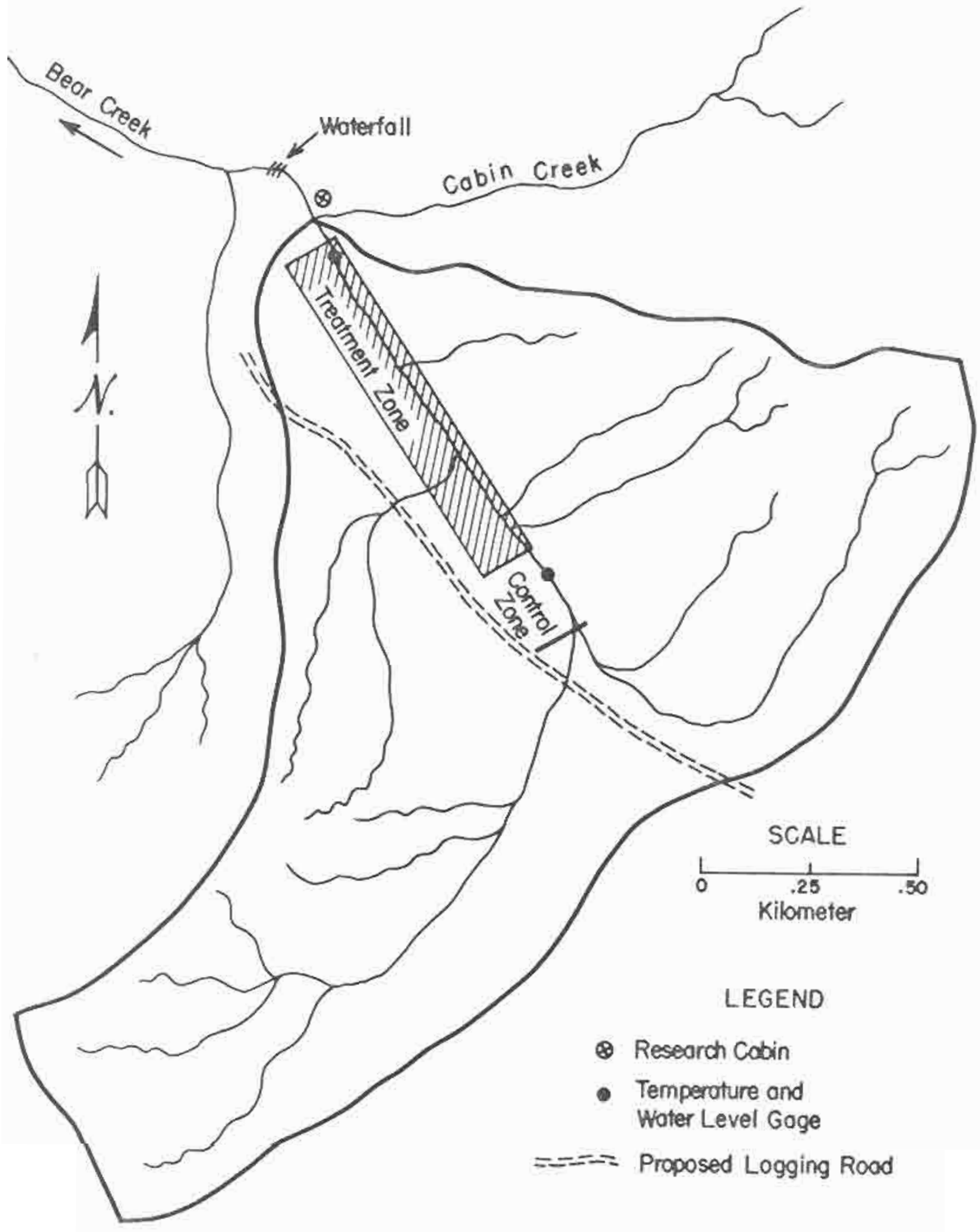

Fig. 2. Upper Bear Creek watershed and study area.

MATERIALS AND METHODS

Study Design

The experimental design separates the biological and physical effects of logging in space and time. The lower 1000 meters of the study area were designated as the "treatment zone" and the upper 200 meters as the "control zone" (Fig. 2). Wooden stakes positioned at 25-meter intervals within the 1200-meter study area were used as reference points (Fig. 3).

The study began in 1977 and was separated into three phases: Phase I, pre-treatment study period (1977-1978); Phase II, Post-treatment biological impact study period (1979-1980); and Phase III, post-treatment biological and physical impact study period, scheduled for 1981-1982.

Streamside Timber Removal (Treatment)

The objective was to simulate a clearcut with a SMZ containing enough understory vegetation and standing timber as deemed sufficient to protect streambank integrity. A fisheries biologist, forester and logger cruised the treatment zone and marked all timber that was determined to be important for providing streambank stability. Considerations were made for potential blowdown, potential input of large organic debris, logger safety, and capability of being harvested under the restrictions. Canopy density requirements for temperature control were not considered as part of the SMZ design. Rather, the canopy density remaining was strictly a function of the amount of merchantable timber originally present and incidental to the amount retained for preservation of criteria other than shade.

In February 1979 all timber within the treatment zone (60 meters wide

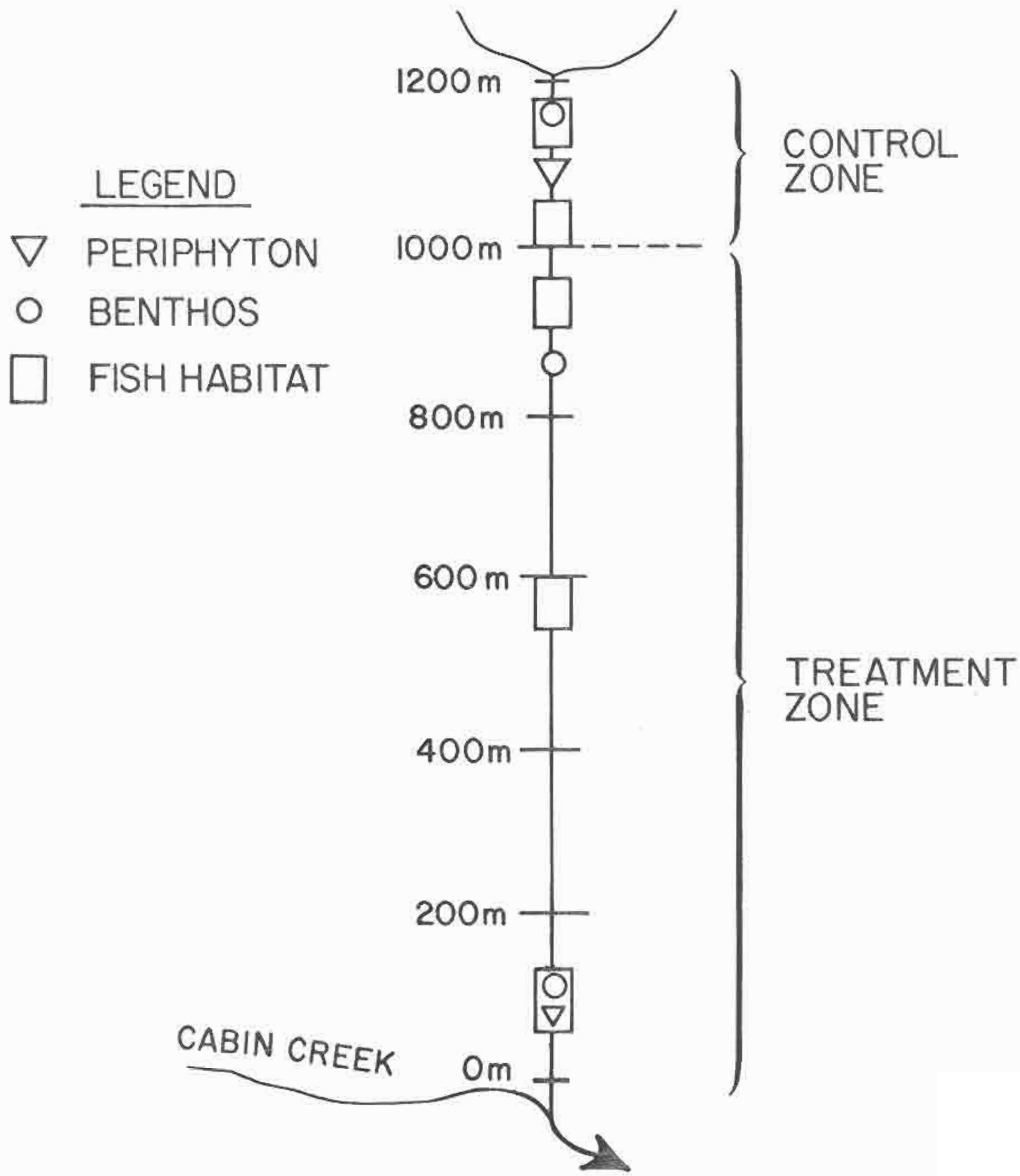

Fig. 3. Diagrammatic representation of upper Bear Creek indicating locations of sampling stations for periphyton, benthos and fish habitat.

wide on the west side of the stream and 10 meters wide on the east side of the stream) was felled except for marked timber and non-merchantable timber within an 8-meter wide SMZ on both sides of the stream. The uneven cut was designed to account for the NW stream aspect (Fig. 2) in order to maximize stream exposure and minimize the area clearcut. Skilled cutters and directional felling methods were used to minimize physical damage to stream banks and understory vegetation. The logs were bucked, limbed and the debris (slash) removed from the stream and placed out of the flood plain. Downed timber remained on the ground during Phase II and will be removed in 1981 by means of a new mid-slope road (Fig. 2).

Physical Environment

Canopy Density

Measurements of direct solar radiation and times of sunrise and sunset were determined by the fisheye canopy-densiometer procedure (Wooldridge and Stern 1979). Pictures of the canopy were taken at 25-meter intervals during winter before and after the streamside timber was removed. A polar graph superimposed on the fisheye image with a plot of the sun track for July 21 was used for measurements of canopy density.

Water Temperature

Water temperatures were recorded in the treatment and control zones (Fig. 2) by two Weather Measure Model T601 temperature recorders. Spot temperature measurements were made with a hand-held thermometer during summer 1979 at 100 meter intervals, and at locations immediately upstream and downstream of each tributary within the study area.

Fish Habitat

Five 50-meter long study sections were used to determine the physical qualities of habitat suitable for cutthroat trout (Fig. 3). Three study sections were located in the treatment zone (stations: 75-125, 550-600 and 900-925) and two in the control zone (stations: 1000-1050 and 1125-1175). Six habitat parameters, depth, velocity, substrate composition, instream cover, streamside cover and overhead shade, important to cutthroat trout, were analyzed using procedures developed by June (1981). The measurements were made during August before (1978) and after (1979) streamside timber removal.

Habitat measurements are expressed as a percent-by-area basis for both actual wetted-surface area and potential full-bank surface area. Substrate composition was divided into five size categories: 1) silt and sand (<5 mm), 2) pea gravel (5 - 25 mm), 3) cobble (25 - 60 mm), 4) small rock (60 - 150 mm), 5) large rock (>150 mm). Instream cover was defined as any submerged or partially submerged object that reduces water velocity or provides shade in the stream (e.g. logs, boulders and root wads). Streamside cover was defined as any object providing shade and extending over the stream at levels from the surface of the water to .5 meters above (e.g. undercut bank and understory vegetation). Overhead shade was defined as objects greater than .5 meters above the water surface that provided shade (e.g. trees and tall understory vegetation).

Fixed Energy Inputs

Algae

Primary production and periphyton biomass were measured periodically at station 100 (treatment zone) and at station 1100 (control zone) (Fig. 3).

Primary production was measured with the enclosed-chamber technique similar to methods used by Thomas and O'Connel (1966) and Hansmann et al. (1971). Substrate from the stream was placed in the chamber and incubated in the stream to simulate natural light and temperature conditions. Water in the chamber was recycled continuously by a small submersible pump. Periphyton biomass, expressed as chlorophyll a, was sampled by scraping a standard surface area from three to five rocks.

Detritus

Input of particulate detritus (size >1 mm) via litterfall was measured by 25-1 m^2 litter traps randomly placed within the study reach. The traps operated continuously and were emptied at monthly intervals. Contents from each trap were dried at 60°C for 24 hrs and weighed to the nearest 0.1 gram.

Lateral movement of detritus was sampled for one year and then discontinued because the amounts of material trapped were insignificant. Low hillslope gradient and thick underbrush near the stream restricted lateral movement.

Fish Food Supply

Benthos

Benthic macroinvertebrates were sampled with a modified Neill Cylinder (Neill 1938) that samples a 0.1 m^2 area and has a 0.233 mm mesh net. Four replicate samples were collected from three separate riffles at monthly intervals from March through October. Two sample riffles were located in the treatment zone (stations: 85 and 850) and one located in the control zone (station 1175) (Fig. 3). Samples, preserved in 70 percent ethanol, were sorted and enumerated under a 10x lens into

3 mm size groups. Wet weights, to the nearest 0.1 mg - after blotting on a towel -, were determined for each size group.

Insect Fallout

Terrestrial insect fallout was sampled by 36 circular water traps (27 cm diameter), randomly placed in the study area. The samplers were operated continuously for two one-week periods each month from March through October. The insects were removed and counted, separated by treatment and control zones, and preserved in 70 percent ethanol. Samples were sorted under a 10x lens, into 3 mm size groups and wet weights measured to the nearest 0.1 mg after blotting on an absorbent towel.

Fish

Population Estimation

Cutthroat trout population censuses were conducted during July and October in 1977, April, July and October in 1978 and 1980, and in April, May, July, August and October in 1979. Trout were captured with a backpack electroshocker and the population estimated for each age group by the mark and recapture method. Age structure was determined from scales and from length frequency distribution of known-age individuals. Known-age stocks were established by permanently marking each year class with a distinctive fin clip when individuals of a year class were collected as age 0 in July and October.

Population estimates were calculated using the Chapman modification of the Peterson formula (Chapman 1951):

$$\hat{N} = \frac{(m+1)(c+1)}{(r+1)}$$

where $\hat{N}$ = estimated number of fish in population

m = number of marked fish in population

c = number of fish in sample

r = number of marked fish in c

Ninety-five percent confidence limits were calculated by the standard error method of Youngs and Robson (1978):

$$95\% \text{ confidence limits} = \hat{N} \pm 2\ (SE)$$

$$\text{where } SE\ (\hat{N}) = \sqrt{\frac{\hat{N}^2(\hat{N}-m)(\hat{N}-c)}{mc(\hat{N}-1)}}$$

Biomass

The biomass for each age group was calculated as the product of the mean weight of fish and the population estimate:

$$\hat{B} = \hat{\bar{W}}\ \hat{N}$$

where $\hat{B}$ = estimated population biomass

$\hat{\bar{W}}$ = estimated mean weight

$\hat{N}$ = estimated number of fish in population

Ninety-five percent confidence limits for biomass estimates were calculated by the standard error method of Chapman (1978):

$$95\% \text{ confidence limits} = \hat{B} \pm 2\ (SE)$$

$$\text{where } SE\ (\hat{B}) = \sqrt{\hat{\bar{W}}^2\ \hat{V}(\hat{N}) + \hat{N}^2\ \hat{V}(\hat{\bar{W}})}$$

Movement

Cutthroat trout movement was monitored in 1978 and 1979 within the study area. Groups of fish within several 50-meter sections in the treatment zone and control zone were given a unique cold brand during each spring. Movement was quantified during subsequent sampling surveys conducted at the end of four time periods: early spring, late spring, early summer, and late summer. Additional fish were branded during each survey as the brands disappeared after two to three months.

