THE EFFECTS OF COARSE GRANITIC SEDIMENT ON THE DISTRIBUTION AND ABUNDANCE OF SALMONIDS IN THE CENTRAL IDAHO BATHOLITH

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ABSTRACT

The effects of coarse granitic sediment on the abundance, distribution, growth, and behavior of juvenile salmonids and the abundance of aquatic insect drift were assessed by adding sediment to artificial and natural stream channels. These data were compared to two natural streams in the central Idaho batholith which already contained large amounts of sediment by correlating fish and insect drift abundance with percentage riffle sediment, riffle size, percentage cover in the pools, and average pool substrate imbeddedness.

Densities of juvenile steelhead trout (*Salmo gairdneri* Richardson), chinook salmon (*Oncorhynchus tshawytscha* (Walbauum)), and cutthroat trout (*Salmo clarki* Richardson) in the artificial stream channels decreased as we increased the amount of sediment in the channels. The densities of fish remaining in the channels during the winter tests (water temperature below 5 C) were smaller than in the summer tests (water temperature above 5 C).

Total insect drift density was not affected by the addition of sediment to the riffles in the artificial streams, but evidence of a community shift to Diptera was observed.

Addition of sediment into Knapp Creek reduced fish densities due to loss of cover and pool volume. Insect benthos and drift abundance was not significantly changed.

Fish density correlated best with cover and insect drift density in the natural streams studied. Sediment altered the amount and quality of cover in the pools studied. Insect drift density correlated best with riffle size, and to a lesser degree with percentage sediment in the riffles.

INTRODUCTION

This study was part of an interdisciplinary effort (fisheries, entomology and engineering) to: 1) develop a model and collect field data for verification that can be used to predict the transport of bedload sediment in mountain streams, 2) to quantify changes in habitat for aquatic organisms as sediment is added to natural and laboratory stream channels, 3) to assess the short and long-term effects of sediment on the distribution and abundance of fish and aquatic insects, and 4) to develop criteria useful to resource managers in predicting potential sediment problems and possible impacts upon the aquatic resources of a stream. Engineering was concerned with the first objective and entomology and fisheries with the last three.

The objectives of the fisheries portion of the study as concerned the artificial stream channels were to add sediment to the channels in summer and winter and assess the effects on: 1) fish density, 2) fish food habits, 3) fish behavior, 4) fish growth and condition, and 5) insect drift abundance. Sediment was also introduced into a natural stream previously containing little sediment to assess the effects on fish density and fish distribution. Correlational stream surveys were conducted on two streams in the central Idaho Batholith to correlate fish density in pools with: 1) percentage sediment in riffles, 2) percentage sediment in pools, 3) percentage cover in pools, 4) insect drift density, and 5) riffle size.

During the 1964-65 winter storms large amounts of coarse granitic sediment entered the South Fork of the Salmon River. The sediment filled pools and imbedded riffles in the river, reducing the available fish habitat. Logging activities, road building, and forest fires coupled with high run-off were named as the causes of this sediment deposition (Corley, 1975; Platts, 1972 and 1974). The Idaho Batholith is characterized by steep slopes and easily-eroded soils (Megahan, 1972), thus susceptible to watershed disturbances.

Changes in both the physical and biological characteristics of this river resulted from the large amount of granitic sediment that entered the river. The majority of the studies that have been done on these changes have been concerned with the degradation of spawning habitat and resultant egg to emergence mortalities of salmon and steelhead. Little work has been done on the effects of granitic sediment on the rearing capacity of a stream for juvenile salmon and steelhead. In order to better understand the relationships surrounding these effects and arrive at conclusions and recommendations to reduce the possibility of similar degradation in other streams, a study was initiated in 1972 in the Idaho Batholith (Stuehrenberg, 1975). The present study, initiated in 1974, is a continuation of the previous research.

STUDY SEGMENTS

This study involved three major segments: 1) artificial stream studies in which we introduced sediment (less than 6.3 mm in diameter) into laboratory stream channels and monitored the effects on fish and insect abundance, 2) the Knapp Creek study in which we introduced sediment into a natural stream channel and monitored the effects on fish and insect populations, and 3) correlational stream surveys on Elk and Bearskin Creeks in which I correlated physical parameters to differences in fish and insect distribution and abundance. The study area locations are presented in Figure 1.

Artificial Stream Studies

We used four artificial stream channels located at Hayden Creek Research Station in laboratory studies to determine the effects of granitic sediment on fish and insect populations. We added sediment to test channels in the summer and fall to determine the effects of sediment on the summer and winter holding capacities of the channels and winter hibernating behavior of the fish.

The pool and riffle configuration we constructed in the channels were identical in all the channels. Traps installed at the downstream ends of the channels captured emigrating fish, and drum screens at the uppermost ends of the channels prevented fish from entering or leaving.

We piped insects into the channels from Hayden Creek during the summer of 1974 to colonize the channels with a natural population. We didn't use the insect supply line in 1975, but insect production within the channels along with insects in the inlet water supply adequately supported the densities of fish used in the tests in 1975.

Knapp Creek Study

During August of 1974 we introduced coarse granitic sediment (less than 6.35 mm in diameter) into a section of Knapp Creek. The purpose of this study was to determine the effects of granitic sediment on fish and insect distribution and abundance in a section of natural stream where little sediment occurred naturally. The sediment addition was similar to a natural bank slumpage into the stream.

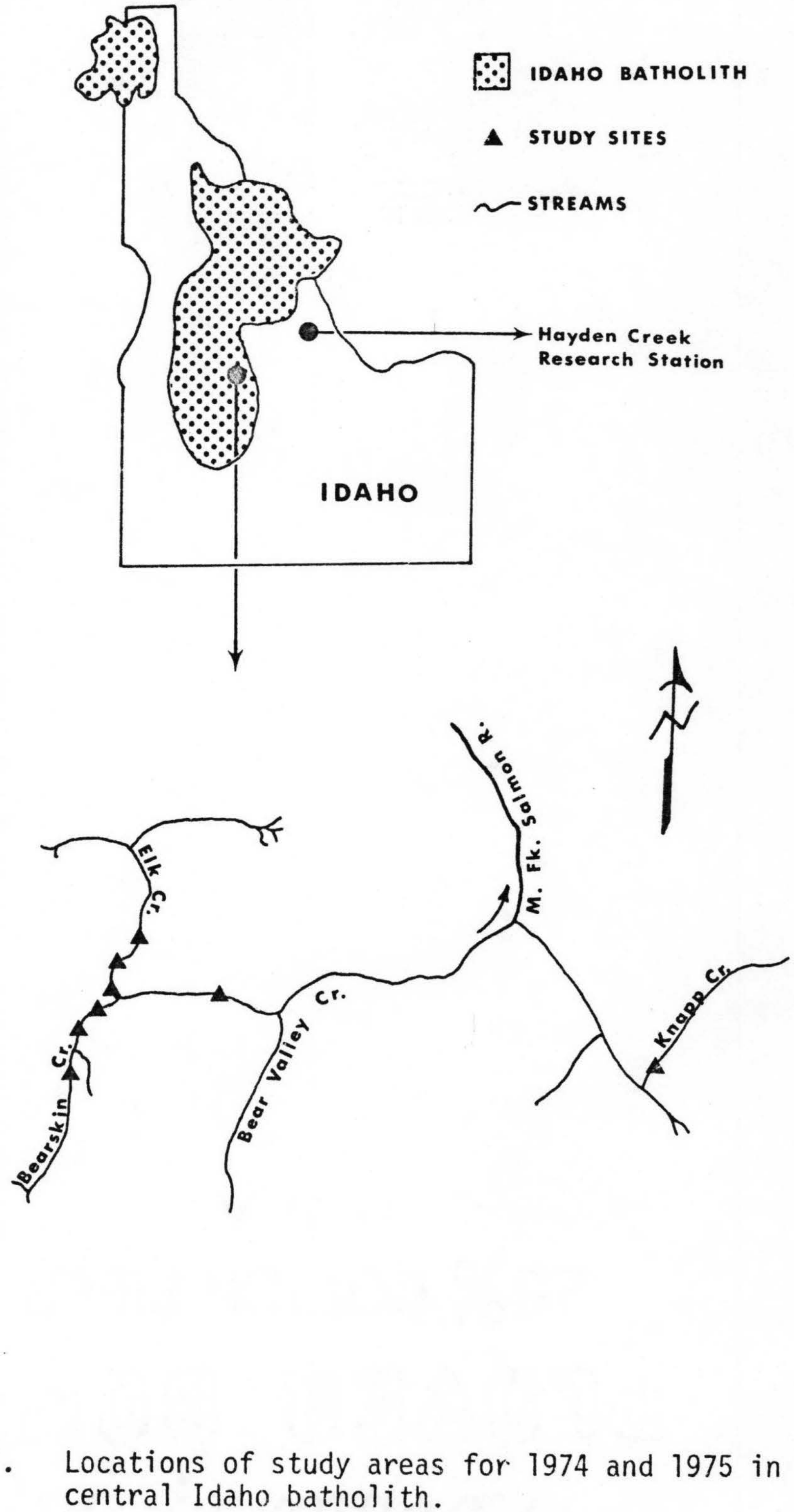

Figure 1. Locations of study areas for 1974 and 1975 in the central Idaho batholith.

The section of stream we studied flowed through a meadow, had a low gradient, and a pool-riffle configuration. We measured fish and insect distribution and abundance prior to and after the addition of sediment in the test area and in control areas (upstream and downstream from the affected section of stream). We added sediment in three steps to the test area and monitored the percentage of sediment in the substrate before and after the additions.

Fish and insect abundance in the test and control sections was measured in August of 1975 to assess any long-term effects of sediment added in 1974.

Correlational Stream Surveys

During the summer of 1975 I assessed fish and insect abundance in Elk and Bearskin Creeks in relation to the amount of sediment in riffles to determine if a correlation existed. Elk and Bearskin Creeks had low gradients and flowed through meadows. I selected pool-riffle combinations as study sites. These streams contained natural populations of chinook salmon (*Oncorhynchus tshawytscha* (Walbaum)), steelhead trout (*Salmo gairdneri* Richardson), and mountain whitefish (*Prosopium williamsoni* (Girard)).

METHODS

Artificial Stream Studies

We evaluated the effects on fish of sediment added to pools by assessing the number of fish which would remain in channels without sediment versus channels with varying amounts of sediment. Each of the four artificial stream channels measured 21 meters (m) long, 1.2 m wide, and 0.6 m deep (Figure 2). I observed fish in the channels through plexiglas windows located every 2.4 m. Screens of parachute cloth draped along the channels reduced disturbance during behavior observations. Cobble averaging 0.15 m in diameter covered the riffles (Plate 1). The pools contained a zig-zag pattern of boulders (0.3 m average diameter) which afforded cover and hiding places for fish (Plate 2). Traps at the downstream ends of the channels collected fish moving downstream out of the channels. Drum screens at the uppermost ends of the channels prevented fish from entering or exiting at the head ends. In 1974 we introduced insects from Hayden Creek through a collecting funnel and pipe into the headbox. In 1975 insect production within the channels and drift in the normal water supply from Hayden Creek adequately supported the densities of fish used in the tests. A minimum-maximum thermometer located in one channel recorded water temperatures throughout each test.

The procedure for each test followed this scheme: 1) sampling of insect drift at one hour before sunset until sunset, 2) introduction of sediment into the test channels (lower channels) to the desired amount, 3) sampling of insect drift and benthos, 4) introduction of test fish into all channels, 5) monitoring the fish emigration and behavior for five days, and 6) removal of remaining fish from the channels by electroshocking. In 1974 we measured the abundance of the insect benthos in the riffles, but not in 1975. I observed behavior of the fish in the morning, at mid-day, and in the evening just before twilight. I measured length of fish used in the tests at the start and end of each test.

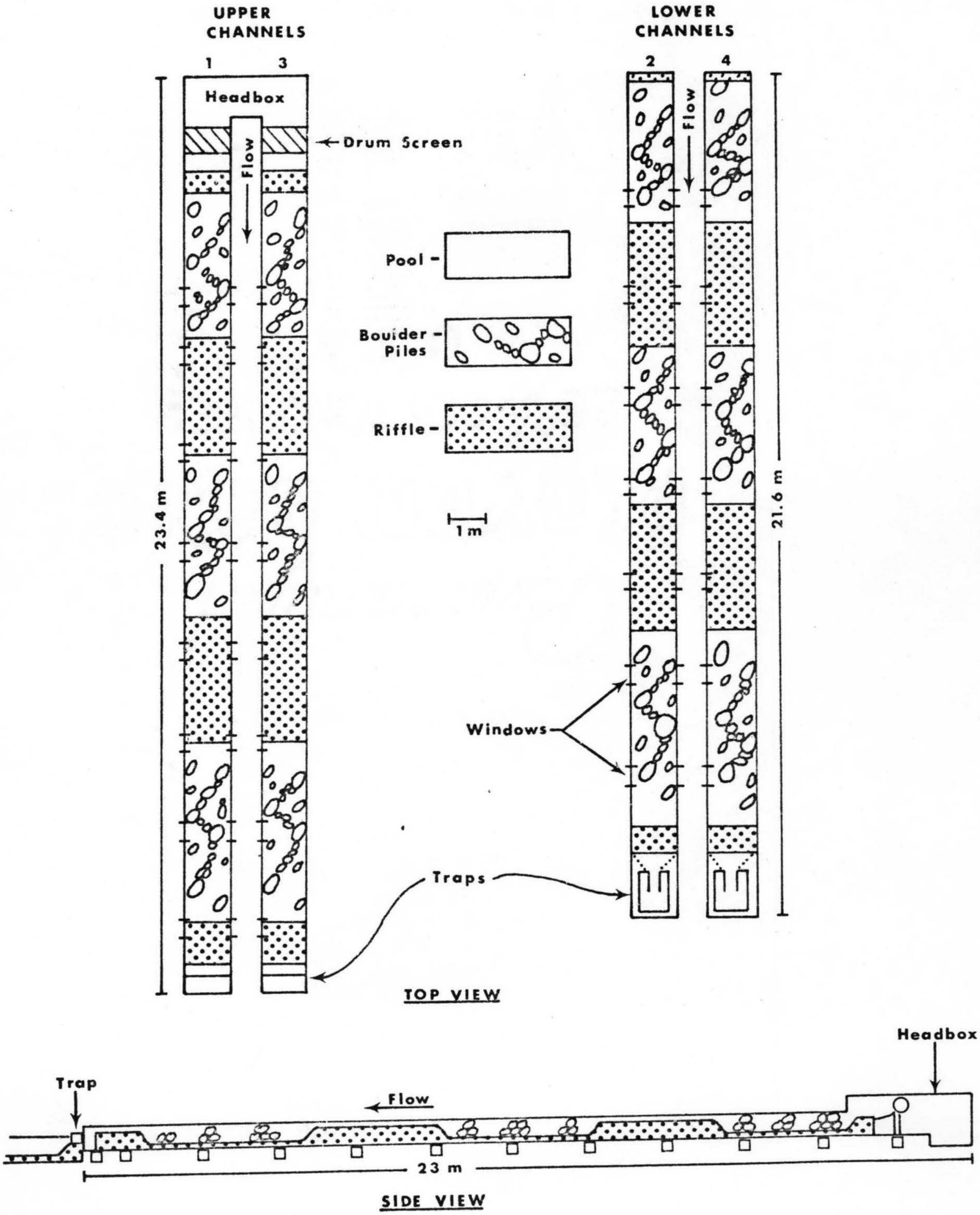

Figure 2. Artificial stream channels used in summer and winter holding capacity tests in 1974 and 1975.

Plate 1. A typical riffle in the artificial stream channels at Hayden Creek Research Station, 1974 and 1975.

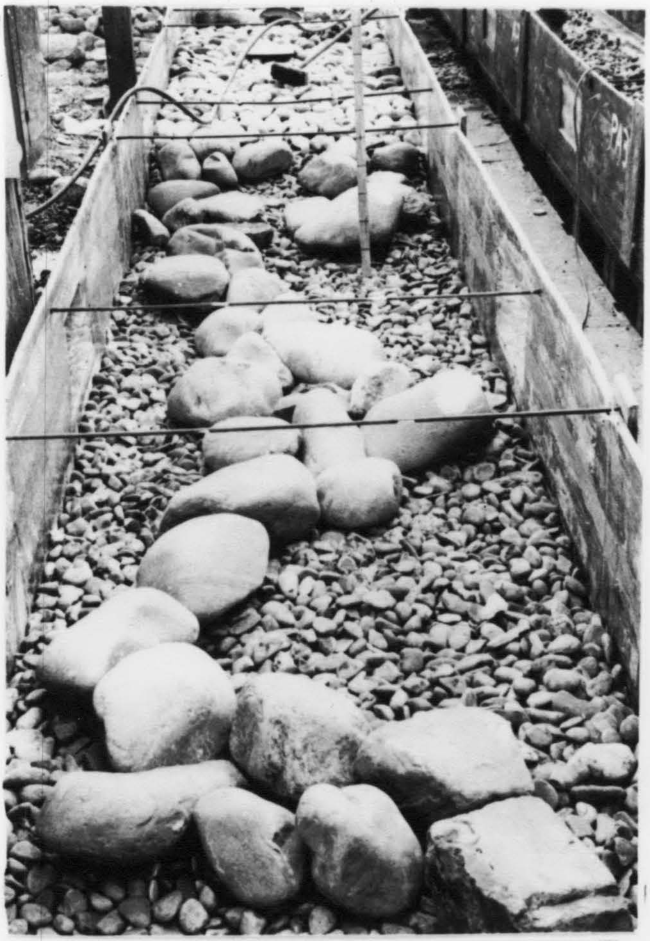

Plate 2. A typical pool in the artificial stream channels at Hayden Creek Research Station, 1974 and 1975.

I took stomach samples for food habit studies in the evening from the fish in the traps and at the end of each test from those fish electroshocked from the channels. Insect drift sampling corresponded to the times when stomach samples were taken. We positioned the drift nets (1.2 m wide) at three locations in each set of channels: 1) at the inlet to the upper channel, 2) at the downstream end of the upper channel, and 3) at the downstream end of the lower channel. This allowed for comparisons of drift arising from each channel and drift in the inlet water supply. Volumetric and numerical analysis of the samples (keyed to order) allowed comparisons of feeding habits and food availability.

We conducted five summer tests in 1974, four summer tests in 1975, and seven winter tests in 1975 (Table 1). We tested the effects of sediment on summer holding capacity for wild, age I steelhead (tests 1 - 3); wild, age 0 steelhead (test 4); hatchery, age 0 steelhead (tests 5, 6, & 9); wild, age 0 chinook salmon (test 8); and hatchery, chinook salmon (test 7). Growth differences were observed in test 9 by extending the test for 35 days and noting differences in the length, weight, and condition factor of fish in channels with and without sediment. We tested the effects of sediment on the winter holding capacity of the channels for hatchery, age 0 steelhead (tests 11, 13, & 16); wild, age 0 chinook salmon (tests 10, 12, & 13); wild, age I and II cutthroat trout (_Salmo_ _clarki_ Richardson) (test 15); and hatchery, age 0 cutthroat trout (test 14). Test 13 was run with both chinook salmon and steelhead together. The wild steelhead used in the tests came from Big Springs Creek, the hatchery steelhead and chinook from the Hayden Creek Research Station, and the wild chinook salmon from the Lemhi River. The hatchery cutthroat trout (Henry's Lake stock) used in the tests came from the Mackay Hatchery and the wild cutthroat from the St. Joe River. In 1974 the four channels contained fish and sediment during the tests as follows: channel 1) no fish, no sediment; channel 2) no fish, sediment; channel 3) fish, no sediment; and channel 4) fish, sediment (Figure 3). Channel 1 served as a control for channel 2, and channel 3

Table 1. Tests conducted at Hayden Creek Research Station in the artificial stream channels during the summers of 1974 and 1975 and the fall of 1975.

Test number	Type of test	Date of test	Imbeddedness	Test duration	Repetitions	Fish species	Age	Average total length
1	summer	8/9/74	1/3	5 days	1	wild SH [1]	I	173 mm
2	"	8/15/74	2/3	"	"	"	"	167
3	"	8/23/74	full	"	"	"	"	163
4	"	9/1/74	"	"	"	"	0	71
5	"	8/31/74	"	"	"	hatchery SH	"	61
6	"	7/26/75	1/2	"	2	"	"	54
7	"	8/5/75	"	"	"	hatchery CK [2]	"	111
8	"	8/14/75	full	"	"	wild CK	"	96
9	"	8/23/75	"	35 days	"	hatchery SH	"	53
10	winter	10/19/75	1/2	5 days	2	wild CK	0	98
11	"	10/26/75	"	"	"	hatchery SH	"	116
12	"	10/31/75	full	"	"	wild CK	"	104
13	"	11/5/75	"	"	"	hatchery SH	"	106
						& wild CK	"	122
14	"	11/9/75	"	"	1	hatchery CT [3]	"	59
15	"	11/9/75	"	"	"	wild CT	I,II	134
16	"	11/13/75	"	"	2	hatchery SH	0	119

[1] steelhead trout = SH

[2] chinook salmon = CK

[3] cutthroat trout = CT

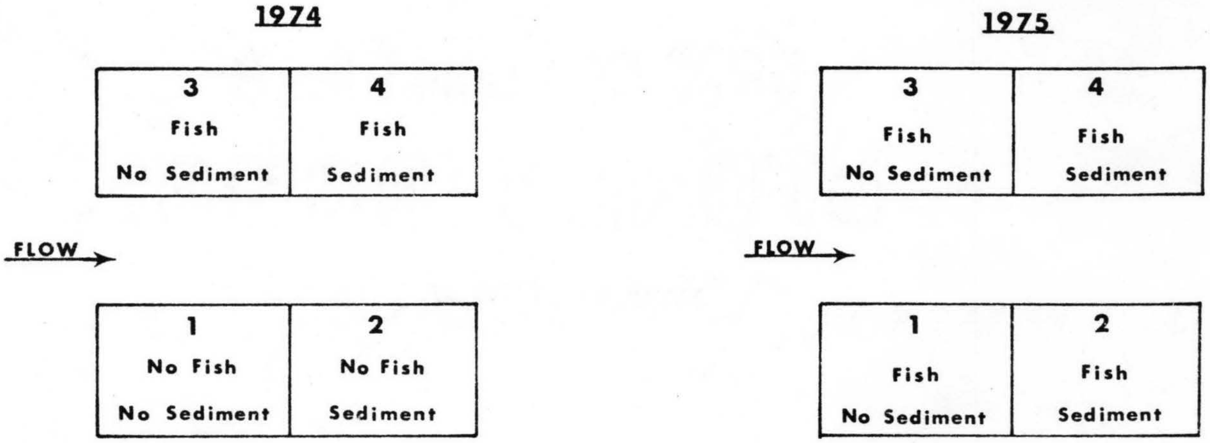

Figure 3. Schematic representation of the experimental set-up of the Hayden Creek artificial stream channels during the tests of 1974 and 1975.

