THE EFFECTS OF GRANITIC SAND ON THE DISTRIBUTION AND ABUNDANCE OF SALMONIDS IN IDAHO STREAMS

A Master's Thesis

by

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THE EFFECTS OF GRANITIC SAND ON THE DISTRIBUTION AND ABUNDANCE OF SALMONIDS IN IDAHO STREAMS

A Thesis

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by

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

FIGURE PAGE

ABSTRACT

In the summers of 1972 and 1973 an interdisciplinary team studied the effects of different levels of Central Idaho Batholith sediment on the aquatic biota in streams. The work was conducted in artificial stream channels at the Hayden Creek Experimental Research Station and in streams in the Central Idaho Batholith.

In the fisheries part of the study I assessed: (1) the effects of sediment in summer habitat on juvenile steelhead trout (*Salmo gairdneri*) and chinook salmon (*Oncorhynchus tshawytscha*), and (2) the effect of sediment in winter habitat on juvenile steelhead trout and and chinook salmon.

I concluded that juvenile steelhead trout and chinook salmon were not affected by the levels of batholith sediment we added to riffle sections during summer but a reduction of pool area by sediment caused a direct decrease in the number of fish present in the pools.

Under winter stream conditions I found that age-0 steelhead trout and chinook salmon did not remain in riffle sections when sediment filled the interstitial spaces of the gravel substrate.

INTRODUCTION

As one part of an interdisciplinary study on the effects of batholith sediment on the aquatic biota, I tested the hypothesis that increased amounts of batholith sediment from the Central Idaho Batholith would not reduce summer or winter holding capacity of streams for juvenile steelhead trout and chinook salmon. The transport of sediment in streams and the effects of sediment on aquatic insects were treated in other portions of the study.

Idaho contains the Central Idaho Batholith and the North Idaho Batholith (Fig. 1). The Central Idaho Batholith drains primarily into the Clearwater and Salmon Rivers, the natal streams of the steelhead trout and chinook salmon which enter Idaho.

The granitic base rock in the Central Idaho Batholith readily decomposes into coarse sand that becomes bedload sediment (sediment defined as material less than 1/4 inch in diameter) when it enters streams. Many of the watersheds of the batholith are steep and relatively unstable. Development of roads and other activities that disturb the steep slopes result in large amounts of sediment entering the streams. We conducted these studies to evaluate the effects of this sediment on aquatic organisms and the capability of the streams to transport the sediment.