RESULTS

Streamside Timber Removal

The removal of the streamside timber resulted in a SMZ similar to that planned in the experimental design. Differences occurred when several trees fell into the stream and from blowdown caused by heavy winds of February 13, 1979 (> 100 mph). The wind storm occurred when the timber felling was about 80 percent completed, causing a reduction in the density of timber left standing in the SMZ. Blowdown in the control zone averaged 1.5 trees/100 meters whereas blowdown in the treatment zone (SMZ) averaged 2.7 trees/100 meters. The root wads of several trees fell into the stream channel causing localized changes in channel morphology. Also, some of the blowdown trees fell across the stream channel in a bridge-like fashion, causing minor damage to the stream banks.

Stream Exposure

Streamside timber removal caused a significant ($p < 0.05$) increase in exposure to direct solar radiation. Exposure time for July 21 averaged 3.4 hours before treatment and 7.4 hours after treatment. Increased solar exposure occurred during the afternoon because the time of effective sunset was later following treatment (Fig. 4). The treatment also caused the exposure time to be more uniform along the 1000 meter treatment zone.

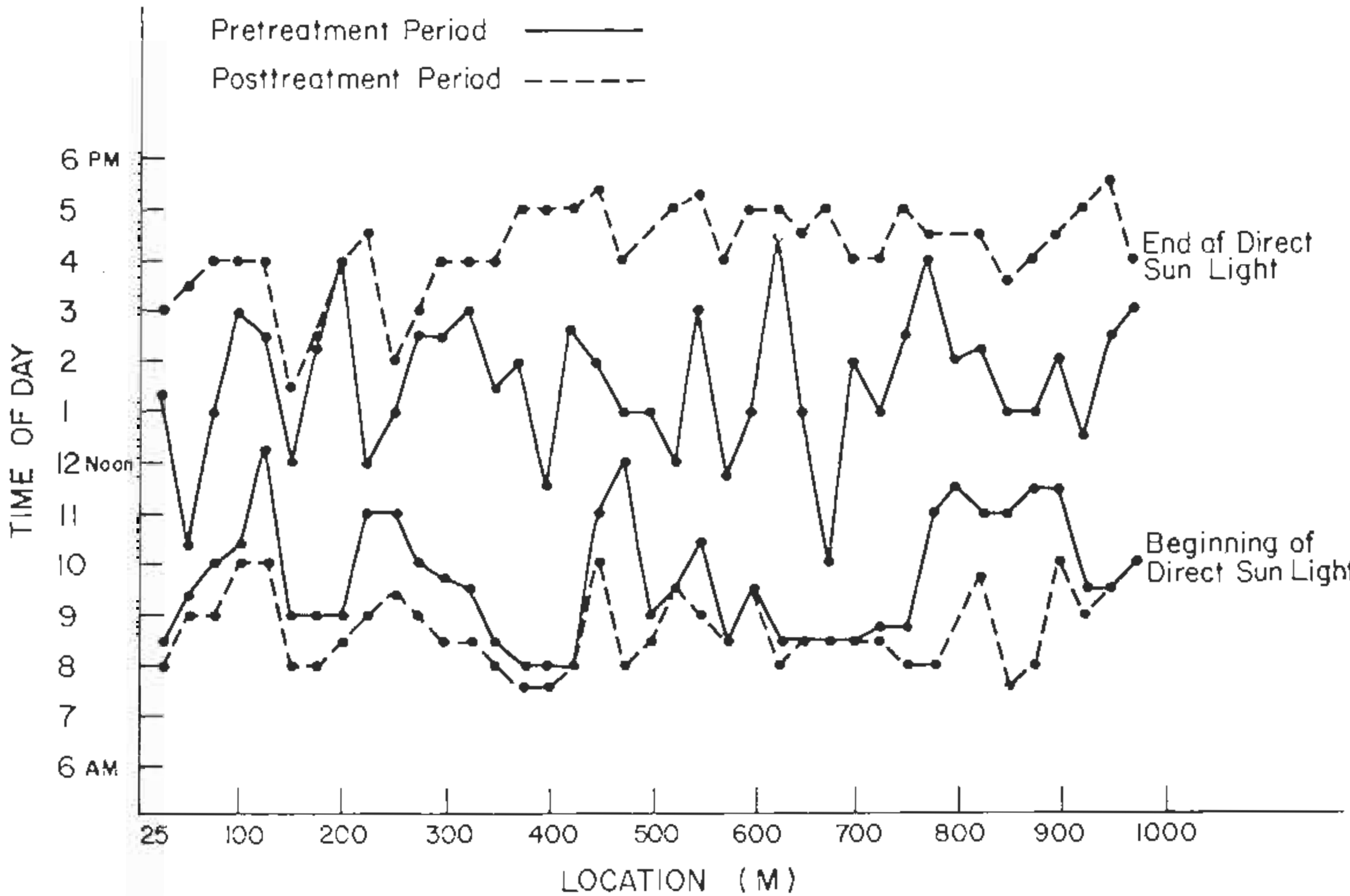

Fig. 4. Time of effective sunrise and sunset, calculated for July 21, for the treatment zone of Bear Creek, before and after streamside timber removal.

Temperature

Weekly mean water temperature in the treatment zone was significantly greater ($p < 0.05$) than in the control zone following streamside timber removal (Fig. 5). Water temperature in the treatment zone averaged 2°C greater during June through September. The maximum daily temperature and greatest daily temperature fluctuations occurred during the period July 16 through August 31. Maximum daily temperatures in the treatment zone were 14.8°C to 15.6°C (1977-78) before treatment and 17.2°C to 17.3°C (1979-80) after treatment (Table 1). Daily temperature fluctuations after treatment were significantly greater ($p < 0.05$) in the treatment zone compared with both the control zone and pre-treatment period (Table 1).

Total temperature units (TU = sum of daily mean temperature above freezing) accumulated in the treatment zone during the 7-month period April through October increased by an average of 165 TU's after treatment (Fig. 6). Differences in TU accumulation between the treatment and control ranged from 71 to 74 TU's before treatment and 194 to 270 TU's after treatment. The greater TU difference after treatment occurred as a result of greater TU accumulation in the treatment zone during the late-summer to fall period.

The temperatures of tributary streams and seeps were equal to or cooler than the water temperature in the control zone following treatment. A comparison of temperature measurements above and below such coolwater inputs indicated that temperature buffering was occurring. Water entering the treatment zone from tributaries and seeps averaged 43 percent of the total discharge during the summer low-flow period.

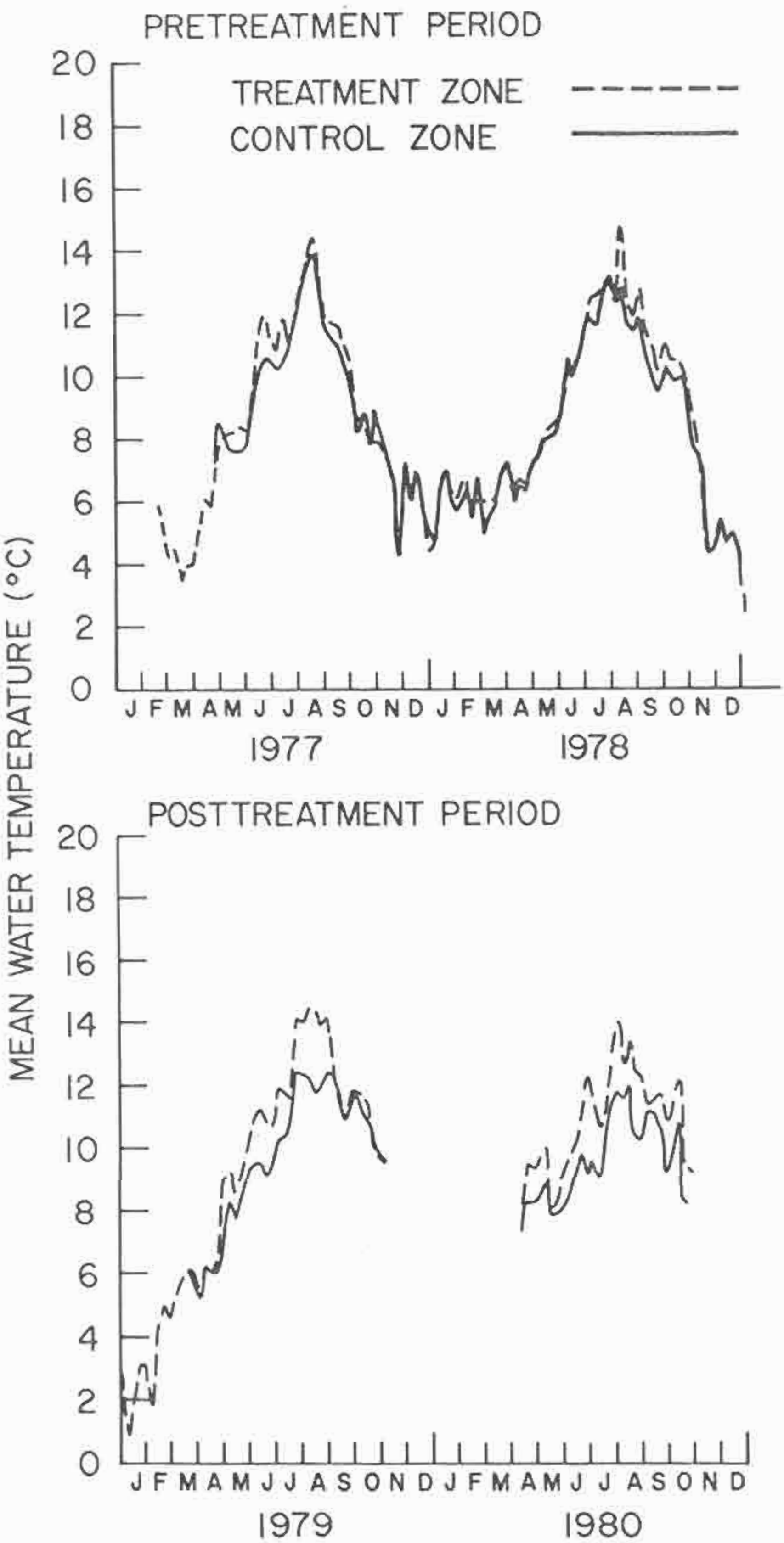

Fig. 5. Weekly mean water temperatures for the treatment zone (station 100) and control zone (station 1125) of Bear Creek, before (1977-1978) and after (1979-1980) streamside timber removal.

Table 1. Maximum water temperatures and daily temperature fluctuation statistics for the period July 16 through August 31 in Bear Creek.

Period/ year	Treatment (Station 100)					Control (Station 1125)				
	Max. temp. (°C)	Diel fluctuation (°C)			N	Max. temp. (°C)	Diel fluctuation (°C)			N
		Max.	Mean	SD			Max.	Mean	SD	
Pre-treatment										
1977	14.8	1.2	0.70	0.36	47	14.9	1.6	0.84	0.40	47
1978	15.6	1.4	0.71	0.37	46	14.6	1.4	0.77	0.32	45
Post-treatment										
1979	17.3	4.6	2.20	1.05	47	13.7	1.6	0.92	0.35	47
1980	17.2	5.5	2.51	1.47	47	13.0	1.4	0.61	0.32	28

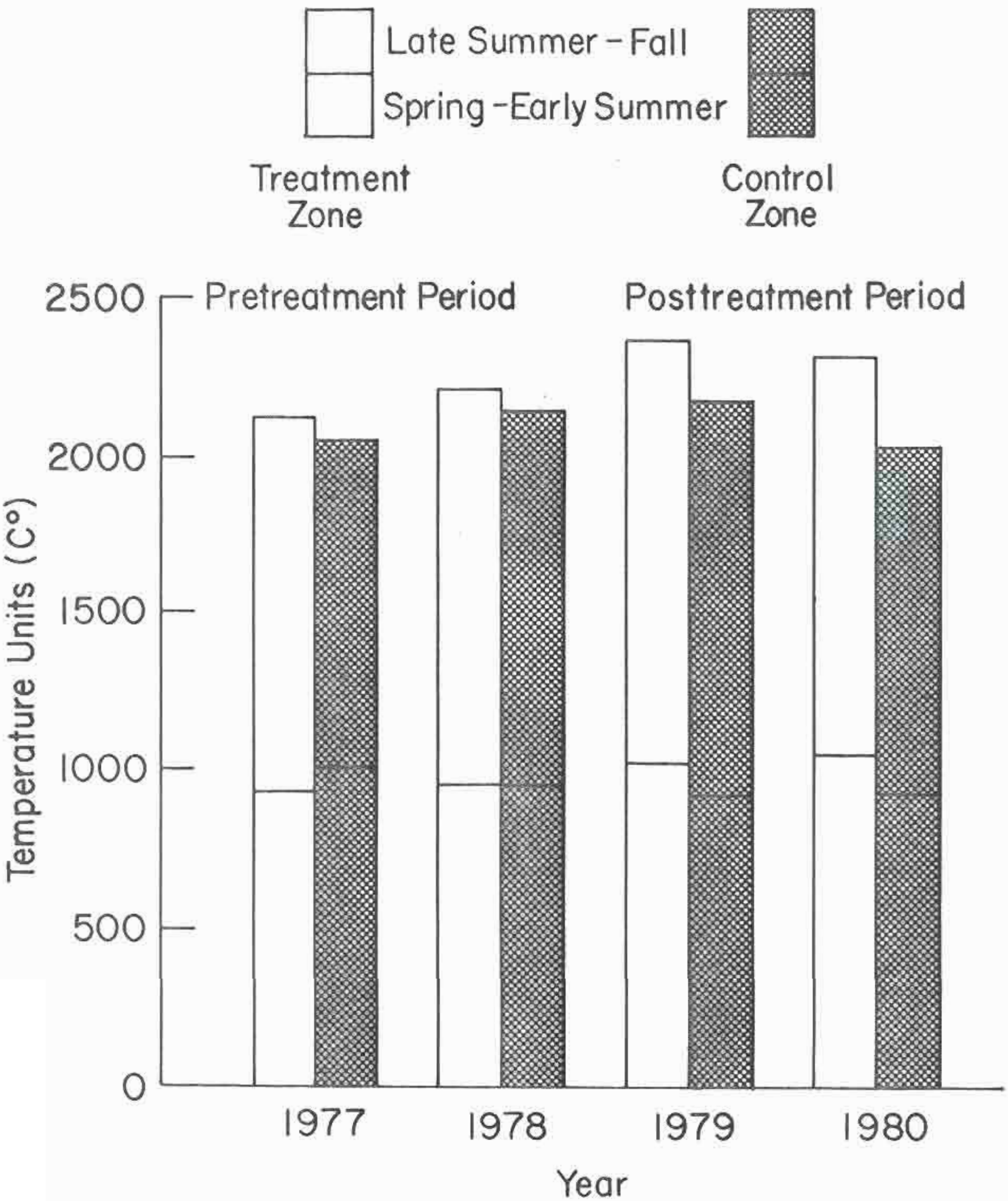

Fig. 6. Total and seasonal temperature units accumulated during the 7-month period, April through October, in the treatment and control zones of Bear Creek, before (1977-1978) and after (1979-1980) streamside timber removal.

