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THE EFFECTS OF LOGGING ON CUTTHROAT TROUT (*SALMO CLARKI*) IN SMALL HEADWATER STREAMS[1]

by

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Submitted by

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FINAL REPORT

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Approved

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Abstract

THE EFFECTS OF LOGGING ON CUTTHROAT TROUT (SALMO CLARKI) IN SMALL HEADWATER STREAMS

By Jeffrey Gard Osborn

Chairperson of the Supervisory Committee: Professor Ernest L. Brannon
College of Fisheries

Five streams were monitored in a study of effects of logging: one unlogged control and four logged experimental in various stages of recovery. Baseline data were collected in two streams in a study conducted five years prior to this study (Lestelle 1978).

Population size, biomass, and density of trout and cottids in all streams remained unchanged over the course of the study. However, the amount of habitat, in the form of forest debris, in the most recently logged stream decreased drastically, from 19.59 m^3 to 9.82 m^3. The control stream remained virtually unchanged, decreasing from 28.1 m^3 to 26.55 m^3. The reduction of habitat occurred primarily in the bank area. Debris from this area resupplies the instream debris after washout and biodegradation. Continual loss of instream debris without resupply may cause stream instability and degradation, and loss of fish populations.

The three other logged study streams continued to support good populations of trout and cottids in the postlogging recovery period because large boulders and cobbles were the primary source of habitat rather than forest debris, and streambed disruption was considerably less during yarding operations.

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Jeffrey G. Osborn

INTRODUCTION

Numerous small streams and rivers drain the forested mountain regions of the Pacific Northwest. Many of the streams are utilized by resident and anadromous salmonids. The prosperity of the salmonids inhabiting these streams is closely related to the amount of desirable habitat available to them.

Much of the stream habitat required by the salmonids is associated with forest debris, such as boles, limbs, branches, and root wads. This material is required for cover and shelter (Giger 1973), overwinter protection (Bustard 1973; Chapman and Bjornn 1969; Bjornn 1971) and primarily, a stable stream environment (Swanson and Lienkaemper 1976a; Sedell and Triska 1976; Froehlich 1973; Hall and Baker 1975). A stable stream environment is critical to resident trout as they have a home territory, such as a small pool, in which they may spend their entire lives (Miller 1957). Any alteration in the amount or type of forest debris reaching the streams could have deleterious effects on the fish population and stream morphometry. On the Olympic Peninsula coast, the most common cause of debris alteration is the felling and yarding of trees associated with logging operations.

Logging contributes considerably to the amount of forest debris contained in small headwater streams (Froehlich 1973). Increased volume of debris can be caused directly by logging and road construction operations, or by mass movement of material after such operations are

completed. For convenience of discussion, I have divided forest debris into two general categories: large and small debris.

Large debris consists of boles and large branches, and small debris of twigs, small branches, needles, leaves, and other fine material (Hall and Baker 1975). Some large, coarse debris can have a relatively long residence time (greater than 200 years) in or near the stream channel. The decaying and weathering processes are sometimes interrupted by extreme floods and sluice-outs. Finer material moves more readily through the system and either decays rapidly or is flushed out during high flows (Froehlich 1973).

The study of large debris has been limited in the past, but there is some direct evidence that debris has both positive and negative biological and physical roles in the stream system. Positive effects of large debris occur when it creates rearing and resting habitat for fish; and in its acting as a sediment trap, which creates habitat for invertebrates and enables microorganisms to process fine particulate matter and detritus (Hall and Baker 1975; Swanson and Lienkaemper 1976a; Martin 1976). Large debris can act to benefit stream morphometry by: 1) reducing stream velocity, which reduces the stream's erosive force (Meehan et al. 1969; Heede 1975); 2) protecting against freshet damage (Larkin and graduate students 1969); 3) trapping spawning gravel, and 4) creating pools and habitat for fish and other aquatic organisms (Anderson 1975).

Large debris in excessive amounts, however, creates the potential of deleterious effects with regard to channel morphology and streambed stabilization. A change in size, quantity, or position of large debris could produce extensive and prolonged erosion of the stream bank, bed, and channel (Hall and Baker 1975). Large accumulations of debris can divert flows which cut new channels or undercut banks, causing accelerated hillside failure and increased sediment input (Swanson and Lienkaemper 1976a). Bank cutting, gravel shifting, and related sedimentation attributed to excessive large debris jams can cause entrapment and scouring of eggs and fry, as well as hindering the oxygen exchange between surface and intragravel water (Bishop and Shapley 1963; McNeil 1966; Tagart 1976; Hall and Baker 1975; Hall and Lantz 1969).

The removal of large organic debris from streams could have serious adverse, long-term effects on small streams by inducing channel degradation and channelization. After excessive debris removal, streams which previously flowed in a series of steps assume a more uniform, steep profile and experience other changes in channel morphology. These factors decrease the diversity of the stream habitat by eliminating pools, which are primary areas of productivity. Fine organic matter is transported more rapidly through the system because of increased water velocity, and the opportunity for use by aquatic organisms is decreased. The removal of large debris reduces the long-term biological productivity and increases the rate of sediment transfer from headwater areas to downstream areas (Swanson et al. 1976b).

Small debris also has the potential for both beneficial and adverse effects. Small debris is an important food source for many aquatic invertebrates (Cummins 1974) which are very important in the food chain of trout, especially in small headwater streams.

Adverse effects of small debris are evidenced in changes of the stream channels. The stream may push small debris, such as branches, into piles resembling beaver dams. These piles may deflect the water out of the existing channel into a bank, causing heavy erosion. Piles which stack up in midstream sometimes form sediment traps, therefore preventing the stream from flushing itself (Anderson 1975).

Removal of streamside vegetation can significantly increase temperatures in small headwater streams (Brown and Krygier 1967; Chapman 1962; Narver 1972; Hall and Lantz 1969). Both summer maxima and diurnal fluctuations can be greatly increased. In a clearcut study stream on the Alsea watershed in Oregon the summer maximum temperature recorded immediately after clear-cutting operations was 24°C, 8° higher than the previous maximum. The maximum diurnal fluctuation was 8°C, while previous values ranged from 0.5° to 1.5°. The following summer the maximum temperature was recorded at 30°C with a maximum diurnal fluctuation of 16°C (Hall and Lantz 1969). These maximum temperatures are probably above the lethal temperature for trout juveniles and adults, and are well above lethal temperatures for eggs and alevins (Dr. Ernest Brannon, personal communication). A more subtle effect of increased temperature is increased parasitism and disease (Chapman 1962; Narver 1972; Davis 1953).

Removal of stream-side vegetation can also lower winter minima (Green 1950) which is harmful to incubating embryos (Chapman 1962). Decreased temperatures create a longer incubation time which subjects the eggs to greater probability of scour due to flooding. Chapman (1962) found that increased incubation time decreased growth for the first year, which increased losses due to predation.

In some instances, increased temperature in spring and summer may be beneficial (Chapman 1962; Narver 1972). Increased temperature may increase primary productivity, which would create more available energy along the aquatic food chain. An increase in fish metabolism, due to warmer water, coupled with a more abundant food source could result in more rapid fish growth. Increased growth can remove fish from the predator-vulnerable range sooner (Chapman 1962) and increase size at ocean entrance for anadromous fish (Shapovalov and Taft 1954), thus reducing mortality in both instances. However, the likelihood of increased secondary infections in juvenile fish, lethal temperature, and other adverse effects are very real (Narver 1972).

Water-soluble extractions from western red cedar, heartwood, bark, and foliage have been found toxic to fish to certain degrees (Peters et al. 1976; Hall and Baker 1975). Heartwood, lignins, and bark extractions were found to be moderately toxic, but foliage terpenes and heartwood tropolones were much more toxic. Tropolones were more toxic to coho salmon than to invertebrates, and more toxic to fry than to eyed eggs. The effect of tropolones on coho fry was moderated by a previous sublethal exposure or the presence of a chelatable cation. Substances

toxic to fish have been documented from Sitka spruce and western hemlock (Buchanan and Tate 1975).

The primary reason that large debris, and to some extent small debris, is so important is that cutthroat trout utilize log jams, upturned roots, and small accumulations of debris as winter habitat (Bustard 1973). Bustard indicated that at low temperatures cutthroat juveniles preferred overhanging banks with root wads and branches as opposed to barren areas, and clean rubble as opposed to silted rubble. Similarly, steelhead fry preferred rubble substrate as over-winter habitat. They burrowed under the rubble and remained in the interstices between rocks. Larger steelhead juveniles, however, preferred root wads and logs as over-winter habitat (Bustard 1973). Chapman and Bjornn (1969) and Bjornn (1971) have shown that steelhead trout migrate out of small tributaries into larger streams when winter habitat in small streams is poor. Removal of too much large debris, causing debris torrents or sluice-outs, may drastically reduce the amount of over-winter habitat in small headwater streams.

This study was initiated to investigate the effects of clearcut logging on resident and anadromous cutthroat trout (Salmo clarki). The objectives were to determine any changes in cutthroat population, biomass and densities, and to compare survival and growth of the trout. Stream morphometrics were monitored throughout the study.

Two streams which had been previously investigated, were chosen for intensive study. Lestelle (1978) conducted a debris removal study

in 1972 and 1973 on one of the streams, and used the other one for a control. During Lestelle's study, almost all old growth boles were cut up and removed from the experimental stream to determine the reliance of cutthroat trout on this material. Standing timber adjacent to the stream was not disturbed. The control stream was left in its natural state. Lestelle concluded that after one year the trout biomass and densities had returned to pre-treatment levels. In 1978 Lestelle's unlogged control stream was logged, and our study was initiated. Thus, the roles of Lestelle's streams were reversed; his control stream became our logged experimental stream and Lestelle's recovered experimental stream became our control. The sampling procedures used by Lestelle were followed in this study. Both streams contained only resident nonanadromous cutthroat trout and two species of cottids.

Three other streams were chosen for an extensive study which would be comparable to the streams used for intensive study. These three extensive streams contained populations of resident and sea-run cutthroat trout. The watersheds for these streams had been logged and were in various stages of recovery. The purpose of the extensive part of the study was to determine the long-term effects of logging assuming that these streams would exhibit results, after various periods of post-logging, similar to those which would be observed by continually monitoring a single stream after logging (Hall et al. 1978).

DESCRIPTION OF STUDY AREAS

Intensive Study Areas

The intensive study area is located in the remote headwater area of the Clearwater River in Jefferson County, Washington (Fig. 1). Two small feeder streams of 'C' Tributary were used as experimental streams. "C" Tributary is a main branch of Stequaleho Creek, which enters the Clearwater River 38.6 km upstream from its mouth.

The area is characterized by deep, V-shaped drainages with very steep hillside slopes. The hillsides consist mainly of sandstones and siltstones with a thin soil covering. This highly erosive combination of rock and soil contributes to accumulations of debris in the basin bottoms.

The old growth areas adjacent to the experimental streams are comprised mainly of Sitka spruce, Picea sitchensis; western hemlock, Tsuga heterophylla; Douglas fir, Pseudotsuga menziesii; and western red cedar, Thuja plicata.

Weather conditions are normally wet, with the area averaging 350-460 cm of rainfall per year. The majority of the precipitation occurs during the extremely wet winters, as the summers are usually fairly dry. Frequent storms have the capacity of producing large quantities of rainfall over a short period of time; over 13 cm in 24 hr for example. Examples of large storms are 77.5 cm in 12 days, with 24.6 cm in one

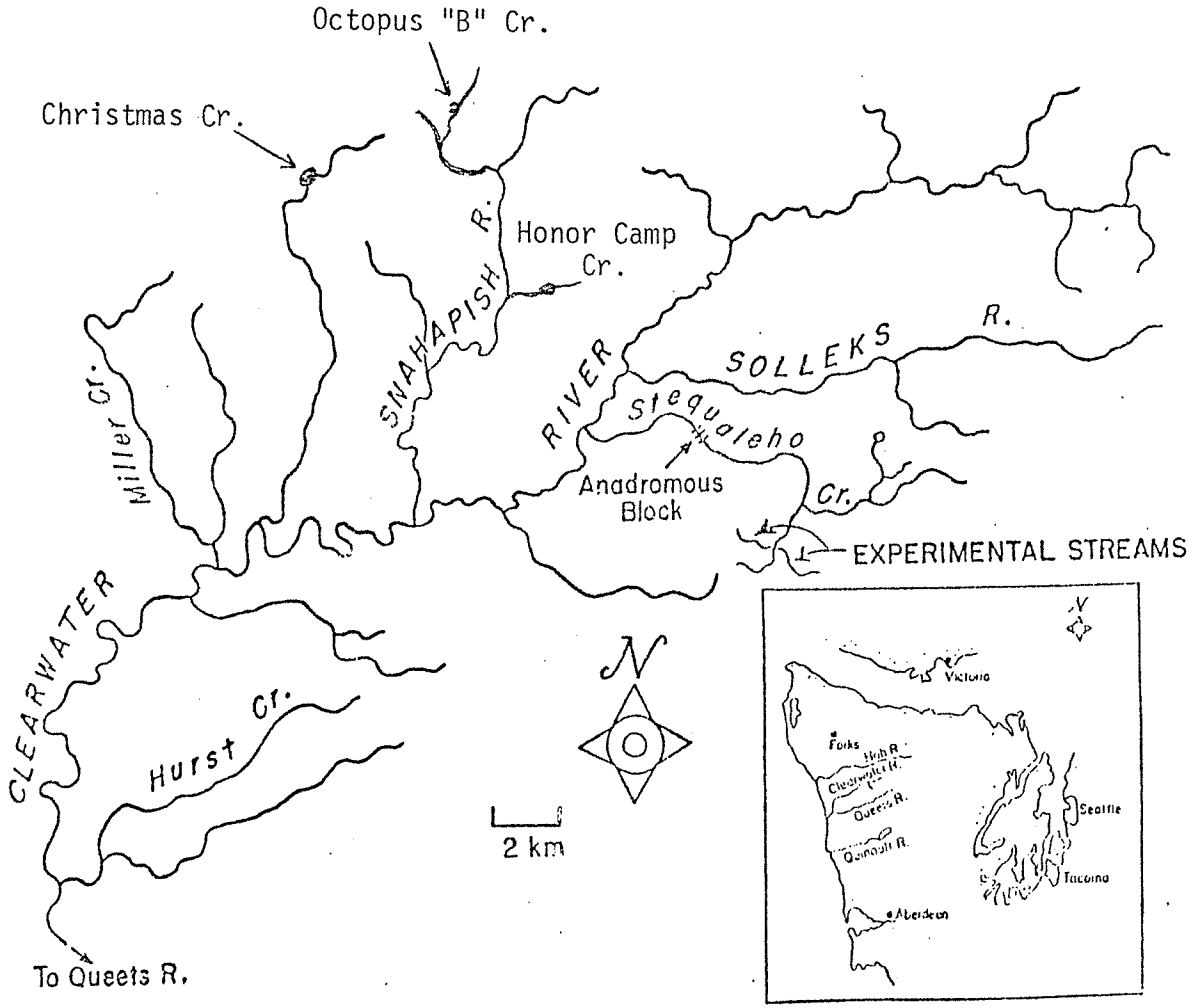

Fig. 1. The Clearwater River and the location of effects of logging on cutthroat trout study.

24-hr period, which occurred in December 1972, and 79.5 cm in 8 days in December 1979.

The two experimental streams were called East Fork (Plate 1) and West Fork (Plate 2) of "C" Tributary (Fig. 2). East Fork was used as the experimental stream and West Fork as the control stream. The watershed areas were:

East Fork	81 ha
West Fork	108 ha
"C" Tributary	469 ha

The average gradient of each study section in East and West Fork was 6.2 percent and 5.1 percent, respectively.

Discharges were taken for East and West Forks in July 1978 and 1979, and were approximately 7 liters/sec. These values would be close to summer low flow. Discharges were not taken during winter storms, but an estimate of the low flow:high flow ratio is 1:400-500.

East Fork and West Fork are inhabitated by natural resident (non-anadromous) populations of cutthroat trout, Salmo clarki, and three species of cottids: the torrent sculpin, Cottus rhotheus; the prickly sculpin, Cottus asper; and the mottled sculpin, Cottus bairdi. A large falls permits penetration by anadromous fishes to only the lower 3.4 km of Stequaleho Creek.

Plate 1. East Fork Stequaleho Creek (experimental stream).

Plate 2. West Fork Stequaleho Creek (experimental stream).

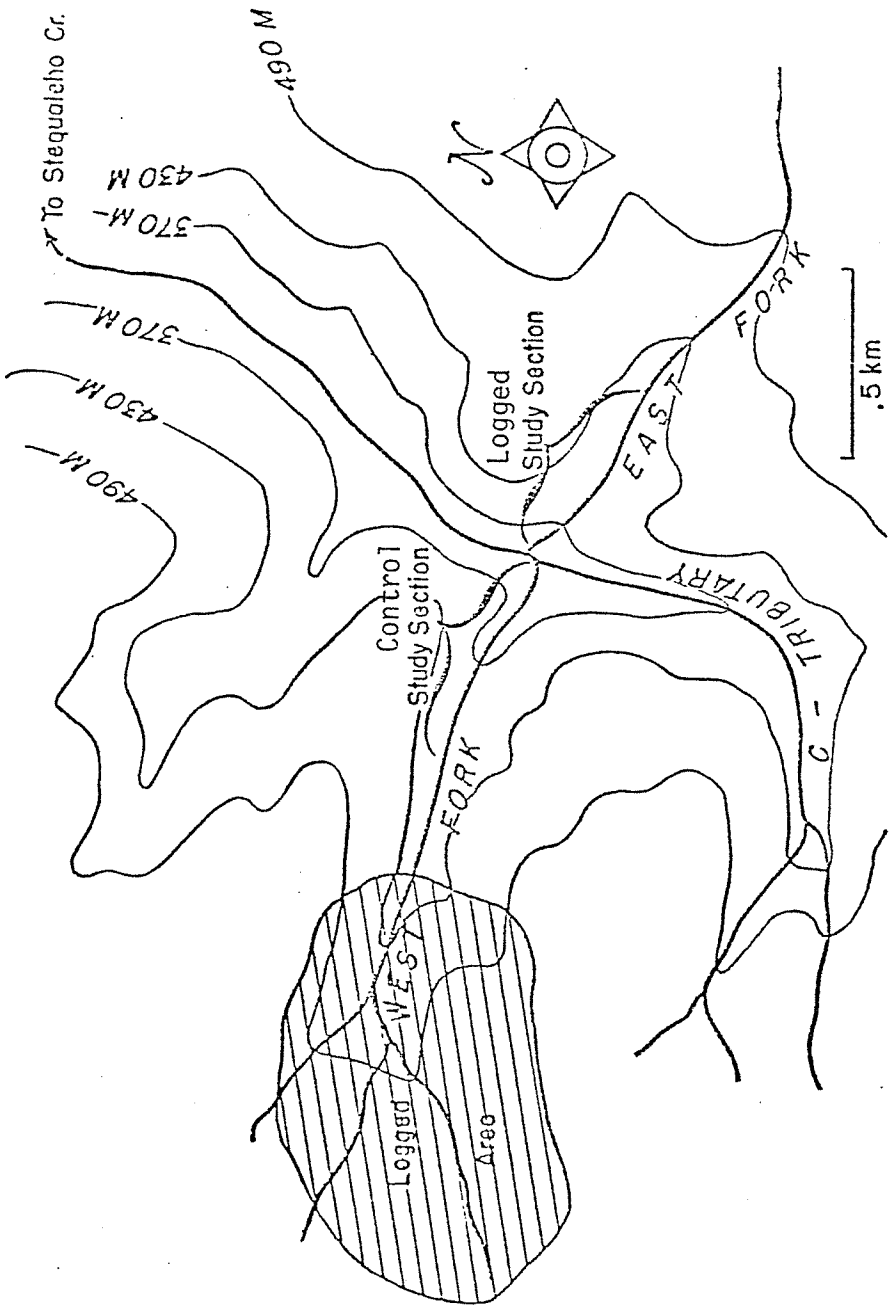

Fig. 2. Locations of the study sections within West Fork and East Fork of "C" Tributary, Stequaleho Creek.