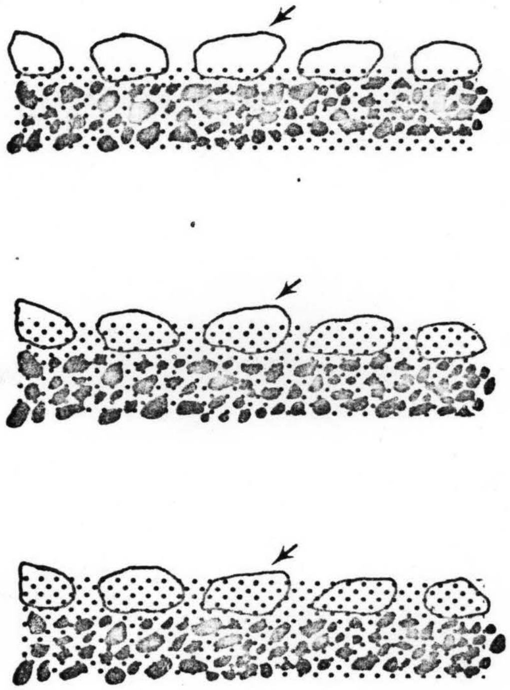

Figure 4. Diagramatic representation of three cobble imbeddedness levels.

served as a control for channel 4. In 1975 I ran two replicates for most of the tests, using channels 1 and 3 as controls (fish, no sediment) for channels 2 and 4 (fish, sediment), respectively (Figure 3).

In 1974 we added sediment to the test channels in three levels of imbeddedness: one-third, two-thirds, and full. In 1975 I used two levels of imbeddedness: one-half and full. Imbeddedness was defined as the level to which a key rock was surrounded by a smaller size material, in this case coarse granitic sediment (less than 6.35 mm diameter) (Figure 4). Either a predetermined size of rock was used as a key (as in imbedding the pools), or the dominant size was used (as in imbedding the riffles). We added more sediment to the pools than to the riffles due to the larger size of the rocks in the pools to achieve similar imbeddedness in pools and riffles.

Knapp Creek Study

In August of 1974 we introduced coarse granitic sediment (less than 6.35 mm diameter) into a test section of Knapp Creek to assess the effects of sediment in a stream where little sediment occurred naturally. Our sediment addition simulated a natural bank slumpage into a riffle in the stream.

Knapp Creek was selected because it contained natural populations of steelhead and chinook salmon, was small enough to work with easily, and was easily accessible by road. The stream at the study site flowed through a meadow with low gradient and a pool-riffle configuration. The study site was representative of the lower section of Knapp Creek.

We mapped the study section using a survey transit. We set up two control areas, an upper and a lower, with the test section between them (Figure 5). The surface areas of these sections were: upper control - 506.8 m^2, lower control - 233.4 m^2, and test section - 290.8 m^2. The length of the study section was 165 meters. We measured water depths and velocities along transects in the study section to obtain volumes, fish densities, depth contours, and habitat preferences of fish observed.

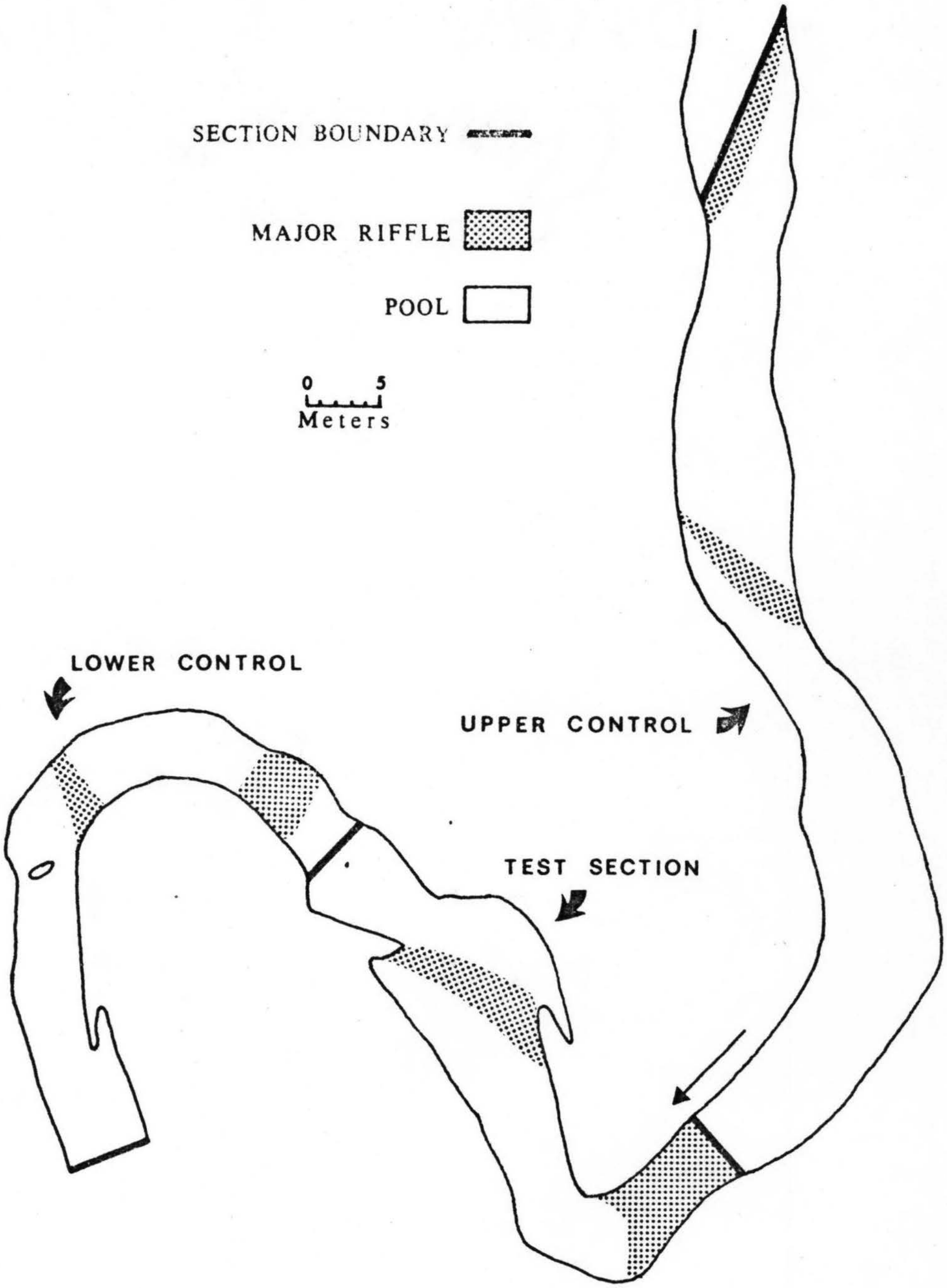

Figure 5. The Knapp Creek study area where we introduced coarse granitic sediment into the test section in 1974.

We assessed the amount of sediment in the substrate in the test section before, during, and after each addition of sediment. We took core samples from the riffle substrate in a random manner with a modified sampler described by McNeil and Ahnell (1960) (Plate 3). We volumetrically analyzed the samples using the following sizes of sieves: 37.50 mm, 18.85 mm, 9.42 mm, 6.35 mm, 4.70 mm, and 2.36 mm. We also classified the surface of the substrate at each core sampling location with a modification of Prather's (1971) classification (Table 2).

We counted the number of fish and noted their location in each section by snorkeling. A person on the bank plotted the fish numbers and locations on maps of the study sections while I snorkeled through the area. These numbers and locations were used to determine densities and preferred habitat in terms of depth and velocity for the fish species observed. Age of chinook was designated as age 0 and I, and steelhead as age 0 and age I and older. I snorkeled the study sections prior to the first, one day after the first, 1 and 4 days after the second, and 3 and 13 days after the third additions of sediment to the stream.

Insect benthos in the test section and upper control was sampled prior to the first addition of sediment and 1, 3, 14, and 23 days after the last addition. The substrate at each benthos sampling site was classified as per Prather (1971). We also classified other portions of the substrate in the study area.

In August of 1975, I conducted a follow-up survey of the Knapp Creek study area. I mapped the site and obtained fish densities to determine if there were any long-term effects from the sediment additions.

Correlational Stream Surveys

I selected 15 pool-riffle complexes on Elk Creek and eight such sites on Bearskin Creek to correlate fish densities, fish size and insect drift abundance with the amount of sediment in riffles, size of riffles and pools and cover for fish (Figure 6). We mapped

Plate 3. The substrate core sampler used to sample for percentage sediment in the riffles in 1974 and 1975.

Table 2. Modified ranked sediment scheme (from Prather, 1971) used to classify stream bottom substrate.

Dominant sbustrate

Rank	Substrate size
1	less than 1.5 mm in diameter
2	1.5 - 6.35 mm in diameter
3	6.35 - 25.4 mm in diameter
4	25.4 - 63.5 mm in diameter
5	greater than 63.5 mm in diameter

Imbeddedness of dominant substrate

Rank	
1	nearly 100% imbedded (heavy)
2	75% imbedded (moderate)
3	50% imbedded (intermediate)
4	25% imbedded (light)
5	unimbedded

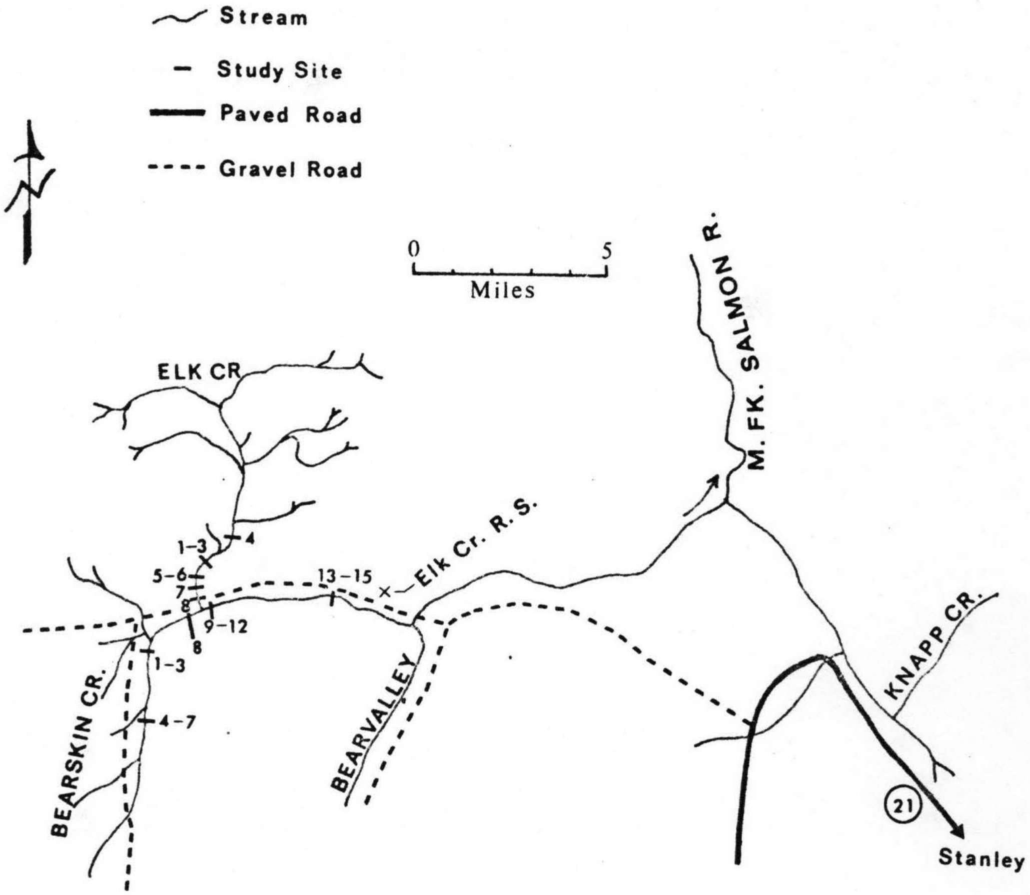

Figure 6. Correlational survey study sites on Elk and Bearskin Creeks in the central Idaho batholith.

the sites using a baseline method. We selected the sites to provide a wide range of sediment concentrations in the riffles. Elk Creek is about 11 miles long, and Bearskin Creek about 7 1/2 miles long. Discharges in early September of 1975 were 0.84 cubic meters per second (cms) for upper Elk Creek (mile 5) and 1.30 cms for lower Elk Creek. Bearskin Creek had a flow of 0.28 cms at the mouth at this same time.

I obtained fish densities in the same way as on Knapp Creek. I snorkeled through the sites, counted fish by species and age and converted these numbers to densities. Fish densities were expressed as fish per square meter. Only the area of preferred habitat (depth greater than 0.15 m) was used in the density calculations.

Samples of insect drift at each site were taken at one hour before sunset for one hour with 0.7 mm mesh nylon drift nets. Two nets were placed at the downstream end of each riffle and the samples combined for analysis. The nets were positioned to each side of the main flow over the riffle. We measured velocities through the nets so we could calculate the volume of flow through the nets. Weather conditions and sunset times were recorded for each sampling. The samples were preserved in 70% ethanol and the insects keyed to order and numerically and volumetrically analyzed. Drift was expressed as numbers and volume per cubic meter of flow.

I estimated the percentage of substrate material smaller than 6.35 mm in diameter in each riffle from five core samples (taken randomly) from the substrate of each riffle. I analyzed the samples volumetrically using the same set of sieves used on Knapp Creek. We compared the mean percentage of sediment in each riffle with an analysis of variance and a multiple range test of the means (Steel and Torrie, 1960). A value for the average pool imbeddedness was assigned to each site. I also classified the surface of the substrate at each core sampling site.

Cover was evaluated in each study site using a two-type classification. Surface cover (type 1) included overhanging vegetation, under-cut banks, and surface turbulence. Bottom cover (type 2) included boulders and logs laying in the bottoms of the pools. Both types of cover were expressed as percentages of the total pool area.

A minimum-maximum thermometer at each site recorded the temperature range during the period of data collection. These data were then compared among sites in each stream to account for possible variability due to temperature differences.

I conducted a test to increase the fish density by adding wild age 0 chinook salmon to pools. The hypothesis tested was H_0: The addition of fish to pools downstream from riffles with large or small amounts of sediment will not increase the density. The sites for this test had a range of sediment concentrations in the upstream riffles. I observed and counted the fish after 24 hours to determine if the densities had changed after the addition of fish.

RESULTS

Artificial Stream Studies

The immediate effects of adding sediment to the channels were a reduction in available habitat (depth of pools and filling of interstices in boulder piles in the pools and cobble in the riffles) and an increase in the turbidity of the water.

The turbidity decreased within minutes after the additions of sediment. The reduction in cover for fish (mainly in the pools) and habitat for insects (in the riffles) affected both organisms.

Summer Tests - Fish

Fish densities in the channels stabilized within three to four days after the traps were opened and fish allowed to leave (Figure 7). We released more fish into each channel than would remain to insure that the channels would be at carrying capacity.

Fewer fish remained in the channels with sediment than without sediment in the summer holding capacity tests of 1974 and 1975 (Table 3 and Figure 8). The number of wild, age I steelhead remaining in the channel with sediment was 86, 40 and 11% of the numbers staying in the channel without sediment at 1/3, 2/3, and full imbeddedness of the rubble in the pools. Fewer wild, age 0 steelhead remained in the fully sedimented channel than in the unsedimented channel (test 4, 68% of the number in the unsedimented channel) but the reduction was not as large as for wild, age I steelhead.

More of the smaller age 0 steelhead remained in the channels (sedimented and unsedimented) than did the age I steelhead. Densities of hatchery, age 0 steelhead in the channels with sediment were 94 and 32% of those in unsedimented channels at 1/2 and full imbeddedness in the pools, respectively. Fewer hatchery, age 0 steelhead (test 5) remained in the fully sedimented channels than did wild, age 0 steelhead (test 4).

Age 0, hatchery chinook in the 1/2 imbedded channel was 39% of the density in the unsedimented channel (test 7). We did not have time to test age 0, hatchery chinook at full imbeddedness. The density of age 0, wild chinook in the fully imbedded channel was only 3% of the density in the unsedimented channel (test 8, Figure 8).

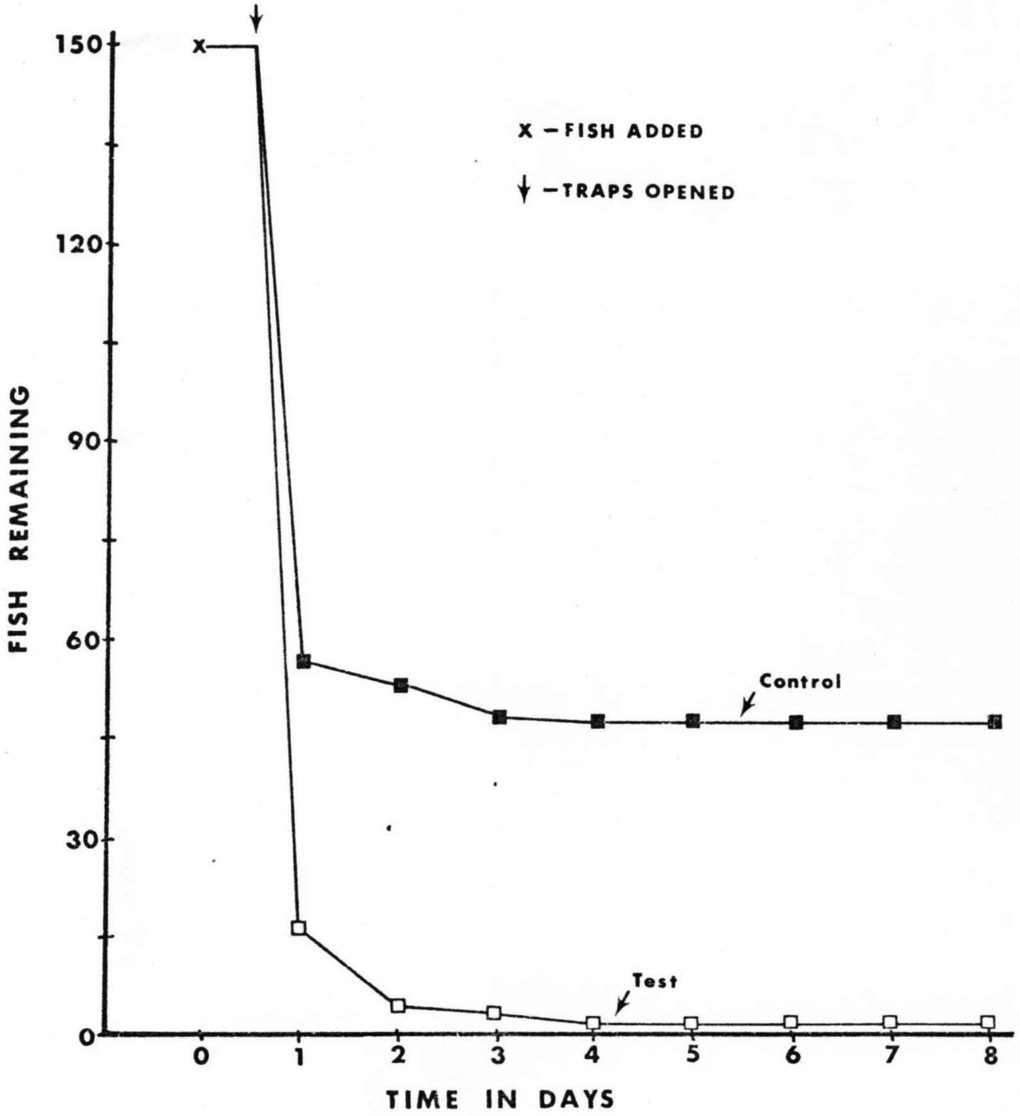

Figure 7. Changes in fish numbers with time in the artificial stream channels. Data is for test 8, wild age 0 chinook (test = fully imbedded with sediment, control = no sediment).

Table 3. Fish remaining in the artificial stream channels during the summer tests of 1974 and 1975.

Test number	Channel number	Imbeddedness levels	Fish introduced: Species/age	Number	Fish remaining after five days: Number	% of fish added	Fish/m^2	mean density
1	3	0	W,SH/1 [1]	60	48	80.0	3.12	3.12
	4	1/3	"	58	28	48.3	2.63	2.63
2	3	0	W,SH/I	60	48	80.0	3.12	3.12
	4	2/3	"	60	17	28.3	1.15	1.15
3	3	0	W,SH/I	60	46	76.7	2.99	2.99
	4	full	"	60	5	8.3	0.34	0.34
4	3	0	W,SH/0	150	127	84.7	8.10	8.10
	4	full	"	150	82	54.7	5.54	5.54
5	3	0	H,SH/0	150	126	84.0	8.20	8.20
	4	full	"	150	41	27.3	2.77	2.77
6	1	0	H,SH/0	225	195	86.7	8.46	8.83
	2	1/2	"	"	185	82.2	8.11	
	3	0	"	"	212	94.2	9.20	8.26
	4	1/2	"	"	192	85.3	8.42	
7	1	0	H,CK/0 [2]	100	26	26.0	1.73	1.90
	2	1/2	"	"	8	8.0	0.51	
	3	0	"	"	31	31.0	2.07	0.77
	4	1/2	"	"	16	16.0	1.03	

[1] Steelhead trout

[2] Chinook salmon

Table 3. Continued.