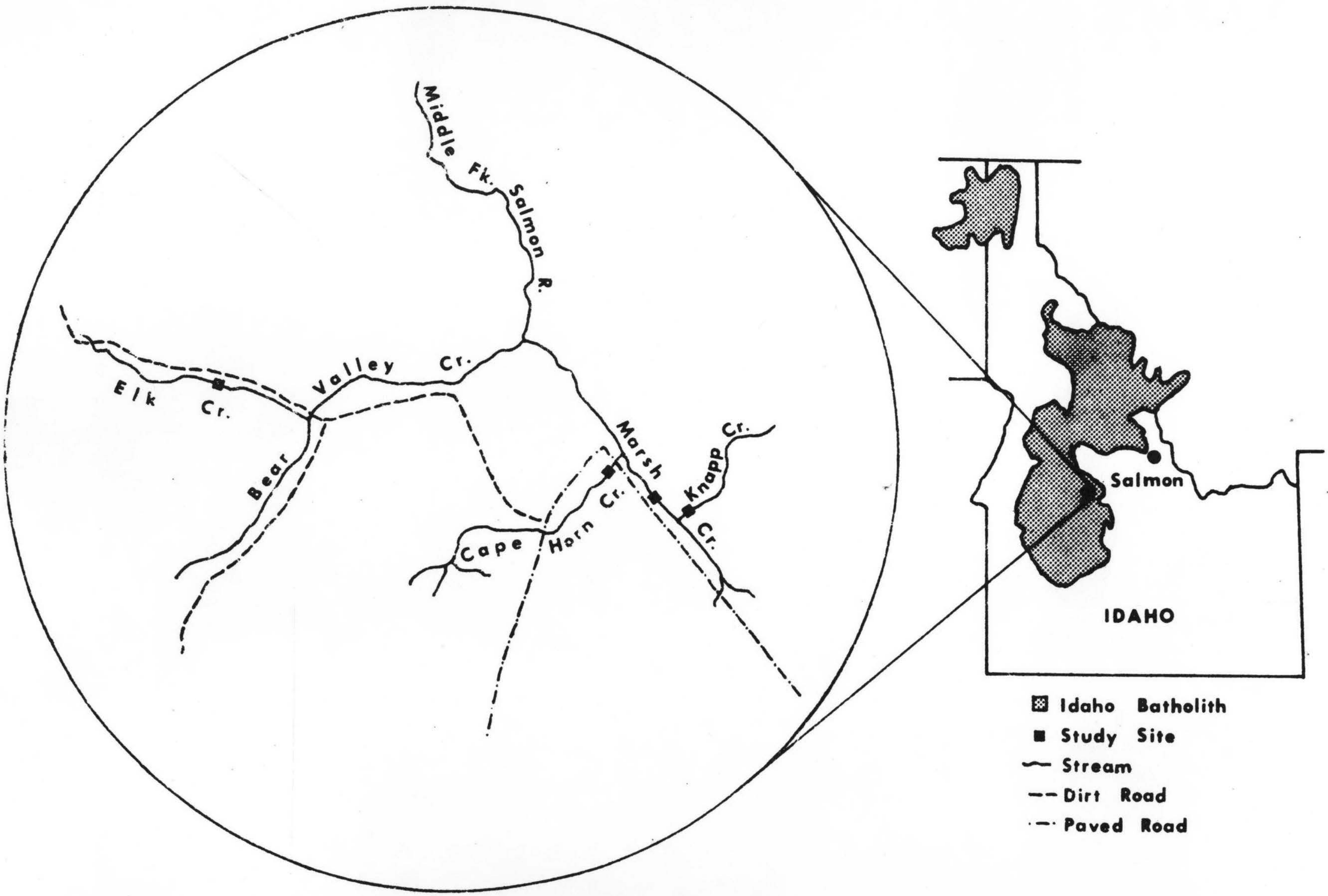

Figure 1. Map of the North and Central Idaho Batholiths, the study areas and study sites on each stream, 1972 and 1973.

STUDY SEGMENTS AND FACILITIES

The study team conducted: (1) surveys in streams of the batholith to correlate the abundance and distribution of aquatic organisms with physical features of the streams; (2) tests in artificial stream channels where we establish fish and insect populations and introduced sediment; and (3) tests in Knapp Creek where we added sediment to a natural stream.

Correlational Stream Surveys

During the summers of 1972 and 1973 the study team surveyed tributaries of the Middle Fork of the Salmon River to correlate the distribution and abundance of fish and aquatic insects with sediment and other parameters of the habitat.

We surveyed Marsh, Capehorn, and Elk Creeks in 1972 and Capehorn and Elk Creeks in 1973 (Fig. 1). In 1972, an average runoff year, stream discharge in August ranged from 1.2 cms (41 cfs) for Capehorn Creek to 2.0 cms (72 cfs) for Elk Creek. In 1973, a year with less than average runoff, discharge ranged from .95 cms (34 cfs) in Capehorn Creek and 1.8 cms (64 cfs) in Elk Creek. Nielson (1974) gives a more detailed description of these streams and their watersheds. All of the streams had naturally occurring populations of juvenile steelhead trout and chinook salmon.

Artificial Stream Studies

We conducted tests in artificial stream channels in the summer and fall of 1973 to assess the effects of riffle sedimentation on summer and winter holding capacities of streams for juvenile steelhead trout and chinook salmon.

Two channels 140 feet long, 4 feet wide, and 2 feet deep were constructed on the covered concrete slab at the Hayden Creek Experimental Research Station during the summer of 1972 (Fig. 2). We divided each channel in half to provide four test sections and placed rotary drum screens at the upstream and downstream ends of each test section to prevent fish from leaving or entering the channels (Fig. 2 and 3).

The study team used two water supplies in the channels: spring water with a relatively constant temperature of 52°F to 54°F, and water from Hayden Creek with natural stream temperatures.

Drift insects from Hayden Creek were introduced into the water supplies at the headbox. A scoop trap picked up the insects in Hayden Creek and they were transported to the artificial stream channels through a six-inch pipe.

Traps were installed at the downstream end of each section to collect fish which elected to leave the channels (Fig. 4).