The upper 48.6 ha of the control stream had been logged prior to this study (Fig. 2), but the study section was sufficiently downstream to not be significantly affected by siltation, bedload movement, or forest debris accumulations.

East Fork was logged from its mouth to 323 m upstream in May and June 1978. It was mistakenly classified as type 5 water,[1] which offers no protection for the stream. Logs were yarded across the stream bed. Stream clean-out was performed after completion of the yarding operations.

Extensive Study Areas

The extensive study areas were also located in the Clearwater River drainage. Three streams were chosen with similar physical characteristics to East and West Forks, which were in various stages of recovery from logging. The three streams chosen were Octopus "B" Tributary (Plate 3), Christmas Creek (Plate 4), and Honor Camp Creek (Plate 5).

Octopus "B" Tributary is a tributary of Octopus Creek. Octopus Creek feeds into the Snahapish River, which is the largest tributary of the Clearwater River.

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[1] Appendix I from Washington Forest Practices, Rules and Regulations. See Literature Cited.

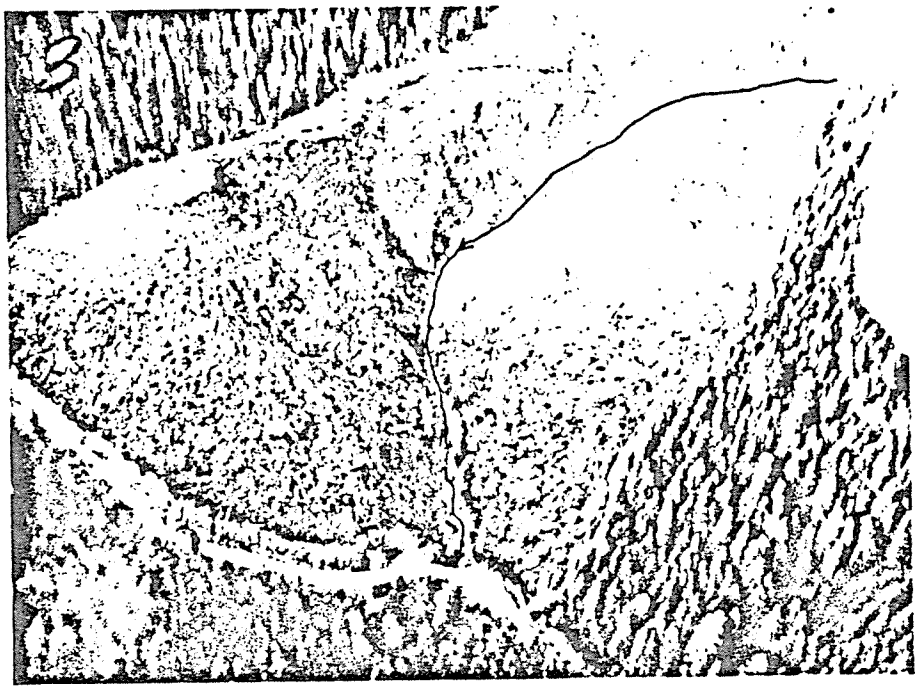

Plate 3. Octopus "B" Creek.

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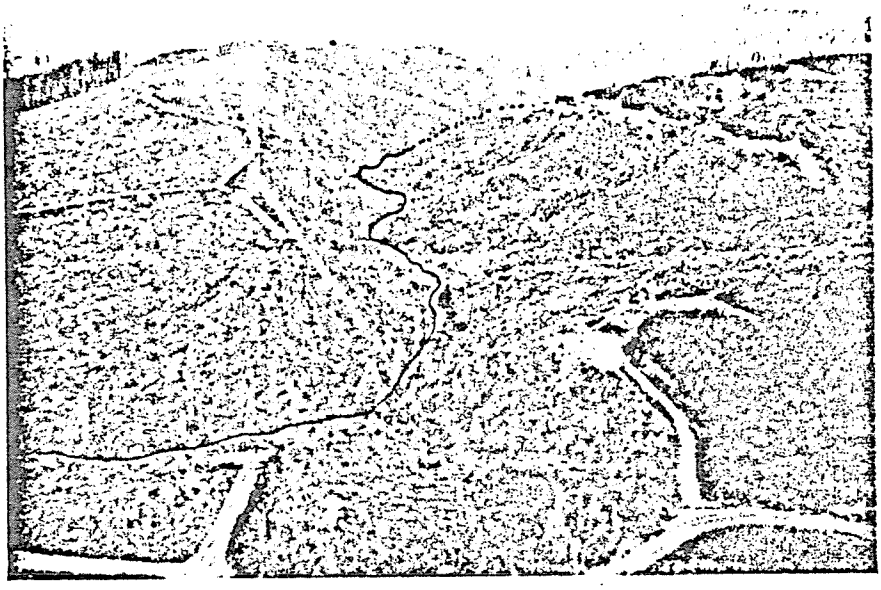

Plate 4. Christmas Creek.

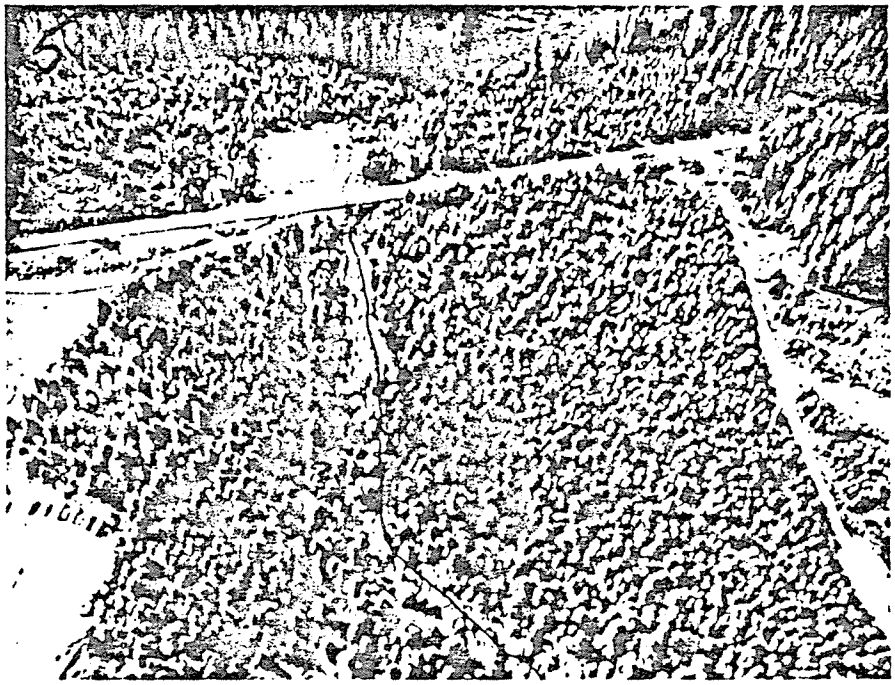

Plate 5. Honor Camp Creek.

Octopus "B" was completely clearcut as a type 3 water[2] in 1977. The yarding was done across the stream, but logs were suspended above streambed to minimize damage. Stream clean-out was performed after completion of the yarding operations.

The average gradient of the study section was 9.6 percent. Discharge taken in July 1978 and 1979 was approximately 11 liters/sec.

Christmas Creek flows directly into the Clearwater River. The watershed was logged in September-October 1973. The stream bed was yarded across, and stream clean-out was performed.

The watershed of Honor Camp Creek, a tributary of the Snahapish River, which feeds the main Clearwater River, was logged in 1960 or 1961. The trees were yarded across the stream and the stream was not "cleaned-out."

The average gradient of the study section was 6.3 percent. Discharge taken in July 1978 and 1979 was approximately 17 liters/sec.

The post-logging recovery periods for the extensive study streams were:

Octopus "B" - 1 yr

Christmas Creek - 5 yr

Honor Camp Creek - 18 yr

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[2] See footnote 1.

The watershed areas for the extensive study streams are:

Octopus "B" - 107 ha

Christmas Creek - 324 ha

Honor Camp Creek - 135 ha

All three extensive study streams are inhabited by natural sympatric populations of resident and searun varieties of cutthroat trout (Salmo clarki) and two species of cottids: the torrent sculpin (Cottus rotheus); and the prickly sculpin (Cottus asper). Octopus "B" also contained a third cottid, the coastrange sculpin (Cottus aleuticus).

METHODS AND MATERIALS

The intensive study part of the project consisted of monitoring changes in East Fork and West Fork of Stequaleho Creek. To complete the extensive study part of the project several streams in various stages of recovery needed to be selected. Some of the criteria used for selection were basin size, gradient, fish habitat, stream discharge, and date and type of logging. The aim was to find streams similar in these characteristics to East and West Fork.

Once the streams used for extensive study were selected, a study section was established in all five streams. Each section ranged in length from 154 m in Octopus "B", Honor Camp, and Christmas Creeks, to 253 m in West Fork and 323 m in East Fork. The sections were further subdivided into 15 m intervals.

Fish population surveys were conducted in each stream five times during the course of the study: July and October 1978, and April, July, and October 1979. A Smith-Root Type V battery-powered electrofisher was used for all surveys. Before shocking, stop nets were installed at the downstream and upstream ends of the sections to prevent immigration or emigration.

Electroshocking procedures were conducted from the bottom of the study section upstream until the entire section was covered. Trout and cottids received the same treatment throughout the study. Captured fish were placed in buckets along the stream bank in the general proximity of

the place where they had been caught. Individual fish were then anesthetized with MS-222, measured and weighed, marked, and placed in freshwater for recovery. Lengths (fork length) were measured to the nearest mm and weights to the nearest 0.1 g. An Ohaus dial balance was used for measuring weight. The mark, which was used for population estimation, consisted of a clip of the dorsal lobe of the caudal fin. All fish were marked on the first electrofishing pass through the section. After recovery from the anesthetic the fish were replaced in the stream as close as possible to the site of original capture. The fish population was allowed to recover for a 24-hr period to assure resumption of normal activity and random distribution of marked fish.

After a 24-hr period, the electroshocking procedures were repeated in the same manner. The numbers of marked and unmarked fish were recorded. Marked fish were measured for length only. Unmarked fish were measured for length and weight. No fish were marked on the second pass.

The formula used for computing population estimates is the modified Peterson estimate (Chapman 1951):

$$\frac{(M+1)\ (C+1)}{R+1} - 1 = \hat{N}$$

where:

M = # marked fish

C = # fish captured on second pass (marked and unmarked)

R = # marked fish recaptured on second pass

$\hat{N}$ = estimated population

Ricker (1975) has shown this to be an accurate estimator.

Population estimates were computed for all year-classes on each sampling date. The total population was obtained by summing the estimates of the individual year-classes. Year-classes were divided into three groups: 0+, I+, and $\geq$ II+. Age 0+ fish were the young of the year. Age I+ fish were those which had experienced one winter, and had formed one annulus. Age $\geq$ II+ were those fish which had experienced two or more winters and formed two or more annuli. The numbers of III+ and IV+ fish were so small that individual population estimates could not be calculated, so they were lumped with the II+ age fish. The only exception to the age group designations was in April 1979, where the age groups were designated as I, II, and $\geq$III, because the fish were forming an annulus at this time of year.

Year-classes were differentiated by the use of length-frequency histograms and by scale analysis. For further verification, scales were analyzed from fish taken from the study streams as well as from several streams in the adjacent area (Fuss, in preparation).

Confidence limits of 95 percent were calculated for each population estimate with the following formulae from Seber (1967):

Confidence limits of 95 percent were calculated for each population estimate with the following formulae from Seber (1967):

1) $\frac{R}{C} = \hat{P}$

2) $\hat{P} \pm 1.96 \sqrt{\frac{\hat{P}(1-\hat{P})}{C} \quad (1 - \frac{C}{N})}$

Formula 2 generates $\hat{P}$ upper and $\hat{P}$ lower. Since $R = C\hat{P}$, from equation 1, $C\hat{P}$ can be substituted back into the Peterson estimate formula to give the 95 percent confidence limit. This is accomplished as follows:

$$\frac{(M+1)(C+1)}{C\hat{P}_u + 1} - 1 \leq N \leq \frac{(M+1)(C+1)}{C\hat{P}_L + 1}$$

where $\hat{P}_u = \hat{P}$ upper

$\hat{P}_L = \hat{P}$ lower

When C is less than 50, binomial tables should be used to obtain an accurate value for $\hat{P}_u$ and $\hat{P}_L$. This being the case, the computer subroutine Belbin, from the International Mathematical and Statistical Libraries, was used to obtain exact values for $\hat{P}_u$ and $\hat{P}_L$. The computer then generated the confidence limits with the values obtained from Belbin. Confidence limits calculated by the Belbin method were used because of their higher precision than the Seber equation.

Pool, riffle, and depth measurements were taken to document any morphometric changes which might have occurred over the course of the study. Stream widths were measured every 5-6 m starting at the bottom of the section and working upstream to the end. Depths were taken along the thalweg of the stream, one on each width transect and one half-way between each transect. Pool data were recorded, starting at the upper end of the section, and lengths, widths, and depths of all pools in the section were measured in a downstream direction.

Measurements of accumulated logging debris within and just above the highwater mark were conducted twice (October 1978 and October 1979) in East and West Forks. Two sections were established in each stream; one from 92 to 154 m and one from 215 to 277 m. Measurements of twigs, small branches, large branches, and large coarse debris, such as logs, were recorded. Coarse debris was divided into three categories: actual, potential, and bank potential. "Actual" coarse debris was in, or less than 1 m above, the stream, and was directly providing habitat for the fish. "Potential" coarse debris was contained within the high water mark, was not directly providing habitat for fish, but might be claimed by the stream at higher water levels. "Bank potential" coarse debris was contained outside the highwater mark and might be claimed by the stream only during severe flood conditions.

A method from Van Wagner (1968) and Froehlich et al. (1972) was used for measuring debris volumes in each of the three categories. A transect line was stretched across the stream every 10 m from just outside the high water mark on each side of the stream. The length of each transect line was recorded. Transect line lengths were used in the computation of small debris (<10 cm) volumes. However, small debris volumes are not presented beacuse this debris type did not seem to be utilized by fish for habitat. The main emphasis of the debris study was to determine the movement of debris being utilized as habitat by fish and, therefore, centered on large, coarse debris. Lengths and diameters of each individual bole or log was measured between each transect and recorded. Volumes of debris were calculated using the formulae:

$$V = \frac{\pi}{4} \cdot d^2 \cdot h$$

where: V = volume

d = average log diameter

h = length

All volumes were summed over the entire debris measurement section to obtain a total volume for the section.

Stream discharge was taken on all population estimate dates in all streams, using a pygmy Gurley meter and staff, and water temperature was measured continuously throughout the study in all streams using continuous recording thermographs.

Average stream gradients were measured in all five study streams using a hand clinometer

Individual trout were branded during population estimate survey to monitor individual growth and movement. Trout greater than 80 mm in length were cold branded using branding irons submerged in dry ice and acetone. The point of original capture was recorded, as well as recapture, in order to calculate distance and direction of movement.

Seasonal mortality rates were computed for the various trout year-classes and for the total populations of trout in the study streams. In 1972 and 1973 Lestelle was not able to document the 0+ year class trout in July because fry emergence from the gravel was not complete and the fry were too small to capture when the population was assessed. Since emigration from the study sections cannot be distinguished from actual mortality, these rates are the relative rates of change between population or year-class size. The disappearance of fish, regardless of cause, will be referred to as mortality. Seasonal rates (A) were computed for each period between sampling dates. The formula is (Ricker 1975):

$$A = 1 - S$$

where

$$S = \frac{\hat{N}_2}{\hat{N}_1}$$

$\hat{N}_2$, $\hat{N}_1$ = estimates of population size or year-class size at times t_1 and t_2, respectively.

RESULTS

Intensive Study

Population Surveys

Differences in trout population size estimates did occur between 1972-73 and 1978-79 in East Fork, the experimental stream (Table 1). Comparison of 0+ age fish was not possible in July of either year because estimates were not computed in 1972 or 1973. The number of fish in East Fork increased, overall, from 1972-73, prior to logging, to 1978-79, after logging. Increases in population estimates were found in October 1978, July 1979, and October 1979 (Fig. 3).

Differences in trout population size estimates between 1972-73 and 1978-79 in West Fork, the control stream, were not nearly as evident as in East Fork (Table 2). Comparison of 0+ age fish in July was not possible. The only difference was in April, and was negligible (Fig. 4). Very good over-winter survival of 0+ age fish appeared to be the cause. No significant difference existed in the control stream over the course of the study.

The comparison of East and West Forks over the course of the 1978-79 study shows no significant differences between the experimental stream and the control stream (Fig. 5). Population estimates were nearly identical in the two streams except for slight differences in July 1978 and 1979.

Table 1. Trout population estimates and 95% confidence intervals for East Fork "C" Tributary.