Test number	Channel number	Imbeddedness levels	Fish introduced:		Fish remaining after five days:			
			Species/age	Number	Number	% of fish added	Fish/m^2	mean density
8	1	0	W,CK/O	150	48	32.0	3.20	3.06
	2	full	"	"	2	0.1	0.13	
	3	0	"	"	44	29.3	2.93	0.06
	4	full	"	"	0	0.0	0.00	
9	1	0	H,SH/O	300	300	100.0	13.02	13.02
	2	full	"	"	53	17.7	2.32	
	3	0	"	"	300	100.0	13.02	1.64
	4	full	"	"	22	7.3	0.96	

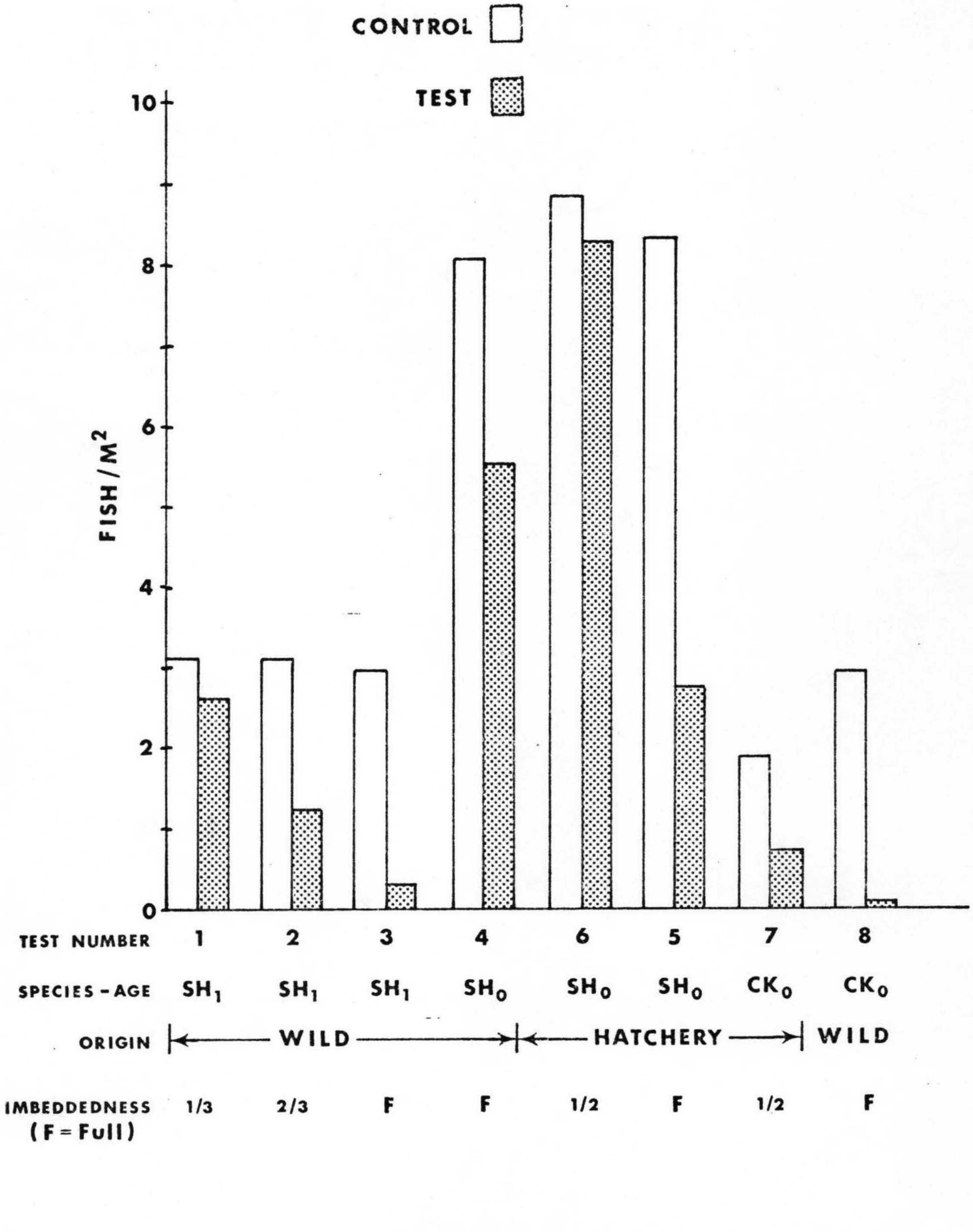

Figure 8. Densities of fish remaining after five days in the artificial stream channels during the summer tests of 1974 and 1975. (control = no sediment, test = sedimented; SH_1 = age I steelhead, CK_0 = age 0 chinook; 1/3 imbeddedness = boulders in pools 1/3 imbedded with sediment.)

Fish exhibited hierarchical behavior in the channels with 2/3 or full imbeddedness of sediment, but territorial behavior in the channels without sediment. As we increased the imbeddedness level in the channels with sediment, the amount of available cover decreased in both pools and riffles. The smaller age 0 steelhead utilized the riffles as well as the pools in the control channels and in the test channels with 1/3 levels of imbeddedness. As we increased the imbeddedness of the riffles, the age 0 steelhead using the riffles moved into the pools. As cover became increasingly scarce, hierarchical behavior predominated in the pools. The main holding areas for fish were at the upstream and downstream areas of the pools.

Fish in the control channels exhibited territorial behavior patterns. As cover did not decrease from one test to another, and densities remained high, this type of behavior predominated. Fish selected holding areas in the pools and riffles within one-half hour after introduction into the channels. These territories remained essentially the same throughout the test.

I extended one 5-day test to 35 days to monitor the effects of full sediment imbeddedness on the growth of age 0, hatchery steelhead (Figure 9). Densities of fish in channels with or without sediment decreased during the test, perhaps a response to fish growth. The density of fish in the fully sedimented channel stabilized at 12% of the density in the unsedimented channel after 35 days (Figure 9), a smaller density than at the end of 5 days (test 5, Figure 8). Fish in both the sedimented and unsedimented channels grew in length and weight, but fish in the unsedimented channel at the end of the test were longer and weighed more than fish in the sedimented channels. Even though the control fish were longer and weighed more than the test fish at the end of the experiment, the condition factor (k) of the control fish had decreased while the condition factor of the test fish was unchanged.

Few of the age I steelhead and age 0 chinook I examined in 1974 had food in their stomachs. The reason for littel food in the stomachs could be a result of acclimation to the channels or perhaps

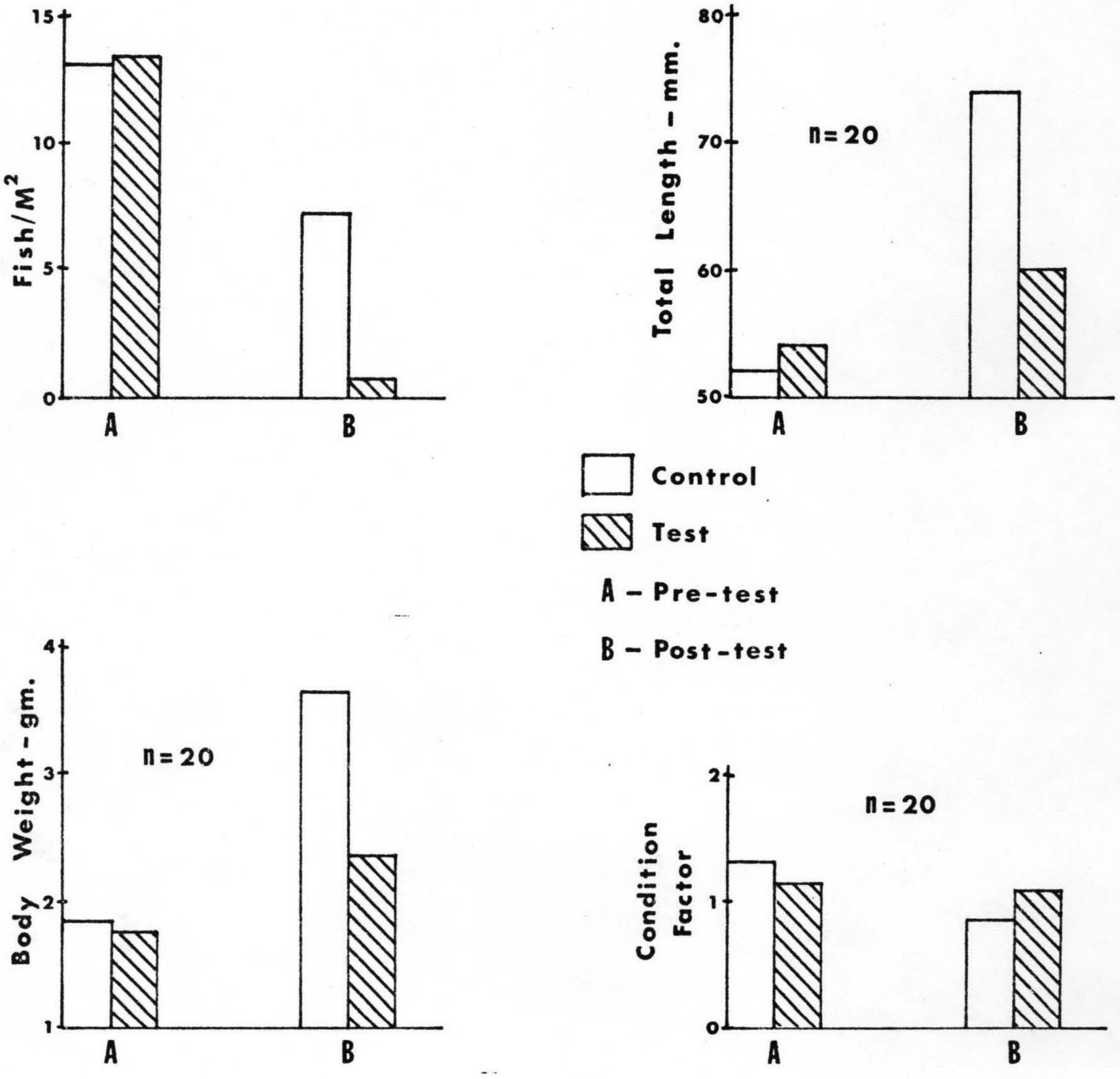

Figure 9. Results of the 35-day test in the Hayden Creek stream channels using age 0, hatchery steelhead trout at full imbeddedness, 1975. (control = no sediment, test = sediment.)

the small size of the insects in relation to the size of the fish.

Fish showed equivalent preferences for Diptera and Ephemeroptera during tests 6 and 7, 1975 (Table 4). Age 0 chinook and steelhead in tests 8 and 9 (1975) showed some preference for Ephemeroptera over Diptera (Table 4). Increased length of fish in tests 8 and 9 could account for this shift in preference, larger fish selecting larger food items.

Summer Tests - Insects

During the first three tests (during 1974) the entomology student sampled the insect drift at sunset and two and a half hours after sunset (midnight drift). Insect drift at sunset is probably most important in terms of food for fish (Jenkins, Feldmeth, and Elliott, 1970). Although midnight drift is of little importance in terms of food availability for fish, the largest numbers in the diurnal periodicity occur during this time for a number of species (Anderson, 1965; Brusven, 1970; Waters, 1969 and 1962). We sampled drift at midnight to obtain an idea of maximum drift and to compare the abundance of organisms in the drift at sunset to those at midnight. Organisms were enumerated only as Ephemeroptera and total insects. Adults and pupae were not included in the enumerations for midnight and sunset drift.

Insect drift at sunset during tests 1, 2, and 3 in 1974 was not related to imbeddedness level (Figure 10). Ephemeropterans were most abundant in channels with or without sediment. Total numbers of drifting insects was not substantially different in channels with or without sediment.

Insects drifting at midnight during tests 1, 2, and 3 in 1974 were mostly Ephemeropterans of the genus Baetis (Figure 11). A detrimental impact on the abundance of insect drift from adding sediment to the riffles in 1974 was not evident in either the data for each test or in the averages for the tests combined (Figure 12). Midnight insect drift was six times more abundant than insect drift at sunset in the inlet water supply and 4 to 6 times more abundant in the channels (Figure 12). I attribute the drop in drift rate

Table 4. Average numbers and percentages of Diptera, Ephemeroptera, and terrestrial insects occurring in the stomachs of age 0 chinook and steelhead in tests 6, 7, 8, and 9, 1975.

						Average numbers			% of total numbers		
Test number	Fish species	Channel number	Imbeddedness	"n"	"n" with food	Diptera	Ephemeroptera	Total	Diptera	Ephemeroptera	Terrestrial
6	SH_0[1]	1	0	9	6	7	5	14	50	36	7
		2	1/2	10	5	3	9	16	19	56	19
		3	0	11	7	7	7	18	39	39	17
		4	1/2	11	8	7	7	20	35	35	25
7	CK_0[2]	1	0	10	5	7	9	27	26	33	18
		2	1/2	5	2	20	16	42	48	38	10
		3	0	10	5	9	6	19	47	32	20
		4	1/2	11	4	9	9	22	41	41	14
8	CK_0	1	0	10	7	9	19	31	29	61	6
		2	full	3	3	8	19	33	24	58	15
		3	0	10	6	12	23	39	31	59	8
		4	full	No fish in the channel							
9	SH_0	1	0	10	6	4	10	16	25	62	12
		2	full	10	5	4	9	17	24	53	21
		3	0	10	5	4	7	14	29	50	18
		4	full	7	5	5	9	19	26	47	21

[1] Age 0 steelhead

[2] Age 0 chinook

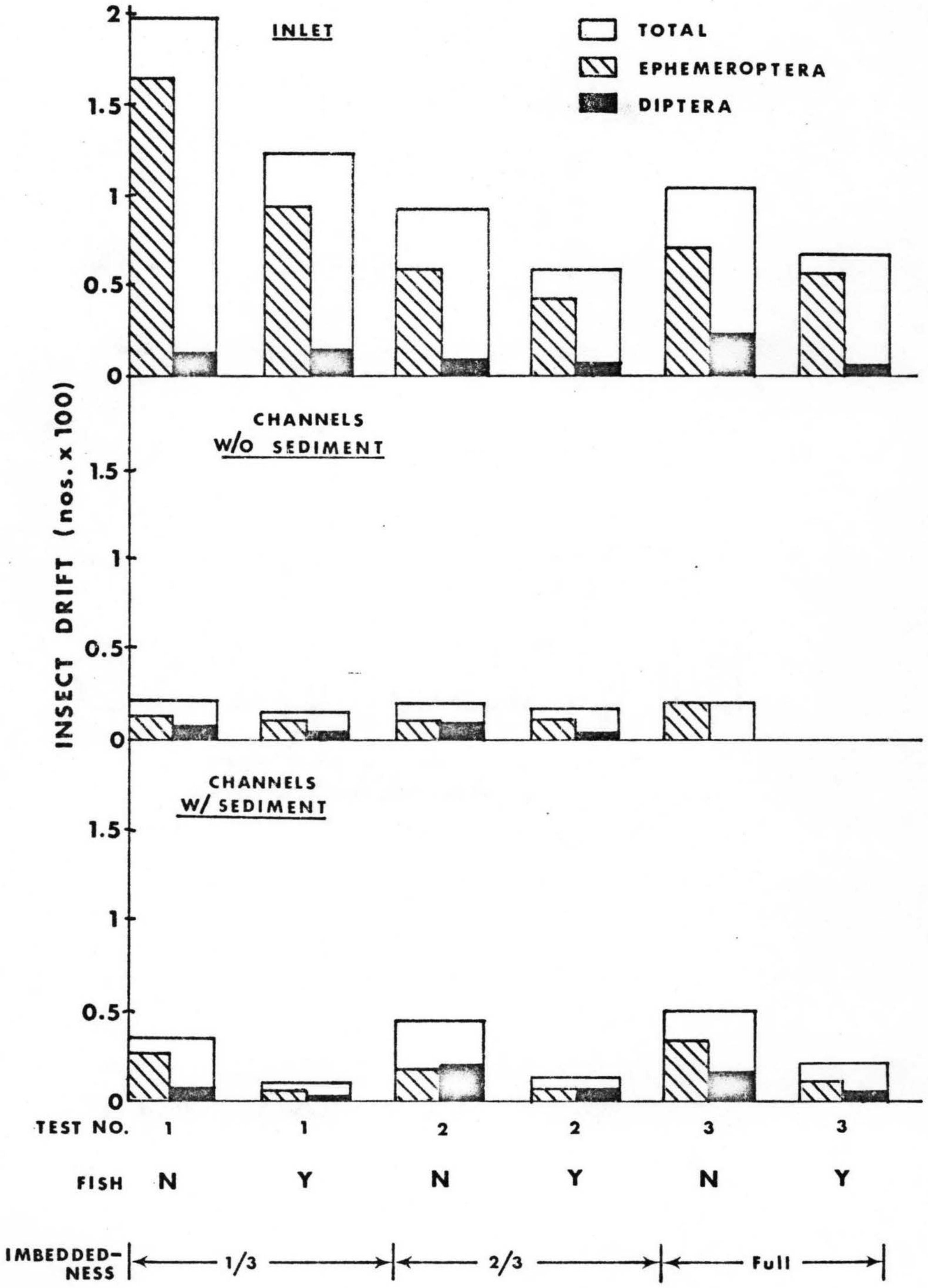

Figure 10. Total insect drift at sunset in the artificial stream channels during summer tests 1, 2, and 3 in 1974. (1/3 = one-third cobble imbeddedness with sediment; Y = fish in channel, N = no fish in channel).

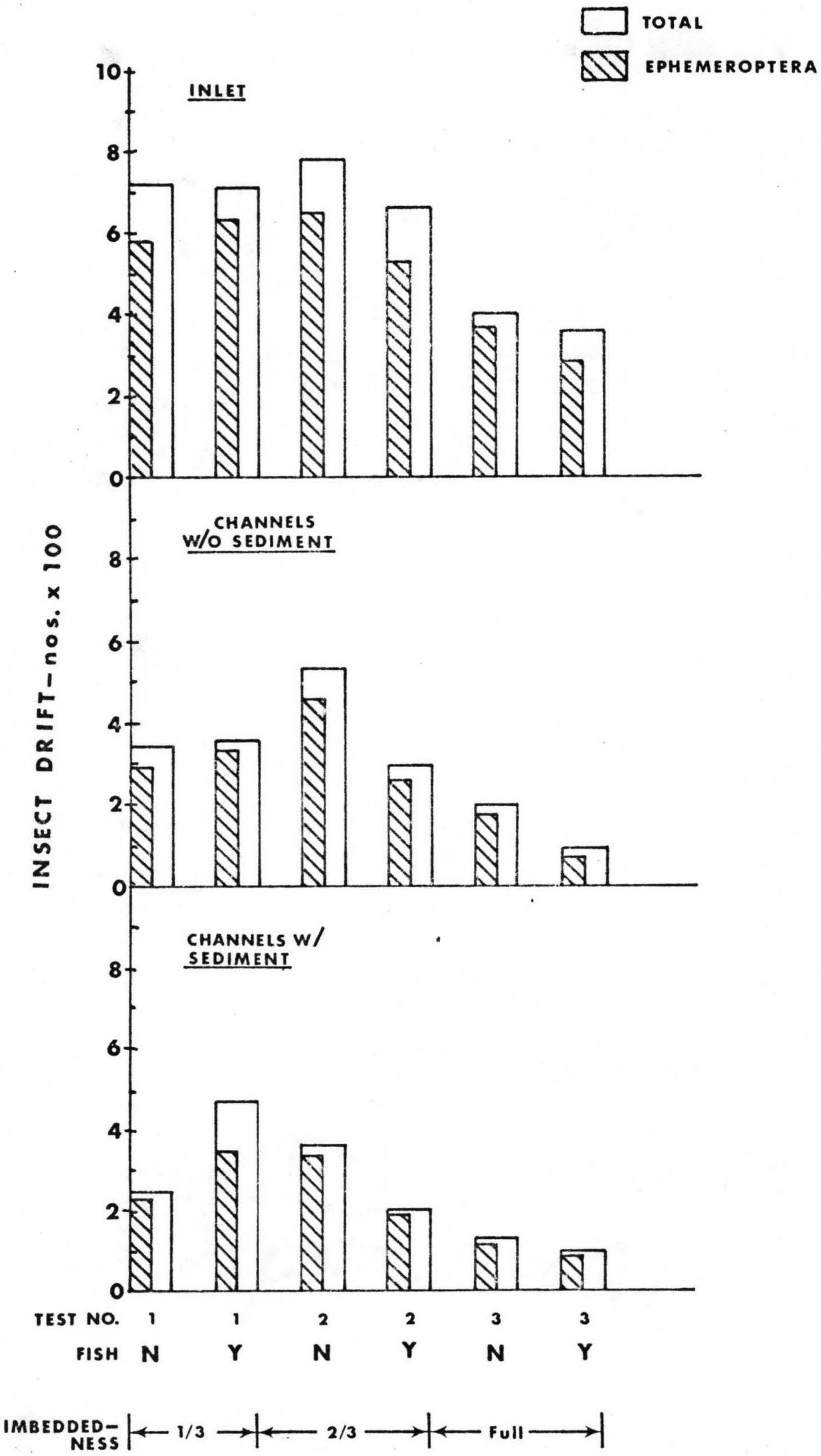

Figure 11. Total insect drift at midnight in the artificial stream channels during summer tests 1, 2, and 3 in 1974. (1/3 = one-third cobble imbeddedness with sediment; Y = fish in channel, N = no fish in channel).