Fish Habitat

The effects of streamside timber removal on the physical structure of the stream ecosystem are best measured by changes in fish habitat. Shade from overhead vegetation in the treatment zone, following treatment, averaged 23 percent of pre-treatment levels (Fig. 7) and was furnished by alders and tall understory vegetation in the SMZ. Habitat section 1000-1050 in the control zone had shade reduced to 43 percent of pre-treatment levels as a result of blowdown caused by the February 13 windstorm.

Habitat defined as streamside cover (p. 10) was not significantly different after treatment except in sections 1000-1050 (control zone) where cover was reduced by 74 percent (Fig. 8). Reductions in section 1000-1050 were due to disturbances of small streamside vegetation caused by blowdown (Feb. 13). Streamside cover was not affected in the treatment zone because care was taken to fell timber away from the stream bank. Most of the streamside habitat consisted of dense clumps of salmonberry and small alders.

Instream cover was unchanged after streamside timber removal except in section 900-950 (treatment zone) (Fig. 8), where blowdown from the February 13 windstorm more than doubled the original amount. Instream cover was provided by large organic debris (LOD) embedded in the stream channel or bank and alder root wads secured into the channel banks. The presence of LOD in the stream was the most important element controlling channel morphology and stability in Bear Creek. Bedrock and rock outcrops occurred in very few locations, and most of the pools and riffles were created by LOD. Channel morphology was equally dynamic in treatment and control zones and was a function of the presence of LOD and the magnitude of storm events.

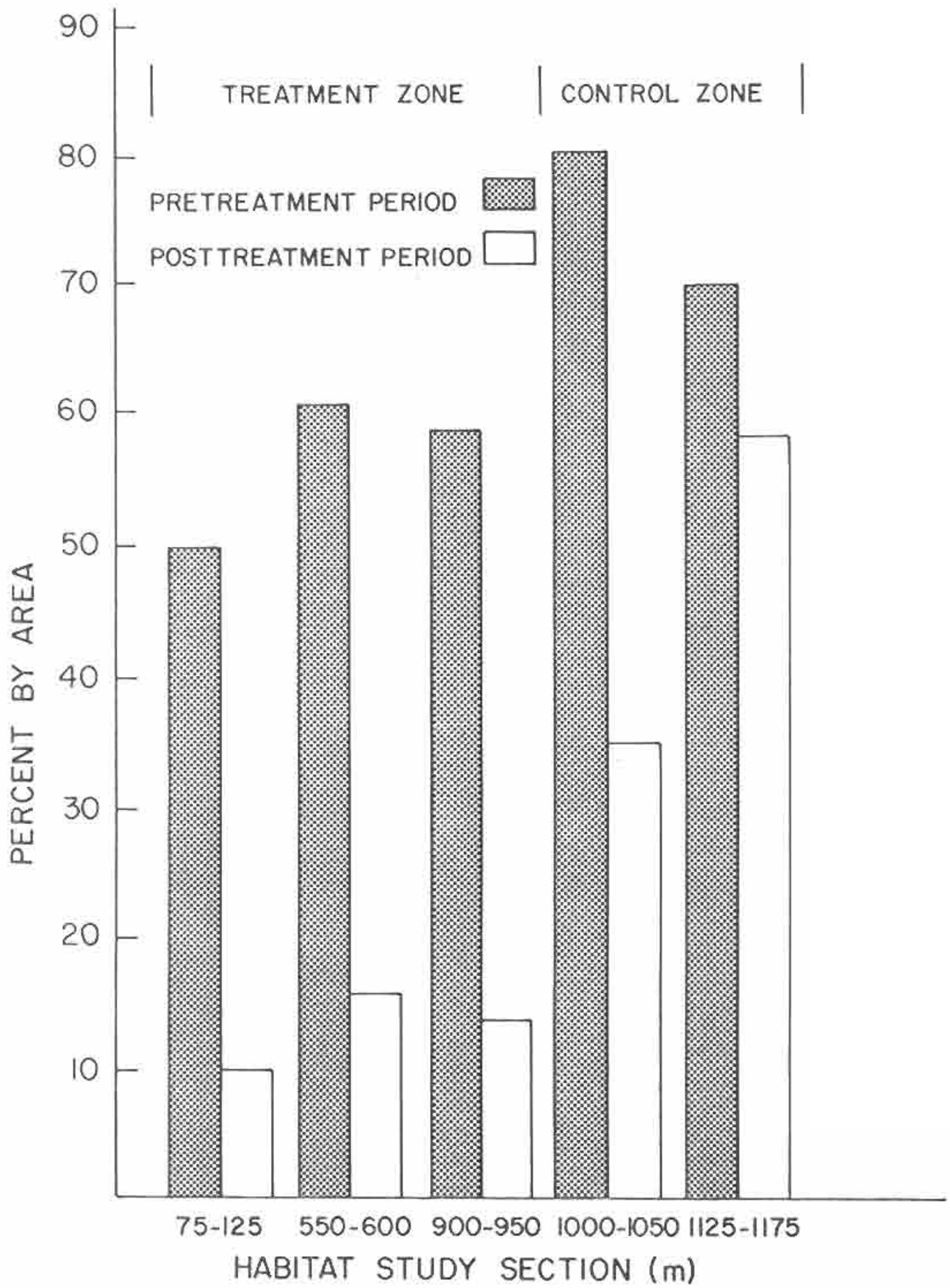

Fig. 7. Percentage of stream wetted surface area shaded by overhead vegetation in five habitat study sections of Bear Creek, before (1978) and after (1979) streamside timber removal.

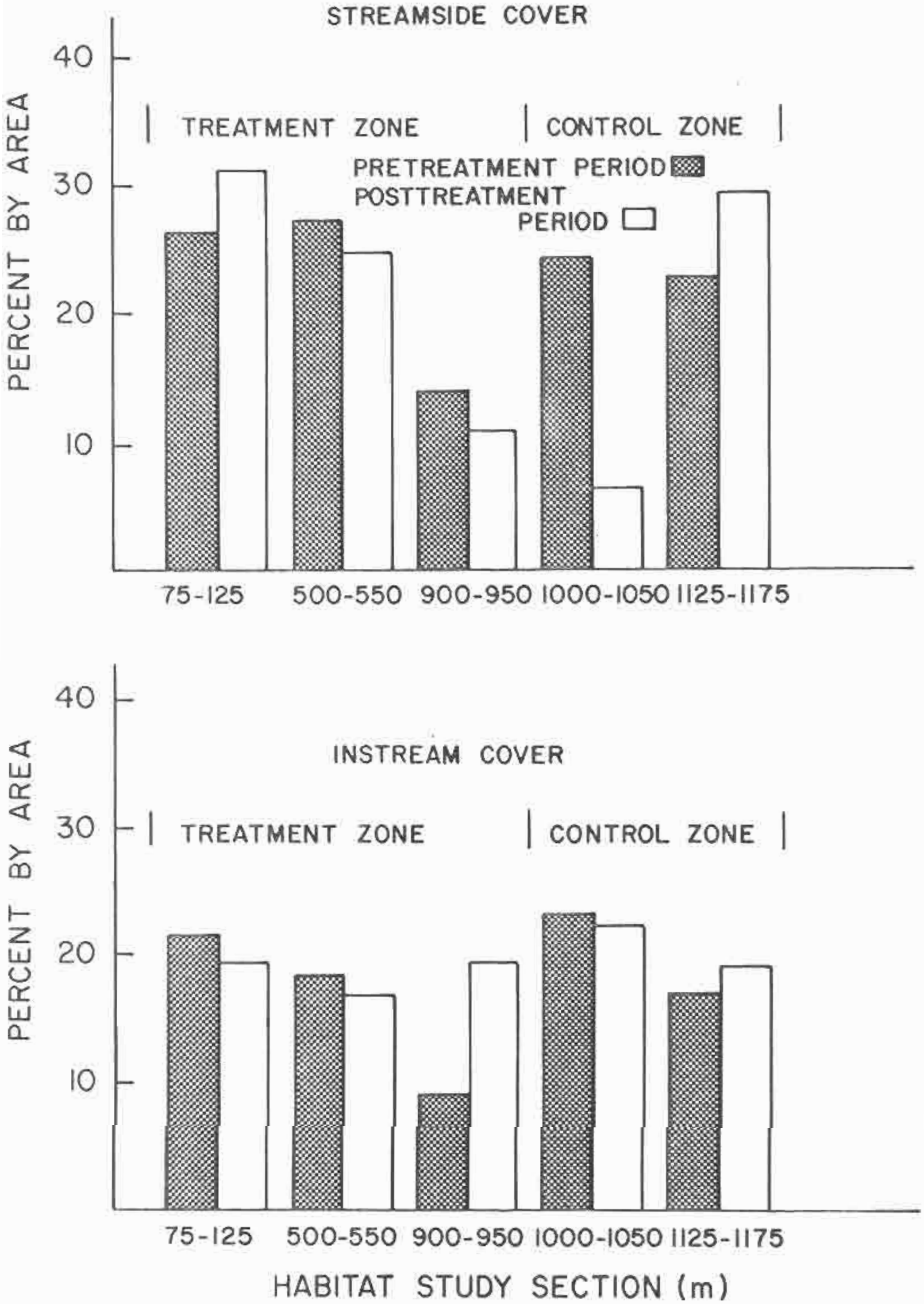

Fig. 8. Percentage of stream area when the stream is at bank full flow covered by streamside habitat and instream habitat in the five habitat study sections of Bear Creek, before (1978) and after (1979) streamside timber removal.

Habitat defined as stream substrate changed little in all sections except section 75-125 (Fig. 9), where the composition changed to a dominance of smaller particle sizes (i.e. sand and pea gravel) during the post-treatment period. Winter freshets caused a change in channel morphology, causing a greater accumulation of smaller substrate materials in pools.

Primary Production

Determinations of periphyton biomass and primary production were made in the spring and early summer periods of 1978 and 1979. Chlorophyll *a* biomass in the treatment zone was consistently lower than in the control zone for all dates sampled before and after streamside timber removal (Fig. 10). The patterns of abundance of chlorophyll *a* biomass during spring were similar for both stations in 1978 but differed in 1979 (Fig. 10).

Net primary production in the periphyton community during pre-treatment was similar for both treatment and control stations and no consistent trend between stations was evident (Fig. 10). But, following treatment, the treatment station had a consistently greater production than the control station for all dates except February when production at both stations was equal.

Detritus

Input of particulate detritus from litter fall followed a seasonal pattern with a small pulse in spring from conifer needles and plant catkins, and a large pulse during autumn from red alder leaves (Fig. 11). Detrital input in the treatment and control zones was not significantly different during the

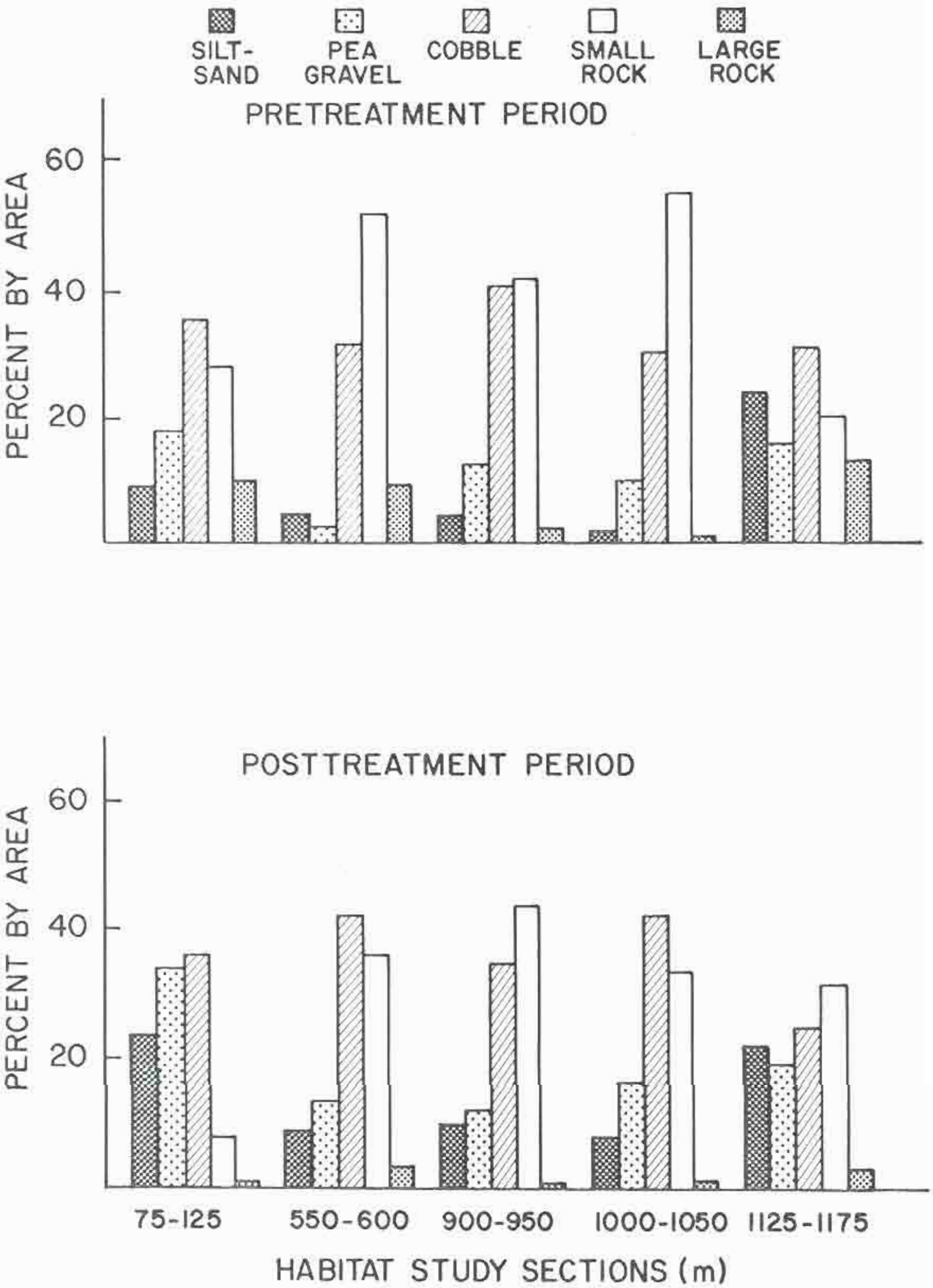

Fig. 9. Substrate composition in five habitat study sections of Bear Creek, before (1978) and after (1979) streamside timber removal.