	July 1972		July 1978
0+	-	0+	137 (91-230)
I+	39 (25-60) N = 82 (67-106)	I+	76 (59-111) N = 256(214-318)
≥II+	43 (34-58)	≥II+	43 (31-71)(N = 119(102-140))[1]
	October 1972		October 1978
0+	94 (74-132)	0+	110 (71-192)
I+	18 (13-28) N = 160 (143-181)	I+	75 (61-100) N = 226 (190-280)
≥II+	48 (42-58)	≥II+	41 (28-71)
	April 1973		April 1979
I	29 (20-45)	I	42 (26-32)
II	24 (17-39) N = 102 (80-141)	II	69 (45-127) N = 128 (104-168)
≥III	49 (33-70)	≥III	17 (9-42)
	July 1973		July 1979
0+	-	0+	151 (113-215)
I+	48 (41-60)N = 78 (73-84)	I+	72 (51-114) N = 297 (255-356)
≥II+	30 (27-38)	≥II+	74 (50-130) N = 146 (122-189)[1]
	October 1973		October 1979
0+	59 (50-73)	0+	205 (181-240)
I+	45 (39-59) N = 130 (119-144)	I+	45 (39-58) N = 301 (277-330)
≥II+	26 (22-35)	≥II+	51 (43-71)

[1]Population estimates and confidence intervals for year-class I+ and ≥II+ only.

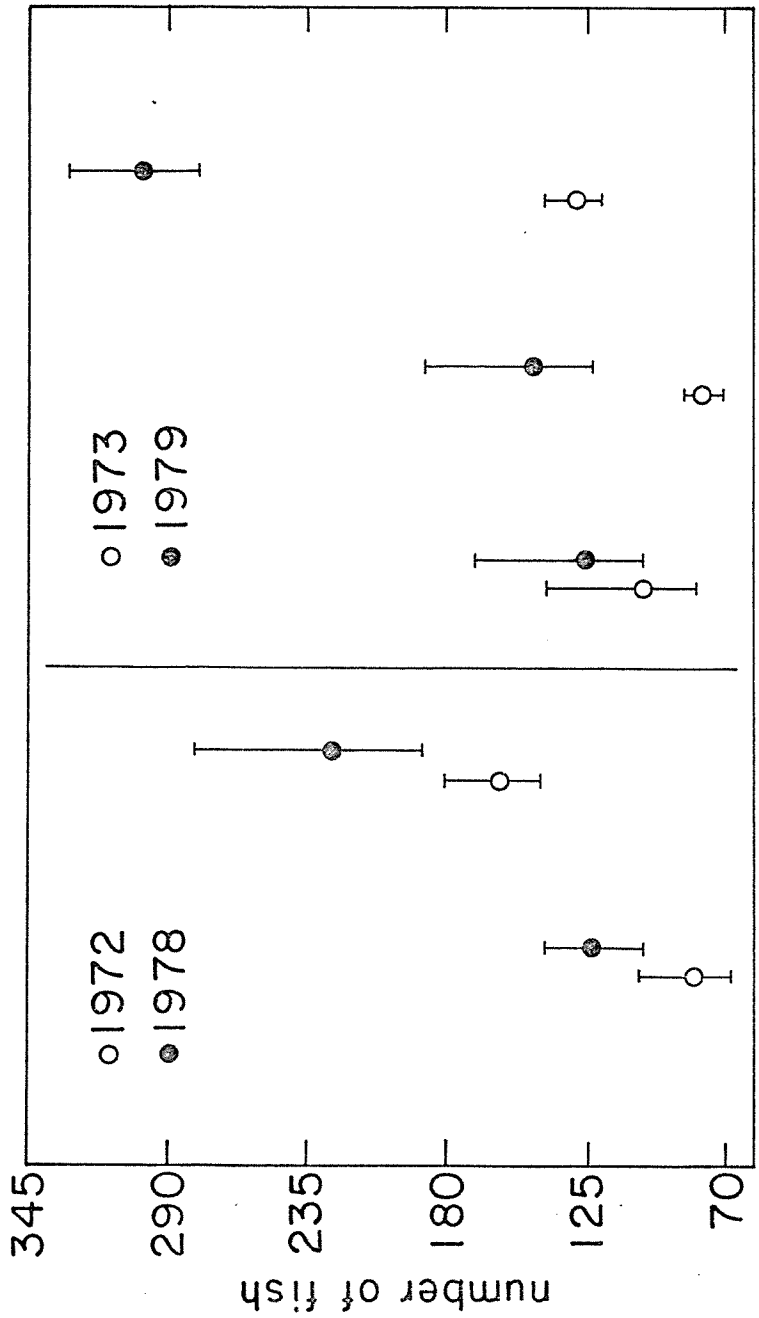


Fig. 3. Trout population estimates and 95% confidence intervals for East Fork "C" Tributary.

Table 2. Trout population estimates and 95% confidence intervals for West Fork "C" Tributary.

	July 1972		July 1978
0+	-	0+	224 (164-330)
I+	89 (65-133) N = 172 (127-266)	I+	91 (73-125) N = 352 (298-430)
≥II+	83 (57-125)	≥II+	37 (28-58)(N = 128 (114-149))[1]
	October 1972		October 1978
0+	62 (53-76)	0+	94 (47-221)
I+	96 (75-132) N = 251 (220-292)	I+	73 (54-110) N = 199 (158-269)
≥II+	93 (71-132)	≥II+	32 (24-50)
	April 1973		April 1979
I	33 (22-56)	I	71 (40-156)
II	40 (29-59) N = 97 (83-116)	II	68 (45-119) N = 160 (128-212)
≥III	24 (18-38)	≥III	21 (13-48)
	July 1973		July 1979
0+	-	0+	75 (41-172)
I+	42 (31-61) N = 120 (101-148)	I+	88 (71-120) N = 220 (185-271)
≥II+	78 (58-94)	≥II+	57 (40-92)(N = 145 (133-180))[1]
	October 1973		October 1979
0+	162 (126-223)	0+	139 (107-193)
I+	56 (46-81) N = 263 (232-304)	I+	79 (68-99) N = 255 (225-295)
≥II+	45 (38-58)	≥II+	37 (31-51)

[1]Population estimates and confidence intervals for year-class I+ and ≥II+ only.

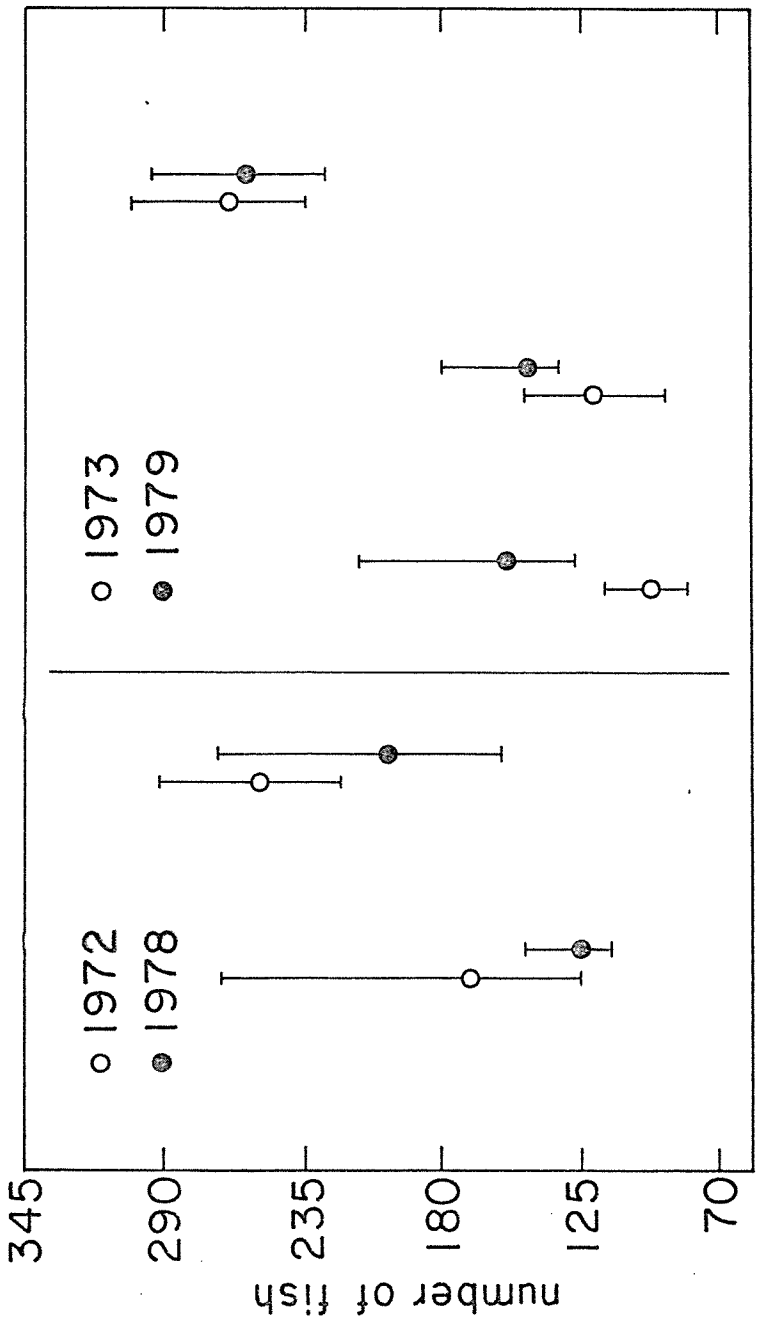


Fig. 4. Trout population estimates and 95% confidence intervals for West Fork "C" Tributary.

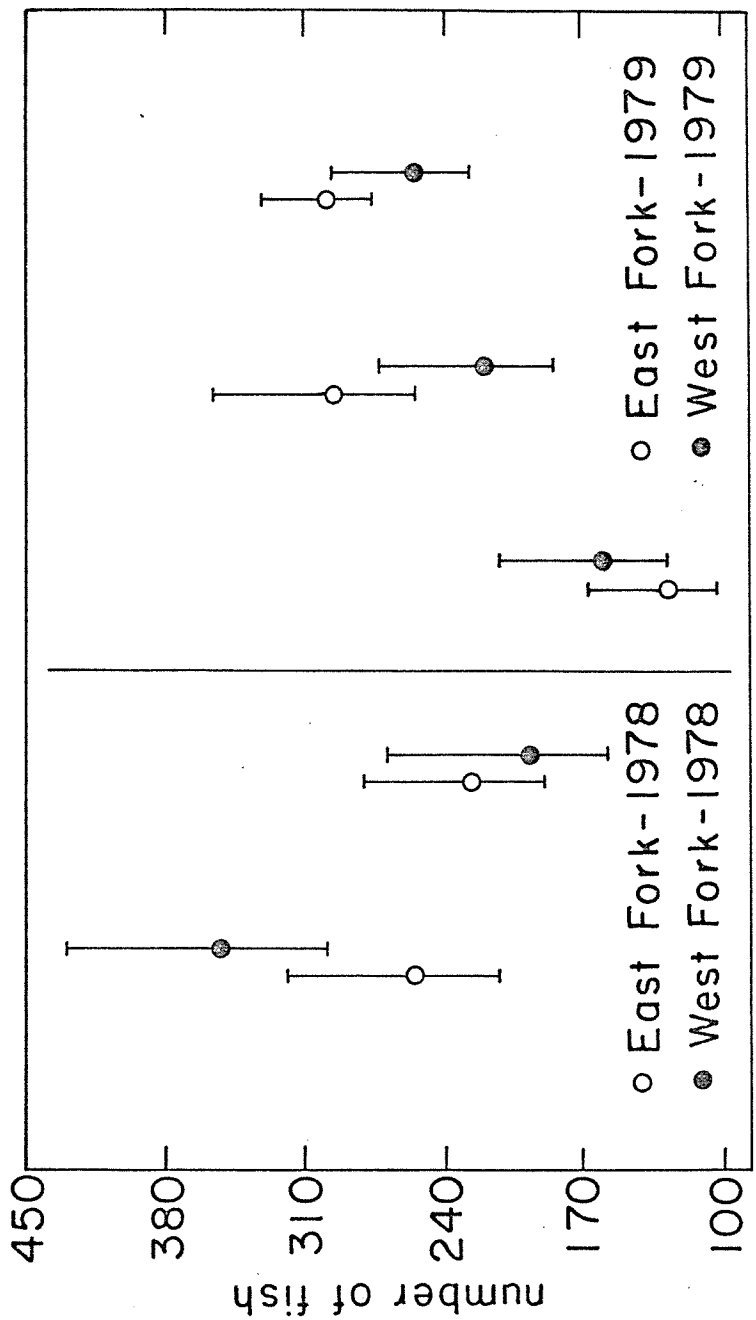


Fig. 5. Trout population estimates and 95% confidence intervals for East and West Fork "C" tributaries.

No differences in sculpin population size estimates occurred between 1972-73 and 1978-79 in either East Fork or West Fork (Table 3). Comparison of the estimates shows them to be very similar (Figs. 6 and 7).

The comparison of East and West Forks over the course of the 1978-79 study shows no significant differences between the experimental stream and the control stream (Fig. 8).

Biomass and Density

Trout biomass (g/m^2) and density ($\#/m^2$) for East Fork revealed few differences between 1972-73 and 1978-79 (Table 4). The biomass estimates in 1978-79 were slightly higher than in 1972-73 in several instances, alluding to the increased population estimates, but no consistent trend was indicated. The same held true for density estimates.

Trout biomass and density estimates for West Fork were similar to those of East Fork (Table 5). However, biomass estimates showed there to be an increase in I+ age fish in 1978-79 over that in 1972-73. For I+ age fish the low biomass estimate in 1978-79 was .73 and the high in 1972-73 was .49. Density estimates for West Fork in 1972-73 and 1978-79 were similar, and reflected, slightly, the increased biomass of the I+ age fish.

Comparison of biomass and density of trout in East and West Fork showed very consistent figures over the course of the 1978-79 study, and no significant differences.

Table 3. Sculpin population estimates and 95% confidence intervals for East and West Fork "C" Tributary.

Date	East Fork	West Fork
July 1972	-	-
October 1972	345(169-521)	1663(686-2640)
April 1973	322(106-549)	721(245-1197)
July 1973	554(315-791)	1670(651-2689)
October 1973	466(209-723)	1222(797-1647)
July 1978	520(369-777)	823(565-1284)
October 1978	597(311-1289)	789(436-1645)
April 1979	450(173-1086)	692(300-1701)
July 1979	1043(512-2366)	475(270-939)
October 1979	815(493-1478)	554(360-930)

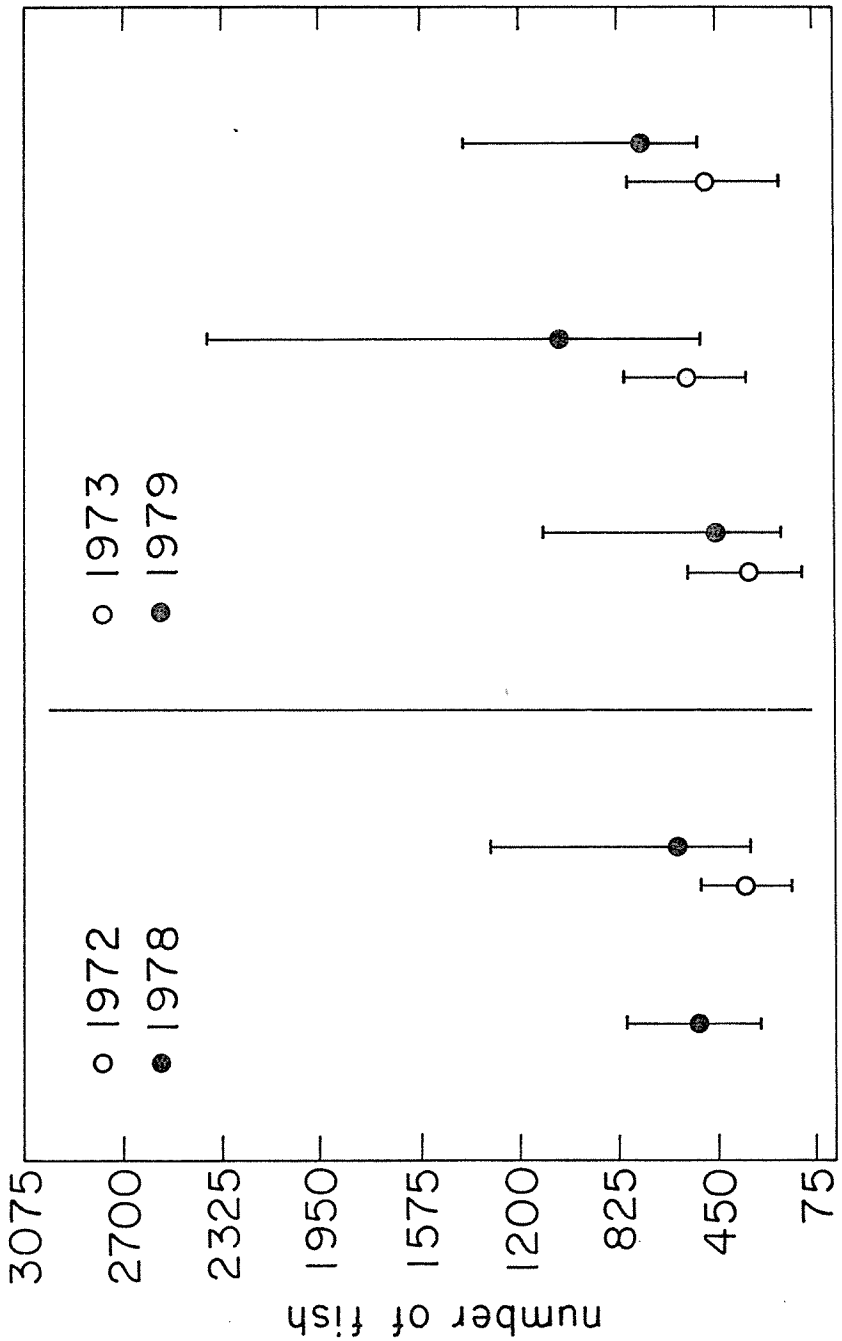


Fig. 6. Sculpin population estimates and 95% confidence intervals for East Fork "C" Tributary.