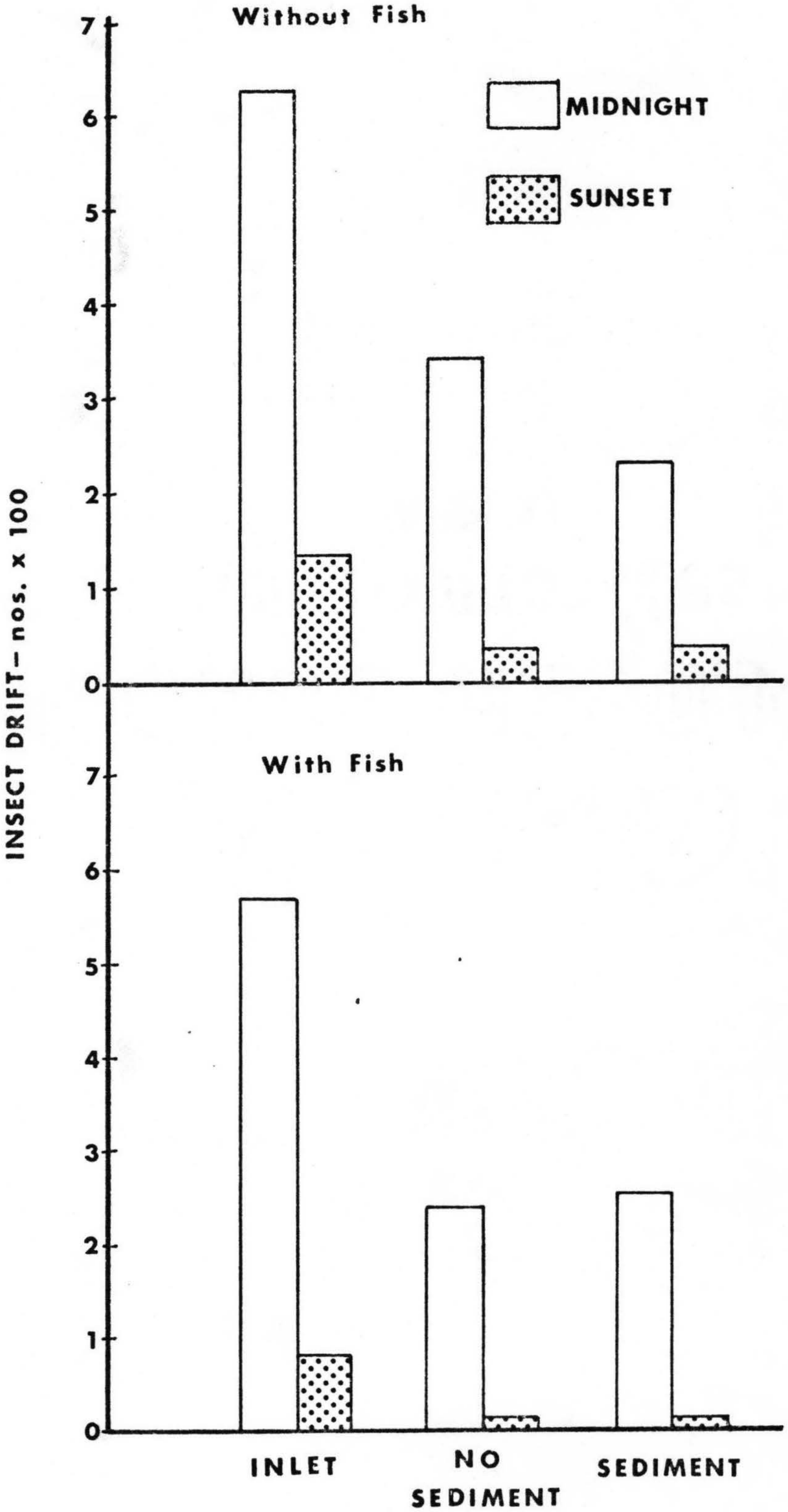

Figure 12. Average abundance of total insect drift during tests 1, 2, and 3 in the aritifical stream channels during 1974.

during test 3 to a full moon. Drift of some insects (especially Ephemeroptera) is suppressed by moonlight (Anderson, 1966; Holt and Waters, 1967).

Schaye (1976) could not find a relationship between abundance of benthos and drift rate in the same artificial channels. The relationship of drift to benthos is not fully understood. Many factors may cause variability in drift (Brusven, 1970; Hildebrand, 1974; Holt and Waters, 1967; Muller, 1953; Needham and Usinger, 1956; Waters, 1961).

A shift in the species abundance of Ephemeroptera occurred in the benthos in the test channels (Schaye, 1976). Benthic densities of Epeorus albertae decreased when we increased imbeddedness levels from 2/3 to full. E. albertae inhabits the interstices of the cobble, a habitat which became limited at full imbeddedness. On the other hand, Baetis bicaudatus was not affected by sediment level increases because they preferred the surface of the substrate, which was not altered by the addition of sediment.

Insect drift at sunset in 1975 (Figure 13) was more abundant than in 1974 (Figure 10). Adults and pupae were included in the analysis in 1975 and not in 1974. This accounts for the difference in abundance. Ephemeropterans were less abundant than Dipterans in 1975 particularly in the sedimented channels at full imbeddedness (Figure 13). No difference in total insect drift between sedimented and unsedimented channels existed in 1975.

Winter Tests

The number of fish which remained in the channels, particularly those with sediment, in the winter tests was smaller than in the summer tests (Figures 8 and 14; Table 5). Colder water temperatures caused this difference. At water temperatures below 5° C. salmonids we tested enter the interstices of the substrate (Everest, 1969; Miller, 1970: Morrill, 1972). As we increased the imbeddedness levels in the channels with sediment, fish densities decreased. The differences in fish densities in channels with one-half versus full

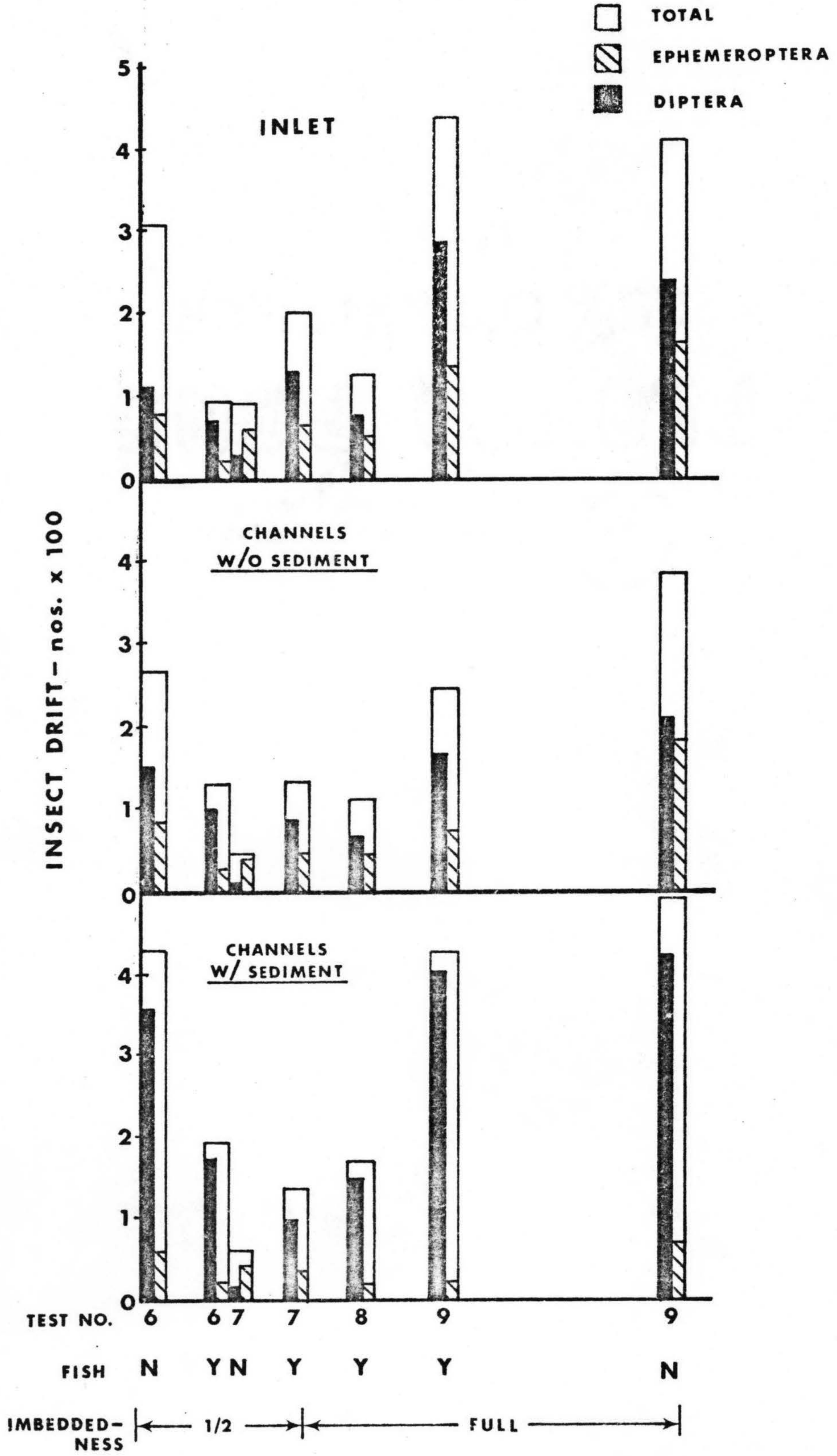

Figure 13. Total insect drift at sunset in the artificial stream channels during summer tests 6, 7, 8, and 9 in 1975. (average of two channels) (1/2 = one-half cobble imbeddedness with sediment; Y = fish in channels, N = no fish in channels; horizontal scale is on a time basis.)

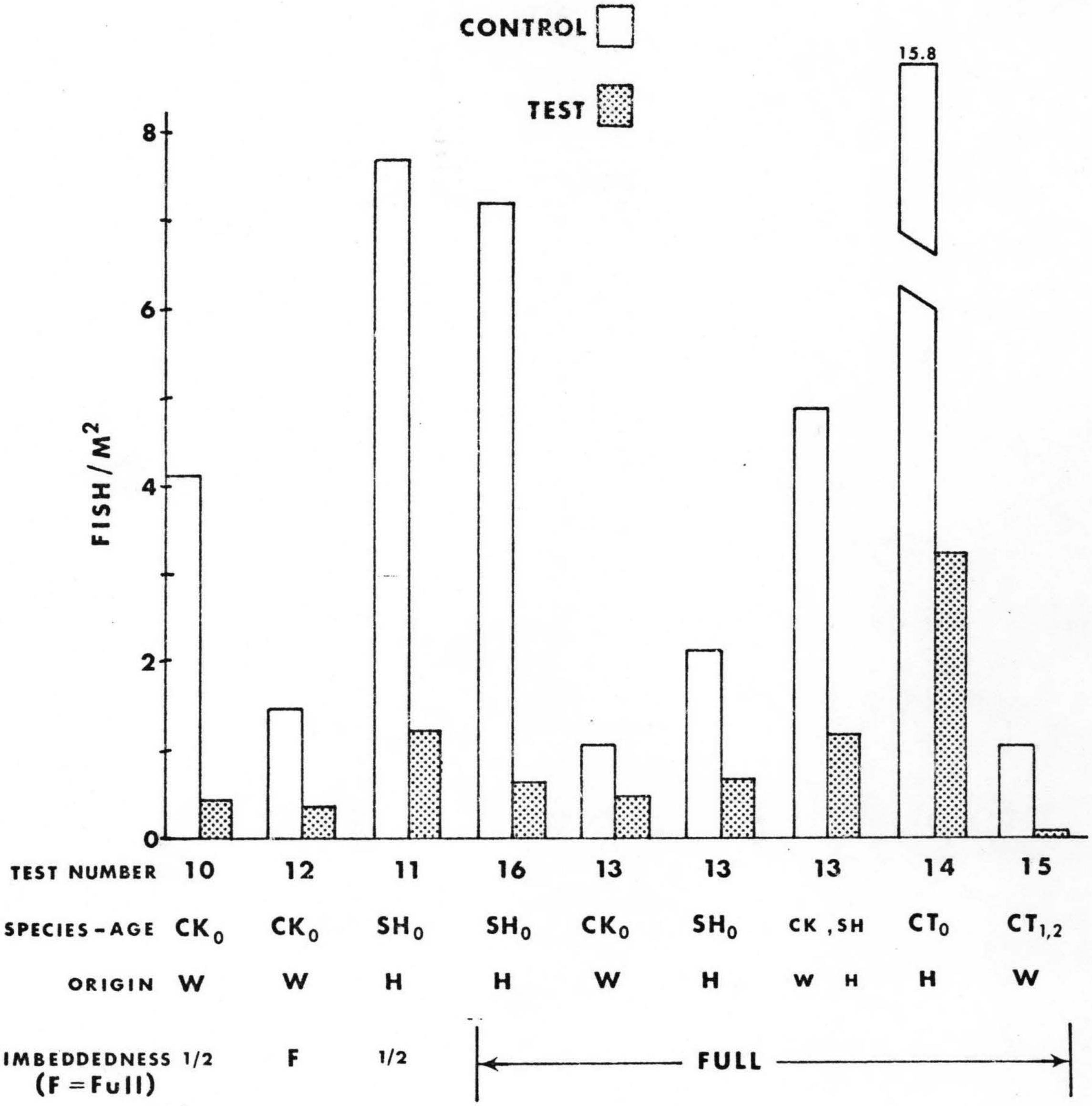

Figure 14. Densities of fish remaining after five days in the artificial stream channels during the winter tests of 1975. (control = no sediment, test = sediment; W = wild, H = hatchery; 1/2 imbeddedness = boulders in pools 1/2 imbedded with sediment; CK_0 = age 0 chinook, SH_0 = age 0 steelhead, CT = cutthroat trout).

Table 5. Fish remaining in the artificial stream channels during the winter tests of 1975.

Test number	Channel number	Imbeddedness levels	Fish added:		Fish remaining after five days:			
			Species/age	Number	Number	% of fish added	Fish/m^2	Mean density
10	1	0	W,CK/p [1]	100	59	59.0	3.93	4.10
	2	1/2	"	"	7	7.0	0.45	
	3	0	"	"	64	64.0	4.27	0.45
	4	1/2	"	"	7	7.0	0.45	
11	1	0	H,SH/O [2]	200	111	55.5	7.40	7.70
	2	1/2	"	"	17	11.3	1.09	
	3	0	"	"	120	60.0	8.00	1.22
	4	1/2	"	"	21	14.0	1.35	
12	1	0	W,CK/O	100	20	20.0	1.33	1.43
	2	full	"	"	0	0.0	0.00	
	3	0	"	"	23	23.0	1.53	0.22
	4	full	"	"	7	7.0	0.45	
13	1	0	W,CK/O	75	15	20.0	1.00	
			H,SH/O	"	56	74.7	3.73	1.06
	2	full	W,CK/O	"	6	8.0	0.39	3.80
			H,SH/O	"	12	16.0	0.77	
	3	0	W,CK/O	"	17	22.7	1.13	0.48
			H,SH/O	"	58	77.3	3.87	0.68
	4	full	W,CK/O	"	9	12.0	0.58	
			H,SH/O	"	9	12.0	0.58	

---

[1] Wild chinook salmon

[2] Hatchery steelhead trout

Table 5 (cont'd.)

Test number	Channel number	Imbeddedness levels	Fish added:		Fish remaining after five days:			
			Species/age	Number	Number	% of fish added	Fish/m^2	Mean density
14	1	0	H,CT/0 [3]	300	237	79.0	15.80	15.80
	2	full	"	200	50	25.0	3.22	3.22
15	3	0	W,CT/I,II	48	16	33.3	1.07	1.07
	4	full	"	15	1	6.7	0.06	0.06
16	1	0	H,SH/0	130	108	83.1	7.20	7.20
	2	full	"	50	9	18.0	0.58	
	3	0	"	150	108	83.1	7.20	0.61
	4	full	"	50	10	20.0	0.64	

[3] Hatchery cutthroat trout.

imbeddedness were less in the winter tests than in the summer tests. Age 0, wild chinook stabilized at a density of 0.45 fish/m^2 in the channels with one-half imbeddedness (test 10) and 0.39 fish/m^2 when at full imbeddedness (test 12). The difference in densities of fish in the unsedimented channels for tests 10 and 12 was probably caused by colder water temperatures during test 12 (<5° C.). Water temperatures for the tests conducted during 1975 appear in Appendix A.

Age 0, hatchery steelhead in the channels with one-half and full imbeddedness stabilized at 15.8 and 8.5% of the fish densities in the channels without sediment (Figure 14). Age 0, hatchery cutthroat trout in the channel with full imbeddedness stabilized at 20.4% of the fish density in the channel without sediment (Figure 14). Age I and II, wild cutthroat trout in fully imbedded channels stabilized at 5.6% of the fish density in unsedimented channels.

In test 13 I placed both age 0 steelhead and chinook together in the channels. The combined fish density in the fully imbedded channels stabilized at 24.7% of the density in the unsedimented channels, with steelhead at 17.8% and chinook at 45.5%.

Behavioral observations were not made during the winter test. Upon introduction into the channels the fish immediately sought out spaces in the substrate. They remained in these spaces until the water temperatures were increased just prior to electroshocking. For this same reason no stomach samples or drift samples were taken during the winter tests.

Knapp Creek Study

As we introduced sediment into the test section of Knapp Creek several changes occurred. The physical characteristics of the stream section were changed in terms of volume, available habitat, and water velocity. Fish densities were affected, but insect benthos in the riffles were relatively unaltered by the sediment additions.

As sediment was introduced onto the riffles and allowed to wash into the pools the volume of the test pools was reduced and water velocities increased. This increase in velocity tended to spread the sediment over a larger area until a point of stabilization was reached and the sediment delta stopped its downstream movement in the pools (Plates 4, 5, and 6; Figure 15).

I observed four species of salmonids in the study section: chinook salmon (age 0 and age I), steelhead reainbow trout (age I and older), brook trout (Salvelinus fontinalis (Mitchill)), and dolly varden trout (Salvelinus malma (Walbaum)). Age 0 chinook comprised the largest percentage of fish present.

We added 19.0 m^3 of sediment to the upper test pool during the first addition. During the second addition we added 1.0 m^3 to the upper test pool and 4.8 m^3 to the lower test pool. During the last addition we introduced 14.5 m^3 into the upper test pool.

As the amount of sediment added to the test section increased, the amount of cover for fish decreased and fish densities decreased (Figure 16 and Table 6). Densities in the unsedimented sections remained relatively stable.

We decreased the volume of the upper test pool (depth >0.15 m) with the additions of sediment to 48% of the original volume. Total fish in the upper test pool decreased to 29% of the number prior to the additions of sediment, while age 0 chinook decreased to 25% of the original number (Table 6). The density of fish expressed as fish/m^2 surface area deeper than 0.15 m decreased to 39% of the original density. The density of fish expressed as fish/m^3 volume (deeper than 0.15 m) decreased to 38% of the original density.

The relationship of fish numbers to percentage pool volume deeper than 0.15 m after each addition of sediment appeared linear (Figure 17). The fish numbers-percentage volume data for the period after the second addition of sediment was not included in the fitting of the line. Fish numbers decreased from 169 after the first addition of sediment to 77 after the second, whereas pool volume did not change (41.3 versus 41.5 m^3). The large decrease in fish numbers with no decrease in pool volume was due to a decrease in depth in one area of the pool where large numbers of age 0 chinook were located (Figure 18). Although we added 1.0 m^3 of sediment to the pool, the deposition of the sediment was such that the pool volume did not decline. After

Table 6. Fish counted in the Knapp Creek study area before the sediment was added (8/1), after the first addition (8/3), after the second (8/5 & 8/9), and after the third addition (8/13 & 8/23) and on 8/15/1975. Sediment added on 8/2, 8/5, and 8/10/1974.

		Number of fish counted:		
Date of count	Fish species/age	Lower control section	Upper control section	Test section
8/1/74	CK/0	84	314	233
	CK/I	9	17	12
	SH/I+	11	11	29
	EB/I+	15	12	28
	DV/I+	1	0	6
8/3/74	CK/0	126	314	198
	CK/I	4	5	14
	SH/I+	4	3	7
	EB/I+	9	4	22
	DV/I+	2	2	8
8/5/74	CK/0	103	248	149
	CK/I	7	8	9
	SH/I+	5	5	14
	EB/I+	12	8	16
	DV/I+	1	2	5
8/9/74	CK/0	79	204	97
	CK/I	6	5	6
	SH/I+	3	3	10
	EB/I+	8	5	11
	DV/I+	3	2	3
8/13/74	CK/0	80	223	73
	CK/I	7	7	14
	SH/I+	3	7	7
	EB/I+	5	4	14
	DV/I+	1	2	2
8/23/74	CK/0	75	209	53
	CK/I	10	25	12
	SH/I+	1	10	9
	EB/I+	7	12	10
	DV/I+	1	1	2
8/15/75	CK/0	36	49	90
	CK/I	5	9	9
	SH/0	0	32	0
	SH/I+	9	3	19
	EB/I+	4	3	6
	DV/I+	1	1	4

Note: CK/0 = age 0 chinook, CK/I = age I chinook, SH/0 = age 0 steelhead, SH/I+ = age I and older steelhead, EB/I+ = age I and older brook trout, DV/I+ = age I and older dolly varden trout.