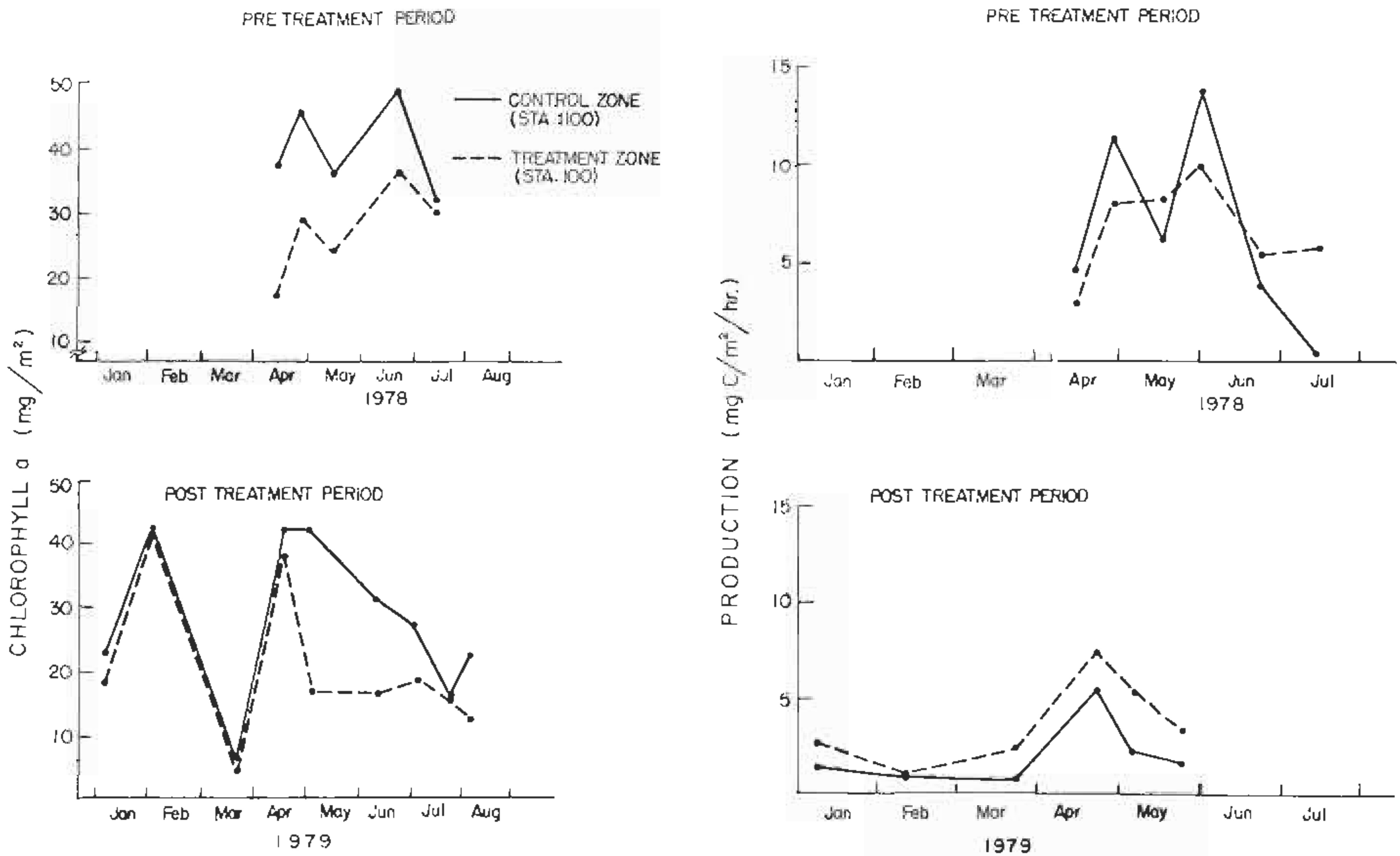

Fig. 10. Periphyton chlorophyll a biomass and net primary production for the treatment zone (station 100) and control zone (station 1100) of Bear Creek, before (1978) and after (1979) streamside timber removal.

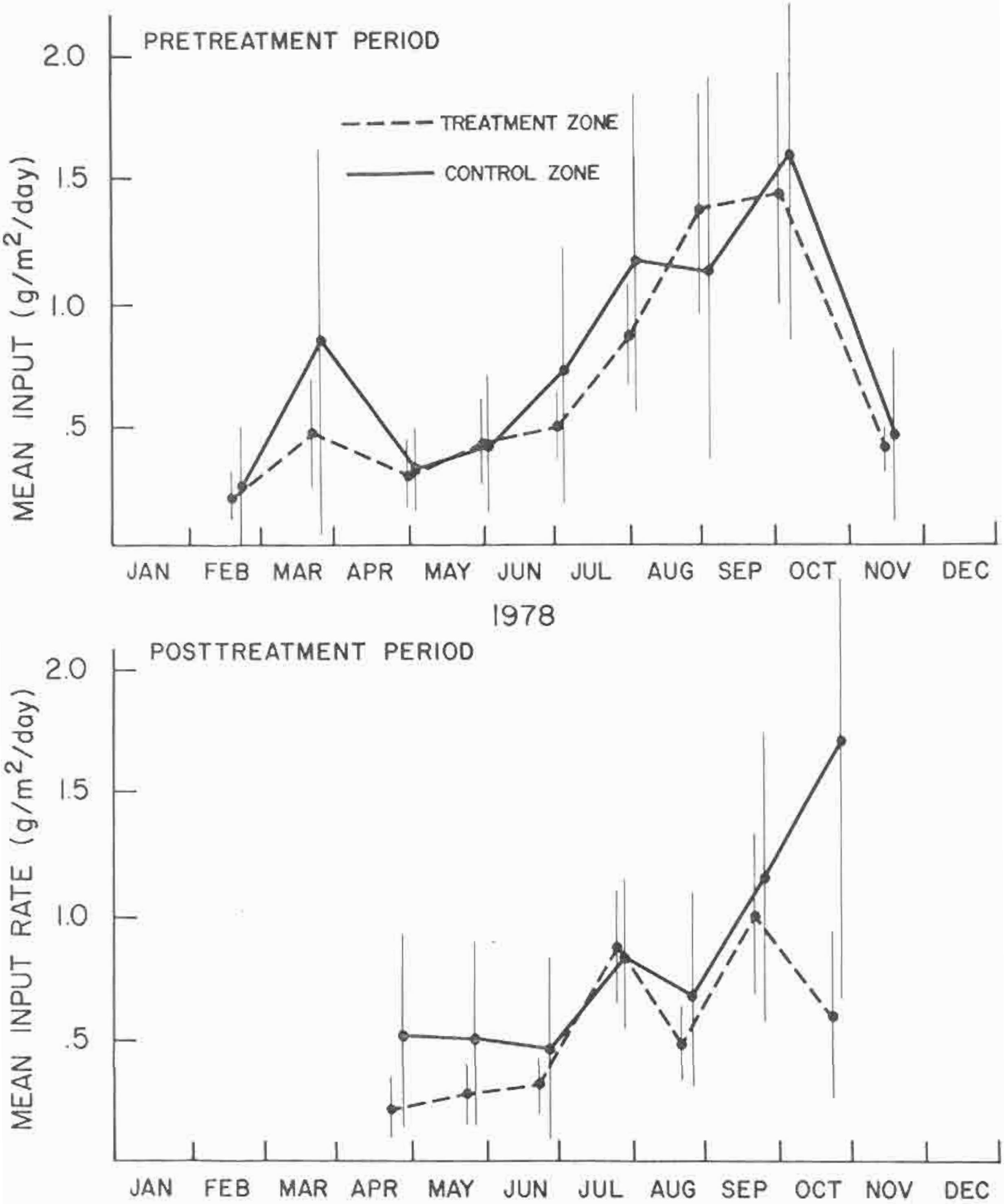

Fig. 11. Particulate detrital input rate ($g/m^2/day$) with 95 percent confidence intervals for the treatment and control zones of Bear Creek, before (1978) and after (1979) streamside timber removal.

pre-treatment period nor was there a significant difference between 1978 and 1979 for the control zone. After treatment, the treatment zone received significantly less ($p < 0.05$) input of detritus than the control zone, but only for the months of April, August and October. Detrital input during late spring and summer was not significantly different indicating that the detrital source, during this period, was streamside understory vegetation that was not disturbed by the treatment.

Insect Fallout

Terrestrial insect fallout data were transformed by logarithms and tested with the analysis of variance (ANOVA) procedure. Analysis within years between zones indicated that fallout numbers were significantly greater ($p = 0.006$) within the control zone during the pre-treatment period but not significantly different ($p = .309$) during the post-treatment period (Fig. 12 and Appendix Table 1). The control zone received 25 percent and 20 percent more fallout than the treatment zone during pre-treatment and post-treatment periods, respectively. A significant interaction between zones and dates during the post-treatment period was present, indicating that the lack of detectable difference between treatment and control zones is dependent upon the time of year. Tests between years indicated that the fallout rate in 1979 was significantly greater ($p < 0.01$) than in 1978 for both treatment and control zones. Total fallout in 1979 increased by 63 percent and 53 percent for the treatment and control zones, respectively. The consistent relationship between treatment and control zones for both years, and the similar increase by both zones in 1979 suggests that total fallout was not affected by the treatment but by annual climatic variations.

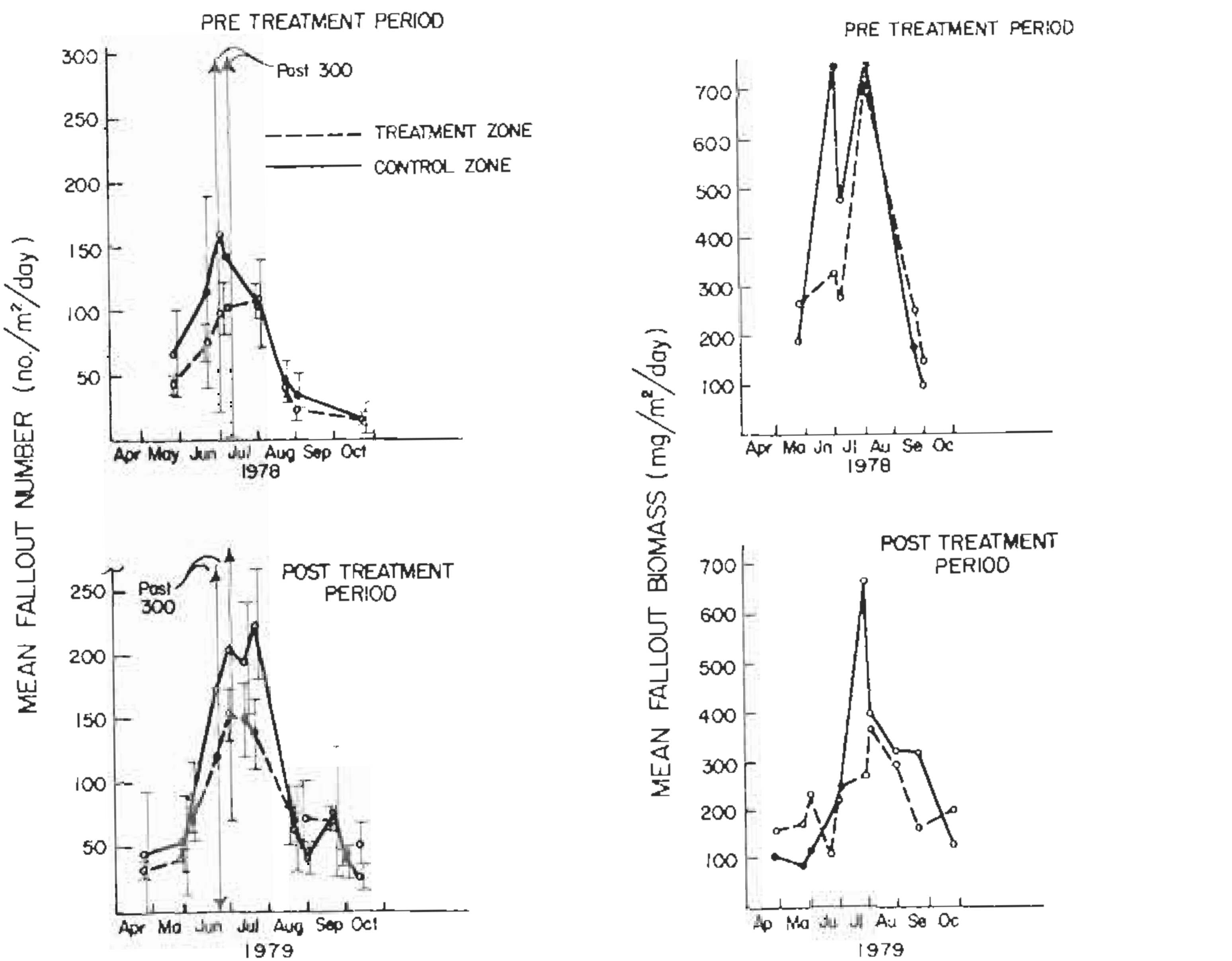

Fig. 12. Terrestrial insect fallout rate mean density (no/m^2/day), with 95 percent confidence intervals, and mean biomass (mg/m^2/day) in the treatment and control zones of Bear Creek, before (1978) and after (1979) streamside timber removal.

Insect fallout biomass could not be tested by the ANOVA because individual trap contents were not weighed. However, a plot of mean biomass (Fig. 12 and Appendix Table 2) indicates that the control zone received a greater fallout biomass than the treatment zone, but the biomass level for both treatment and control zones was greater in 1978 than in 1979. The contrast of greater biomass in 1978 versus greater number in 1979 is due to a difference in relative size composition between years. In 1978, an average of 54 percent of the individuals were less than 3 mm long, whereas in 1979, an average of 70 percent of the individuals were less than 3 mm long. The trend was consistent for both treatment and control zones.

Benthos

Total numbers and biomass of benthos before and after streamside timber removal are shown in Fig. 13 and Appendix Tables 3 and 4. Biomass for individuals greater than 12 mm long is not included because they occurred rarely, and biomass 95 percent confidence intervals are not plotted because of large standard error estimates.