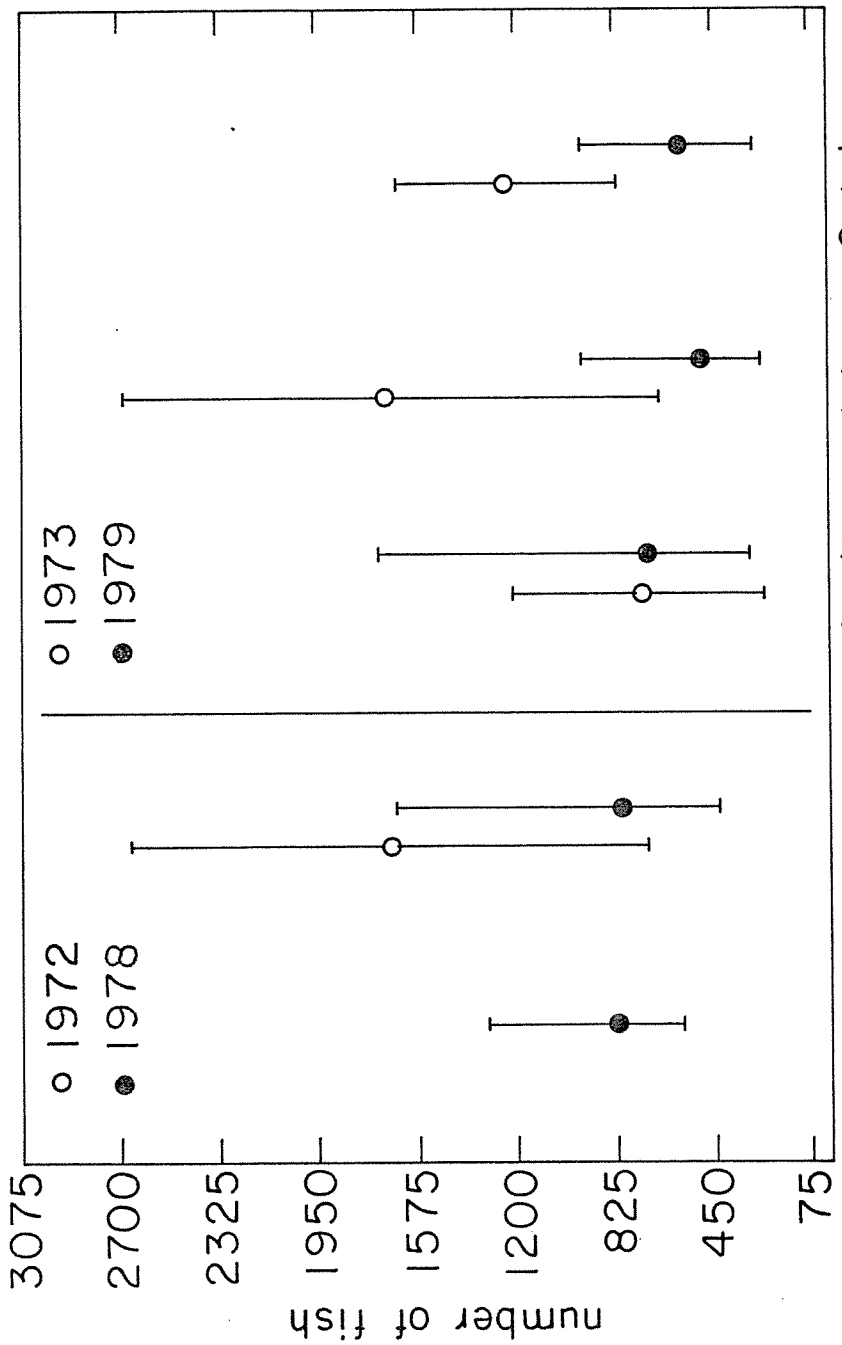


Fig. 7. Sculpin population estimates and 95% confidence intervals for West Fork "C" Tributary.

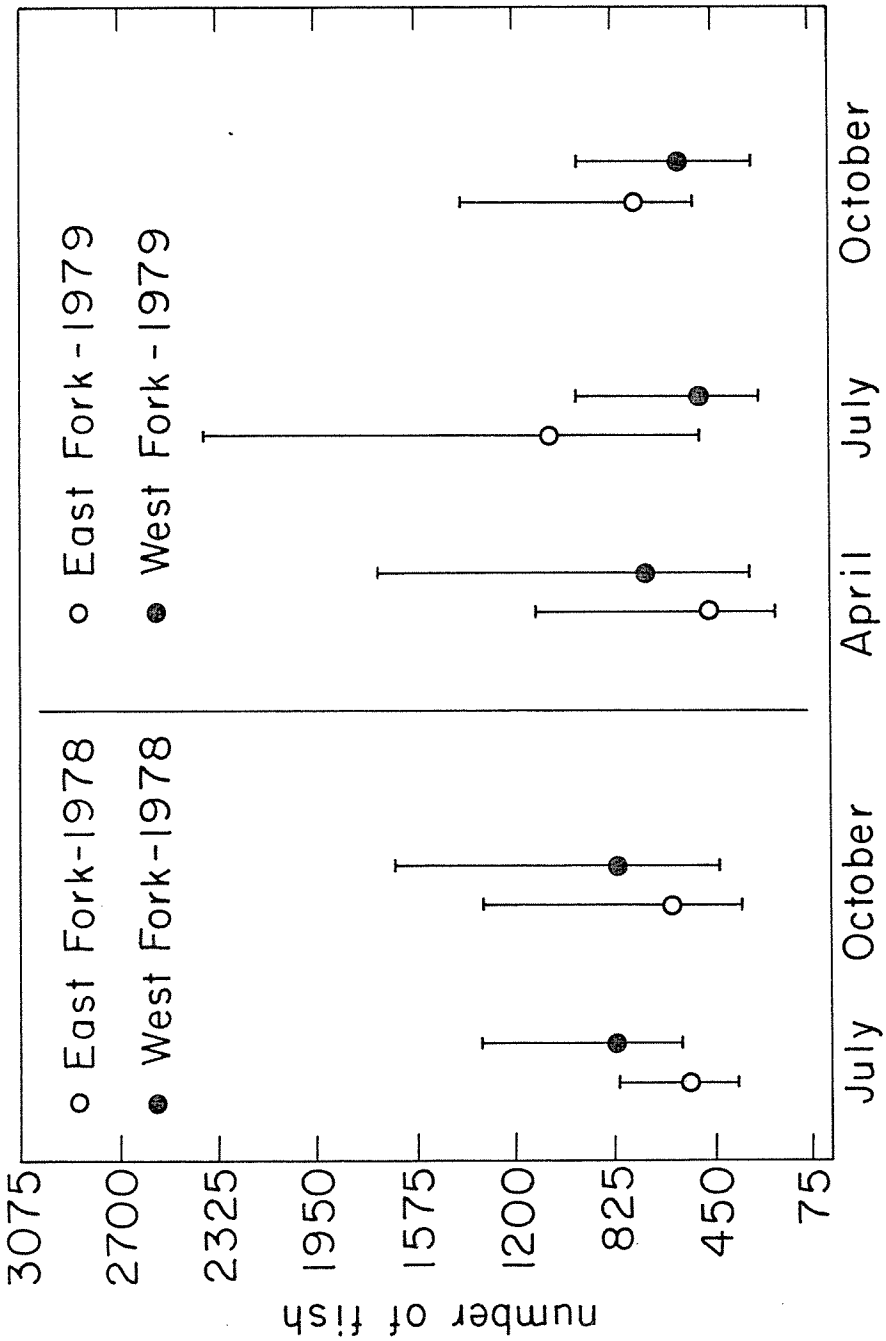


Fig. 8. Sculpin populations estimates and 95% confidence intervals for East and West Fork "C" Tributary.

Table 4. Trout biomass and densities for East Fork "C" Tributary.

Date	Biomass (g/m^2)			Date	Density ($\#/m^2$)		
Year-class[1]	0+	I+	≥II+	Year-class[1]	0+	I+	≥II+
July 1972	-	.30	1.13		-	.08	.10
October 1972	.17	.26	1.54		.19	.07	.13
April 1973	.11	.18	1.08		.09	.04	.08
July 1973	-	.39	1.13		-	.09	.07
October 1973	.16	.66	1.31		.17	.10	.08
July 1978	.11	1.20	1.90		.30	.17	.09
October 1978	.38	1.03	1.30		.16	.11	.06
April 1979	.14	.81	.56		.05	.08	.02
July 1979	.03	.76	1.98		.22	.10	.11
October 1979	.59	.61	1.30		.30	.07	.07

[1]Year-classes for April are I, II, and ≥III.

Table 5. Trout biomass and densities for West Fork "C" Tributary.

Date	Biomass (g/m^2)				Density ($\#/m^2$)		
Year-class[1]	0+	I+	≥II+	Year-class[1]	0+	I+	≥II+
July 1972	-	.38	1.22		-	.09	.09
October 1972	.20	.49	1.31		.22	.09	.09
April 1973	.06	.24	.44		.05	.05	.03
July 1973	-	.39	1.80		-	.07	.11
October 1973	.32	.48	1.42		.29	.07	.08
July 1978	.12	.96	1.10		.34	.14	.06
October 1978	.18	.76	.93		.12	.09	.04
April 1979	.17	.73	.69		.09	.09	.03
July 1979	.01	.87	1.98		.13	.15	.10
October 1979	.24	.82	1.14		.20	.11	.05

[1]Year-classes for April are I, II, and ≥III.

Sculpin biomass and density estimates showed somewhat different results in East and West Fork between 1972-73 and 1978-79 (Table 6). Estimates in East Fork tended to be higher in 1978-79, especially in July and October 1979, than those in 1972-73 on three out of four sampling dates.

Comparison of sculpin biomass and density estimates between East and West Fork during 1978-79 shows very similar figures in 1978, but not in 1979. Estimates in July and October 1979 for East Fork were higher than those for West Fork: 6.3 and 5.6 g/m^2 versus 2.7 and 3.0 g/m^2 for biomass, and 1.5 and 1.2 $\#/m^2$ versus .82 and .80 $\#/m^2$ for density.

Debris Measurement

The volume of coarse debris changed considerably in two of three categories in East Fork from 1978 to 1979 (Table 7). Coarse material that fell into the "Actual" category remained virtually unchanged in both sections; the 91-152-m section decreasing from 2.45 m^3 to 2.17 m^3, and the 213-274-m section increasing from 8.10 m^3 to 8.98 m^3. However, the categories of "Bank Potential" and "Potential" decreased markedly. "Bank Potential" decreased in both sections, with the greatest decrease coming in the 213-274-m section, a decrease from 11.42 m^3 to 3.53 m^3.

The most significant decrease occurred in the volume of "Potential" debris. The stream was left with almost no bank material after the 1978-79 winter. The 91-152 m section decreased from 5.70 m^3 to .53 m^3, a reduction of 5.17 m^3 of material. The 213-274-m section decreased from 6.96 m^3 to 1.01 m^3, an even greater reduction of 5.95 m^3.

Table 6. Sculpin biomass and densities for East and West Fork "C" Tributary.

Date	East Fork Biomass (g/m^2)	Density ($\#/m^2$)
July 1972	-	-
October 1972	2.5	.69
April 1973	2.2	.49
July 1973	4.0	.93
October 1973	3.6	.94
July 1978	4.3	1.20
October 1978	3.4	.84
April 1979	2.0	.53
July 1979	6.3	1.50
October 1979	5.6	1.20
	West Fork	
July 1972	-	-
October 1972	5.5	1.55
April 1973	1.6	.51
July 1973	4.8	1.30
October 1973	5.4	1.15
July 1978	4.1	1.30
October 1978	3.6	1.00
April 1979	3.1	.95
July 1979	2.7	.82
October 1979	3.0	.80

Table 7. Volume of coarse debris in East and West Fork "C" Tributaries (values are in m^3).

East Fork

October 1978

	Potential	Actual	Bank Potential
91 m - 152 m	5.70	2.45	4.83
213 m - 274 m	6.96	8.10	11.12

October 1979

91 m - 152 m	.53	2.17	3.41
213 m - 274 m	1.01	8.98	3.53

West Fork

October 1978

	Potential	Actual	Bank Potential
91 m - 152 m	4.26	5.91	13.87
213 m - 274 m	5.38	8.65	18.13

October 1979

91 m - 152 m	5.1	5.32	13.18
213 m - 274 m	5.37	7.34	16.78

West Fork, the control stream, experienced little or no reduction in the volume of forest debris over the 1978-79 winter. The post- and pre-winter volume estimates in both sections are virtually the same. Debris reduction in both East and West Forks was due to winter and spring high water conditions.

Seasonal Mortality

Seasonal mortality rates for East and West Forks differed on several occasions between sampling dates (Table 8). Mortality rates were higher in West Fork than in East Fork for all year-classes for the period of July 1978 to October 1978. This was the period immediately following the logging of East Fork. The mortality rates for all year-classes were higher in East Fork for the period of October 1978 to April 1979, which is the over-winter period. The total mortality rate was higher in East Fork than in West Fork, .43 compared to .20, and markedly higher for the 0+ and $\geq$ II+ age-classes; .62 to .24 and .59 to .34, respectively. Mortality rates in 1979, between April and October, were similar in both streams.

Pool-Riffle Measurement

Pool-riffle measurements for East and West Fork are shown in Table 9. West Fork maintained the same surface area, volume, and percentage of pools over the course of the study. East Fork showed an increase in the surface area and volume pool-riffle ratio, from 2.7 to 3.6 and 1.6 to 2.6, respectively. These data indicate that the pool surface area and pool volume decreased from July 1978 to October 1979. The percentage of

Table 8. Seasonal mortality rates of trout in East Fork and West Fork "C" Tributary.

	July 78-Oct 78	Oct 78-Apr 79	Apr 79-July 79	July 79-Oct 79
East Fork				
0+	.20	.62	--[1]	--
I+	.01	.08	--	.38
≥ II+	.05	.59	--	.31
Total	.12	.43	--	--
West Fork				
0+	.58	.24	--	--
I+	.21	.07	--	.10
≥ II+	.14	.34	--	.35
Total	.43	.20	--	--

[1]Indicates increase in population size.

Table 9. Pool-riffle ratio and percentage of pools in East and West Fork "C" Tributary.

Date	Pool-riffle ratio[1] East Fork m^2	East Fork m^3	West Fork m^2	West Fork m^3
July 1978	2.7	1.6	3.1	2.1
October 1978	2.9	1.9	4.8	7.8
April 1979	3.0	2.4	3.8	1.9
July 1979	3.6	2.6	3.2	2.4
October 1979	2.9	2.5	2.5	2.0
	Percentage of Pools			
July 1978	37	63	32	48
October 1978	34	53	21	36
April 1979	33	42	26	53
July 1979	28	43	31	42
October 1979	34	40	40	50

[1]All values 1:x.

pool volume supports this theory as it steadily declined from 65% to 40% over the course of the study. Percentage of pool surface area remained relatively constant in both streams and compares favorably to 1972-73 data.

Temperature

Mean monthly temperatures were nearly identical in East and West Fork in 1978 and most of 1979 (Fig. 9). The only variation in temperature profile occurred from May to August 1979 where recorded temperatures in East Fork averaged approximately 1°C higher than in West Fork. Winter minimums were virtually the same.

Growth

Growth between sampling periods was consistent throughout the course of the study in both East Fork (Figs. 10-11) and West Fork (Figs. 12-13). East Fork exhibited slightly larger trout than West Fork for the 0+ and I+ year-class in July and October 1979, but not in 1978, where West Fork exhibited slightly larger fish (Table 10). East Fork 0+ year-classes averaged 7 mm larger for both months, and I+ year-class fish averaged 10 mm larger in October. West Fork 0+ year-class fish averaged 10 mm larger in October 1978, and I+ year-class fish averaged 6 mm larger for the same time period. These data are based on the average size of each year-class. Summary of individual growth from branded trout reflected slightly larger incremental growth between sampling periods for all year-classes in East Fork in 1978 and 1979 (Table 11).

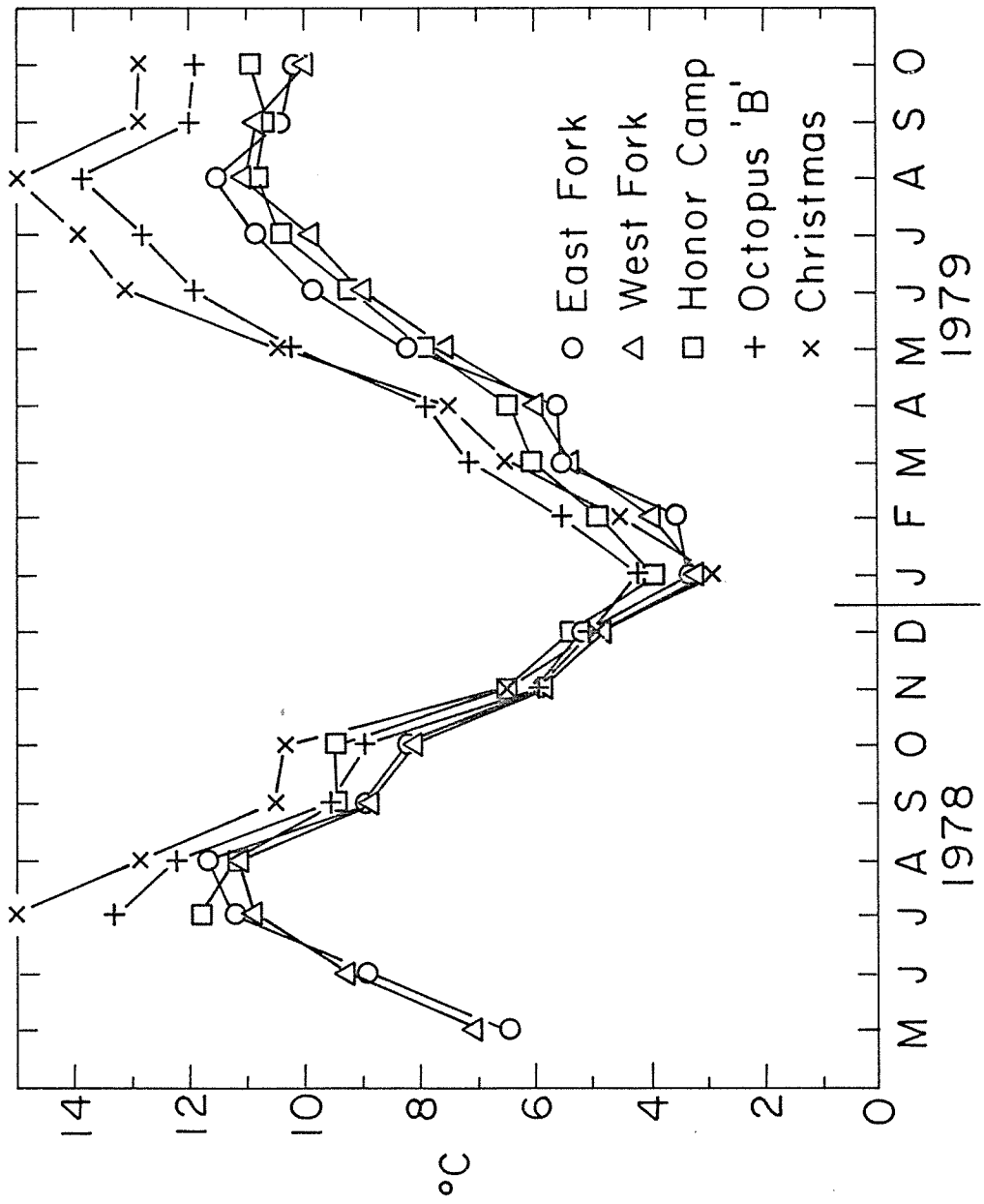


Fig. 9. Monthly mean temperature profile for all study streams.