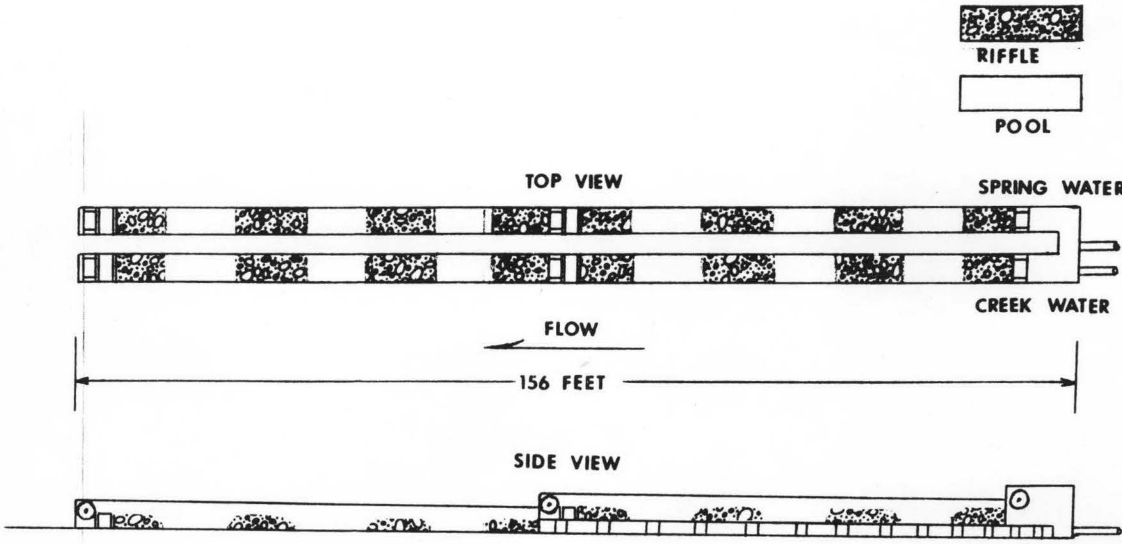

Figure 2. Artificial stream channels showing dimensions and pool-riffle configurations.

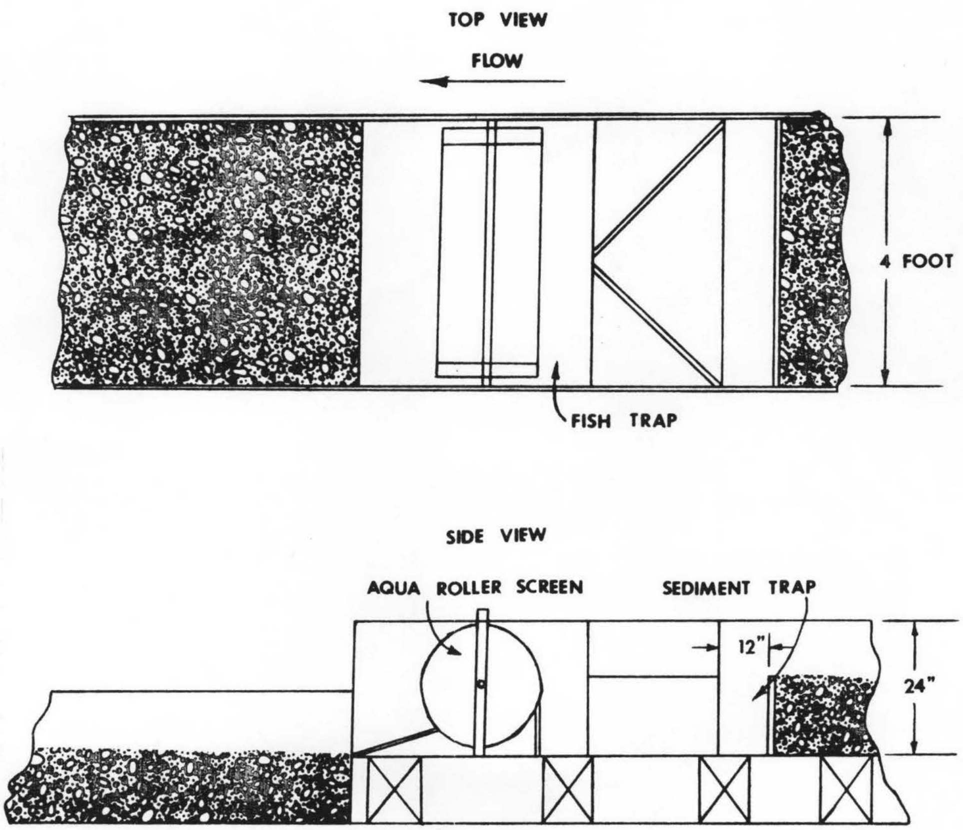

Figure 3. Downstream ends of artificial stream channels, rotary drum screens, and sediment trap.