Benthos total numbers, transformed by logarithms, and total biomass were tested between years and stations by the ANOVA procedure. During 1978, total numbers of benthos were significantly greater at station 1175 than at station 850, but there was no difference between station 85 and station 850 or station 85 and station 1175 (Table 2). Following treatment, benthos numbers at stations 1175 and 850 were not significantly different, but they were both significantly greater than station 85. Stations 1175 and 850 had a significantly greater ($p < 0.05$) density in 1979 than in 1978, whereas densities

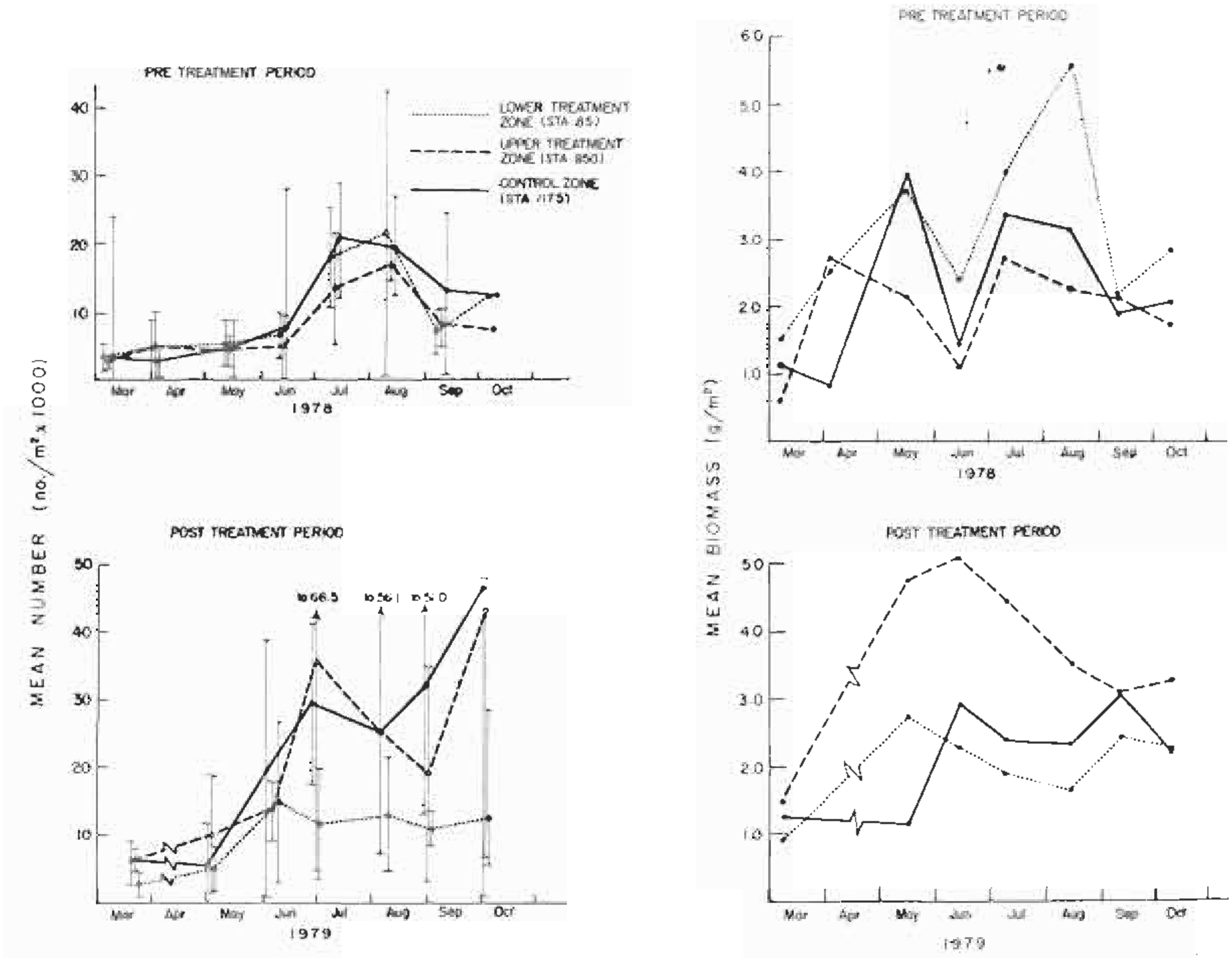

Fig. 13. Benthos mean density (no/m^2), with 95 percent confidence intervals, and mean biomass (g/m^2), for organisms ≤12 mm long, in the treatment (stations 85 and 850) and control (station 1175) zones of Bear Creek, before (1978) and after (1979) streamside timber removal.

Table 2. Results of ANOVA and multiple comparison tests on benthos density and biomass in Bear Creek, before and after streamside timber removal.

Year	Density Station similarity[1]			Significance of F	Biomass Station similarity[1]			Significance of F
1978	1175[2]	85	850	.038	85	1175	850	.052
1979	1175	850	85	.001	850	85	1175	.034

[1]Lines indicate similarity between stations.

[2]Numbers are station location.

at station 85 did not change between years (Fig. 13). In biomass, no significant differences were detected among all stations during 1978, but station 850 was significantly greater than stations 85 and 1175 during 1979 (Table 2). Station 850 had a significantly greater biomass in 1979 than in 1978, although stations 85 and 1175 were not significantly different between years (Fig. 13).

Interpretation of benthos results requires a qualification of the conditions of the benthos habitat at the three sample stations. The stream riffle sampled at station 85 was significantly altered by winter freshets between 1978 and 1979. Riffle morphology changed from a broad uniform reach with shallow depth and low velocity to a more narrow, confined channel with greater depth and higher velocity. Substrate composition shifted toward a dominance of larger cobble size. Station 850 did not change in morphology but had a moderate increase of smaller (pea gravel) substrate deposition in the sample riffle. Station 1175 did not have a detectable change in benthos habitat.

Benthos habitat conditions at station 85 are not comparable between years; consequently the results from station 85 during the post-treatment period reflect changes in both the physical and biological structure of the system. On the other hand, stations 850 and 1175 are assumed to be comparable. Benthos density at stations 850 and 1175 increased significantly from 1978 to 1979, suggesting that conditions (e.g. weather) were more favorable in 1979 for both treatment and control zones. However, station 850, in the treatment zone, not only responded with increased density but a significantly greater biomass during 1979. The results suggest that benthos number and biomass at station 850 increased as a result of both weather and treatment effects.

Cutthroat Trout Population Dynamics

Trends in the density and biomass of cutthroat trout in the treatment zone, measured during mid-summer (Fig. 14) and autumn (Fig. 15) did not change after streamside timber removal (data for all sample dates in Appendix Tables 5 and 6). Differences in density and biomass for age 0 trout between years was a function of sea-run adult escapement in the study area. During the winters of 1976-77 and 1978-79 stream flows were low, therefore passage of migrating cutthroat spawners above the waterfall barrier was limited. Consequently, the densities of age 0 trout in 1977 and 1979 were lower than the densities in 1978 and 1980. Differences in density of age 0 trout between treatment and control zones within years (Figs 14-15) were a function of location of redds (nests) in the study area. Sea-run cutthroat tended to spawn more frequently in the lower half of the treatment zone and resident cutthroat spawned more frequently in the upper treatment zone and in the control zone. Redds often occurred in clumps causing the seeding of fry in each zone to be uneven.

Densities of age I and older trout are remarkably similar between zones and between years for both mid-summer (Fig. 14) and autumn (Fig. 15) periods. Results suggest that streamside timber removal had no effect on density and that density of older trout was not a function of the initial size of the age 0 population.

Trends in population biomass reflect the trends in population density

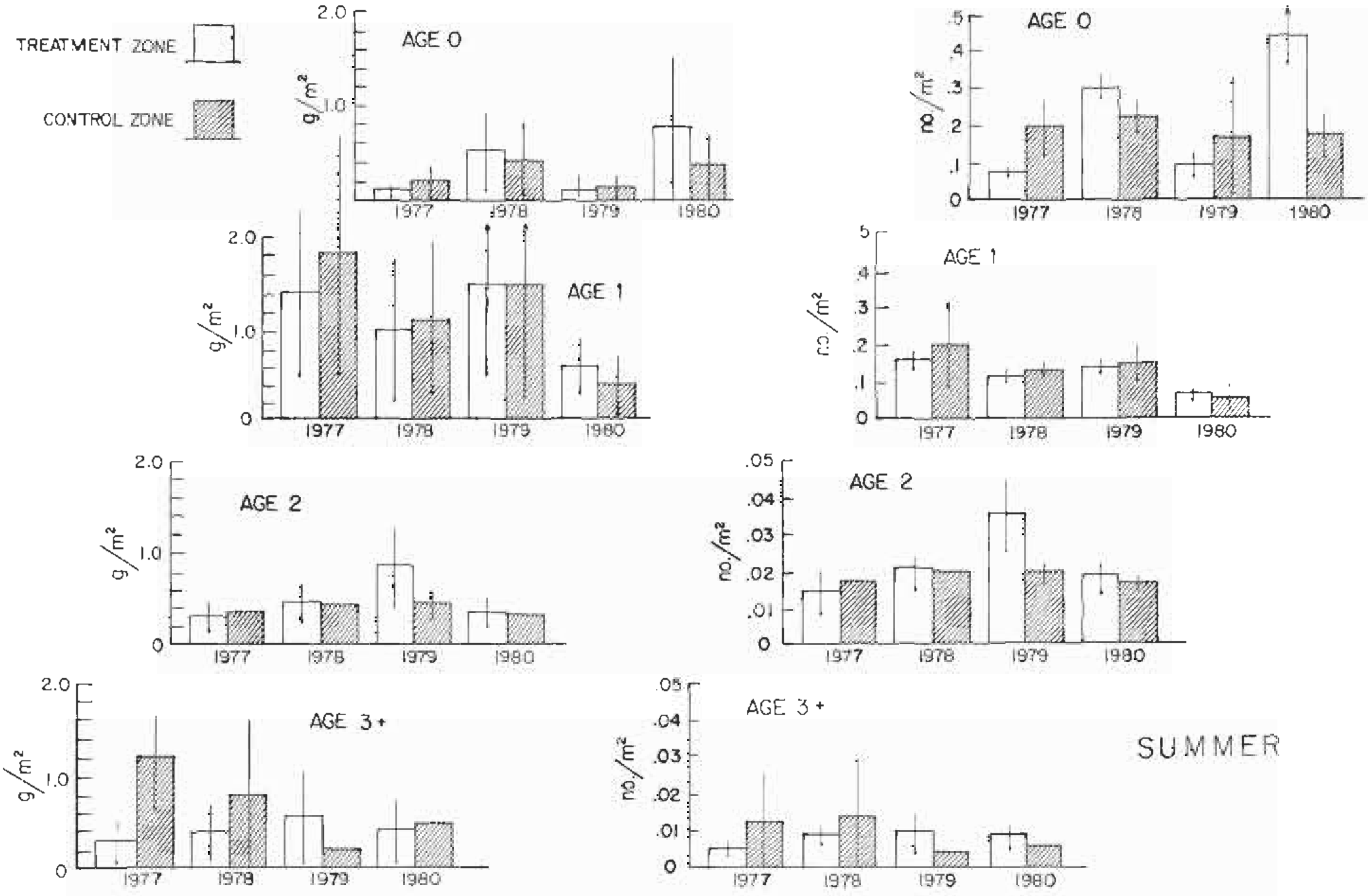

Fig. 14. Cutthroat trout density (no/m^2) and biomass (g/m^2), with 95 percent confidence intervals, during mid-summer in the treatment and control zones of Bear Creek, before (1977-1978) and after (1979-1980) streamside timber removal.

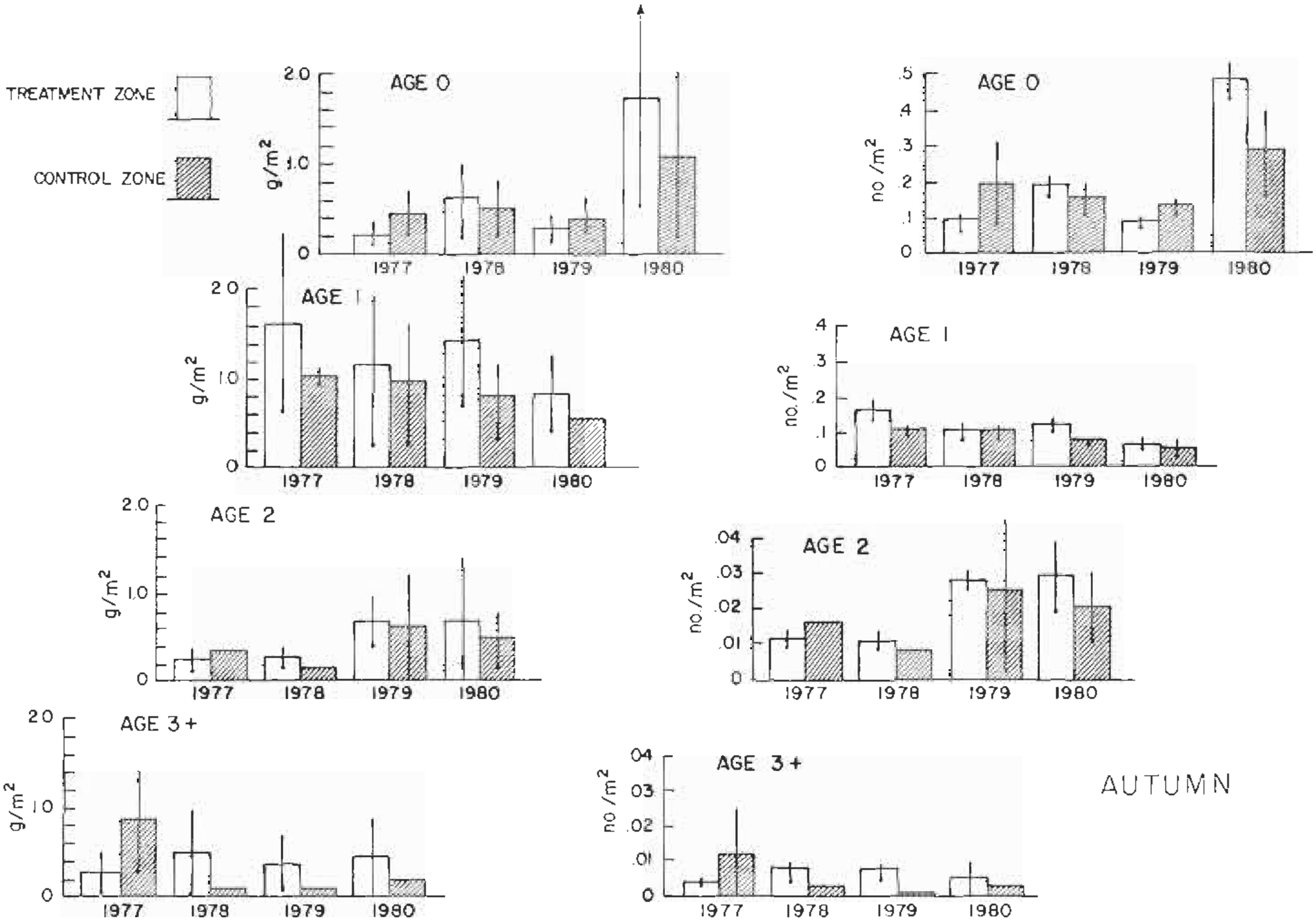

Fig. 15. Cutthroat trout density (no/m^2) and biomass (g/m^2), with 95 percent confidence intervals, during autumn in the treatment and control zones of Bear Creek, before (1977-1978) and after (1979-1980) streamside timber removal.