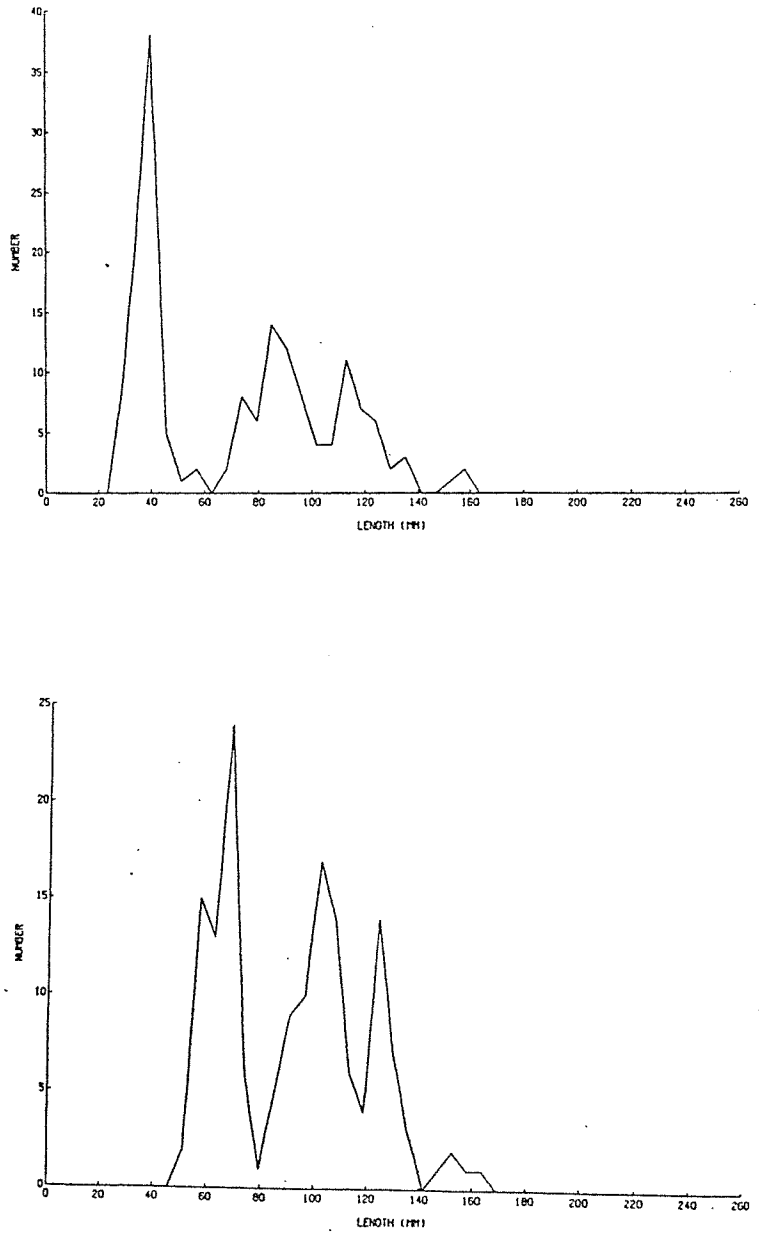
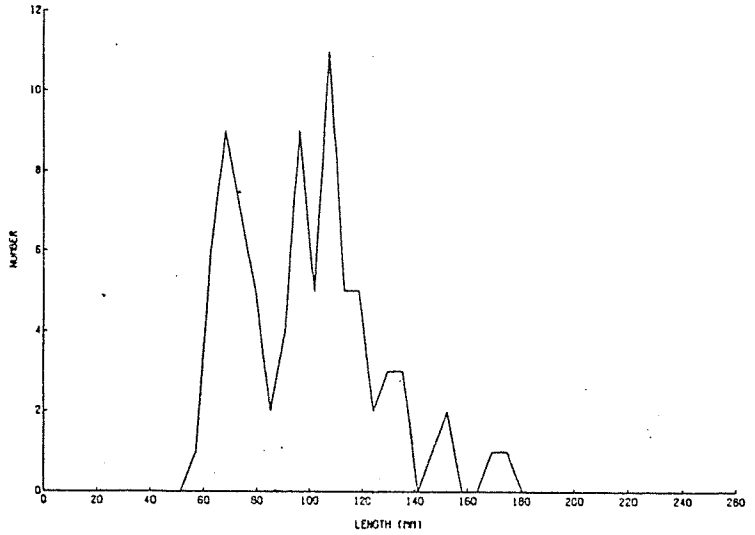


Fig. 10. Length-frequency distribution of trout in East Fork "C" Tributary, July and October 1978.

Fig. 11. Length-frequency distribution of trout in East Fork "C" Tributary, April, July, and October 1979.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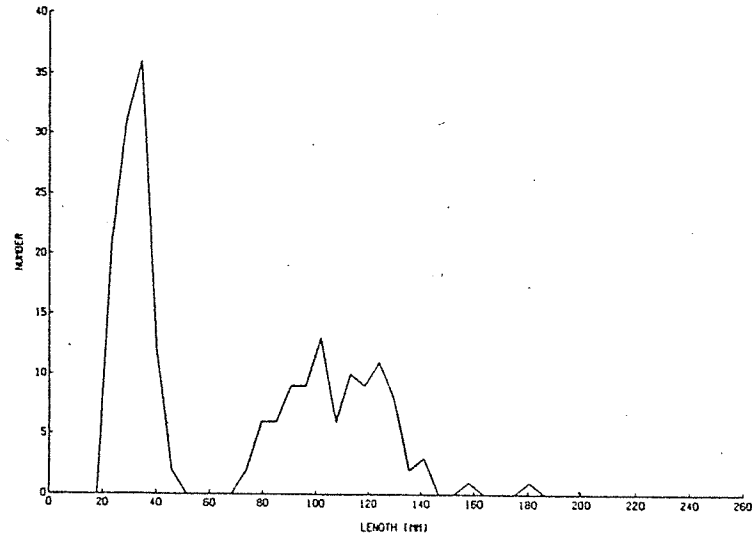
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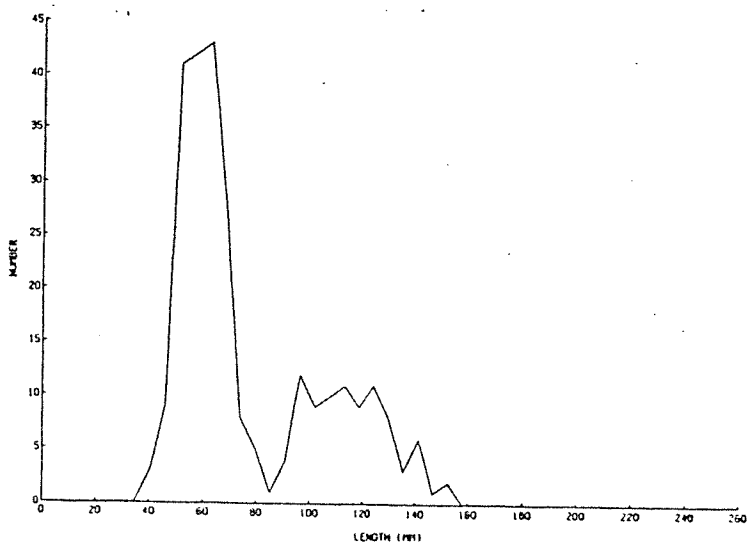
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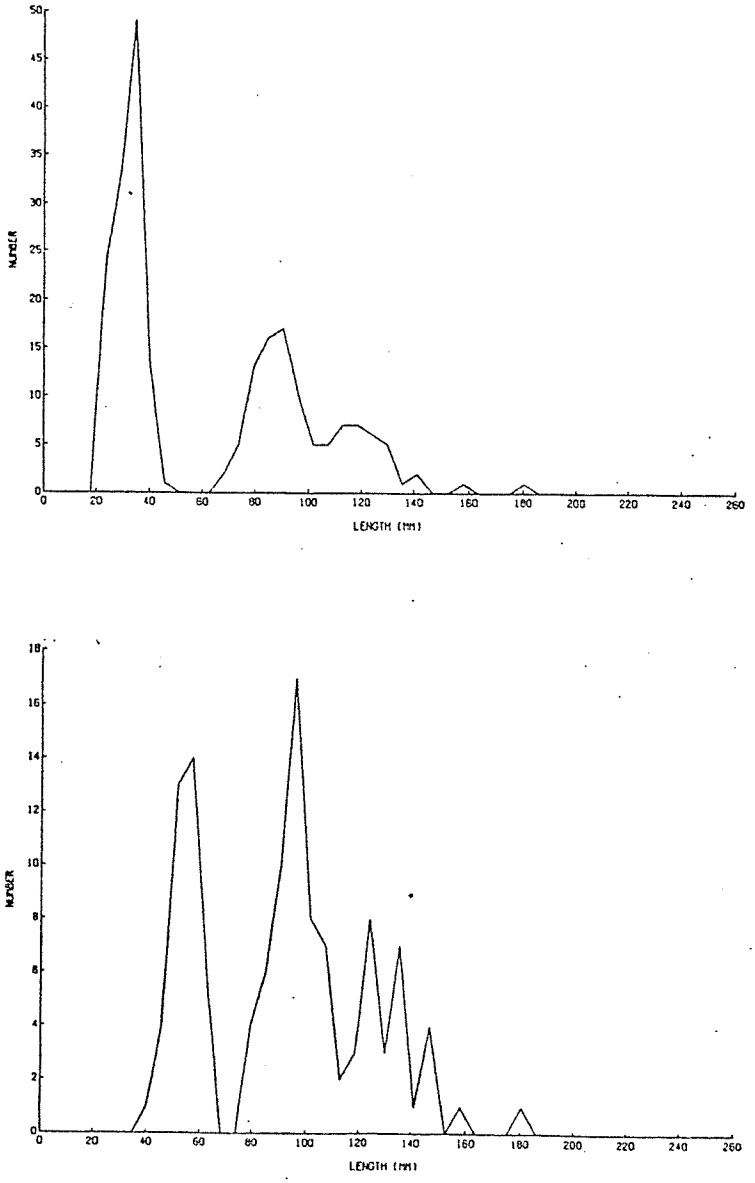
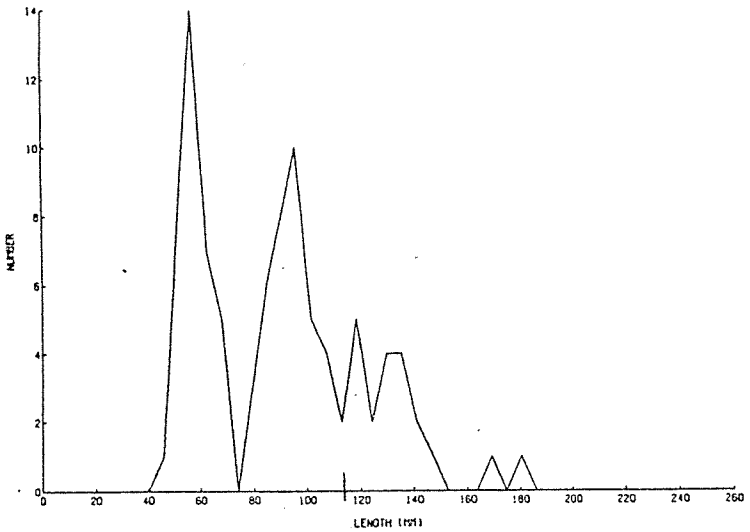


Fig. 12. Length-frequency distribution of trout in West Fork "C" Tributary, July and October 1978.

Fig. 13. Length-frequency distribution of trout in West Fork "C" Tributary, April, July, and October 1979.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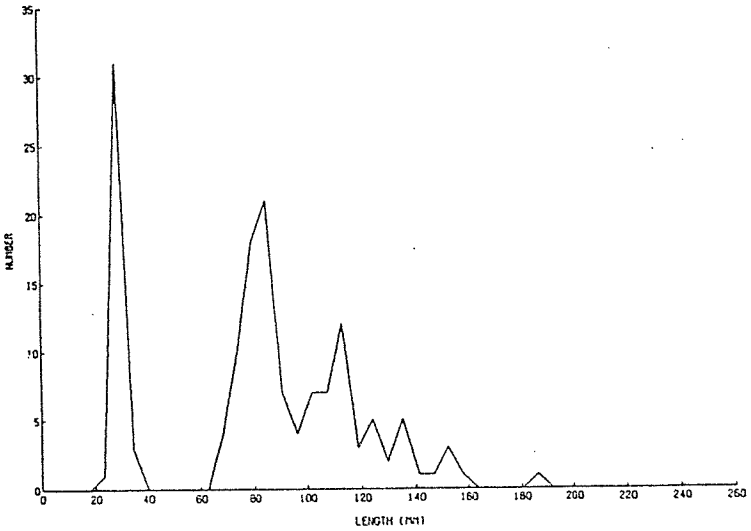
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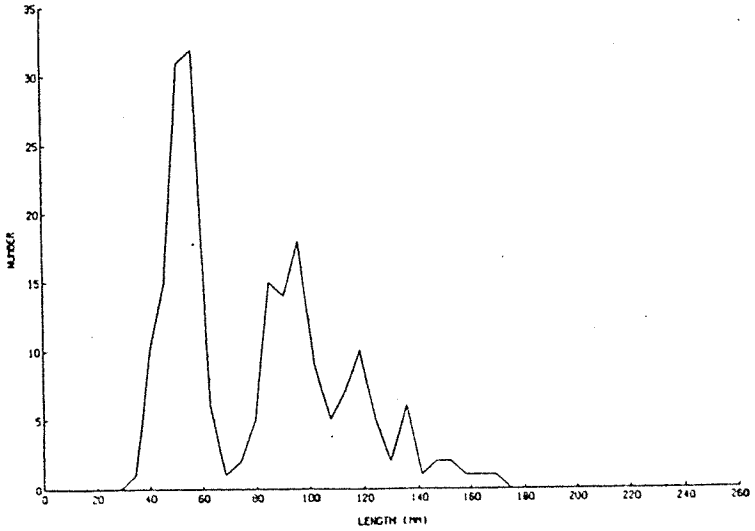
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Table 10. Average length, weight, and range of trout and sculpins in East and West Fork "C" Tributary.

		July 1978		October 1978		April 1979		July 1979		October 1979	
		Lgh (mm)	Wt (g)	Lgh (mm)	Wt (g)	Lgh (mm)	Wt (g)	Lgh (mm)	Wt (g)	Lgh (mm)	Wt (g)
Trout											
East Fork	0+	36(25-48)	.35	61(48-71)	2.5	I 67(56-77)	3.2	0+ 29(20-43)	.13	0+ 56(36-75)	2.0
	I+	84(57-105)	6.9	98(75-114)	9.7	II 101(83-117)	9.6	I+ 91(70-105)	7.4	I+ 98(85-110)	9.3
	≥II+	120(107-158)	19.5	128(117-163)	22.2	≥III 140(120-171)	28.2	≥II+ 121(107-179)	18.1	≥II+ 124(112-149)	17.6
West Fork	0+	30(20-41)	.37	51(40-63)	1.5	I 55(43-69)	1.6	0+ 27(22-32)	.11	0+ 49(35-64)	1.0
	I+	85(63-105)	6.8	92(75-115)	8.0	II 95(75-119)	7.9	I+ 79(63-99)	5.7	I+ 90(73-110)	6.7
	≥II+	122(106-175)	21.5	131(117-178)	22.5	≥III 136(122-178)	22.8	≥II+ 121(101-185)	20.1	≥II+ 126(111-165)	19.5
Sculpins											
East Fork		64	3.7	66	3.9	69	3.8	67	4.2	70	4.7
West Fork		62	3.2	64	3.5	64	3.2	62	3.3	64	3.5

Table 11. Summary of individual trout growth for East and West Fork "C" Tributary.

Date	Stream	Year-Class	Range (mm)	Average (mm)	N
July 1978-October 1978	East Fork	I+	7-13	10.4	9
	West Fork	I+	3-26	8.4	13
		≥II+	4-9	6.4	15
October 1978-April 1979	East Fork	II	3-6	4.5	9
		≥III	4-10	6.7	4
	West Fork	II	1-10	5.2	12
		≥III	0-9	5.6	10
April 1979-July 1979	East Fork	≥II+	8	8	1
	West Fork	≥II+	4-10	6.8	4
July 1979-October 1979	East Fork	I+	0-12	6.8	8
		≥II+	2-22	9.1	14
	West Fork	I+	1-13	6.5	19
		≥II+	0-15	5.9	17

Trout Movement

Trout movement was monitored through capture of previously branded fish. No trends could be established as to distance and direction of movement in conjunction with time of year for any of the five study streams (Table 12). A Movement Index was created in an attempt to quantify the amount of movement in relation to the time of year. From this index it appeared that the greatest amount of movement generally occurred in July and the least amount in October, with April being intermediate (Table 13). Still no trend of direction of movement could be established.

Extensive Study

Population Surveys

Population size estimates remained very consistent for Honor Camp and Christmas Creek (Table 14) and Octopus "B" Tributary (Table 15) throughout the course of the study. Differences did occur in the July 1978 and 1979 estimates in Honor Camp Creek and Octopus "B" Tributary. These differences were attributable to the success of recruitment, as the discrepancy in numbers was due solely to the 0+ year-class. Honor Camp Creek had a 0+ year-class estimate of 427 in July 1978 and 220 in July 1979. Octopus "B" Tributary estimates were 645 and 431, respectively, for the same months and year-class. Recruitment for Christmas Creek in July 1979 was more successful since the 0+ year-class estimate was virtually identical to the July 1978 estimate. Population estimates

Table 12. Summary of trout movement data.

Stream	Date	# fish moved	# fish no move	Gross movement	MI[1]	Direction:	%
East Fork	10/78	4	5	160	17.8	+[2]	.94
West Fork		6	22	745	28.7	+	.95
Honor Camp		6	4	240	24.0	-	.75
Christmas		1	1	35	17.5	+	.50
Octopus "B"		1	0	15	15.0	-	1.00
East Fork	4/79	5	8	2090	160.8	-	.99
West Fork		10	12	1310	59.5	+	.77
Honor Camp		3	3	375	62.5	-	.75
Christmas		5	3	360	45.0	-	.64
Octopus "B"		8	8	1105	69.1	+	.54
East Fork	7/79	1	0	80	80.0	+	1.00
West Fork		4	0	580	145.0	+	.71
Honor Camp		2	1	410	136.7	-	.80
Christmas		1	1	40	20.0	-	.50
Octopus "B"		6	0	1005	167.5	+	.77
East Fork	10/79	13	7	1220	61.0	+	.73
West Fork		12	25	635	17.2	+	.80
Honor Camp		9	5	2005	143.2	+	.75
Christmas		5	12	195	11.5	+	1.00
Octopus "B"		13	14	495	18.3	-	.87

[1]A Movement Index was calculated as: $\frac{\text{Gross Movement}}{\text{Total Fish}}$

[2]+ denotes upstream movement.
- denotes downstream movement.