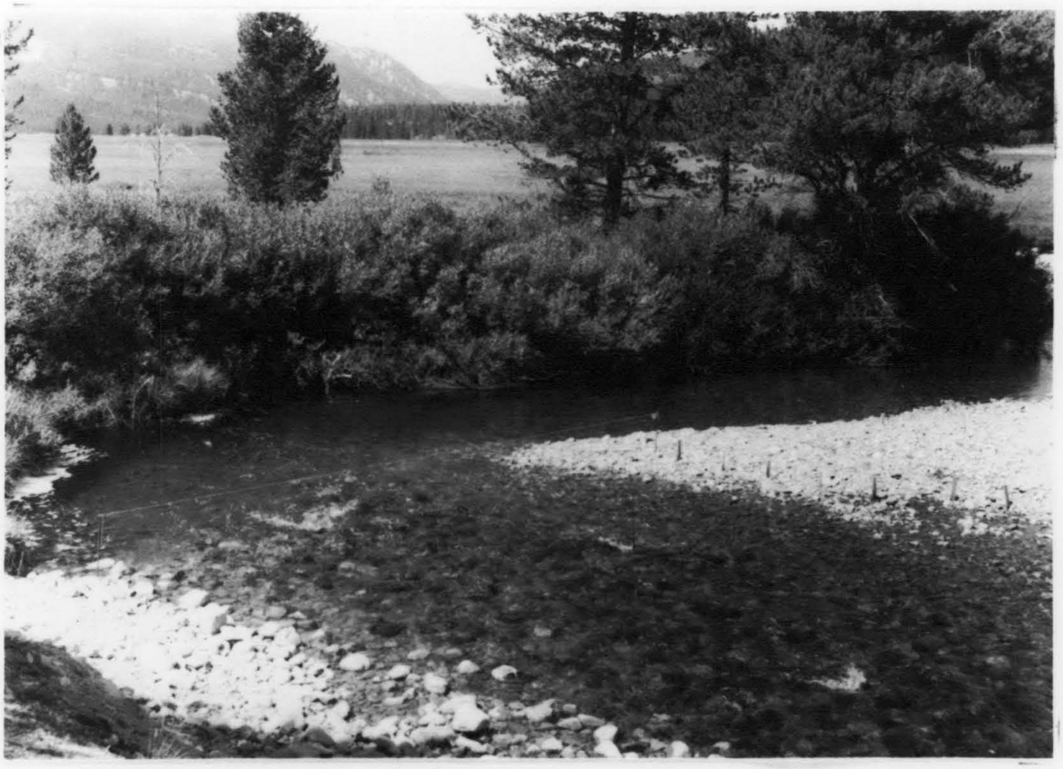

Plate 4. The main pool in the Knapp Creek test section before sediment was introduced into the stream in August of 1974. (looking downstream)

Plate 5. The main pool in the Knapp Creek test section after the second addition of sediment and just prior to the last addition of sediment. (looking downstream)

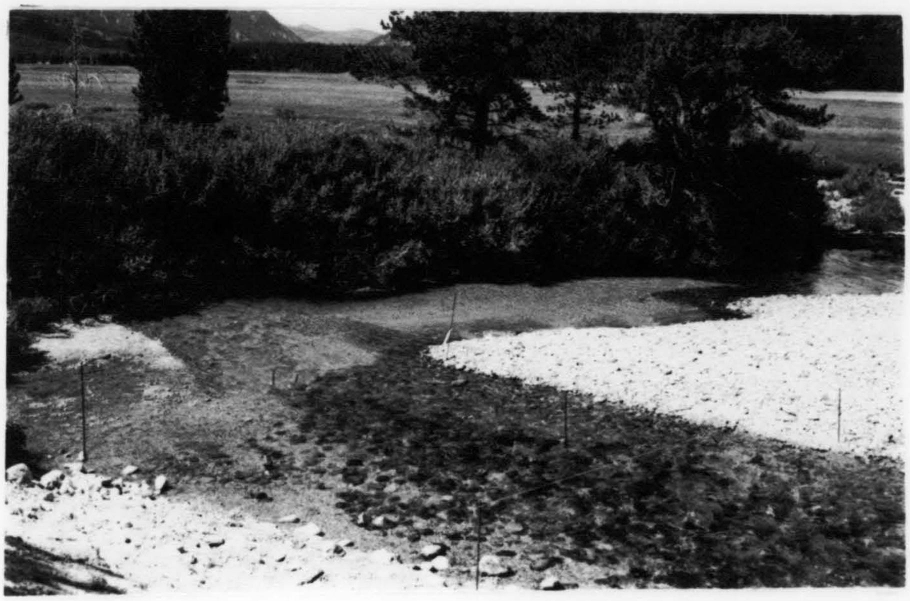

Plate 6. The main pool in the Knapp Creek test section after the last addition of sediment. (looking downstream)

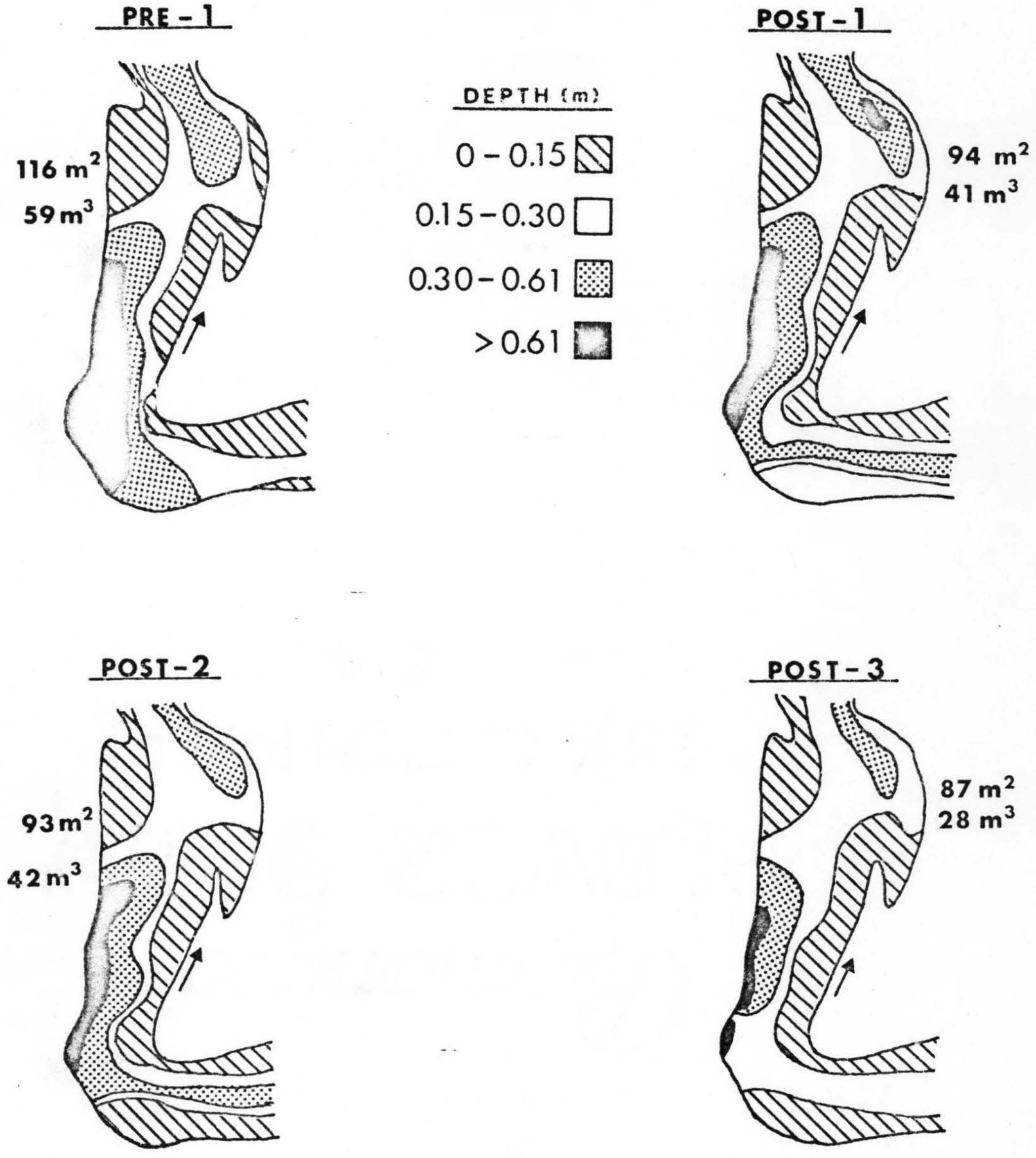

Figure 15. Depth contours in the Knapp Creek test section during the sediment additions of 1974. Pool areas and volumes deeper than 0.15 m for the upstream pool appear next to each figure. (pre-1 = before first sediment addition (8/1), post-1 = after first (8/3), post-2 = after second (8/9), and post-3 = after third sediment addition (8/13/74)).

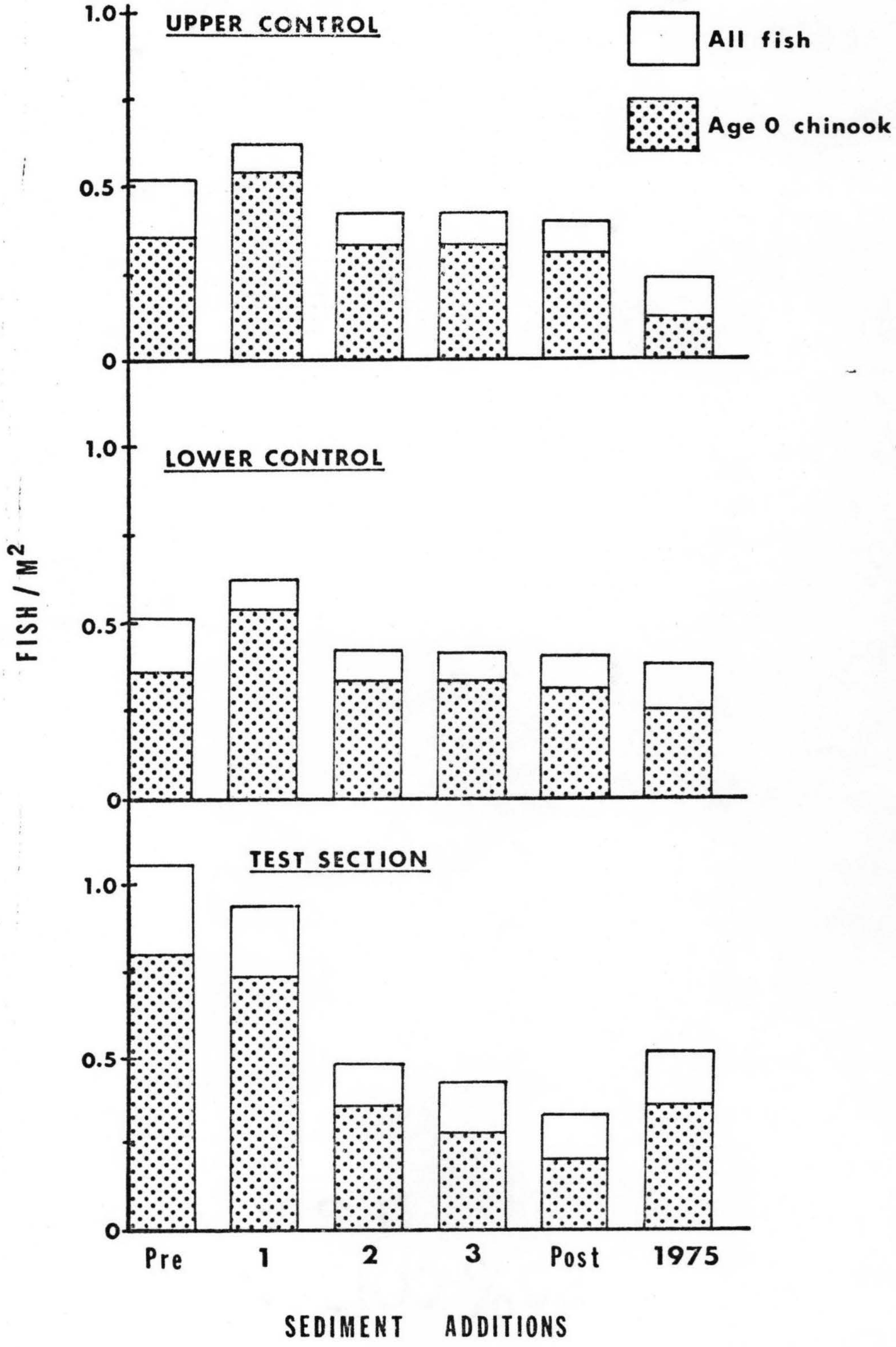

Figure 16. Total fish and age 0 chinook densities in the control (unsedimented) and test (sedimented) sections of Knapp Creek prior to the first addition (8/1/74), one day after the first (8/3), 4 days after the second (8/9), and 3 and 13 days after the third addition of sediment (8/13 & 8/23) and a year later on 8/15/75.

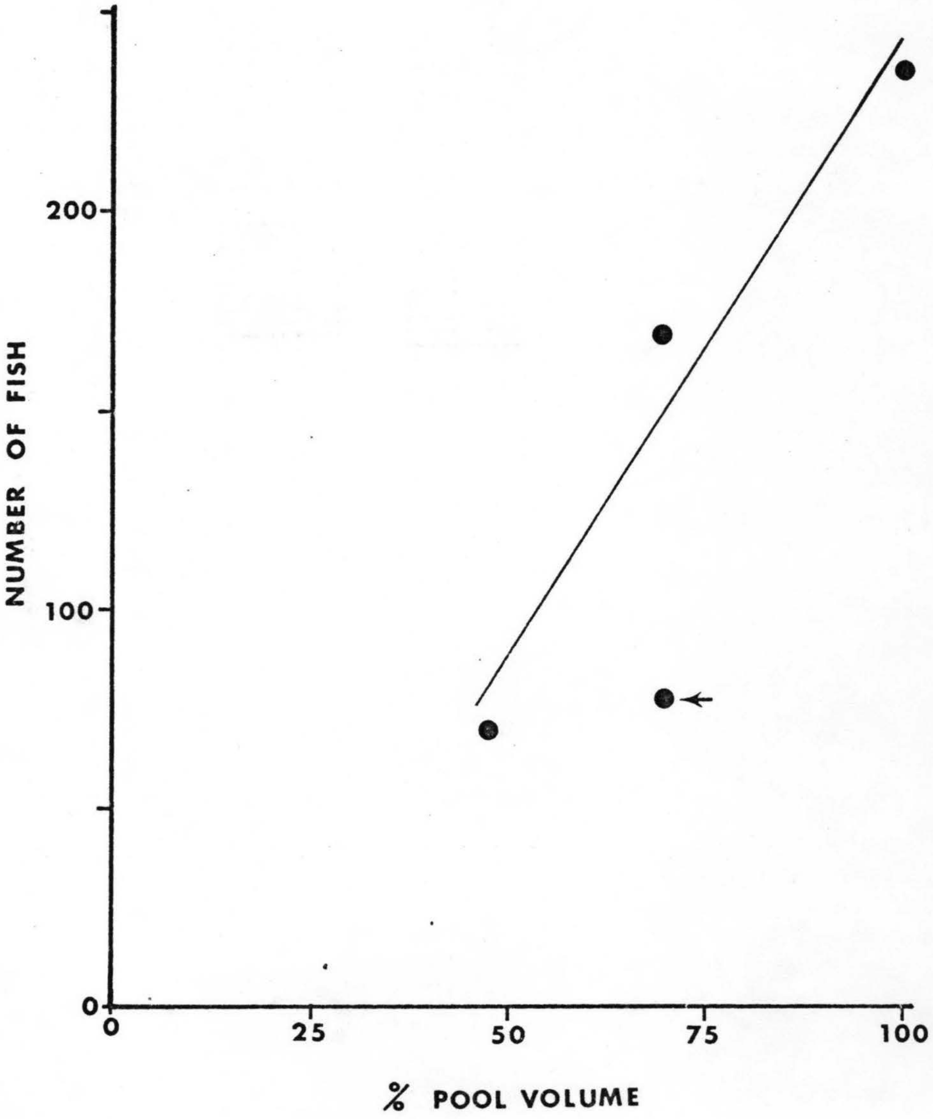

Figure 17. Fish numbers in the upper test pool versus the percentage pool volume deeper than 0.15 meters during the sediment additions into Knapp Creek in 1974. Arrow denotes observation not included in fitting line by regression.

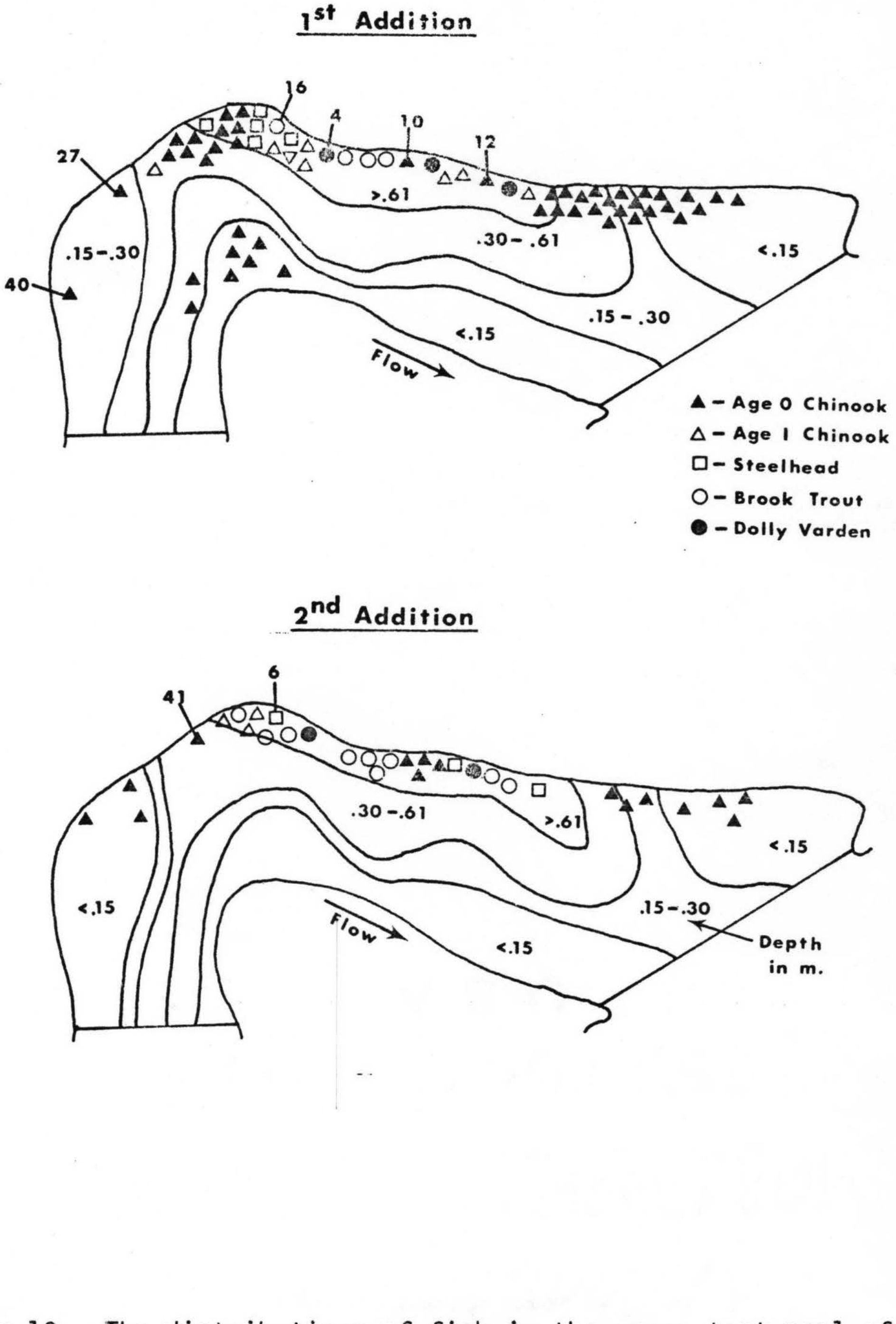

Figure 18. The distributions of fish in the upper test pool of the Knapp Creek test section after the first and second additions of sediment into the pool.

the first addition of sediment, 67 age 0 chinook were located in a small eddy area at the upstream end of the pool where depth was 0.15 to 0.30 m. When we added sediment the second time we decreased the depth of this section of the pool to less than 0.15 m and the age 0 chinook moved into the deeper part of the pool or out of the test section entirely (Figure 18). The presence of large predators (brook and dolly varden trout) in the deeper parts of the pool probably influenced the behavior of the age 0 chinook, forcing them to remain mostly in the deeper upstream end of the pool, a habitat not preferred by the chinook prior to the sediment additions.

The relationship between number of fish in the upper test pool and percentage pool area deeper than 0.15 m was not linear for the full range of 0 to 100% pool area (Figure 19). We only decreased the area deeper than 0.15 m to 75% of the original area. The depth of 0.15 m may not be the critical depth in the relationship of fish numbers and percentage pool area. The relationship of fish numbers to percentage pool area deeper than 0.30 m was approximately linear (Figure 20). We did not include the observation after the second addition of sediment in the fitting of the line. A decrease in pool area deeper than 0.30 m caused a decrease in fish numbers in the pool.

Total fish densities in 1975 in the study area were about 50% of the pre-sediment condition of 1974 (Figure 16). This was probably due to a decrease in chinook salmon seeding rates (escapement of adults to the spawning grounds) between the autumns of 1973 and 1974. Other streams in the Stanley Basin area experienced a decrease in fish densities from 1974 to 1975 (Sekulich, 1976).

Schaye (1976) could not find a significant difference in insect benthos between control and test riffles in total numbers of insects of species composition in Knapp Creek in 1974 or 1975.