(Figs. 14-15) although the variability of biomass estimates is greater (data for all sample dates in Appendix Tables 7 and 8). Differences between treatment and control zones are similar between years, indicating no detectable effect occurred as a result of streamside timber removal.

Growth

Cutthroat trout growth rates were tested between control and treatment zones by comparing the slopes of the lines for mean weight (Fig. 16 and Appendix Table 9) during the spring-early summer (April-July) period and the late summer-autumn (July-October) period for each age group. Growth rates were not significantly different ($p > 0.05$) between treatment and control zones at any time before or after streamside timber removal. Growth rates were greatest during the spring-early summer period for all age groups. Trends between years were similar for all age groups except for age II during late summer-autumn 1980, when growth continued at a high rate. No relationship between growth rate and the effects of streamside timber removal was evident.

Movement

Little movement (> 50 meters) was displayed by cutthroat trout before and after streamside timber removal. The greatest movement occurred during the late-spring period when 62 percent and 11 percent of the fish observed moved in 1978 and 1979, respectively (Table 3). The percentage of fish moving either upstream or downstream was similar for each year.

During the post-treatment period, trout movement within the treatment

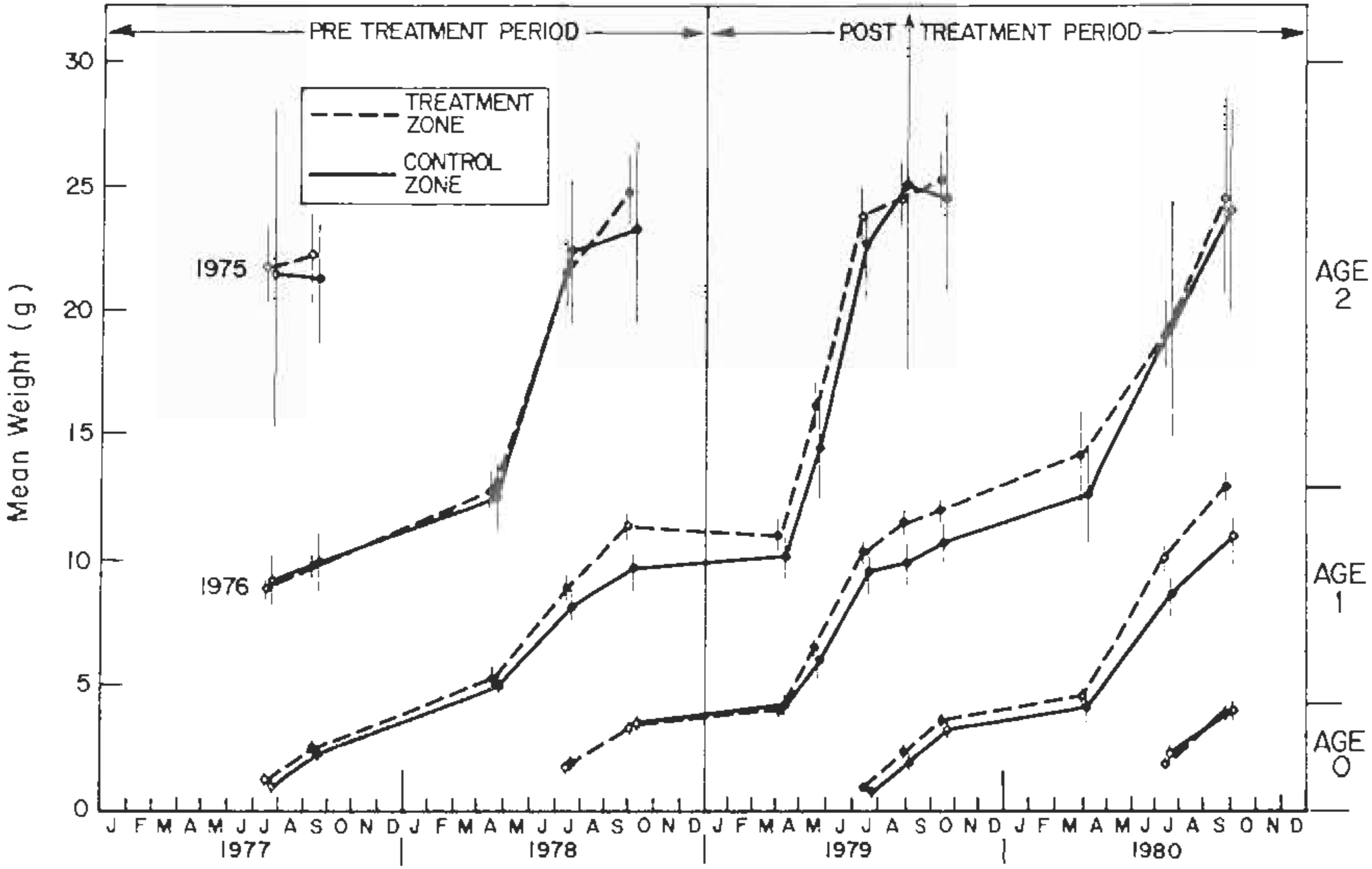

Fig. 16. Cutthroat trout mean weight (g), with 95 percent confidence intervals, by year class and age group, in the treatment and control zones of Bear Creek, before (1977-1978) and after (1979-1980) streamside timber removal.

Table 3. Numbers of trout exhibiting movement and no movement before (1978) and after (1979) streamside timber removal.

Pre-treatment period

Period	No. of fish observed	No. moving upstream (%)	No. moving downstream (%)	No. not moving (%)
Early-spring	3	0	0	3 (100)
Late-spring	13	5 (38)	3 (24)	5 (38)
Early-summer	9	0	1 (11)	8 (89)
Late-summer	1	0	0	1 (100)
Combined	26	5 (19)	4 (15)	17 (76)

Post-treatment period

Period	No. of fish observed	No. moving upstream (%)	No. moving downstream (%)	No. not moving (%)
Early-spring	39	2 (5)	1 (3)	36 (92)
Late-spring	90	6 (6)	4 (5)	80 (89)
Early-summer	91	4 (4)	1 (1)	86 (95)
Late-summer	93	0	0	93 (100)
Combined	313	12 (4)	6 (6)	295 (94)

zone was not significantly different ($p > 0.05$) from movement within the control zone (Table 4). Furthermore, no significant differences ($p > 0.05$) were detected between movements of different age groups (Appendix Table 10).

Table 4. Fish movement in the treatment and control section during the post-treatment period, 1979.

Period	No. of fish observed	No. moving downstream (%)	No. moving upstream (%)	No. not moving (%)
		Treatment zone		
Early-spring	39	2 (5)	1 (3)	36 (92)
Late-spring	74	6 (9)	4 (5)	64 (86)
Early-summer	61	3 (5)	0	58 (95)
Late-summer	89	0	0	89 (100)
Combined	263	11 (4)	5 (2)	247 (94)
		Control zone		
Early-spring[1]	—	—	—	—
Late-spring	16	0	0	16 (100)
Early-summer	30	1 (3)	1 (3)	28 (94)
Late-summer	4	0	0	4 (100)
Combined	50	1 (2)	1 (2)	48 (96)

[1]Fish were not branded at the beginning of this time period.

DISCUSSION

The SMZ tested at Bear Creek maintained the physical and biological structure of the stream ecosystem within limits that were not detrimental to salmonid production. Even though physical and biological changes (i.e. water temperature, shade, algal production, detrital input and benthos biomass) were significant, their magnitude was not great enough to manifest changes in population numbers, growth, and behavior of cutthroat trout.

The reduction in density of canopy causes changes in the quantity and quality of fixed energy inputs entering the stream and influences the density and biomass of the fish food supply. Streamside timber removal, at Bear Creek, reduced canopy density (Fig. 4), causing a corresponding reduction in detrital input (Fig. 11) and an increase in algal production (Fig. 10). The shift in benthic food base coupled with a moderate temperature increase resulted in an increased biomass of benthic invertebrates in the upper treatment zone (Fig. 13). Similar results were reported by Murphy et al. (1981) in Oregon, where open clearcut stream sections exhibited greater standing crops of aufwuchs and benthic invertebrates than did shaded old-growth and second-growth sites. Erman et al. (1977) also found a greater density of aquatic insects in open logged streams than in streams with an undisturbed buffer strip. Furthermore, L. Wasserman (personal communication) found a significant inverse correlation between the density and biomass of scraper (periphyton grazers) organisms and canopy shade. Periphyton, because of its low C/N ratio, provides a higher quality food than allochthonous organic matter for aquatic insects (Anderson and Cummins 1979). Therefore, the results suggest that canopy density regulates aquatic insect production by controlling the quantity and quality of the food base of the stream. On the other hand, benthos density and biomass at station 85 was not affected by canopy removal, but by physical disturbance of channel morphology, suggesting that physical instability can override and mask the biological benefits of an improved food base.

Streamside timber removal did not affect the fish food supply derived from terrestrial insect fallout, indicating that the habitat associated with terrestrial insects was not significantly altered by the treatment. The insect fallout source area is closely associated with understory vegetation, especially overhanging brush (i.e. salmonberry, huckleberry, and small alder). Therefore, we would expect that complete removal of riparian vegetation would cause significant changes in the quantity and quality of habitat for terrestrial insects resulting in a shift in fallout rate. Previous research by Hess (1969) in Northern California indicated that disturbance of riparian vegetation, by road construction parallel to a stream, resulted in a twofold increase in numbers and biomass of insect fallout. But, Hess reported that "a more than proportionate amount of the increase occurred in those adult insects having aquatic immature stages." Hess's results may be reflecting a biological stimulation of the aquatic insect community rather than an effect on terrestrial insect fallout. Other studies concerning insect fallout are unknown. We surmise that clearcutting of riparian vegetation would cause a reduced insect fallout rate for several years because terrestrial insect habitat would be destroyed. But the rapid re-establishment of dense herbacious understory, after several years, would provide habitat and a better quality food base resulting in a greater fallout rate than pre-timber removal conditions.

Does an increased fish food supply affect fish biomass or production?

Research by Murphy et al. (1981), in Oregon, indicated that a significantly greater biomass of trout at clearcut sites (7-10 yrs. old) than at shaded old-growth (450 yrs. old) and second-growth (35 yrs. old) sites was linked to an improved fish food supply. Aho (1976) compared a clearcut (8 yrs. old) and an old-growth section of Mack Creek, Oregon, and found a significantly greater production of cutthroat trout in the unshaded section and attributed it to a greater abundance of prey and water temperature. Our results indicated that the increased benthos biomass (station 850) did not affect fish growth or fish biomass, hence no change in fish production. But several factors may have contributed to the different responses in production between our study and those in Oregon: 1) The increased benthos biomass detected at station 850 may not have occurred in the rest of the treatment zone (e.g. station 85). Therefore, no response would be expected; 2) The cutthroat population in Bear Creek is not food-limited. Although the food supply has increased, the growth rate and density of fish present may be constrained by temperature and habitat conditions; 3) There may be a lag time greater than two years required after canopy removal for the effect to be detectable in fish growth and biomass. Both Oregon studies were conducted on streams from 7 to 10 years after clearcutting. Therefore the growth rate and density of trout were in balance with food supply and habitat conditions. We conclude that the biomass and production of trout can be governed by the fish food supply and that the food base of northwest streams is regulated by the density of riparian vegetation.

Habitat quantity and quality controls the density and age structure of cutthroat trout populations in Bear Creek. We found that cutthroat fry occupy a broad range of habitat types, but the density of fry remaining after an early autumn freshet depended upon the availability of low velocity areas and instream cover habitat (i.e. logs and root wads). On the other hand, older trout ($\geq$ 1 yr old) preferred a narrow range of habitat parameters (i.e. depth, velocity, and substrate size) and the individual weight of trout was significantly correlated with the quality of habitat. Larger trout seek higher quality habitat composed of deep, low-velocity pools with streamside and instream cover. Edie (1975) reported similar results for cutthroat trout in the Clearwater River, where age 0 trout make heavy use of riffle areas and older fish utilize pools. Therefore, the density of older/larger trout depends upon the availability of high-quality habitat.

In Bear Creek the density and age structure of the cutthroat population remained unchanged (Figs. 14 and 15) after treatment because habitat quantity and quality was not altered by the managed streamside timber removal. Understory vegetation and streamside timber provided bank armoring to resist channel erosion and provided essential streamside cover habitat. Logs that were keyed into the channel banks formed pools and riffles providing channel stability and instream cover habitat. On the contrary, clearcut logging without riparian zone protection has caused alterations in fish habitat resulting in a significant reduction in cutthroat trout populations (Wustenberg 1954; Hall and Lantz 1969; Narver 1972; Moring and Lantz 1974). Furthermore, the loss of high quality pools in logged streams has caused a reduction in the relative composition of older age trout in the population (J. R. Sedell, personal communication, and C. J. Cederholm, personal communication). Consequently, the functional importance of riparian vegetation in providing physical stability and the development of habitat, actually determines the density and age structure of salmonid populations in streams.

The results indicate that biological and physical structure of the riparian vegetation zone has a strong influence on the growth, biomass and density of salmonids in streams. Moreover, the functional relationship between riparian vegetation management and fish production can be thought of as a food and habitat regulatory mechanism. Canopy density controls the primary energy inputs to the stream ecosystem thus regulating the fish food supply that can govern salmonid biomass and production. Large organic debris from the riparian zone and the physical integrity of riparian vegetation controls channel morphology and stability, thus regulating habitat quantity and quality that determines salmonid density and age structure.

Changes in fish habitat caused by riparian vegetation removal are more important to the salmonid population than changes in the fish food supply. Regulation of the fish food supply through management of canopy density can only govern the biomass and production of salmonids. The presence or absence of riparian vegetation does not cause changes in the food supply that are detrimental, whereas regulation of fish habitat through the presence of large organic debris and maintenance of streambank stability can limit the density and age composition of salmonid populations in streams. Sediment-free spawning gravel and stable rearing habitat are essential for the existence of a salmonid population.

The careful removal of streamside timber can maintain the biological and physical structure of the stream ecosystem within levels suitable for fish production. But, only if riparian management is directed at maintaining the physical integrity of the stream ecosystem. Detrimental impacts of logging can be avoided and the beneficial impacts of canopy removal enhanced by a well-designed SMZ. The proper application of the SMZ concept is a satisfactory management practice for protecting fisheries resources yet optimizing for timber production.

MANAGEMENT CONSIDERATIONS

In the state of Washington the SMZ practice is implemented through a set of regulations that are dependent upon water types and criteria for temperature-sensitive streams. Streams are ranked into one of five water types by a combination of: stream size, water quality related to domestic use, and the size or value of their fisheries resources. Lakes and streams greater than 20 feet wide are designated type 1 and 2 waters and are given the greatest protection with a 50 ft SMZ. Smaller streams (greater than 10 feet wide and a low flow greater than 0.3 cfs) are designated type 3 waters and are given less protection with a 25 ft SMZ. The smallest streams and intermittent runoff channels are designated as type 4 and 5 waters respectively, and are given little protection and do not require a SMZ (Washington Forest Practice Board 1976). When water temperature is considered to be a potential problem, the regulations require a specific percentage of existing stream shade to be retained by the SMZ. All nonmerchantable vegetation plus sufficient merchantable timber must be retained to provide the shade specified. If temperature is not a problem, then timber densities are not specified and all timber may be cut, as long as reasonable care is taken during felling and yarding procedures to maintain streambank integrity.