Table 13. Comparison of trout Movement Index (MI) value versus season.

Stream	Date	MI value	
Christmas	10/79	11.5	
Octopus "B"	10/78	15.0	
West Fork	10/79	17.2	
Christmas	10/78	17.5	
East Fork	10/78	17.8	Low
Octopus "B"	10/79	18.3	
Christmas	7/79	20.0	
Honor Camp	10/78	24.0	
West Fork	10/78	28.7	
Christmas	4/79	45.0	
West Fork	4/79	59.5	
East Fork	10/79	61.0	Intermediate
Honor Camp	4/79	62.5	
Octopus "B"	4/79	69.1	
East Fork	7/79	80.0	
Honor Camp	7/79	136.7	
Honor Camp	10/79	143.2	
West Fork	7/79	145.0	High
East Fork	4/79	160.8	
Octopus "B"	7/79	167.5	

Table 14. Trout population estimates and 95% confidence intervals for Honor Camp Creek and Christmas Creek.

Honor Camp			Christmas		
	July 1978			July 1978	
0+	427 (391-473)		0+	189 (157-237)	
I+	44 (38-57)	N = 479 (445-519)	I+	103 (77-151)	N = 303 (266-351)
≥II+	8 (8-8)		≥II+	11 (6-26)	
	October 1978			October 1978	
0+	203 (168-256)		0+	100 (67-168)	
I+	24 (18-39)	N = 232 (201-274)	I+	53 (40-82)	N = 168 (139-213)
≥II+	5 (5-5)		≥II+	15 (10-35)	
	April 1979			April 1979	
I	72 (52-113)		I	76 (57-116)	
II	10 (9-19)	N = 87 (71-113)	II	39 (28-66)	N = 123 (104-150)
≥III	5 (2-11)		≥III	8 (6-21)	
	July 1979			July 1979	
0+	220 (160-327)		0+	180 (119-299)	
I+	41 (28-69)	N = 275 (224-355)	I+	93 (54-187)	N = 307 (248-404)
≥II+	14 (10-34)		≥II+	34 (20-78)	
	October 1979			October 1979	
0+	190 (172-215)		0+	107 (97-123)	
I+	25 (22-34)	N = 224 (208-243)	I+	46 (35-70)	N = 177 (163-194)
≥II+	9 (8-17)		≥II+	24 (19-38)	

Table 15. Trout population estimates and 95% confidence intervals for Octopus "B" Tributary.

		July 1978	
0+	645	(564-749)	
I+	87	(71-114)	N = 749 (675-842)
≥II+	17	(13-29)	
		October 1978	
0+	359	(322-406)	
I+	67	(51-98)	N = 441 (404-465)
≥II+	15	(11-29)	
		April 1979	
I+	173	(153-203)	
II+	20	(17-29)	N = 201 (182-224)
≥III+	8	(6-16)	
		July 1979	
0+	431	(376-504)	
I+	162	(144-188)	N = 610 (557-674)
≥II+	17	(14-28	
		October 1979	
0+	349	(325-380)	
I+	97	(91-109)	N = 458 (434-485)
≥II+	12	(8-23)	

for the other year-classes, I+ and II+, were very comparable between 1978 and 1979 for the same respective months.

Even though differences did occur in July estimates in 1978 and 1979, the October estimates in both years were nearly identical. These October estimates could be a good indicator of stream carrying capacity.

Sculpin population size estimates showed no significant differences between the same sampling periods on consecutive years, in each stream, except between October 1978 and 1979 estimates in Honor Camp Creek (Table 16). The 95% confidence intervals fail to overlap, suggesting a significant difference, but probably this reflects sampling variation rather than a true population size reduction.

Biomass and Density

Trout biomass (g/m^2) and density ($\#/m^2$) estimates for Honor Camp and Christmas creeks and Octopus "B" Tributary were similar for the most part, but some differences occurred at various times of the year (Table 17). Octopus "B" had higher 0+ year-class biomass and density on all sampling dates. Honor Camp 0+ year-class estimates were similar to Octopus "B" in 1978, but were more similar to Christmas Creek in 1979. Octopus "B" tended to have higher biomass and density estimates on all sampling dates and for all year-classes except for the $\geq$II+ year-class in 1979. Honor Camp and Christmas creeks were more similar to each other except for 0+ year-class biomass and density in 1978.

Sculpin biomass and density estimates were similar in all three extensive streams, although there were some seasonal fluctuations

Table 16. Sculpin population estimates and 95% confidence intervals for Christmas Creek, Honor Camp Creek, and Octopus "B" Tributary.

Date	Christmas Creek	Honor Camp Creek	Octopus "B" Tributary
July 1978	570(377-928)	457(343-637)	225(154-361)
October 1978	781(299-1884)	714(332-1696)	505(286-1000)
April 1979	235(109-575)	263(147-539)	499(163-973)
July 1979	1312(704-2721)	373(175-886)	358(215-661)
October 1979	413(202-972)	165(101-307)	511(309-943)

Table 17. Trout biomass and densities for Christmas Creek, Honor Camp Creek, and Octopus "B" Tributary.

Date	Biomass (g/m^2)				Density ($\#/m^2$)		
Year-class[1]	0+	I+	≥II+	Year-class[1]	0+	I+	≥II+
Christmas Creek							
July 1978	.49	1.90	.61		.25	.13	.01
October 1978	.64	.93	.52		.10	.06	.02
April 1979	.76	.93	.36		.09	.05	.01
July 1979	.36	1.80	1.60		.21	.11	.04
October 1979	.59	1.00	1.10		.13	.05	.03
Honor Camp Creek							
July 1978	2.10	1.50	1.20		1.20	.13	.02
October 1978	1.60	1.30	.51		.53	.06	.01
April 1979	.83	.34	.63		.19	.03	.01
July 1979	.45	1.50	1.40		.69	.13	.04
October 1979	1.30	.80	1.30		.54	.07	.03
Octopus "B" Tributary							
July 1978	3.30	2.70	1.70		1.60	.21	.04
October 1978	2.90	1.90	1.10		.69	.13	.03
April 1979	2.30	.82	.76		.41	.04	.02
July 1979	1.40	4.50	1.00		.96	.36	.04
October 1979	2.10	2.60	.76		.74	.21	.03

[1]Year-classes for April are I, II, and ≥III.

(Table 18). For example, Christmas Creek biomass estimates ranged from 1.4 to 3.1 g/m^2 on four sampling dates and jumped to 6.9 g/m^2 in July 1979. Honor Camp Creek biomass ranged from 5.4 to 7.5 g/m^2 on three sampling dates and had two lower estimates in April and October 1979 of 3.3 and 2.7 g/m^2, respectively. In general, the average biomass and density of sculpins were the same in Octopus "B" Tributary and Honor Camp Creek, with Christmas Creek being somewhat lower.

Pool-Riffle Measurement

Physical features in the extensive streams changed very little during the study (Table 19). Pool surface area, volume, and percentage varied slightly but changed very little, reflecting a stable, stream environment. The values obtained in the extensive streams were similar to those in the intensive streams.

Temperature

Mean monthly temperatures for the extensive streams are shown in Fig. 9. Honor Camp exhibited a temperature profile nearly identical to East and West Fork. The winter minima were not quite as low but the summer maxima were not quite as high. Christmas Creek and Octopus "B" Tributary exhibited considerably different profiles. Christmas Creek had a much higher summer maximum than East Fork, 15°C and 11.5°C, respectively, yet also had the lowest winter minimum, 2.9°C and 3.3°C, respectively. Octopus "B" Tributary had the second highest summer maximum, 13.9°C, and also had the highest winter minimum, 4.2°.

Table 18. Sculpin biomass and densities for Christmas Creek, Honor Camp Creek, and Octopus "B" Tributary.

Date	Biomass (g/m^2)	Density ($\#/m^2$)
	Christmas Creek	
July 1978	3.1	.74
October 1978	2.9	.81
April 1979	1.4	.27
July 1979	6.9	1.60
October 1979	2.8	.49
	Honor Camp Creek	
July 1978	5.4	1.30
October 1978	7.4	1.90
April 1979	3.3	.69
July 1979	6.2	1.20
October 1979	2.7	.47
	Octopus "B" Tributary	
July 1978	2.9	.55
October 1978	4.3	.97
April 1979	6.1	1.20
July 1979	4.0	.79
October 1979	7.0	1.10

Table 19. Pool-riffle ratio and percentage of pools in Christmas Creek, Honor Camp Creek, and Octopus "B" Tributary.

Date	Christmas		Honor Camp		Octopus "B"	
	m^2	m^3	m^2	m^3	m^2	m^3
Pool-riffle ratio[1]						
July 1978	2.3	1.6	2.0	1.9	3.5	2.9
October 1978	2.7	2.1	2.3	1.9	3.0	2.9
April 1979	2.6	2.3	2.9	2.6	2.5	1.9
July 1979	2.4	2.2	2.5	2.3	2.7	2.1
October 1979	2.1	1.8	2.6	1.9	2.7	2.3
Percentage of pools						
July 1978	43	63	50	53	29	34
October 1978	37	48	43	53	33	34
April 1979	38	43	34	38	40	53
July 1979	42	45	40	43	37	48
October 1979	48	56	38	53	37	43

[1] All values 1:x.

Growth

Growth of trout in the extensive study streams was similar to the growth in the intensive study streams except from October 1978 to April 1979 (Figs. 14-19). Trout in the extensive study streams averaged approximately 10 mm of growth over this time period, whereas those in the intensive study streams averaged approximately 5 mm. The average size of fish in the 0+ and I+ year-classes on any date in Honor Camp Creek were very similar to East Fork, ranging from only 0 to 10 mm larger, except in July 1978, where the discrepancy in size was greater (Table 20). Christmas Creek and Octopus "B" Tributary exhibited larger average year-class size than Honor Camp Creek, with Christmas Creek having the largest fish at any given time. These streams averaged 15-20 mm more per year-class than the intensive study streams.

The summary of individual growth data supported the previously mentioned findings with Christmas Creek and Octopus "B" Tributary generally having the greatest average incremental growth over a given time period, and Honor Camp, East Fork and West Fork having similar but slightly less average incremental growth (Table 21).

Seasonal Mortality

No definite trends could be determined from mortality rates between any of the extensive study streams (Table 22). However, during October 1978 to April 1979, or over-winter, estimates for all year-classes tended to be higher in Octopus "B" Tributary and Honor Camp Creek than in Christmas Creek. These higher over-winter mortality rates were

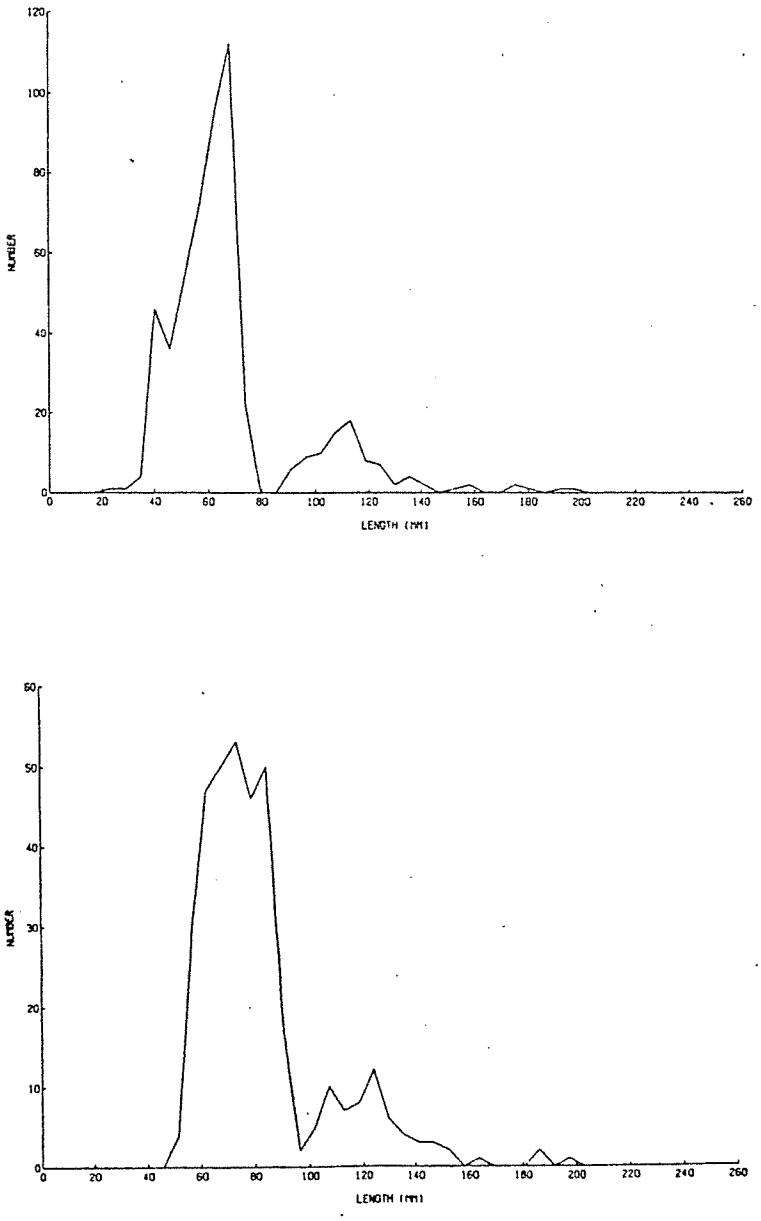
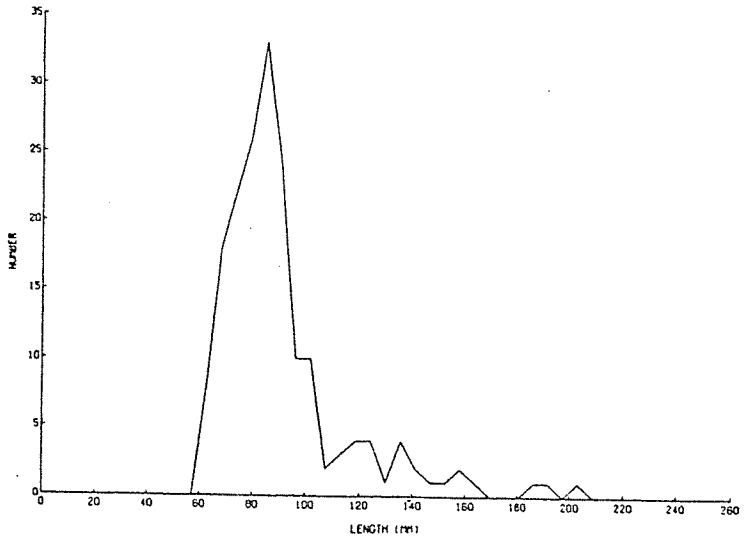


Fig. 14. Length-frequency distribution of trout in Octopus "B" Tributary, July and October 1978.

Fig. 15. Length-frequency distribution of trout in Octopus "B" Tributary, April, July, and October 1979.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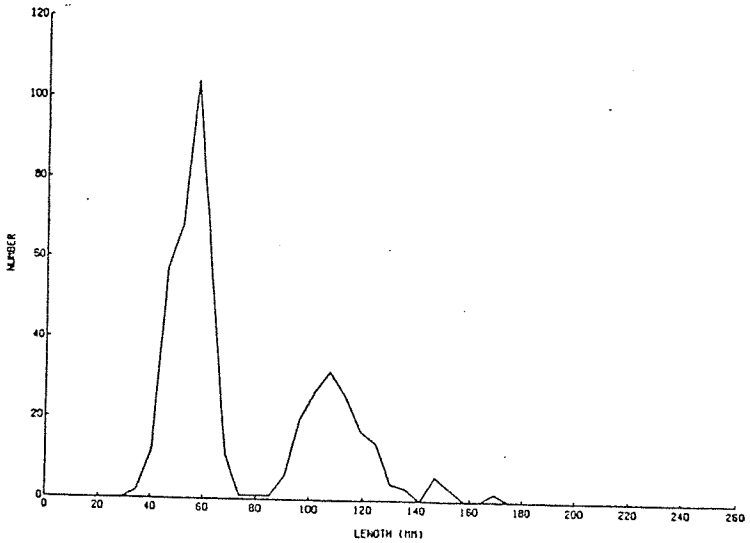
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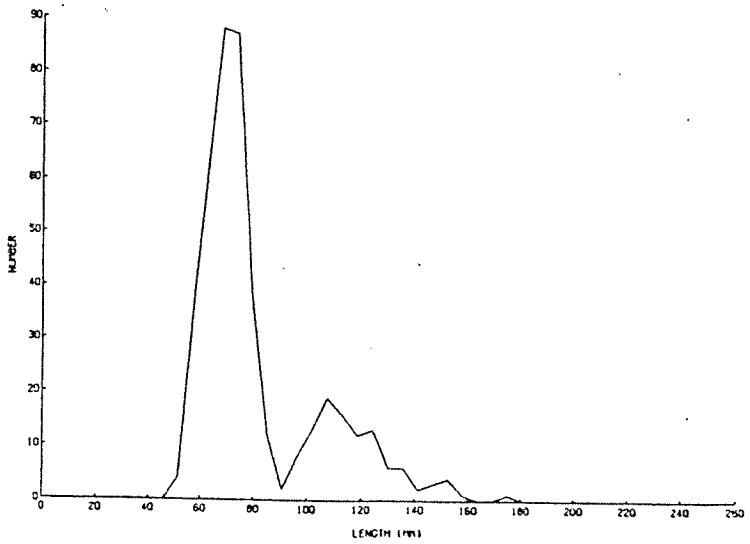
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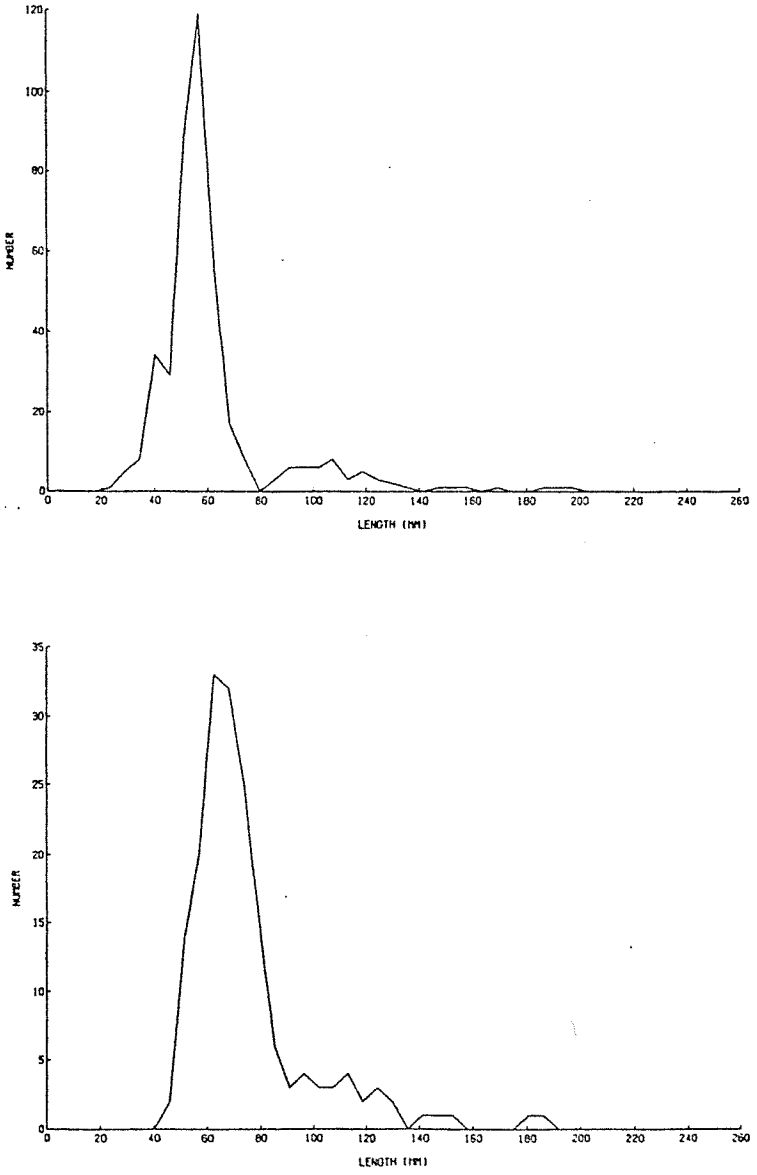
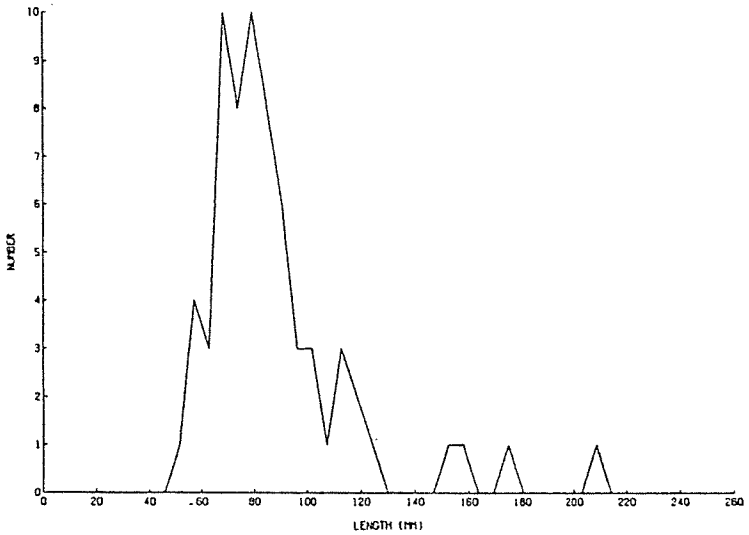