Correlational Stream Surveys

To determine if fish density was limited by food abundance which in turn might be limited by the amount of sediment in the riffles, I measured the following parameters at 23 pool-riffle sites on Elk

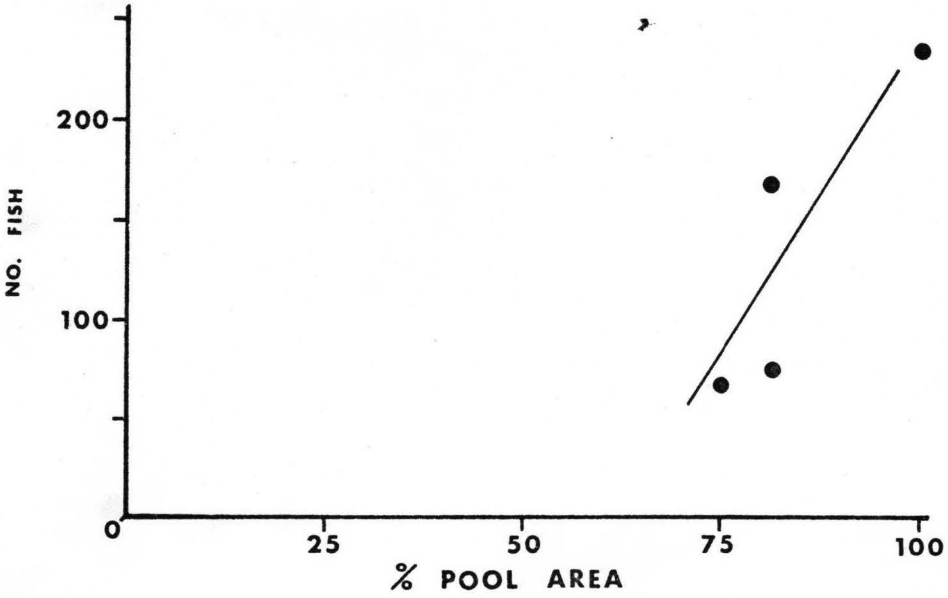

Figure 19. The number of fish in the upper test pool versus the percentage pool area deeper than 0.15 meters during the sediment additions into Knapp Creek in 1974.

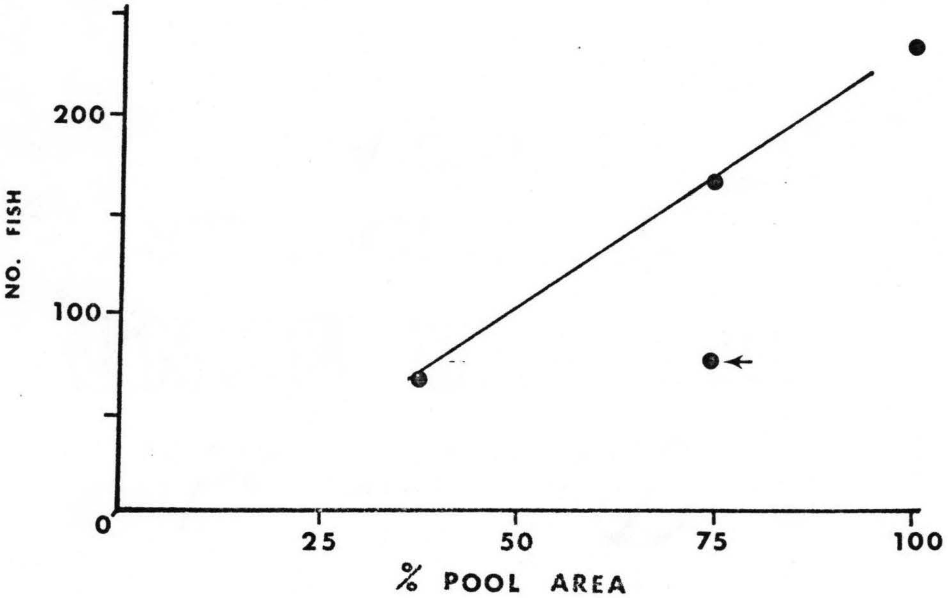

Figure 20. The number of fish in the upper test pool versus the percentage pool area deeper than 0.30 meters during the sediment additions into Knapp Creek in 1974. The arrow denotes the observation not used in fitting the line by regression.

and Bearskin Creeks: riffle length and area, pool length and area, insect drift, percentage sediment in the riffles, average substrate imbeddedness in the pools, percentage cover in the pools, water dpeth, water temperature, fish densities, and fish lengths and weights (Table 7). I then correlated the physical parameters with fish and insect densities.

Elk Creek Correlations

Elk Creek contained three species of salmonids (chinook salmon, steelhead trout, and mountain whitefish, Prosopium williamsoni Girard) which I included in the total fish densities. Total densities in the pools ranged from 0.09 to 0.43 fish/m^2. Age 0 chinook comprised the majority of the fish in the pools studied (Table 8).

Insect drift densities from the riffles in Elk Creek were not correlated with percentage sediment in the riffles ($r - 0.126$, $P<0.85$; Figure 21). Correlation of fish densities in the Elk Creek pools with insect drift gave an r value of 0.559 ($0.972<P<0.975$; Figure 22). This correlation suggests that a relationship exists between insect drift density and fish density. Fish densities in the pools were not correlated with percentage sediment in the riffles ($r - 0.164$, $P<0.85$; Figure 23). One would expect this correlation to be low if insect drift was affecting fish density, since insect drift did not correlate with percentage sediment in the riffles.

Cover for fish has been shown to limit fish density in some cases, so I correlated fish density with the amount of cover in the pools (Figure 24). The largest r attained was with bottom cover ($r - 0.574$, $0.975<P<0.978$), an indication that cover in the pools may also affect the density of fish in Elk Creek.

To see if these factors in combination affected fish density, I correlated percentage sediment in the riffles, insect drift, bottom cover, and the ratio of drift/pool area (Table 9). I used the ratio of drift density/pool area on the hypothesis that the amount of available food per unit area of pool could affect fish density. Fish density correlated best with percentage sediment and drift per m^2 of

Table 7. Ranges and means of the parameters measured during the correlational stream surveys on Elk and Bearskin Creeks, September of 1975.

Stream section and number of sample sites		Riffle length - m	Riffle area - m^2	Pool length - m	Pool area - m^2	% Riffle sediment	Average pool imbeddedness	Water temperature °Centigrade	% Surface cover	% Bottom cover	Insect drift nos./m^3 flow
Upper Elk	Range	5-14	29-195	14-30	62-269	23-47	1/4-3/4	7-13.5	10-60	0-30	.40-1.80
n = 8	Mean	9	90	22	154	32	1/2		35	9	0.98
Lower Elk	Range	5-15	13-158	10-38	51-235	38-59	1/2-F	7-13.5	20-60	0-10	.05-3.70
n = 7	Mean	9	80	22	129	44	3/4		39	6	1.40
Upper Bearskin	Range	2-8	8-25	7-12	29-52	20-37	1/4-1/2	2-11	40-50	10-30	.31-0.71
n = 4	Mean	4	16	10	39	28	1/2		45	22	0.53
Lower Bearskin	Range	4-8	25-84	9-22	29-133	61-75	Full	4-13	25-40	0-20	.43-1.60
n = 4	Mean	6	52	13	65	66	Full		31	22	1.10

Table 8. Fish densities in Elk Creek pools during the correlational surveys of September, 1975.

Site no.	Fish per square meter in pools: CK/0	CK/I	SH/I+	WF	Total
1	0.10	0.07	0.004		0.18
2	0.09	0.01	0.01		0.11
3	0.28	0.07		0.02	0.37
4	0.16	0.01		0.004	0.17
5	0.18	0.05	0.04	0.005	0.28
6	0.14	0.06			0.20
7	0.28				0.28
8	0.10	0.02		0.008	0.13
9	0.31	0.10		0.02	0.43
10	0.10	0.02			0.12
11	0.05	0.03		0.02	0.10
12	0.10	0.05			0.15
13	0.03	0.01	0.005	0.04	0.08
14	0.13	0.04	0.01	0.01	0.19
15	0.09	0.03			0.12

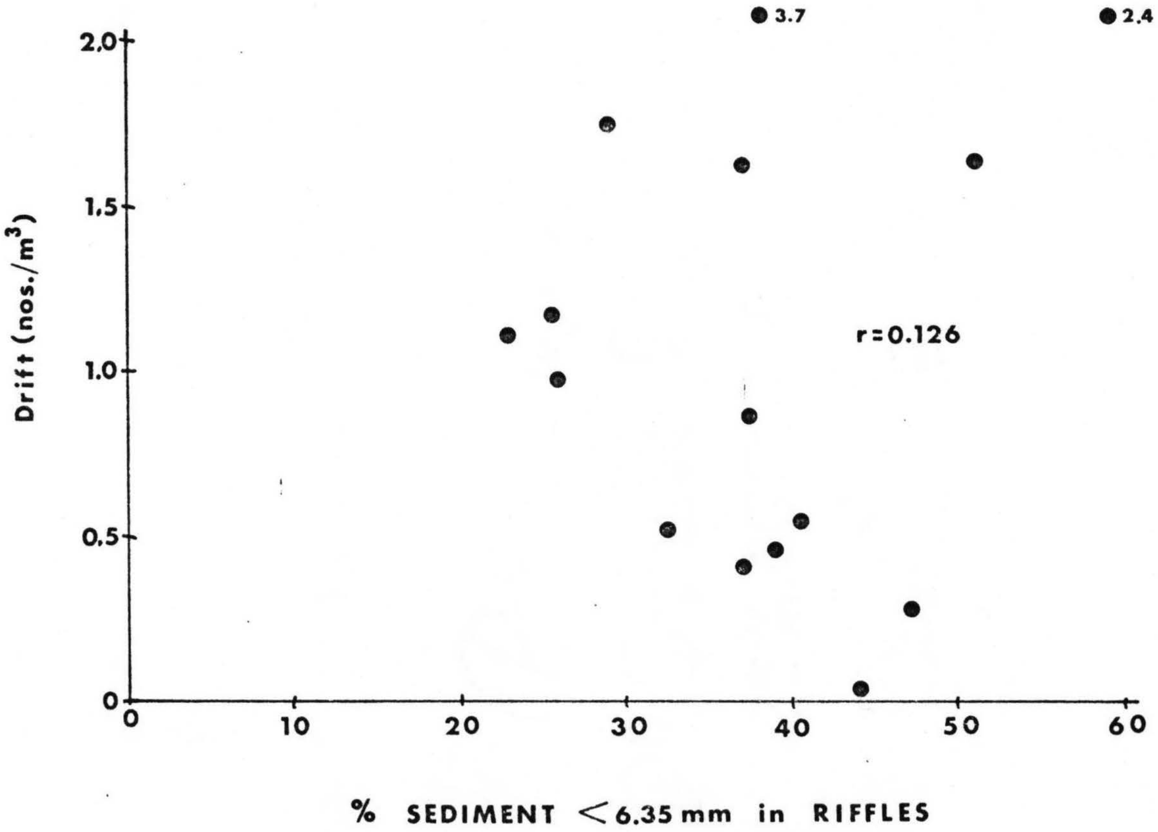

Figure 21. Insect drift density versus percentage sediment in the riffles in Elk Creek, September of 1975.

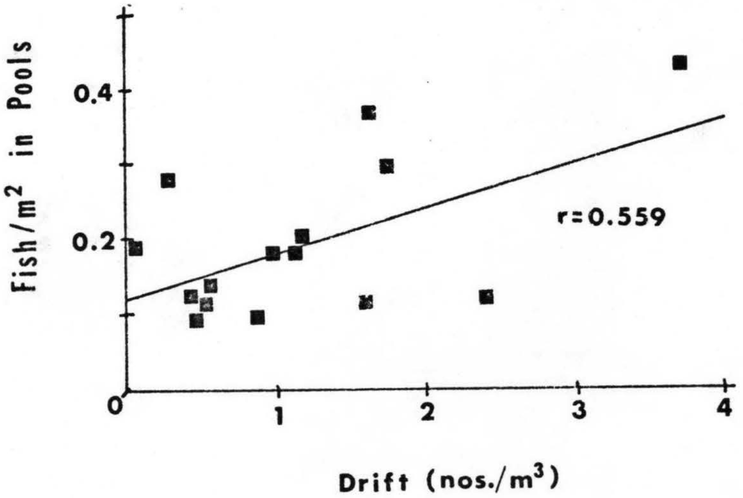

Figure 22. Fish densities in the pools versus insect drift entering the pools in Elk Creek, September of 1975.

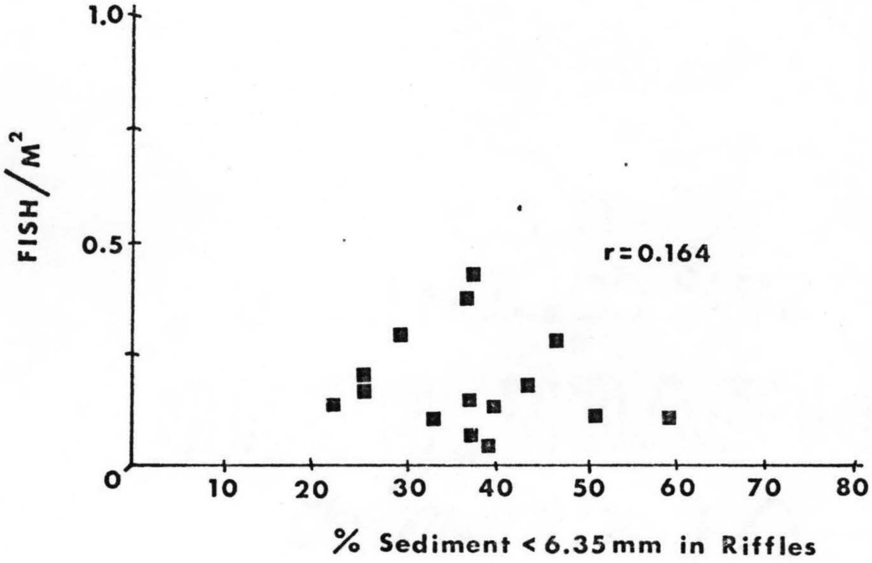

Figure 23. Fish densities in the pools versus percentage sediment in the riffles in Elk Creek, September of 1975.

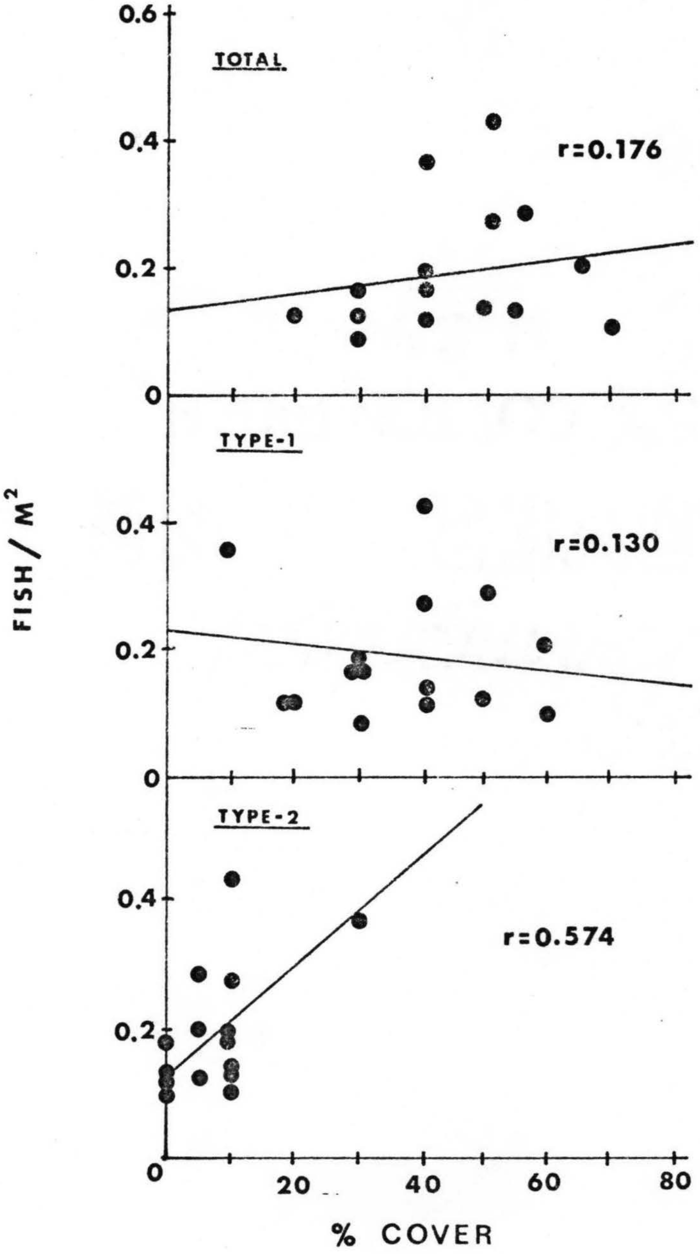

Figure 24. Fish density in the pools versus the percentage of the pool area with cover in Elk Creek, September of 1975. (Type 1 = surface cover, Type 2 = bottom cover).

Table 9. Multiple correlations for Elk Creek in 1975 using the model: $Y = a + bX_1 + cX_2$.

Y	X_1	X_2	R
Fish/m^2 in pools	% Riffle sediment	Drift density	0.324
"	"	Drift/pool area	0.780*
"	"	Bottom cover	0.582
"	% Bottom cover	Drift density	0.602
"	% Bottom cover	Drift/pool area	0.767*
Drift density	% Riffle sediment	Riffle area	0.138
Drift density	% Riffle sediment	Riffle length	0.197

* - significant at alpha = 0.01

pool area (R = 0.780, significant at alpha = 0.01), and the amount of bottom cover and drift per m^2 of pool area (R = 0.767, significant at alpha = 0.01). The correlation of fish density versus bottom cover and drift density (R = 0.602) may be more valid, as artifacts can be produced by using a ratio as a variable in a multiple regression model.

Comparison of age 0 chinook lengths and weights for upper and lower Elk Creek showed a significant difference at alpha = 0.01 for lengths and at alpha = 0.05 for weights (Table 10). The difference in insect drift between upper and lower Elk Creek (Table 7) may be responsible for the larger size of fish in lower Elk Creek. Water temperatures were the same in both upper and lower Elk Creek during the surveys.

I could not find any evidence that insect drift density was related to percentage sediment in the Elk Creek riffles (Figure 21). Among other factors, riffle size may affect the density of insect drift (Brusven, 1970). The correlations of insect drift to riffle area (Figure 25) and riffle length (Figure 26) also had small r values (0.032, $P<0.85$ and 0.16, $P<0.85$, respectively). The multiple correlation of insect drift to percentage sediment in the riffles and riffle length had an R value of 0.197 (Table 9).

Bearskin Creek Correlations

Bearskin Creek contained the same species of fish as Elk Creek with age 0 chinook comprising the majority of the fish counted (Table 11). Total fish densities in Bearskin Creek ranged from 0.60 to 1.47 fish/m^2 in the pools, substantially larger than in Elk Creek.

Insect drift density was not related to percentage sediment in the riffles of Bearskin Creek in any obvious way (r = 0.467, $P<0.85$; Figure 27). I did find, however, evidence of a community shift to Diptera with larger percentages of sediment in the riffles. Such a shift was also noted in the 1975 drift samples collected in the artificial stream channels at Hayden Creek. Insect drift density was correlated with riffle area (r - 0.834, $0.988<P<0.990$; Figure 28)

Table 10. Results of Duncan's multiple range test of the means for age 0 chinook length and weight in Elk and Bearskin Creeks, September of 1975.

		Total length (mm):		Body weight (g):	
Stream	n	Mean	Different at alpha 0.01	Mean	Different at alpha 0.05
Upper Elk	20	63.0	yes	2.60	yes
Lower Elk	20	70.9	no	3.90	no
Bearskin	20	72.2	no	4.28	no

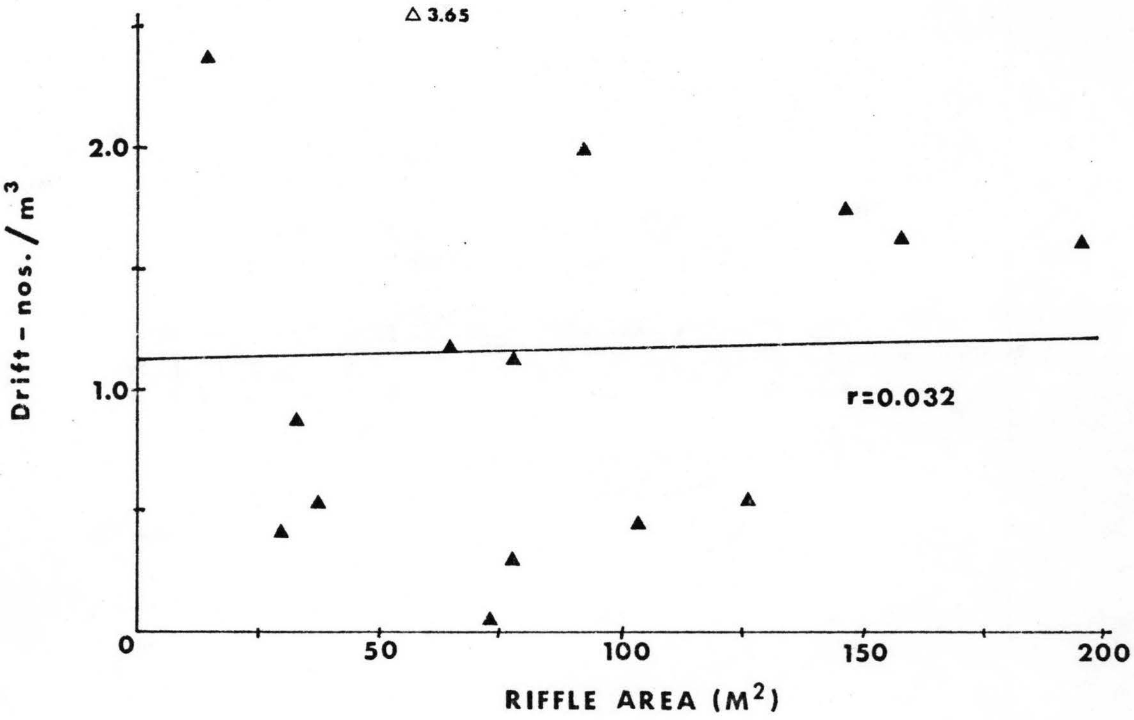

Figure 25. Insect drift density versus riffle area in Elk Creek during September of 1975.

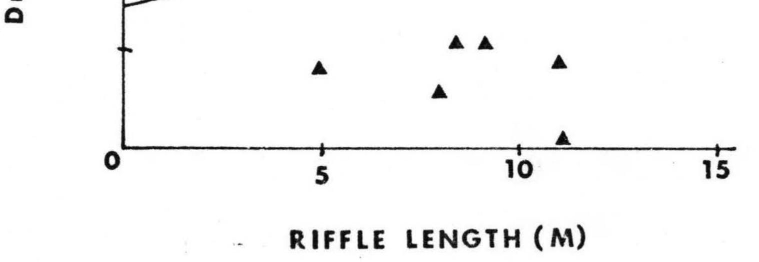

Figure 26. Insect drift density versus riffle length in Elk Creek during September of 1975.