The SMZ regulations neglect the functional aspects of riparian vegetation as a regulator of the physical and biological structure of the stream ecosystem. Understory vegetation and streamside timber are necessary, regardless of temperature consideration, to maintain and provide habitat suitable for salmonids and their food supply. When temperature sensitive criteria are not required, the SMZ regulations do not specify a design for stream habitat protection. Thus the operators' interpretation of reasonable care to maintain streambank integrity has resulted in great variability in stream protection. The Washington Department of Ecology (in press) conducted a survey of SMZ's in Western Washington and found SMZ densities ranging from complete clearcuts to undisturbed buffer strips. Fish habitat ratings varied greatly as a result of streamside timber removal and from natural differences inherent to streams. The results indicate that SMZ regulations place too much emphasis on temperature control and not enough protection for fish habitat.

The proper implementation of the SMZ concept requires that the zone must be designed to maintain the physical and biological structure of the stream ecosystem within limits suitable for fish production. All understory vegetation and non-merchantable timber must be protected within the SMZ. In addition, all merchantable timber that is keyed into the streambank and provides instream fish habitat and bank stability must be retained. Long term requirements for large organic debris for instream habitat needs to be evaluated in relation to potential blowdown. Temperature sensitive criteria should be considered, and canopy densities adjusted to meet requirements if not already adequate. Lastly, the maintenance of an undisturbed vegetation zone is more important than a specific SMZ width. Therefore adjustments in SMZ widths should be made to conform with natural breaks in topography.

The development of a SMZ practice to accomplish management goals requires recognition that stream ecosystems are unique and require a site specific management plan. Regulations that are designed to govern forest operators are not specific enough to produce an effective SMZ for any given stream. Instead regulations should be developed as guidelines for professional managers to design SMZ's. Considerations for fish production, timber harvest, geology, topography, vegetation density, and temperature need to be reviewed and evaluated by experienced professionals that are resolved to optimization for both fisheries and forest resources. Finally, ending up with an SMZ according to the design is dependent upon skilled loggers using modern technology and methods to minimize physical impacts in the SMZ.

Phase I and II of the Bear Creek Study is a case history example of a SMZ that was designed in recognition of fisheries and timber resources. The maintenance of understory vegetation and key streamside timber has resulted in no detrimental effect on fisheries resources from streamside timber removal. A productive fisheries resource should remain as long as physical integrity of the SMZ is maintained during the future log yarding and road construction phase.

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APPENDIX

Appendix Table 1. Insect fallout rate (mean No./m^2/day), 95% confidence limits, and sample interval for the treatment and control zones in Bear Creek, before (1978) and after (1979) streamside timber removal.

Period / Sample date	Sample interval (days)	Treatment zone Mean No./m^2/day	Treatment zone ± 95% C.L.	Control zone Mean No./m^2/day	Control zone ± 95% C.L.
Pre-treatment period					
5 - 23 - 78	6	44.5	5.6	67.7	32.7
6 - 20 - 78	7	77.1	15.2	117.5	74.9
6 - 28 - 78	7	99.7	20.2	162.5	139.9
7 - 5 - 78	7	103.1	20.6	143.5	166.7
8 - 1 - 78	7	110.5	13.0	105.6	34.5
8 - 21 - 78	7	42.1	5.2	47.2	13.8
8 - 29 - 78	7	25.2	3.5	36.2	15.6
10 - 23 - 78	16	16.1	3.1	16.5	12.1
Post-treatment period					
4 - 24 - 79	6	33.0	4.9	46.6	47.6
5 - 23 - 79	6	40.4	7.8	53.0	41.5
5 - 31 - 79	8	71.0	10.4	90.8	37.6
6 - 21 - 79	8	121.6	12.9	173.6	189.1
6 - 27 - 79	6	154.4	20.0	205.6	134.0
7 - 26 - 79	8	149.6	27.9	195.6	44.5
7 - 31 - 79	5	140.5	25.2	224.0	43.3
8 - 21 - 79	8	71.5	8.8	62.6	32.1
8 - 27 - 79	6	72.2	29.1	41.4	12.3
9 - 20 - 79	6	70.8	8.9	76.8	51.1
9 - 26 - 79	6	45.3	5.5	40.2	14.1
10 - 12 - 79	8	52.4	15.6	27.0	8.9

Appendix Table 2. Insect fallout biomass (mean $mg/m^2/day$, wet wt.) and sample interval for the treatment and control zones in Bear Creek, before (1978) and after (1979) streamside timber removal.

Period / Sample date	Sample interval (days)	Treatment zone Mean $mg/m^2/day$	Control zone Mean $mg/m^2/day$
Pre-treatment period			
5 - 23 - 78	6	266.1	188.0
6 - 20 - 78[1]	7		
6 - 28 - 78	7	330.8	961.5
7 - 5 - 78	7	279.8	481.1
8 - 1 - 78	7	727.1	999.5
8 - 21 - 78	7	256.8	174.3
8 - 29 - 78	7	145.4	101.0
10 - 23 - 78[1]	16		
Post-treatment period			
4 - 24 - 79	6	159.6	105.7
5 - 23 - 79	6	174.2	84.2
5 - 31 - 79	8	237.4	118.9
6 - 21 - 79	8	112.7	191.9
6 - 27 - 79	6	249.9	223.9
7 - 26 - 79	8	273.0	668.2
7 - 31 - 79	5	366.0	402.7
8 - 21 - 79[1]	8		
8 - 27 - 79	6	295.6	324.7
9 - 20 - 79	6	163.2	320.2
9 - 26 - 79	6	200.3	129.5
10 - 12 - 79[1]	8		

[1] Samples not analyzed for biomass.

Appendix Table 3. Benthic macroinvertebrate mean density (No./m^2) and 95% confidence limits, separated by size groups, for the treatment zone (Sta. 85 and 850) and control zone (Sta. 1175) in Bear Creek, before (1978) and after (1979) streamside timber removal.

Size group (mm)	Pre-treatment period (1978) 3-9	4-3	5-16	6-13	7-11	8-14	9-12	10-11	3-19	4[1]	Post-treatment period (1979) 5-4	6-6	7-2	8-1	9-4	10-3
Station 85 — Lower treatment zone																
0-3	2625	2770	3512	4210	15590	18830	6042	10932	2150		3292	12800	10500	9420	7715	9007
3-6	887	1635	1762	1972	2237	2302	727	1350	302		1272	1750	823	2930	2620	2615
6-9	77	110	200	205	260	262	152	215	52		135	160	100	200	265	395
9-12	15	37	18	23	33	43	29	15	3		8	10	0	20	0	120
> 12	3	15	10	37	30	35	35	30	5		20	0	0	90	60	43
Combine	3607	4567	5502	6447	18150	21472	6985	12542	2512		4727	14720	11423	12660	10660	12180
95% C.L. ±	2165	4386	3546	3485	7130	20830	3231	2516	1821		3380	11722	3203	8545	2567	10561
N	4	4	4	4	4	4	4	4	4		4	4	4	4	4	4
Station 850 — Upper treatment zone																
0-3	2363	3830	2745	3260	11510	15775	7260	6742	5377		7043	9640	31700	21760	17540	41050
3-6	160	1152	1187	1110	1476	1125	740	702	892		2406	3350	3070	2373	1140	1670
6-9	23	70	107	80	260	175	86	57	50		303	450	450	213	60	210
9-12	10	32	15	0	13	20	20	8	3		11	0	60	27	20	20
> 12	0	3	13	3	17	20	40	8	3		17	20	0	13	40	60
Combine	2556	5087	4067	4453	13276	17115	8146	7517	6325		9780	13460	35280	24386	18800	43010
95% C.L. ±	595	5067	2265	5407	8224	2483	5536	3089	1667		8535	4093	31051	31712	16021	36017
N	3	4	4	3	3	4	3	4	4		3	4	4	3	4	4
Station 1175 — Control zone																
0-3	2851	2075	2922	6080	18772	17935	12333	12076	5513		4180	16440	25985	23170	30020	45000
3-6	327	622	1574	1335	1762	1217	520	380	643		1020	3020	2875	1380	1940	1240
6-9	63	25	176	135	195	168	120	36	50		140	320	375	200	260	200
9-12	18	5	9	5	25	47	26	23	4		10	30	22	10	0	80
> 12	16	10	9	10	18	28	53	18	3		7	0	0	30	20	20
Combine	3277	2737	4690	7565	20772	19395	13053	12533	6213		5357	19810	29257	24790	32240	46540
95% C.L. ±	21026	2219	4319	21773	8777	7350	11261	11948	2837		6034	18837	11929	15520	18811	45115
N	2	4	2	2	4	4	3	3	3		4	4	4	4	4	4

[1] Samples not collected during this period.

Appendix Table 4. Benthic macroinvertebrate mean standing crop (grams wet wt./m²) and 95% confidence limits, separated by size groups, for the treatment zone (Sta. 85 and 850) and control zone (Sta. 1175) in Bear Creek, before (1978) and after (1979) streamside timber removal.

Size group (mm)	Pre-treatment period (1978) 3-9	4-3	5-16	6-13	7-11	8-14	9-12	10-11	Post-treatment period (1979) 3-19	4[1]	5-4	6-6	7-2	8-1	9-4	10-3
							Station 85 — Lower treatment zone									
0-3	0.24	0.23	0.27	0.22	0.99	1.90	0.61	0.85	0.18		0.27	0.47	0.45	0.28	0.32	0.17
3-6	0.56	1.32	1.70	1.03	1.59	2.01	0.98	1.17	0.42		1.54	1.14	0.75	0.97	1.54	0.79
6-9	0.61	0.55	1.37	0.93	0.81	1.14	0.43	0.37	0.29		0.87	0.49	0.71	0.40	0.62	0.83
9-12	0.12	0.46	0.38	0.23	0.61	0.60	0.21	0.44	0.04		0.05	0.19		0.01		0.47
> 12	0.18	1.31	1.43	1.49	2.40	4.52	2.07	4.08	0.97		0.82			1.82	3.14	4.29
Combine	1.71	3.87	5.15	3.90	6.40	10.17	4.30	6.91	1.90		3.55	2.29	1.91	3.48	5.62	6.55
95% C.L. ±	1.10	3.96	4.87	2.65	2.04	12.80	2.63	11.34	2.94		3.14	2.53	2.44	3.68	2.54	11.23
N																
							Station 850 — Upper treatment zone									
0-3	0.28	0.29	0.15	0.20	0.65	1.05	0.53	0.74	0.45		0.59	0.38	0.96	1.18	1.08	1.17
3-6	0.19	1.35	1.14	0.66	1.05	0.65	0.70	0.80	0.73		2.68	3.41	1.98	1.81	1.32	1.09
6-9	0.13	0.49	0.67	0.30	0.80	0.36	0.32	0.12	0.29		1.35	1.27	1.10	0.49	0.43	0.66
9-12	0.11	0.57	0.19		0.25	0.21	0.56	0.20	0.03		0.08		0.39	0.03	0.28	0.32
> 12		1.21	2.54	0.43	1.12	1.76	2.58	0.54	0.60		1.74	0.90		0.56	2.85	11.02
Combine	0.71	3.91	4.69	1.59	3.87	4.03	4.69	2.39	2.10		6.44	5.96	4.43	4.07	5.96	14.26
95% C.L. ±	0.59	5.24	3.88	1.03	6.34	2.79	9.25	2.74	1.61		3.72	3.91	3.15	7.35	7.28	25.56
N	3	4	4	3	3	4	3	4	4		3	4	4	3	4	4
							Station 1175 — Control zone									
0-3	0.21	0.18	0.37	0.25	0.76	0.77	0.76	0.85	0.33		0.09	0.51	0.59	0.75	0.70	0.65
3-6	0.14	0.43	2.38	0.79	1.57	0.92	0.51	0.44	0.44		0.65	1.36	1.31	0.94	1.46	0.74
6-9	0.14	0.09	0.97	0.35	0.74	0.52	0.25	0.14	0.49		0.36	0.76	0.49	0.40	0.88	0.22
9-12	0.57	0.09	0.27	0.06	0.31	0.94	0.39	0.62	0.02		0.07	0.28	0.04	0.26		0.64
> 12	2.36	1.17	0.94	0.43	1.79	1.41	5.22	1.02	0.06		0.28			2.86	1.78	1.15
Combine	3.42	1.96	4.93	1.88	5.17	4.56	7.13	3.07	1.34		1.45	2.91	2.43	5.21	4.82	3.40
95% C.L. ±	39.76	4.03	14.02	13.70	3.50	1.77	16.82	3.82	1.49		0.61	2.74	0.73	6.50	6.06	3.00
N	2	4	2	2	4	4	3	3	3		4	4	4	4	4	4

[1] Samples not collected during this period.

Appendix table 5. Cutthroat trout total number and density (no./m^2) with 95 percent confidence limits in the treatment zone of Bear Creek before (1977-1978) and after (1979-1980) streamside timber removal.

Sample date	1974	1975	1976	1977	1978	1979	1980	Total N
				YEAR CLASS				
7-20-77	3+ 14 ± 8 .005 ± .002	2 38 ± 16 .025 ± .006	1 419 ± 51 .161 ± .020	0 219 ± 41 .084 ± .016				696 ± 70 .267 ± .027
9-7-77	3+ 12 ± 4 .005 ± .001	2 31 ± 8 .012 ± .002	1 433 ± 69 .166 ± .025	0 226 ± 47 .087 ± .018				703 ± 54 .270 ± .031
4-26-78		3+ 41 ± 27 .016 ± .010	2 141 ± 55 .054 ± .021	1 147 ± 39 .056 ± .016				336 ± 76 .129 ± .029
7-17-78		3+ 20 ± 6 .008 ± .002	2 54 ± 18 .021 ± .006	1 300 ± 29 .115 ± .012	0 776 ± 67 .298 ± .025			1151 ± 75 .438 ± .029
10-1-78		3+ 22 ± 8 .008 ± .002	2 30 ± 8 .011 ± .002	1 267 ± 39 .103 ± .016	0 490 ± 69 .188 ± .025			805 ± 78 .309 ± .029
4-1-79			3+ 50 ± 10 .019 ± .004	2 190 ± 63 .073 ± .023	1 286 ± 45 .114 ± .018			525 ± 67 .201 ± .025
5-12-79			3+ 34 ± 25 .013 ± .010	2 92 ± 27 .035 ± .010	1 447 ± 76 .172 ± .029			579 ± 86 .222 ± .033
7-18-79			3+ 24 ± 14 .009 ± .006	2 92 ± 25 .035 ± .010	1 381 ± 51 .146 ± .020	0 235 ± 84 .090 ± .031		715 ± 86 .275 ± .033
8-29-79			3+ 11 ± 2 .004 ± .001	2 55 ± 10 .021 ± .004	1 342 ± 47 .131 ± .018	0 222 ± 31 .085 ± .012		626 ± 57 .241 ± .021
10-15-79			3+ 20 ± 6 .008 ± .002	2 72 ± 8 .028 ± .002	1 314 ± 23 .121 ± .010	0 212 ± 18 .081 ± .006		619 ± 31 .238 ± .012
4-7-80				3+ 47 ± 39 .018 ± .016	2 125 ± 33 .048 ± .012	1 166 ± 65 .064 ± .025		336 ± 78 .129 ± .029
7-15-80				3+ 20 ± 6 .008 ± .002	2 48 ± 12 .018 ± .004	1 156 ± 37 .060 ± .014	0 1124 ± 190 .432 ± .072	1292 ± 167 .496 ± .065
9-25-80				3+ 17 ± 14 .006 ± .006	2 75 ± 23 .029 ± .010	1 171 ± 47 .066 ± .018	0 1228 ± 155 .472 ± .059	1494 ± 165 .574 ± .063

Appendix table 6. Cutthroat trout total number and density (no./m²) with 95 percent confidence limits in the control zone of Bear Creek before (1977-1978) and after (1979-1980) streamside timber removal.