Fig.16. Length-frequency distribution of trout in Honor Camp Creek, July and October 1978.

Fig. 17. Length-frequency distribution of trout in Honor Camp Creek, April, July, and October 1979.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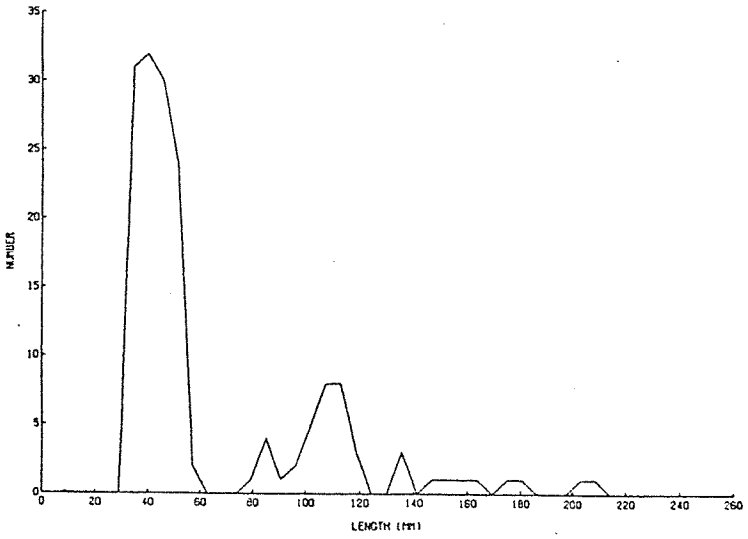
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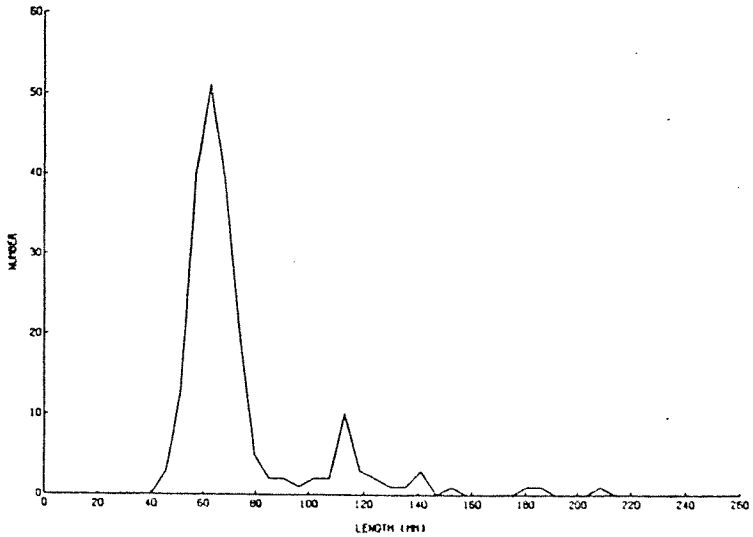
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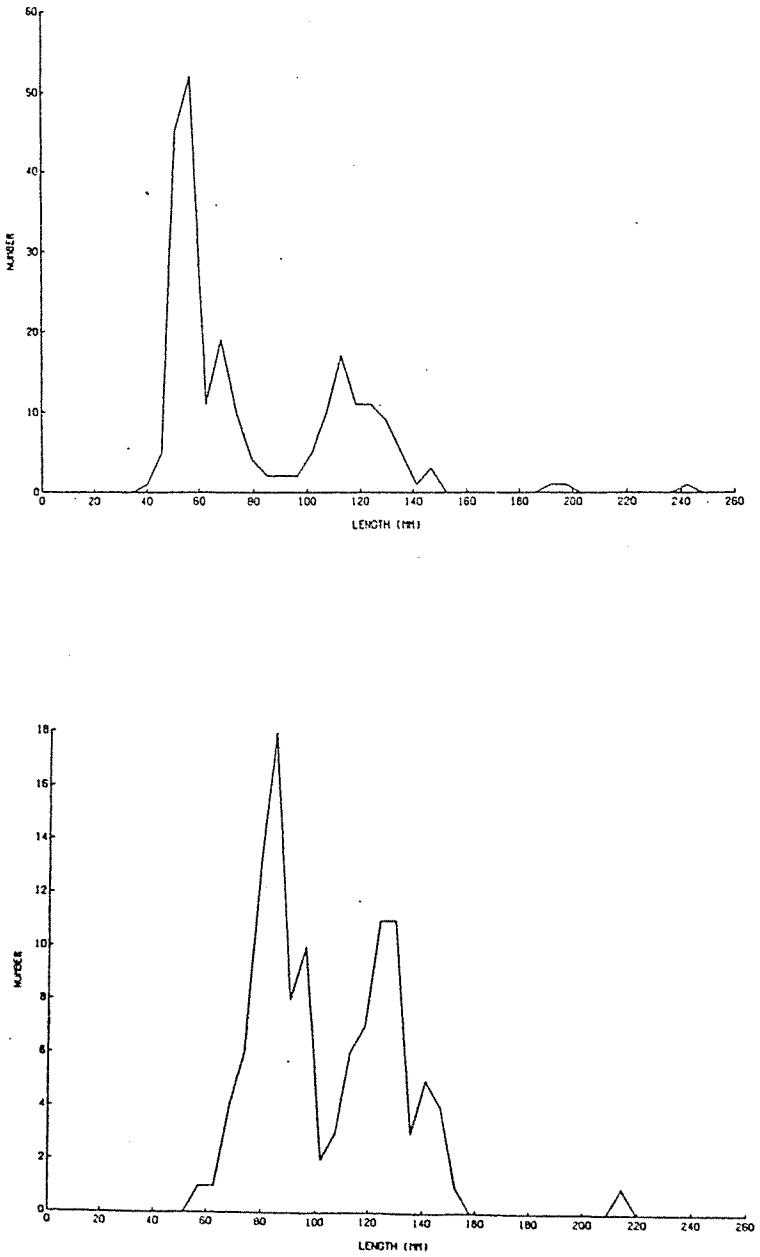
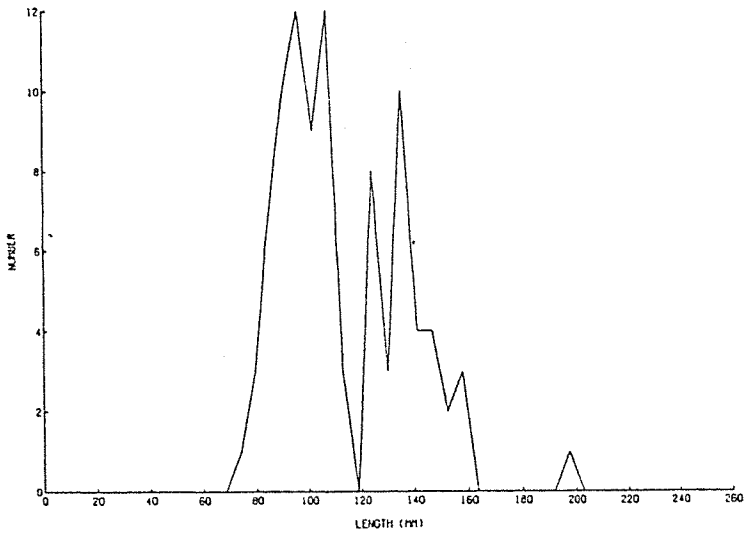


Fig. 18. Length-frequency distribution of trout in Christmas Creek, July and October 1978.

Fig. 19. Length-frequency distribution of trout in Christmas Creek, April, July, and October 1979.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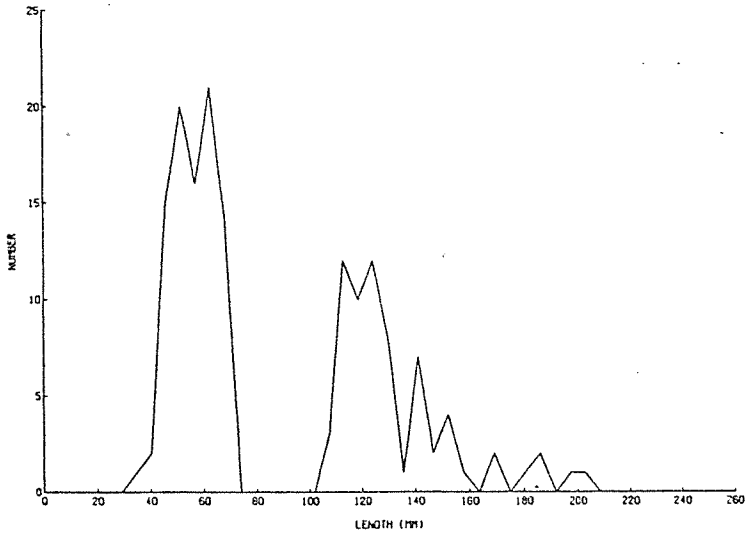
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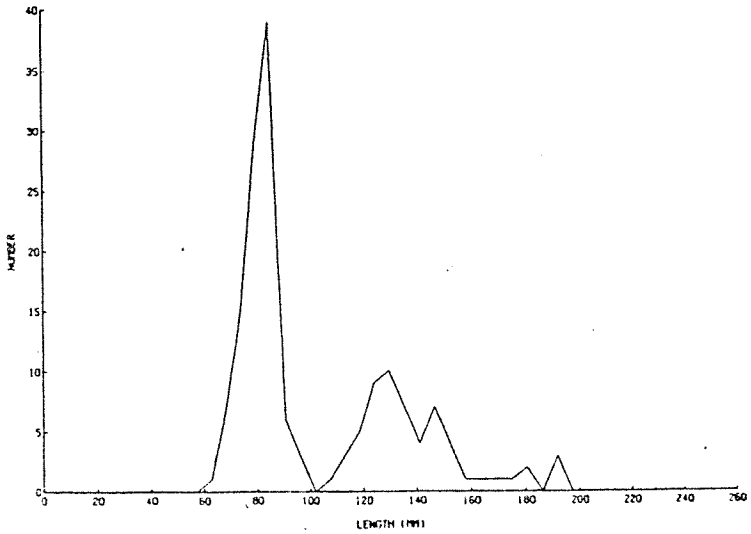
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Table 20. Average lengths, weights, and ranges of trout and sculpins in Christmas Creek, Honor Camp Creek, and Octopus "B" Tributary.

		July 1978			October 1978			April 1979			July 1979			October 1979	
		Lgh (mm)	Wt (g)		Lgh (mm)	Wt (g)		Lgh (mm)	Wt (g)		Lgh (mm)	Wt (g)		Lgh (mm)	Wt (g)
Trout															
Christ-	0+	55(37-75)	2.0	0+	81(55-94)	6.1	I	93(73-108)	8.5	0+	53(34-68)	1.7	0+	78(63-93)	4.6
mas	I+	110(82-130)	14.2	I+	118(99-130)	16.5	II	129(120-145)	20.6	I+	118(103-133)	16.5	I+	125(107-136)	18.2
Cr.	≥II+	156(134-239)	40.0	≥II+	145(136-210)	32.5	≥III	155(146-195)	37.2	≥II+	152(136-200)	37.7	≥II+	159(141-191)	38.2
Honor	0+	51(22-71)	1.8	0+	63(43-87)	2.9	I	73(48-94)	4.3	0+	39(30-52)	.65	0+	60(40-80)	2.2
Camp	I+	100(62-125)	11.7	I+	108(91-126)	13.8	II	109(98-123)	12.5	I+	102(82-116)	11.6	I+	105(89-126)	10.7
Cr.	≥II+	165(134-195)	50.6	≥II+	159(140-185)	38.6	≥III	170(150-208)	48.0	≥II+	162(130-206)	29.6	≥II+	168(135-255)	50.5
Octo-	0+	57(23-72)	2.3	0+	70(50-92)	4.2	I	79(60-105)	5.5	0+	52(31-72)	1.4	0+	66(58-86)	2.8
pus	I+	105(87-125)	12.5	I+	114(96-128)	14.7	II	120(110-139)	16.7	I+	105(85-125)	12.5	I+	110(91-135)	12.8
"B"	II+	151(128-197)	42.0	≥II+	152(130-198)	36.5	≥III	168(149-189)	42.0	≥II+	146(129-169)	30.8	≥II+	147(141-170)	29.2
Sculpins															
Christmas Cr.		66	4.2		63	3.7		65	5.0		66	4.4		72	5.6
Honor Camp Cr.		60	4.1		63	3.9		65	4.8		66	5.2		71	5.6
Octopus "B"		73	5.2		63	4.5		67	5.3		73	5.1		70	6.5

Table 21. Summary of individual trout growth for Christmas Creek, Honor Camp Creek, and Octopus "B" Tributary.

Date	Stream	Year-Class	Range (mm)	Average (mm)	N
July 1978-October 1978	Christmas	I+	12-15	13.5	2
	Honor Camp	I+	0-14	6.6	8
		≥II+	0	0	2
	Octopus "B"	I+	5	5	1
October 1978-April 1979	Christmas	I	3-5	4.3	3
		II	4-9	6.3	4
		≥III	7	7	1
	Honor Camp	I	9	9	1
		II	3-13	7.8	4
		≥III	1	1	1
	Octopus "B"	I	0-9	5.9	8
		II	0-15	6.3	6
		≥III	2-3	2.5	2
April 1979-July 1979	Christmas	I+	26-31	28.5	2
	Honor Camp	≥II+	4-5	4.5	2
	Octopus "B"	I+	1-34	17.5	2
		≥II+	16-27	20.0	4
July 1979-October 1979	Christmas	I+	3-14	6.6	10
		≥II+	3-19	7.7	7
	Honor Camp	I+	4-12	7.0	8
		≥II+	0-7	2.6	6
	Octopus "B"	I+	0-21	4.5	21
		≥II+	1-26	9.7	6

Table 22. Seasonal mortality rates of trout in Octopus "B" Tributary, Honor Camp, and Christmas creeks.

	July 78-Oct 78	Oct 78-Apr 79	Apr 79-July 79	July 79-Oct 79
Octopus 'B'				
0+	.44	.52	--[1]	.19
I+	.23	.70	—	.40
≥ II+	.12	.47	--	.29
Total	.41	.54	—	.25
Christmas				
0+	.47	.24	—	.41
I+	.49	.26	--	.51
≥ II+	—	.47	--	.29
Total	.45	.27	--	.62
Honor Camp				
0+	.52	.65	—	.14
I+	.45	.58	--	.39
≥ II+	.38	0.00	—	.36
Total	.52	.63	--	.19

[1]Indicates increase in population size.

comparable to those in East Fork, which was experiencing its first winter after logging (Table 8). The lower Christmas Creek estimates were similar to those found in West Fork, the control stream.

DISCUSSION

Logging appeared to have subtle effects on the population of trout and no effect on the population of sculpins in East Fork during this study. Population size, biomass, and density estimates did not show any decrease in comparison to West Fork, the control stream, or between sampling dates before and after the first winter in either stream. Population size actually had increased in East Fork since 1972-73 (Lestelle 1978), and from 1978 to 1979 (Fig. 3).

These findings are consistent with other studies conducted in southwest Washington and Oregon (Dr. Jim Sedell, personal communication). The pattern is that after logging and canopy removal the stream shows an increase in population size and biomass over a short-term period (Fig. 20). This increase is attributed to a changeover from allochthonous production to autochthonous production due to increased sunlight. Temperature is also increased to a level closer to the fishes' preferred temperature and maximum scope for growth.