I hung curtains made of green nylon along the sides of the channels to prevent outside activities from disturbing the fish and to prevent fish from jumping out of the channels.

Knapp Creek Study

During August, 1973 we added sediment to two pools and riffles in Knapp Creek to assess its effect on the abundance and distribution of juvenile steelhead trout and chinook salmon.

Knapp Creek is a tributary of Marsh Creek, in the headwaters of the Middle Fork of the Salmon River (Fig. 1). During August of 1973, Knapp Creek had a discharge of .14 cms (5.0 cfs). The study team studied the effects of sediment on fish and insects in a section of Knapp Creek that meandered through a meadow. For a more detailed description of the study area and the Knapp Creek watershed see Nielson (1974).

PROCEDURES

Correlational Stream Surveys

To correlate fish and insect abundance and distribution with physical aspects of the habitat, the study team measured: (1) the amount of sediment present in the substrate of each stream to a depth of six inches; (2) the amount of suitable habitat available to juvenile steelhead trout and chinook salmon; (3) the number and location of steelhead trout and chinook salmon in each study area; (4) the abundance of benthos and drifting insects; and (5) the food habitat of juvenile steelhead trout and chinook salmon.

We selected the study streams for their differences in sediment levels and the populations of juvenile steelhead trout and chinook salmon they contained. Marsh and Capehorn Creeks contained a relatively small amount of sediment and Elk Creek appeared to have a large amount of sediment. At least three pool-riffle combinations were studied in each stream.

In 1972, I analyzed fish distribution and abundance using macro-habitat techniques. We mapped the location of each fish in the study sections by age group and species using a wet suit and snorkel (Ellis, 1961). I then placed map overlays of water velocities (1/2 depth), water depth, and streambed material classification on maps of fish distribution to obtain the number of fish per velocity, depth, and bottom material classification. I could not distinguish between age-1 and older juvenile steelhead trout, so they are reported as age-group 1 and older steelhead trout. After the fish population had been mapped, fish were collected from the study area by electro fishing, length measured and stomachs preserved in 10% formalin for later analysis.

I calculated fish densities in two ways: fish per total area mapped, and fish per area of preferred habitat. I defined preferred habitat as pool areas with a depth of over 0.5 feet. I used the depth contour maps to determine the area of preferred habitat in each stream. The pool surface area was planimetered from the previously prepared base map, and divided the number of age-1 and older steelhead trout and juvenile chinook salmon in the pool by the surface area to obtain the density in preferred habitat. Similarly the fish density for the total area was obtained by dividing the number of juvenile steelhead trout and chinook salmon counted in the section by the surface area of the section.

I analyzed the fish stomachs by counting the number of insects of each order for each age group and species of fish. The insect count was then converted to percentage of fish diet for comparison with percentage composition of the insect drift in the study streams.

In 1973, we collected more precise information on the distribution of fish in relation to their micro-habitat preferences. We collected 10 fish of each species and age group from their focal point (most frequently occupied .11 m^2) using the blasting cap gun described by Everest (1969). Measurements at the focal point included water depth, fish depth, focal velocity, and bottom classification. We measured the length of each fish collected and took the stomach for later analysis.

Refer to Nielson (1974) for procedures used to collect and analyze data on the physical features of the streams, and Sandine (1974) for procedures used to collect and analyze insect drift and benthos samples.

Artificial Stream Studies

To assess the effect of sedimentation of riffles on juvenile steelhead trout and chinook salmon during summer and winter periods I conducted nine tests in the channels at Hayden Creek (Table 1). I assessed: (1) the effects of three levels of riffle sedimentation on age-1 steelhead trout (tests 1-3); (2) the effects of fully sedimented riffles on age-1 steelhead trout when insect recruitment from outside the channels was shut off (test 4); (3) the effects of fully sedimented riffles on age-0 steelhead trout from wild and hatchery populations (tests 5 and 6); and (4) the effects of fully sedimented riffles on juvenile

Table 1. The tests of summer and winter capacity for fish in stream channels at Hayden Creek.