Table 11. Fish densities in Bearskin Creek pools during the correlational surveys of September, 1975.

	Fish per square meter in pools:				
Site no.	CK/0	CK/I	SH/I+	WF	Total
1	0.86	0.10		0.03	0.99
2	0.80	0.17			0.97
3	0.82	0.13			0.95
4	0.71	0.06			0.81
5	0.93	0.14	0.05		1.22 [1]
6	1.44		0.03		1.47
7	0.54	0.06	0.03		0.63
8	0.45	0.09	0.06		0.60

[1] age 0 steelhead included in total (0.09)

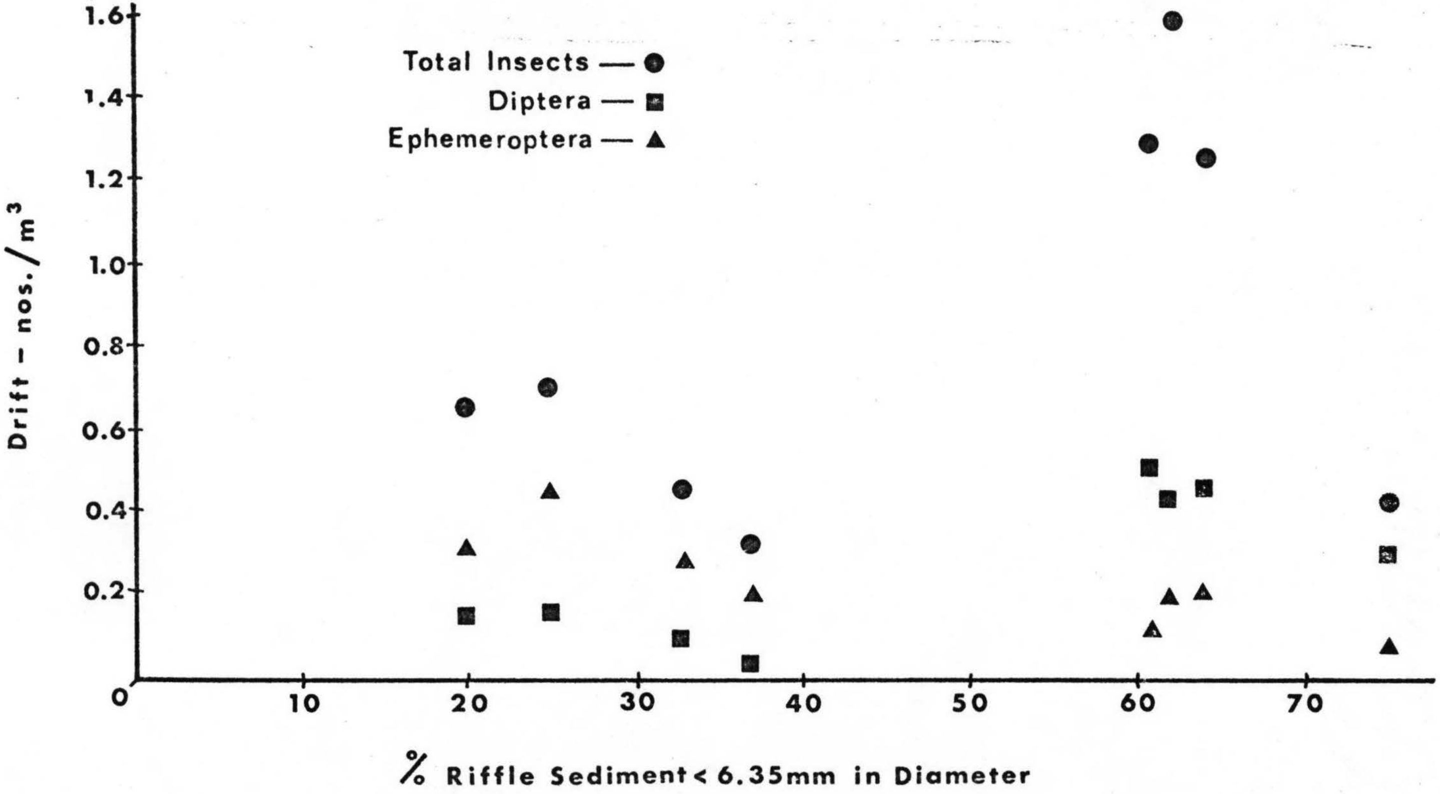

Figure 27. Insect drift density as related to percentage sediment in the riffles in Bearskin Creek, September of 1975.

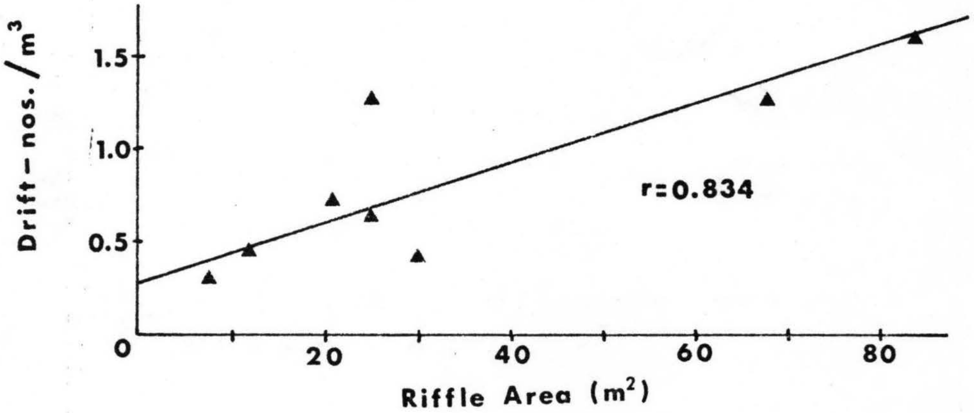

Figure 28. Insect drift versus riffle area in Bearskin Creek during September of 1975.

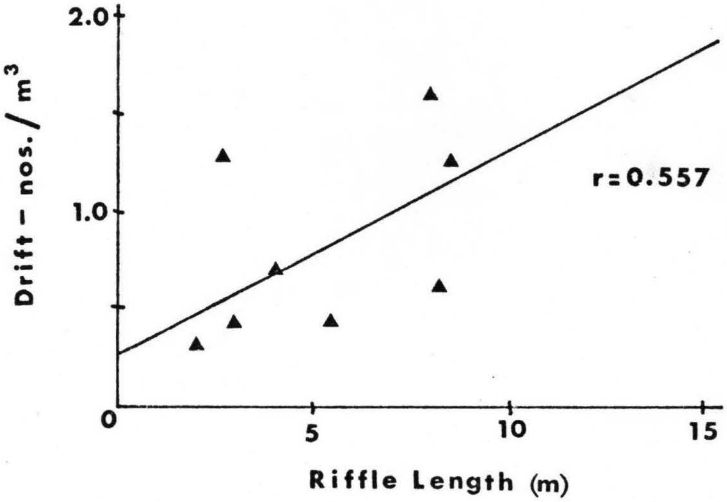

Figure 29. Insect drift versus riffle length in Bearskin Creek during September of 1975.

and explained the large numbers of drifting insects from riffles with large percentages of sediment (Figure 27). The sites with large numbers of drifting insects and large percentages of sediment also had the largest riffle areas. The correlation between riffle length and insect drift was not significant ($r = 0.557$, $P<0.85$; Figure 29). Insect drift density in Bearskin Creek was dependent to an extent on riffle size.

Fish density versus insect drift density (Figure 30) was not linearly correlated ($r = 0.141$, $P<0.85$). The relationship in Figure 30 appeared curvilinear, however, so I performed a correlation using the square of the insect drift as the second "X" variable. The r value of 0.908 was significant ($0.995<P<0.998$), but Ricker (1975) warned of using this function lest significance appear where it does not exist.

As in Elk Creek, fish density in the pools of Bearskin Creek was not significantly correlated with percentage sediment in the riffles ($r - 0.420$, $P<0.85$; Figure 31).

Fish density in Bearskin Creek was loosely correlated with bottom cover ($r - 0.404$, $P<0.85$; Figure 32) and surface cover ($r = 0.590$, $0.872<P<0.875$; Figure 32). A relationship between fish density and cover appears to exist, but cover only partly regulates fish density.

The relationship of fish density to insect drift density may be confounded by the effect of cover. Those sites where fish density was low even though insect drift density was high (Figure 30) had low percentages of cover. Bottom cover was 10, 0, and 0% for these three sites (sites 1, 2, & 8). Combining drift density and percentage bottom cover by multiplying the two variables together a significant correlation with fish density was obtained ($r - 0.758$, $0.975<P<0.978$; Figure 33).

None of the multiple correlations of fish density versus percentage sediment in the riffles, insect drift density, bottom cover, or the ratio of drift/m^2 of pool area were significant for Bearskin Creek (Table 12). Bottom cover and drift density/m^2 of pool area

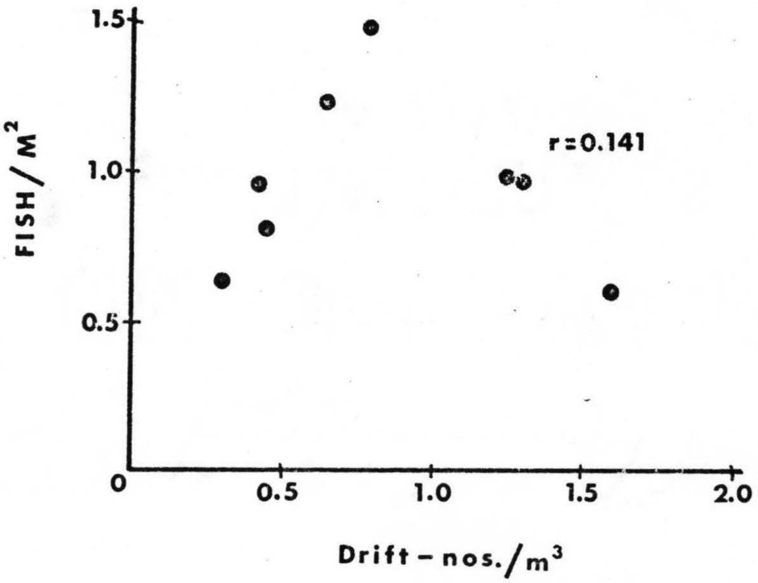

Figure 30. Fish density in the pools versus insect drift density in Bearskin Creek, September of 1975.

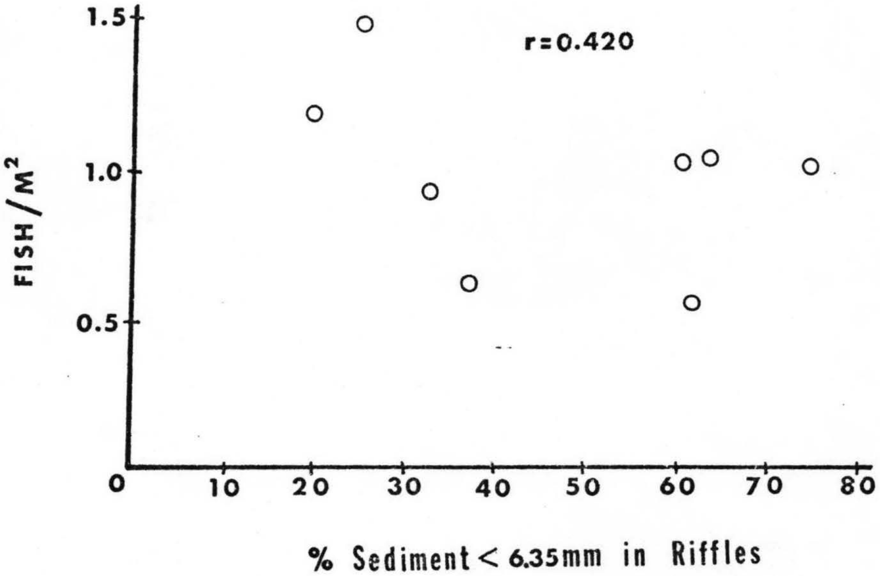

Figure 31. Fish density in the pools versus percentage sediment in the riffles in Bearskin Creek in September of 1975.

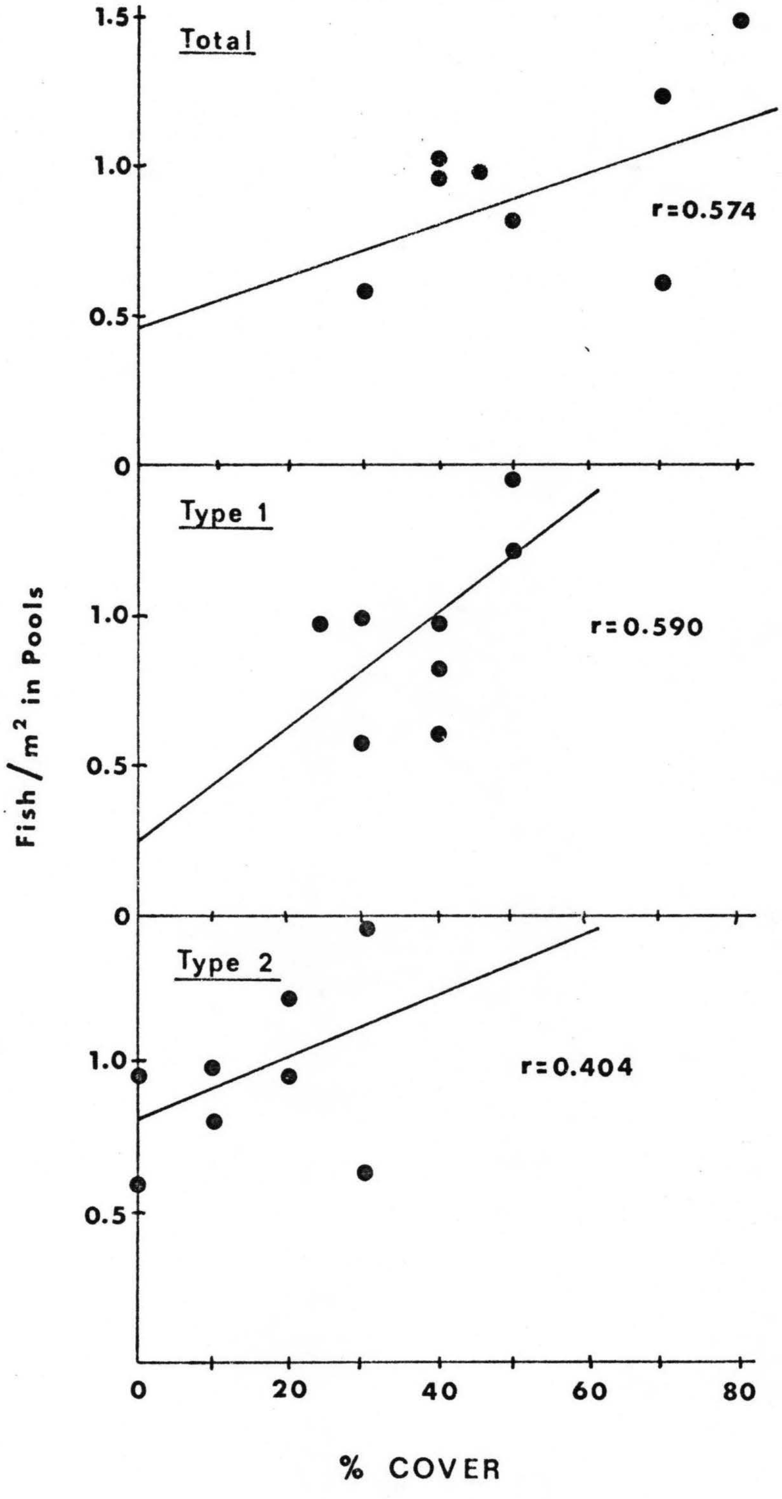

Figure 32. Fish density in the pools versus the percentage of the pool area with cover in Bearskin Creek in September of 1975. (Type 1 = surface cover, Type 2 = bottom cover).

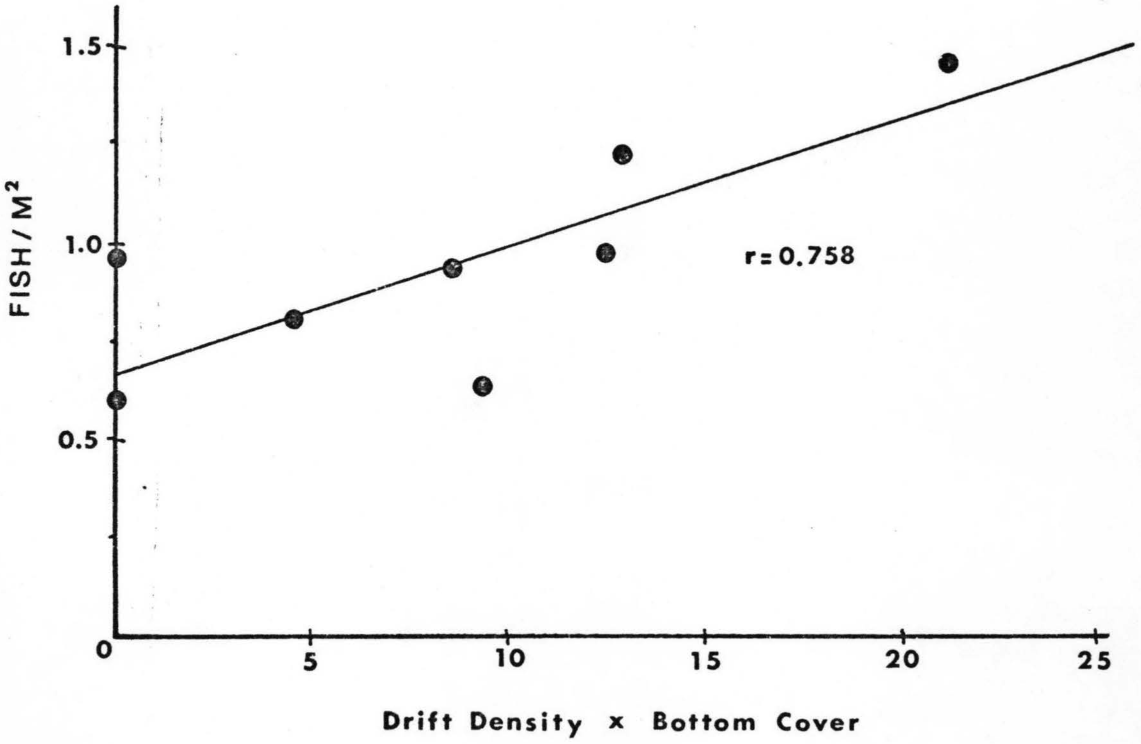

Figure 33. Fish density in the pools versus the index of insect drift times the percentage bottom cover in the pools in Bearskin Creek during September of 1975.

Table 12. Multiple correlations for Bearskin Creek in 1975 using the model: $Y = a + bX_1 + cX_2$.

Y	X_1	X_2	R
Fish/m^2 in pools	% Riffle sediment	Drift density	0.424
"	"	Drift/pool area	0.628
"	"	Bottom cover	0.452
"	Bottom cover	Drift density	0.431
"	"	Drift/pool area	0.669
Drift Density	% Riffle sediment	Riffle area	0.913*
"	"	Riffle length	0.653

* - significant at alpha = 0.05

correlated best with fish density.

Age 0 chinook in Bearskin Creek were the same length and weight as chinook in lower Elk Creek, but significantly larger in length and weight than fish in upper Elk Creek (Table 10). Different water temperatures and insect drift densities did not account for the difference in length and weight between Bearskin Creek and upper Elk Creek (Table 7).

Insect drift density was not related to percentage sediment in the riffles of Bearskin Creek in any obvious way (Figure 23). Insect drift density was significantly correlated with percentage sediment in the riffles and riffle area (Table 12). If percentage sediment in the riffles and riffle area were not merely coincidental correlates, then 83% of the observed variation in insect drift density could be explained by these two factors.

DISCUSSION

In our 1974 and 1975 tests of summer holding capacity in the artificial stream channels, we observed a decrease in fish densities with an increase in sediment in the pools for all species tested. Holding capacities among age classes were size related, the small fish (age 0 steelhead) stabilizing at higher densities. Fish densities decreased more than decreases in volume of the pools. For example, densities of wild, age I steelhead at 1/3, 2/3, and full sediment imbeddedness were reduced to 84, 40, and 11% of their original densities respectively, but volumes were reduced during the same tests to 92, 84, and 75% of the original volumes. Reduction in the amount of cover for fish was the reason for larger reductions in fish densities than in pool volumes. As we increased sediment levels in the channels we decreased cover for fish.

Stuehrenberg (1975) found no decrease in fish densities when he added sediment only to the riffles in the same artificial stream channels in the summer of 1973. In his tests the pools did not contain large rocks as cover for fish and fish densities at the end of each test were smaller than in our tests except for hatchery, age 0 steelhead. Adding sediment to the riffles did not change the pool environment during Stuehrengerg's tests. Food (insect drift) was not limited by the addition of sediment to the riffles in my tests in 1974 and 1975, so reduction of cover (filling the large intersticial spaces with sediment) was the reason for reduction in fish densities. Since insect drift was not limited in Stuehrenberg's tests by the addition of sediment to the riffles and cover was not reduced in the pools, then it is not surprising that fish densities would not be affected.

The differences in behavior of fish in channels with or without sediment were probably the result of changes in available cover. As cover decreased (with increased sediment levels) fish were forced into the open areas of the pools where territories could not be easily maintained. Stuehrenberg (1975) found that age I steelhead "set up a hierarchical structure at the downstream end of the pools in both the test and control sections." He also stated that age 0 steelhead exhibited territorial behavior in the pools with a larger rate of interactions than the age I steelhead. I found a larger rate of interaction in the pools until the density declined as fish moved out of the channels. In the channels without sediment and in the channels with low levels of sediment imbeddedness (where cover was available) I observed few interactions between fish.