The overriding and controlling factor of a continued increase in production is the availability of habitat, in the form of forest debris, which is essential to cutthroat trout for cover (Anderson 1975; Giger 1973; Lestelle 1978; Miller 1957) and overwinter substrate (Bustard 1973; Bjornn 1971; Chapman and Bjornn 1969), and to the stream itself for stability (Froehlich 1973; Hall and Baker 1975; Sedell and Triska 1976; Swanson and Lienkaemper 1976a). As forest debris in the stream is lost due to biodegradation or washout, new material from the bank area is brought into the stream. However, logging practices deplete the stream

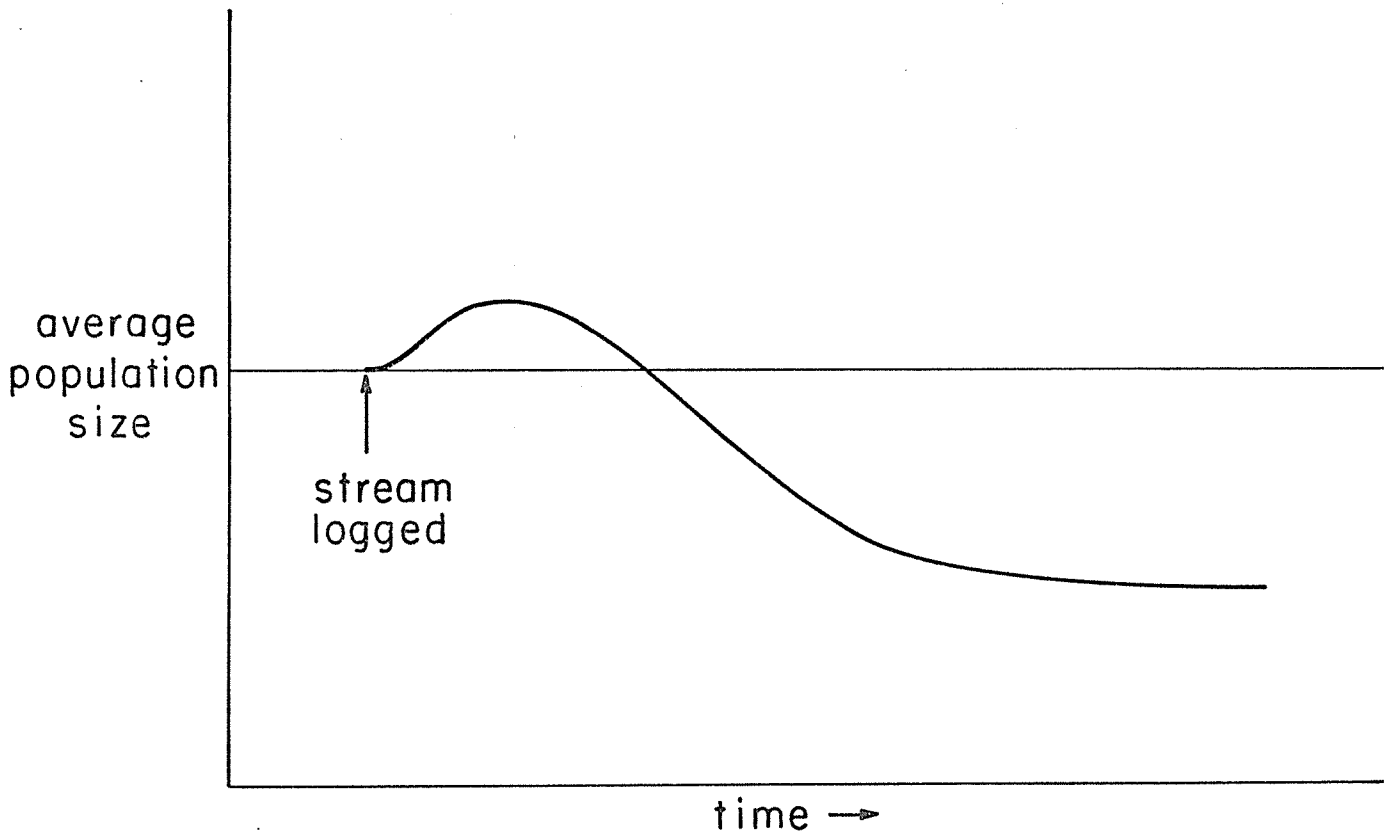

Fig. 20. Theorized effect of logging on population size.

of this bank area material and none remains to replenish the habitat source so critical to fish (Swanson and Lienkaemper 1976b, Froehlich 1973). The hypothesis at this point is that because of habitat loss and instability, fish are unable to survive and the population experiences a sharp decline, well below prelogging levels (Fig. 20). The stream morphology changes considerably, with the stream channel becoming uniformly straight, sluiced-out, and much like a raceway (Sedell, personal communication; Hall and Baker 1975). How long streams remain in this state and if recovery is even possible has not been fully determined. No one stream has been followed closely through this entire process because of the great length of time involved, but study streams which were logged many years ago and were depleted of streamside forest debris have experienced dramatic declines in fish population size and changes in fish species composition (Sedell, personal communication; Hall and Lantz 1969). Data from this study indicate that there is a possibility of this occurring in East Fork.

The amount of "Actual" debris changed very little between 1978 and 1979 (Table 7). However, much of the debris in this category in 1979 was not the same material as in 1978. Instability created by logging operations caused much of this debris to be moved downstream or washed out of the stream. Sources of material from the bank areas resupplied the stream with "Actual" debris.

The most dramatic observation of this entire study was the drastic reduction in East Fork of material in the "Potential" and "Bank Potential" categories (Table 7). The sources for replenishing the instream habitat had been virtually depleted over the course of only one winter after

logging. In contrast, the control stream exhibited virtually no change in the amount of forest debris in any of the three categories measured. This result suggests that loss of instream habitat from lack of debris resupply may ultimately cause marked decreases in the fish community and disrupt the stability of the streambed.

The amount and type of instream debris greatly affects stream morphology. East Fork reflected this condition by exhibiting an increase in pool-riffle ratio and a decrease in pool volume (Table 9). Pools are the primary areas of productivity (Swanson et al. 1976b) and habitat for trout (Miller 1957). Pool reduction, as was experienced in East Fork, can only decrease the stream's ability to produce and hold fish. Depletion of pool-creating debris makes the problem even worse.

The collaborating evidence for the hypothesis from this study was the effect of stream instability on overwinter mortality (defined as loss in population number). Overwinter mortality is closely related to the amount and type of available instream habitat (Bustard 1973). The total overwinter mortality in East Fork was more than twice that of West Fork, and some individual year-class losses were two to three times as high (Table 8). These data may reflect the instability of habitat in East Fork during the first winter after logging. Material that was disrupted, both forest debris and the streambed itself, was being rearranged by winter high flows which resulted in an unstable overwintering environment for the fish. The critical influence is that the advantage gained from an increased production on fish growth, would be negated by high overwinter mortality.

Regardless of initial improvement in growth, the population would

still suffer decreases in numbers from overwinter losses. High overwinter mortality due to stream instability, in combination with loss of habitat, would be expected to cause decreases in the trout population that would conform to the trend suggested in Fig. 20.

One of the temporary benefits of logging and canopy removal is increased spring and summer temperatures (Chapman 1962; Narver 1972). East and West Forks mean monthly temperature profiles were nearly identical except for the period of May through August 1979, when East Fork averaged 1°C higher (Fig. 9). Although the difference was small, this might explain why fish in East Fork averaged slightly larger than in West Fork in July and October 1979 (Table 10).

Trout movement data failed to show any trends in direction compared with season (Table 12). All five study streams were examined together for any movement indications. Comparison of Movement Index values showed Christmas Creek had the least amount of movement, or lowest average values, and Honor Camp had just slightly higher than East and West Fork, and Octopus "B" Tributary (Table 13). An interesting note, however, is that in the "High" movement category, East Fork is the only stream with a high value occurring in April. This may be further evidence of stream instability. The fish might not be able to maintain a position in the stream because of bedload and debris movement. The only trend that did appear is that the most movement occurs in July and the least movement in October. The low movement in October might be explained by fish preparing for winter and stationing themselves near areas of suitable overwinter habitat. The high movement in July is consistent with a hypothesis proposed by Lestelle (1978). He stated that at this time of year the most

critical factor is food availability, and that cover, normally the primary factor, becomes secondary. Fish searching for food may risk being out in the open for better feeding areas.

Extensive Study

Christmas Creek, Honor Camp Creek, and Octopus "B" Tributary exhibited similar results to West Fork, the control stream, in trout and sculpin population estimates, biomass, density, pool-riffle measurements, seasonal mortality, and growth, i.e., they showed indications of a stable stream environment from 1978 to 1979. However, the events following logging predicted for East Fork are not supported by data gathered from these streams. The difference between the predicted logging effects in the intensive study streams and the observed effects in the extensive study streams can be explained by differences in habitat composition and yarding techniques.

The trout populations in East and West Fork rely almost entirely upon forest debris for habitat. Very few large boulders or cobbles were present in the stream channels. Because of this heavy reliance upon forest debris for habitat these streams could be more greatly influenced by logging than the extensive study streams.

The primary form of habitat in Christmas Creek, Honor Camp Creek, and Octopus "B" Tributary consisted of large boulders and large cobbles. Very little forest debris was available or utilized by fish in these streams. Habitat consisting of boulders and cobbles seems to be more stable than that of forest debris and may be able to better withstand adverse effects associated with logging. However, it cannot be

determined from this study which habitat type is better. West Fork and East Fork, for the moment, both support good-sized populations of trout, which indicates that forest debris is also a valuable component of habitat.

Yarding techniques differed considerably between East Fork and the extensive study streams. At Christmas Creek logs were yarded away from, and not across, the stream, and logs were flown above, not through, Octopus "B" Tributary, whereas in East Fork, logs were yarded in and across the stream. The techniques employed at Christmas Creek and Octopus "B" Tributary did not disrupt the streambed, wehre considerable damage was done in East Fork, and greatly increased the recovery period of these streams, and maintained stream stability.

Another factor contributing to the maintenance of trout population in the extensive study streams is that anadromous cutthroat trout had access to the study sections, thus creating a larger recruitment pool from which fish could now be drawn.

A considerable benefit received by the extensive streams was that of increased spring and summer temperatures. Christmas Creek and Octopus "B" Tributary exhibited large increases in mean monthly temperatures, especially in the period of April through October 1979 (Fig. 9). These temperatures approached and fell within, in several cases, the 12-17°C range, which is the preferred temperature range for salmonids (Welch and Wojtalik 1968). Averett (1969) determined that the maximum scope for growth for coho salmon was 14-17°C. The increase in temperature resulted in increased growth and average size of year-classes in both streams (Table 21). Honor Camp Creek had a nearly identical temperature profile

to West Fork because the canopy had regrown to a point that light was effectively filtered out before reaching the water surface. East Fork did not show a marked increase in temperature because the logged section was so short that solar heating would not have such a great effect.

The results of this study indicate that current logging practices are potentially damaging to streams, the extent of which would depend on its location, substrate, etc. Logging may have already permanently damaged many miles of small headwater streams. These streams greatly influence downstream waters which may be open to anadromous fish and may support large numbers of economically important commercial species. Resident trout utilize headwater streams as spawning and rearing areas which may contribute to populations in downstream areas, and to sport fisheries. Protection of headwater streams is vital for continued maintenance of good water quality and, therefore, healthy fish populations.

It should be pointed out that while I have interpreted the results of this study to suggest a potential long-term reduction of population numbers and environmental quality, short-term effects in regard to population numbers have not shown this trend. Moreover, trends in population numbers in West Fork "C" Tributary show that a stream with some logging alteration can recover to prelogging productivity levels. Any evaluations of short-term changes in streams or stream ecology are susceptible to the bias of natural variability, which undoubtedly can affect one's interpretation of results.

LITERATURE CITED

Anderson, J. W. 1975. Fish habitat considerations in stream clean-up. In Logging Debris in Streams Workshop. Oregon State Univ., Corvallis. 13 pp.

Averett, R. C. 1969. Influence of temperature on energy and material utilization by juvenile coho salmon. Ph.D. Dissertation, Oregon State Univ., Corvallis, OR.

Bishop, D. M., and S. P. Shapley. 1963. Effects of log-debris jams on S.E. Alaskan salmon streams. Unpublished report. Inst. of Northern Forestry, Juneau, Alaska.

Bjornn, T. C. 1971. Trout and salmon movements in two Idaho streams as related to temperature, food, streamflow, cover, and population density. Trans. Amer. Fish. Soc. 100:423-438.

Brown, G. W. 1967. Temperature prediction using energy budget techniques on small mountain streams. Ph.D. Dissertation, Univ. Oregon State. 120 pp.

Brown, G. W., and J. T. Krygier. 1967. Changing water temperatures in small mountain streams. J. Soil Water Conserv. 22:242-244.

Buchanan, D. V., and P. S. Tate. 1975. Acute toxicity of spruce and hemlock bark to some estuarine organisms in Southeastern Alaska. J. Fish. Res. Board Can. [in press].

Bustard, D. R. 1973. Some aspects of winter ecology of juvenile salmonids with reference to possible habitat alteration by logging in Carnation Creek, Vancouver Island. Fish. Res. Board Can., Manuscript Report Series No. 1277.

Chapman, D. G. 1951. Some properties of the hypergeometric distribution with applications to zoological sample censuses. Univ. California Publ. Stat. 1:131-160.

Chapman, D. W. 1962. Effects of logging upon fish resources of the West Coast. Journal of Forestry. Vol. 60, No. 8.

Chapman, D. W., and T. C. Bjornn. 1969. Distribution of salmonids in streams, with special reference to food and feeding. Pages 153- 176 in T. G. Northcote, ed. Symposium on salmon and trout in streams. Inst. Fish., Univ. British Columbia.

Cummins, K. W. 1974. Structure and function in stream ecosystems. Biosci. 24(11):631-641.

Davis, H. S. 1953. Culture and disease of game fish. Univ. California Press. 332 pp.

Froehlich, H. A. 1973. Natural and man-caused slash in headwater streams. Loggers Handbook. Vol. 23.

Froehlich, H. A., McGreer, and J. R. Sedell. 1972. Natural debris within the stream environment. In Coniferous Forest Biome.

United States International Biological Program. Internal Report 96.

Fuss, H. (in preparation). Life history characteristics and biology of cutthroat of some coastal tributaries based on scale interpretation. M.S. Thesis, Univ. Washington, Seattle.

Giger, R. D. 1973. Streamflow requirements of salmonids. Oregon Wildl. Comm., Federal Aid Program. Rep. Fish. AFS - 62. Job Final Rep.

Hall, J. D., and C. O. Baker. 1975. Biological impacts of organic debris in Pacific Northwest streams. In Logging Debris in Streams Workshop. Oregon State Univ., Corvallis. 13 pp.

Hall, J. D., M. L. Murphy, and R. S. Ahv. 1978. An improved design for assessing impacts of watershed practices on small streams. Verh. int. Ver. Limnol., Vol. 20. 13 pp.

Hall, J. D., and R. L. Lantz. 1969. Effects of logging on the habitat of coho salmon and cutthroat in coastal streams. Pages 353-375 in T. G. Northcote, ed. A Symposium on Salmon and Trout in Streams. Univ. British Columbia, Vancouver.

Heede, B. H. 1975. Flow and channel characteristics of two high mountain streams. U.S. Dep. Agric., For. Serv., Rocky Mountain Forest and Range Experimental Station Research Paper RM-96. 12 pp.

Larkin, P. A., and Graduate Students. 1969. The effects on freshwater fisheries of man-made activities in British Columbia. Can. Fish. Cult. 25:27-59.

Lestelle, L. C. 1978. The effects of forest debris removal on a population of resident cutthroat trout in a small headwater stream. M.S. Thesis, Univ. Washington, Seattle. 86 pp.

Martin, J. M. 1976. The effects of sediment and organic detritus on the production of benthic macroinvertebrates in four tributary streams of the Clearwater River, Washington. M.S. Thesis, Univ. Washington, Seattle. 79 pp.

McNeil, W. J. 1966. Effects of the spawning bed environment on reproduction of pink and chum salmon. U.S. Fish Wildl. Serv. Fish. Bull. 65(2):495-523.

Meehan, W. R., W. A. Farr, D. M. Bishop, and J. H. Patrick. 1969. Some effects of clearcutting on salmon habitat of two southeast Alaskan streams. Pac. Northwest Foresty and Range Experimental Station USDA Forestry Service Research Paper PNW-82. 45 pp.

Miller, R. B. 1957. Permanence and size of home territory in stream-dwelling cutthroat trout. J. Fish. Res. Board Can. 14(5):687-691.

Narver, D. W. 1972. A survey of some possible effects of logging on two eastern Vancouver island streams. Fish. Res. Board Can. Tech. Rep. No. 323. 55 pp.

Peters, G. B., H. J. Dawson, B. F. Hrutfiord, and R. R. Whitney. 1976. Aquaeous leachates from western red cedar: effects on some aquatic organisms. J. Fish. Res. Board Can. 33:2703-2709.

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

Seber, G. A. F. 1973. The estimation of animal abundance and related parameters. Griffin, London.

Sedell, J. R., and F. J. Triska. 1976. Biological consequences of large organic debris in Northwest streams. In Logging Debris in Streams workshop. Oregon State Univ., Corvallis. 13 pp.

Shapovalov, L., and A. C. Taft. 1954. The life histories of the steelhead rainbow trout Salmo gairdneri gairdneri, and silver salmon, Oncorhynchus kisutch. California Dep. Fish Game, Fish. Bull. 98. 375 pp.

Swanson, F. J., and G. W. Lienkaemper. 1976a. Physical consequences of large organic debris in Northwest streams. In Logging Debris in Streams Workshop. Oregon State Univ., Corvallis. 13 pp.

Swanson, F. J., and G. W. Lienkaemper. 1976b. The history and physical effects of large organic debris in Western Oregon streams. In Logging Debris in Streams Workshop. Oregon State Univ., Corvallis. 13 pp.

Tagart, J. V. 1976. The survival from egg deposition to emergence of coho salmon in the Clearwater River, Jefferson County, Washington. M.S. Thesis, Univ. Washington, Seattle. 101 pp.

Van Wagner, C. E. 1968. The line intersect method in forest fuel sampling. Forest Science. 14:20-26.

Washington Forest Practices: Rules and Regulations. 1976. Washington For. Practices Bd. July 16, 1976. Pp. 10-11.

Welch, E. B., and T. A. Wojtalik. 1968. Some aspects of increased water temperature on aquatic life. Tennessee Valley Auth., Chattanooga, TN. 48 pp.