Sample date	Year class 1974	1975	1976	1977	1978	1979	1980	Total N
7-20-77[1]	3+ 8 ± 8 .013 ± .013	2 11 (2) .017	1 128 ± 76 .200 ± .119	0 125 ± 46 .197 ± .072				272 ± 89 .427 ± .139
9-7-77[1]	3+ 8 ± 8 .013 ± .013	2 11 (2) .017	1 67 ± 4 .105 ± .006	0 123 ± 72 .193 ± .113				164 ± 21 .255 ± .033
4-24-78		3+ 15 ± 21 .023 ± .033	2 20 ± 18 .031 ± .027	1 71 ± 35 .111 ± .055				117 ± 59 .183 ± .092
7-17-78		3+ 9 ± 12 .014 ± .017	2 12 (2) .019	1 88 ± 10 .138 ± .016	0 140 ± 29 .219 ± .055			240 ± 25 .376 ± .039
10-3-78		3+ 2 (2) .003	2 5 (2) .008	1 66 ± 6 .103 ± .010	0 95 ± 29 .147 ± .055			155 ± 20 .243 ± .031
4-1-79			3+ 6 (2) .009	2 55 ± 23 .086 ± .037	1 83 ± 33 .130 ± .053			144 ± 41 .226 ± .065
5-12-79			3+ 4 (2) .006	2 19 ± 8 .030 ± .012	1 86 ± 21 .135 ± .033			112 ± 25 .175 ± .039
7-18-79			3+ 2 (2) .003	2 12 ± 2 .019 ± .002	1 98 ± 35 .153 ± .054	0 105 ± 96 .164 ± .152		183 ± 55 .287 ± .086
8-29-79			3+ 1 (2) .001	2 8 ± 6 .012 ± .010	1 63 ± 16 .099 ± .023	0 77 ± 16 .121 ± .027		151 ± 25 .237 ± .039
10-15-79			3+ 1 (2) .001	2 16 ± 23 .025 ± .037	1 49 ± 4 .077 ± .006	0 81 ± 14 .127 ± .021		135 ± 14 .211 ± .021
4-7-80				3+ 4 ± 4 .006 ± .006	2 35 ± 21 .055 ± .033	1 48 ± 33 .075 ± .053		96 ± 51 .150 ± .081
7-15-80				3+ 6 (2) .005	2 10 ± 2 .016 ± .002	1 30 ± 21 .047 ± .033	0 106 ± 35 .166 ± .055	145 ± 37 .226 ± .059
9-25-80				3+ 2 (2) .003	2 13 ± 6 .020 ± .010	1 33 ± 18 .052 ± .027	0 175 ± 76 .274 ± .119	217 ± 70 .340 ± .109

[1] Data for section 1100-1200 in the treatment zone is not available, so N was estimated by multiplying the fish density (from section 1000-1100) times the total wetted surface area (638 m²) in the treatment zone.

[2] Confidence limits could not be computed.

Appendix Table 7. Cutthroat trout total biomass (g) and relative biomass (g/m^2) with 95 percent confidence limits in the treatment zone of Bear Creek before (1977-78) and after (1979-80) streamside timber removal.

Sample date	YEAR CLASS 1974	1975	1976	1977	1978	1979	1980	Total (± 95%)
7-20-77	3+ 754 ± 663 0.29 ± 0.25	2 829 ± 465 0.32 ± 0.18	1 3741 ± 2384 1.44 ± 0.92	0 246 ± 228 0.09 ± 0.08				5570 ± 3740 2.14 ± 1.43
9-7-77	3+ 719 ± 590 0.28 ± 0.22	2 688 ± 310 0.26 ± 0.12	1 4247 ± 2605 1.63 ± 1.00	0 554 ± 397 0.21 ± 0.15				6208 ± 3902 2.38 ± 1.50
6-24-78		3+ 1562 ± 1842 0.60 ± 0.71	2 1813 ± 1123 0.70 ± 0.43	1 758 ± 615 0.29 ± 0.24				4176 ± 3563 1.58 ± 1.35
7-17-78		3+ 1040 ± 810 0.40 ± 0.31	2 1166 ± 581 0.45 ± 0.22	1 2664 ± 2002 1.02 ± 0.77	0 1350 ± 1132 0.52 ± 0.43			6220 ± 4527 2.39 ± 1.74
10-1-78		3+ 1275 ± 1219 0.49 ± 0.47	2 744 ± 284 0.28 ± 0.11	1 3017 ± 2048 1.16 ± 0.79	0 1592 ± 986 0.61 ± 0.38			6628 ± 4537 2.55 ± 1.74
6-1-79			3+ 2330 ± 5572 0.89 ± 2.14	2 2090 ± 1421 0.80 ± 0.55	1 1154 ± 802 0.44 ± 0.31			5574 ± 7795 2.14 ± 2.99
5-12-79			3+ 1506 ± 2016 0.58 ± 0.77	2 1481 ± 838 0.57 ± 0.32	1 2816 ± 1982 1.08 ± 0.76			5803 ± 4836 2.23 ± 1.85
7-16-79			3+ 1480 ± 1417 0.57 ± 0.54	2 2195 ± 1109 0.84 ± 0.43	1 3886 ± 2508 1.49 ± 0.96	0 199 ± 197 0.08 ± 0.07		7760 ± 5231 2.98 ± 2.01
8-29-79			3+ 643 ± 483 0.25 ± 0.18	2 1353 ± 569 0.52 ± 0.22	1 3905 ± 2511 1.50 ± 0.96	0 512 ± 352 0.20 ± 0.13		6413 ± 3915 2.46 ± 1.50
10-15-79			3+ 1028 ± 802 0.39 ± 0.31	2 1825 ± 667 0.70 ± 0.26	1 3736 ± 1966 1.44 ± 0.75	0 738 ± 428 0.28 ± 0.16		7327 ± 3863 2.81 ± 1.48
6-7-80				3+ 2575 ± 5657 0.99 ± 2.17	2 1762 ± 2112 0.68 ± 0.81	1 745 ± 534 0.29 ± 0.20		5082 ± 8303 1.95 ± 3.19
7-15-80				3+ 1043 ± 927 0.40 ± 0.36	2 914 ± 427 0.35 ± 0.16	1 1560 ± 778 0.60 ± 0.30	0 1933 ± 1935 0.74 ± 0.74	5450 ± 4067 2.09 ± 1.56
9-25-80				3+ 1135 ± 1227 0.44 ± 0.47	2 1843 ± 2217 0.71 ± 0.85	1 2206 ± 1110 0.85 ± 0.43	0 4519 ± 3279 1.73 ± 1.26	9703 ± 7833 3.72 ± 3.01

Appendix Table 8. Cutthroat trout total biomass (g) and relative biomass (g/m^2) with 95 percent confidence limits in the control zone of Bear Creek before (1977-78) and after (1979-80) streamside timber removal.

Sample date	YEAR CLASS 1974	1975	1976	1977	1978	1979	1980	Total (7 81)
7-20-77	3+ 771 ± 420 1.21 ± 0.66	2 238 (1) 0.37	1 1169 ± 841 1.83 ± 1.32	0 121 ± 121 0.19 ± 0.19				2299 ± 1392 3.60 ± 2.16
9-7-77	3+ 556 ± 356 0.87 ± 0.56	2 236 (1) 0.37	1 665 ± 54 1.04 ± 0.08	0 285 ± 160 0.45 ± 0.25				1742 ± 573 2.73 ± 0.87
4-24-78		3+ 571 ± 1014 0.89 ± 1.59	2 250 ± 236 0.39 ± 0.37	1 347 ± 287 0.54 ± 0.45				1168 ± 1535 1.83 ± 2.40
7-17-78		3+ 522 ± 952 0.82 ± 1.49	2 270 (1) 0.42	1 712 ± 531 1.12 ± 0.83	0 266 ± 244 0.42 ± 0.38			1770 ± 1727 2.77 ± 2.70
10-3-78		3+ 64 (1) 0.10	2 116 (1) 0.18	1 633 ± 405 0.99 ± 0.63	0 319 ± 205 0.50 ± 0.32			1132 ± 610 1.77 ± 0.76
4-1-79			3+ 260 (1) 0.41	2 561 ± 410 0.88 ± 0.64	1 340 ± 243 0.53 ± 0.38			1161 ± 651 1.82 ± 1.02
5-17-79			3+ 158 (1) 0.25	2 275 ± 176 0.43 ± 0.27	1 519 ± 394 0.81 ± 0.62			952 ± 570 1.49 ± 0.89
7-16-79			3+ 138 (1) 0.22	2 273 ± 87 0.43 ± 0.14	1 931 ± 752 1.46 ± 1.17	0 82 ± 88 0.12 ± 0.13		1424 ± 927 2.23 ± 1.45
8-29-79			3+ 45 (1) 0.07	2 201 ± 174 0.31 ± 0.27	1 617 ± 414 0.97 ± 0.65	0 142 ± 65 0.22 ± 0.10		1005 ± 653 1.57 ± 1.02
10-15-79			3+ 67 (1) 0.10	2 390 ± 583 0.61 ± 0.91	1 519 ± 299 0.81 ± 0.47	0 251 ± 127 0.39 ± 0.20		1222 ± 1039 1.91 ± 1.58
5-7-80				3+ 161 ± [illegible] 0.25 ± 0.36	2 444 ± 379 0.70 ± 0.59	1 193 ± 185 0.30 ± 0.29		798 ± 794 1.25 ± 1.24
7-15-80				3+ [illegible] (1) 0.47	2 198 ± 119 0.31 ± 0.18	1 248 ± 202 0.39 ± 0.32	0 230 ± 196 0.36 ± 0.31	976 ± 517 1.52 ± 0.81
9-25-80				3+ 126 (1) 0.19	2 313 ± 195 0.49 ± 0.31	1 355 ± 238 0.56 ± 0.37	0 682 ± 598 1.07 ± 0.93	1476 ± 1033 2.31 ± 1.61

[1] Confidence limits could not be computed.

Appendix Table 9. Cutthroat trout mean weight and 95 percent confidence limits for the treatment and control zones of Bear Creek before (1977-1978) and after (1979-1980) streamside timber removal.

Sample date	Treatment Zone YEAR CLASS 1974	1975	1976	1977	1978	1979	1980	Control Zone YEAR CLASS 1974	1975	1976	1977	1978	1979	1980
	3+	2	1	0				3+	2	1	0			
7-20-77	51.88	21.82	8.93	1.12				96.40	21.65	9.14	0.97			
±	14.34	1.72	0.37	0.09				(1)	6.51	1.16	0.16			
	3+	2	1	0				3+	2	1	0			
9-7-77	59.98	22.20	9.81	2.45				69.65	21.27	9.95	2.32			
±	17.70	1.83	0.36	0.14				(1)	2.42	1.19	0.22			
		3+	2	1					3+	2	1			
4-26-78		38.18	12.85	5.12					38.08	12.53	4.91			
±		8.58	0.75	0.43					21.76	1.46	0.55			
		3+	2	1	0				3+	2	1	0		
7-17-78		52.05	21.60	8.89	1.75				58.04	22.49	8.11	1.92		
±		10.40	1.40	0.44	0.07				(1)	2.86	0.69	0.18		
		3+	2	1	0				3+	2	1	0		
10-3-78		57.99	24.80	11.30	3.25				32.27	23.28	9.61	3.47		
±		14.00	1.46	0.55	0.11				(1)	3.71	0.80	0.25		
			3+	2	1					3+	2	1		
4-1-79			46.68	11.06	3.91					43.40	10.17	4.12		
±			18.13	0.68	0.19					(1)	1.09	0.37		
			3+	2	1					3+	2	1		
5-12-79			44.32	16.16	6.32					39.65	14.48	5.92		
±			11.73	1.03	0.22					38.48	2.09	0.36		
			3+	2	1	0				3+	2	1	0	
7-18-79			61.77	23.86	10.24	0.85				69.25	22.86	9.54	0.78	
±			13.39	1.32	0.40	0.08				(1)	2.30	0.93	0.08	
			3+	2	1	0				3+	2	1	0	
8-29-79			58.55	24.60	11.43	2.52				44.71	25.15	9.84	1.85	
±			16.73	1.42	0.48	0.12				(1)	7.35	0.90	0.10	
			3+	2	1	0				3+	2	1	0	
10-15-79			51.43	25.35	11.92	3.51				67.00	24.40	10.63	3.10	
±			10.07	1.15	0.39	0.16				(1)	3.57	0.92	0.19	
				3+	2	1					3+	2	1	
4-7-80				54.79	14.09	4.49					40.53	12.72	4.02	
±				25.86	1.87	0.31					(1)	1.85	0.59	
				3+	2	1	0				3+	2	1	0
7-15-80				57.15	19.06	10.06	1.72				50.08	19.76	8.29	2.17
±				12.38	1.29	0.45	0.07				(1)	4.84	0.88	0.27
				3+	2	1	0				3+	2	1	0
9-25-80				66.83	24.58	12.92	3.68				61.10	24.06	10.77	3.90
±				18.86	4.14	0.55	0.30				(1)	4.08	1.05	0.34

1 N is too small to compute confidence limits.

Appendix Table 10. Contribution by age groups to movement of cutthroat trout in Bear Creek during the post-treatment period (1979).

Age	Period	No. of fish observed	No. moving upstream	No. moving downstream	No. not moving
I	Early spring	31	2	0	29
	Late spring	68	5	4	59
	Early summer	80	2	0	78
	Late summer	71	0	0	71
	Combined (%)	250	9 (4)	4 (2)	237 (94)
II	Early spring	5	0	0	5
	Late spring	19	1	0	18
	Early summer	8	0	1	7
	Late summer	0	0	0	19
	Combined (%)	51	1 (2)	1 (2)	49 (96)
III+	Early spring	3	0	1	2
	Late spring	3	0	0	3
	Early summer	3	2	0	1
	Late summer	3	0	0	3
	Combined (%)	12	2 (16)	1 (8)	9 (76)