Fish densities in the winter tests decreased more than in the summer tests. In the winter tests intersticial cover was more important. The densities in the control channels during the winter tests stabilized at smaller densities than during the summer tests. The capacity of the large rock substrate cover was less in winter than in summer. When water temperatures dropped below 5 C. the fish burrowed into the substrate. The sedimented channels did not afford as much winter hibernating cover as the unsedimented channels, and densities were lower in the sedimented channels.

Stuehrenberg (1975) found that fewer age 0 steelhead and chinook remained in the channels with sediment in the riffles during the winter tests. These fish used the riffles for winter cover. As sediment levels were increased in the riffles, the cover was reduced and fewer fish remained in the channels with sediment.

Schaye (1976) did not find a significant relationship in 1974 between insect drift or benthos density and sediment levels in the riffles. Sandine (1974) found a decrease in abundance of total benthos and a decrease in the diversity of insects in the riffles in the artificial stream channels when sediment was added.

Predation on insect drift and benthos by fish did not significantly reduce the abundance of drifting organisms in 1974 (Schaye, 1976). However, the enumeration of insect drift in 1974 did not include adult stages. Adult stages and emergents may play an important role as food for fish (Chaston, 1968 & 1969; Griffith, 1974). The insect drift was more abundant in 1975 than in 1974 due to the inclusion of the adult and emergent stages in the analysis. A shift in insect species abundance took place at full sediment imbeddedness of the riffles. Diptera predominated after the addition of sediment and Ephemeropterans were most abundant before the sediment was added to the riffles. In spite of the shift in abundance sufficient food for fish was produced in the channels with sediment to maintain the fish remaining in the channels. The reduction in fish densities in channels with or without sediment was probably not food related.

In Knapp Creek fish densities also decreased as sediment was added to the test section. The decrease in fish abundance was probably a result of pool volume reductions in the test section, though fish densities decreased at a faster rate than did pool volume. Observations of the fish in Knapp Creek indicated definite habitat preferences. Age 0 chinook preferred water 0.15 to 1 m in depth near the shore areas of the pools. The addition of granitic sediment into the stream decreased the abundance of age 0 chinook by reducing the area 0.15 to 1 m deep. The larger steelhead, brook trout, and dolly varden preferred the deeper areas of the pools and the undercut banks. As this habitat was reduced by the addition of sediment more of these fish left the test pool. The reductions in fish abundance in Knapp Creek were primarily due to the reductions in pool volume and areas of preferred depth for the fish. The reductions in fish densities in the artificial stream channels were due primarily to loss of cover, as volume of the pools was not reduced as much as in Knapp Creek.

Stuehrenberg (1975) observed little, if any, decrease in fish densities in the test section of Knapp Creek with increased sedimentation and an increase in the control sections. However, I believe the increases in the control sections were insignificant. He also counted more fish in the test section after the first addition of sediment. He stated this was caused by fish movement into the test section to feed on insects dislodged from the riffles when sediment was added. Movement into the test section was not observed in 1974.

Stuehrenberg (1975) found that fish densities (fish/m^3) in the upper test pool increased as the pool volume decreased. He concluded that fish density (fish/m^3) was not at a maximum when the sediment was first added to the test pool. Fish numbers in the 1973 test increased after the first addition of sediment then decreased after subsequent additions of sediment. With the first addition of sediment pool area and volume decreased, few fish left the test section, and density then increased.

Additions of sediment to the upper test pool in Knapp Creek caused decreases in pool area and volume deeper than 0.30 m and corresponding decreases in fish numbers in both 1973 and 1974 (Figure 34). The number of fish prior to the sediment additions was not used in the fitting of the line for 1973 because fish density was not at a maximum and therefore fish numbers in the pool were not affected by the decrease in pool area that occurred during the first sediment addition.

The observations of 1974 indicate the same general linear decline in fish abundance with decreased pool area deeper than 0.30 m as in 1973 (Figure 34). The number of fish after the second addition of sediment was not used in the fitting of the line for 1974 because the large decrease in fish numbers after the second addition of sediment was due to loss of a small area of habitat where age 0 chinook were concentrated.

The slope of the line for 1973 (1.523) is significantly different ($0.995>P>0.990$) from the slope of the line for 1974 (2.6584). The difference in the slopes of the two lines indicates that the data for 1973 is different from the data for 1974 and that the two situations are not similar. For this reason I did not combine the data for the two years or fit a line to the combined data.

From our Knapp Creek data for 1973 and 1974 we have concluded that a decrease in pool area deeper than 0.30 m from the addition of sediment will cause a proportionate decrease in fish abundance in streams the size of Knapp Creek or smaller. Such a direct linear relationship may not hold for large pools (more than 100-200 m^2) in larger streams. My observations in other streams particularly Elk Creek, lead me to believe that juvenile fish use or need only a fraction of the total area available in large pools. In the case of

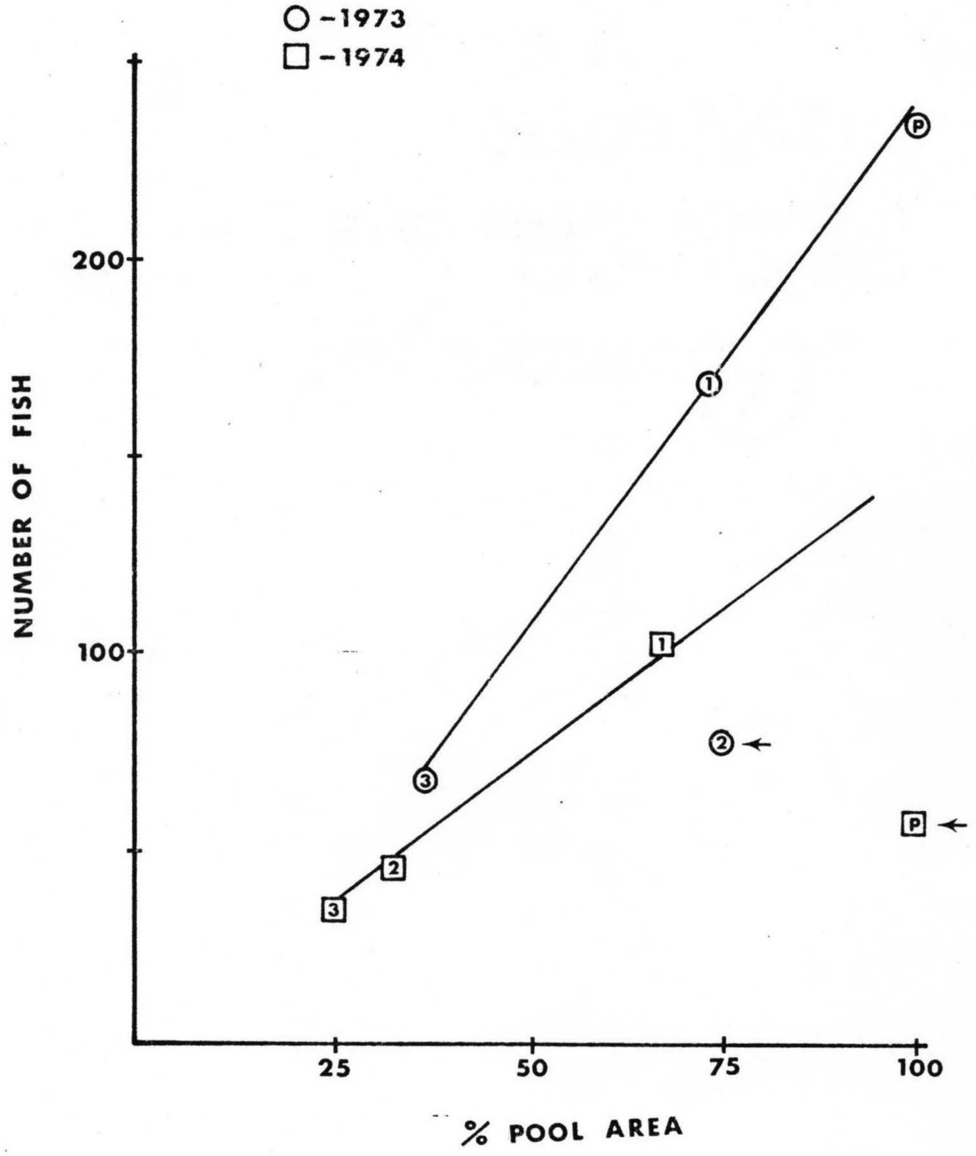

Figure 34. Fish numbers in the upper test pool versus the percentage pool area deeper than 0.30 meters during the sediment additions into Knapp Creek in 1973 and 1974. Arrows denote those observations not used in fitting the line by regression. (P = prior to addition of sediment, 1 = after first addition, 2 = after second, and 3 = after third addition of sediment).

large pools in large streams much larger amounts of sediment than introduced into Knapp Creek would have to be introduced into the pools before fish abundance would be affected.

Elk Creek posed an interesting problem in assessing and quantifying the effects of sediment on the fish and aquatic insects populations. Relatively large and small percentages of riffle sediment occurred throughout most of the stream length. Although larger percentages of sediment in the riffles were common in the lower section of Elk Creek, some riffles in the upper reaches also had large percentages of sediment. I found no relationship of percentage sediment in the riffles and distance of the riffles from the mouth of the stream (see multiple range tests in Appendix B). Fish density and insect drift density were not directly related to riffle sedimentation in Elk Creek. Some relationship of fish density to insect drift and cover did exist. Multiple correlations of insect drift, percentage riffle sediment, and cover indicated that all these factors affect the fish density in Elk Creek to some extent. I believe the fact that Elk Creek contained large amounts of sediment throughout confounds the relationships. Were data available on the stream prior to its sedimented condition (if indeed that was ever the case) comparison to the data I have collected may yield more conclusive results for Elk Creek.

The distribution of sediment in Bearskin Creek differed from that of Elk Creek (see multiple range tests in Appendix C). Between sites 3 and 4 (Figure 6) a tributary which contained large amounts of sediment entered Bearskin Creek and appeared to be the source of the larger amounts of sediment in lower Bearskin Creek. The tributary flows through a gravel pit which is a source of sediment.

The direct correlation of fish density with percentage riffle sediment was extremely small because other factors were also controlling the fish density. Cover and insect drift appeared to be the main factors. Increased sediment reduced the amount of cover and the reduction in cover affected fish density. This relationship appeared in both the artificial stream studies and in the Knapp Creek study.

Sediment coupled with riffle size affected insect drift, the riffle area affecting the drift to a greater extent than percentage riffle sediment. Both of these factors (cover and insect drift density) affected fish density.

In Figure 30 fish density was small with large amounts of insect drift. Smaller amounts of cover may have been partly responsible for the small fish densities in those sites with large amounts of insect drift. The correlation coefficient for the relationship of fish density to insect drift with the three sites that had small amounts of cover omitted was 0.9744 ($0.99>P>0.995$). Using an index of insect drift density and the percentage bottom cover combined (Figure 33) we found a high correlation with fish density in Bearskin Creek. Insect drift/pool area (m^2) and percentage bottom cover correlated best with fish density, however the correlation was insignificant. These two factors, insect drift and percentage bottom cover in the pools, only partly controlled the fish density in Bearskin Creek.

Insect drift density in Bearskin Creek was significantly correlated with riffle area and percentage sediment in the riffles (Table 12). Assuming that these two variables were actually controlling the insect drift, then 83% of the observed variation in insect drift was explained by riffle area and percentage sediment in the riffles.

It appears, then, that fish density in Bearskin Creek was regulated partly by insect drift density and percentage bottom cover. Cover was affected by the amount of sediment in the pools. Insect drift density was regulated in part by the riffle area and the percentage sediment in the riffles.

CONCLUSIONS

The introduction of granitic sediment into pools in small streams causes decreases in fish abundance in proportion to the reduction of the area deeper than 0.30 m and/or the reduction of available cover for fish. The winter holding capacity for fish is affected to a greater degree than the summer holding capacity. The larger decrease in winter holding capacity is due to the filling of the interstices in the substrate, a habitat preferred by salmonids of Idaho batholith streams during low water temperatures.

The introduction of granitic sediment into large pools in large streams probably affects the summer holding capacity less than in small streams. Juvenile chinook salmon and steelhead trout utilize only a small area of large pools. The unutilized area of large pools might be removed by the addition of sediment without large decreases in fish numbers.

Insect drift is regulated to a larger extent by riffle size than percentage riffle sediment. However, large percentages of sediment in riffles may change the composition of insect species in the riffles. Ephemeropteran densities are reduced by large amounts of riffle sediment.

Fish abundance in Idaho batholith streams appeared to be regulated by both insect drift density and percentage bottom cover in the pools. Introduction of granitic sediment to the extent that either of these factors are limited will reduce fish abundance in a stream.

The allowable amount of granitic sediment in any stream in terms of reducing fish abundance must be determined by first knowing the bedload sediment transport capacity of the stream, the time of year of the introduction of sediment, and the amount of cover and preferred habitat in relation to the size of the stream. Sediment introduced into a stream prior to the high discharge of spring run-off will have a smaller effect on fish abundance if the stream can transport the sediment out of the system. Sediment introduced after the spring run-off will most likely remain in the stream throughout the summer and winter, reducing fish abundance in proportion to its impact on preferred habitat, cover, and the insect drift abundance. The fish abundance in a small stream will be affected to a greater extent by the introduction of granitic sediment than a large stream due to the large percentage of area unused by juvenile salmonids in large pools in large streams.

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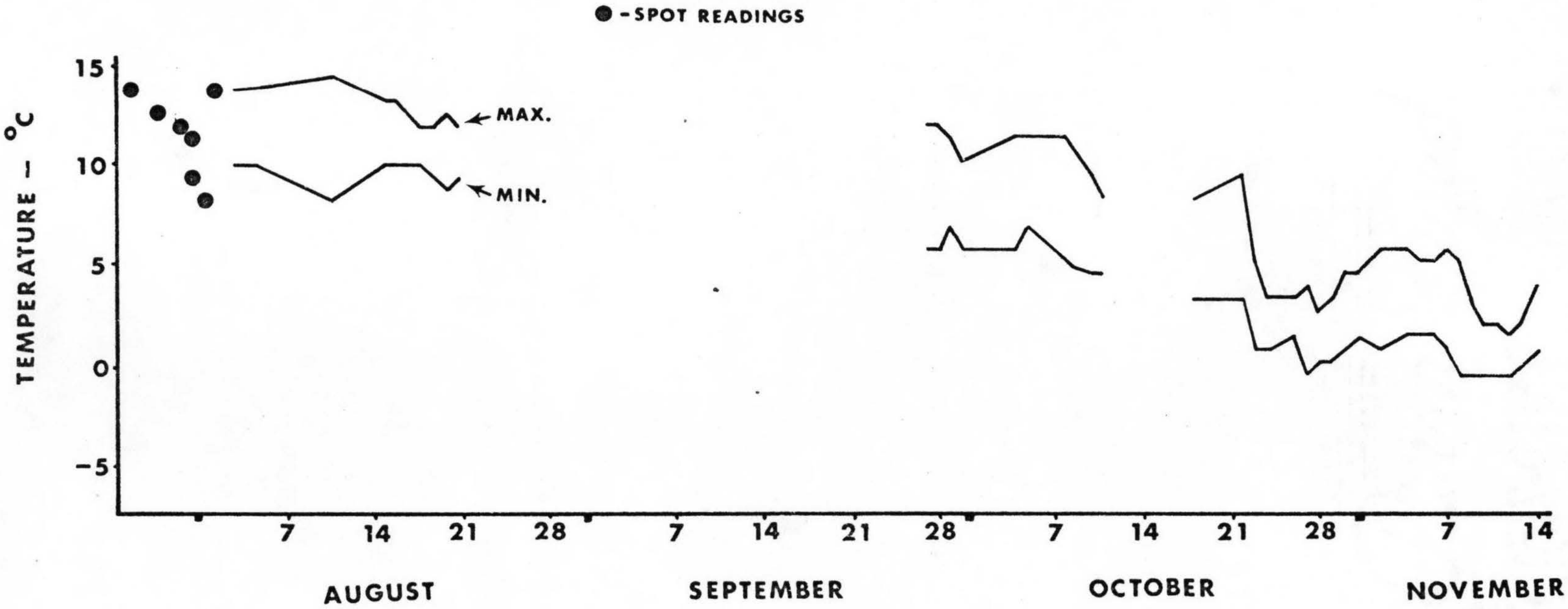
APPENDIX

The data contained herein were presented in the text, but did not appear in tabular or diagramatic form.



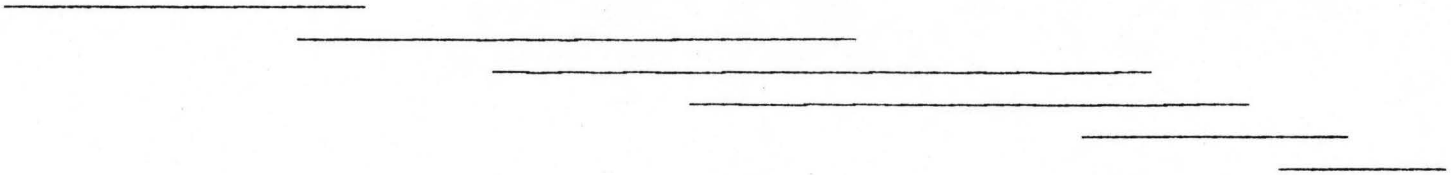
Appendix A. Water temperatures in the Hayden Creek artificial stream channels during the tests of 1975.

Appendix B. Results of Duncan;s multiple range test of the means of percentage sediment in the riffles of Elk Creek during correlational surveys of September, 1975.

Site --	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Mean --	26.0	32.5	36.7	23.1	29.1	25.7	46.9	36.8	38.0	59.2	37.5	40.5	39.2	44.0	51.2

At alpha = 0.05 those means connected by solid lines are similar, but those not connected are significantly different.

Site --	4	6	1	5	2	3	8	11	9	13	12	14	7	15	10
Mean --	23.1	25.7	26.0	29.1	32.5	36.7	36.8	37.5	38.0	39.2	40.5	44.0	46.9	51.2	59.2



Appendix C. Results of Duncan's multiple range test of the means of percentage sediment in the riffles of Bearskin Creek during the correlational surveys of September, 1975.

Site --	1	2	3	4	5	6	7	8
Mean --	64.2	61.2	75.3	32.7	20.3	24.7	36.6	62.1

At alpha = 0.05 those means connected by solid lines are similar, but those not connected are significantly different.

Site --	5	6	4	7	2	8	1	3
Mean --	20.3	24.7	32.7	36.6	61.2	62.1	64.2	75.3
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Appendix D. Parameters for study sites on Elk Creek, 1975.

	RIFFLE PARAMETERS			POOL PARAMETERS				FISH DENSITIES Fish/meter^2					
Site No.	Area m^2	Length m	% Sed.	Area m^2	Length m	Ave. Imbed.	Cover* 1,2	Ck_0	Ck_1	Sh_1	Wf	Total	Insect Drift No./m^3
1	91.4	7.6	26.0	269	30	1/2	30,0	.10	.07	.004		0.18	0.99
2	38.0	8.4	32.5	210	24	1/2	40,0	.09	.01	.01		0.11	0.53
3	195.2	13.1	36.7	149	20	1/4	10,30	.28	.07		.02	0.37	1.62
4	77.7	6.7	23.1	224	22	3/4	30,10	.16	.01		.004	0.17	1.12
5	145.8	14.0	29.1	206	22	1/2	50,5	.18	.05	.04	.005	0.28	1.75
6	67.1	6.1	25.7	180	20	3/4	60,5	.14	.06			0.20	1.17
7	76.8	7.9	46.9	62	14	1/2	40,10	.28				0.28	0.29
8	28.8	5.0	36.8	122	20	1/2	20,10	.10	.02		.008	0.13	0.41
9	53.0	9.2	38.0	51	11	1/2	40,10	.31	.10		.02	0.43	3.65
10	13.4	4.9	59.2	51	10	1/2	50,5	.10	.02			0.12	2.40
11	32.4	7.3	37.5	103	20	1/2	60,10	.05	.03		.02	0.10	0.87
12	125.5	9.2	40.5	153	26	1/2	40,10	.10	.05			0.15	0.55
13	103.7	11.0	39.2	196	26	F**	30,0	.03	.01	.005	.04	0.08	0.46
14	72.5	9.2	44.0	116	21	F	30,10	.13	.04	.01	.01	0.19	0.05
15	158.0	15.2	51.2	235	38	3/4	20,0	.09	.03			0.12	1.64

* - 1 = surface cover, 2 = bottom cover
** - F = Full imbeddedness

Appendix E. Parameters for study sites on Bearskin Creek, 1975.

	RIFFLE PARAMETERS			POOL PARAMETERS				FISH DENSITIES Fish/meter^2					Insect
Site No.	Area m^2	Length m	% Sed.	Area m^2	Length m	Ave. Imbed.	Cover* 1,2	Ck_0	Ck_1	Sh_1	Wf	Total	Drift No./m^3
1	67.7	8.5	64.2	58.4	10	F**	30,10	.86	.10		.03	0.99	1.26
2	25.2	3.6	61.2	28.8	12	F	40,0	.80	.17			0.97	1.28
3	30.1	5.5	75.3	38.0	9	F	25,20	.82	.13			0.95	0.43
4	12.1	3.1	32.7	51.6	12	1/2	40,10	.71	.06			0.81	0.45
5	25.1	8.2	20.3	42.8	10	1/2	50,20	.93	.14	.05		1.22***	0.64
6	20.8	4.3	24.7	29.2	9	1/2	50,30	1.44		.03		1.47	0.71
7	7.8	2.1	36.6	33.2	7	1/4	40,30	.54	.06	.03		0.63	0.31
8	83.7	8.1	62.1	133.2	22	F	30,0	.45	.09	.06		0.60	1.60

* - 1 = surface cover, 2 = bottom cover

** - F = full imbeddedness

*** - age-0 Sh included in total (0.09 fish/m^2)