Test number	Fish used	Length of test (days)	Insect supply to channels	Sediment level	Data Collected			
					Insects benthos and drift	Fish density	Fish behavior	Facial depth and velocity
Summer capacity								
1	Age-1 wild steelhead	6	Pipe	1/3 gasket	X	X	X	X
2	Age-1 wild steelhead	6	"	2/3 gasket	X	X	X	
3	Age-1 wild steelhead	6	"	Full gasket	X	X	X	
4	Age-1 wild steelhead	29	None	"	X	X	X	X
5	Age-0 wild steelhead	6	Pipe	"		X	X	
6	Age-0 hatchery steelhead	6	"	"		X	X	
Winter capacity								
7	Age-0 wild steelhead	6	"	"		X		
8	Age-0 wild chinook	6	"	"		X		
9	Age-1 wild steelhead	6	"	"		X		

steelhead trout and age-0 chinook salmon during the winter (tests 7-9).

I evaluated the effects of riffle sedimentation on juvenile steelhead during the summer by comparing the differences in fish densities, fish behavior, fish lengths, and condition factor between test and control channels during the period of June 25 to September 20, 1973. I evaluated the effect of full riffle sedimentation on steelhead trout and chinook salmon during winter stream conditions by comparing differences in fish densities between test and control channels during the period of October 6-22, 1973.

We set up the four stream channels as follows (Fig. 4):

Channel 1 - We added insects via the insect pipeline from Hayden Creek.

Channel 2 - In addition to insects we added sediment to the riffles.

Channel 3 - In addition to insects we added fish at the start of each test.

Channel 4 - In addition to insects and fish we added sediment to the riffles.

We collected the same type data in the artificial stream channels as in the correlational stream surveys plus data on fish behavior and condition factor.

We added sediment to the riffles in the test channels until a preselected cobble embeddedness (gasketing) had been obtained. The levels of embeddedness that we tested were 1/3, 2/3, and full (Fig. 5).

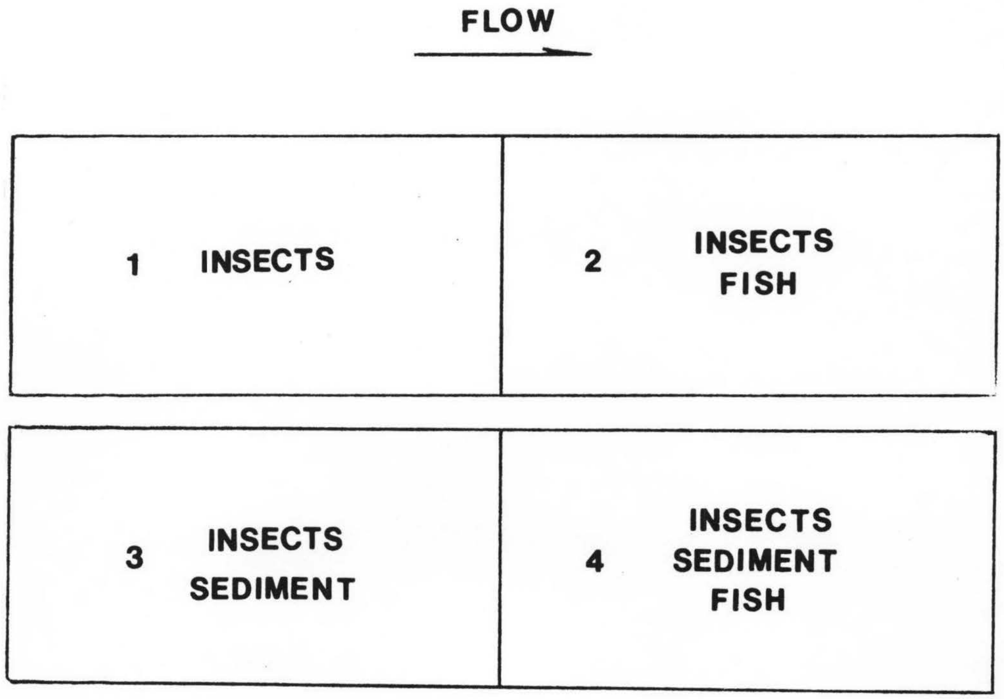

Figure 4. The number of each channel and those with insects, sediment and/or fish added during the tests.

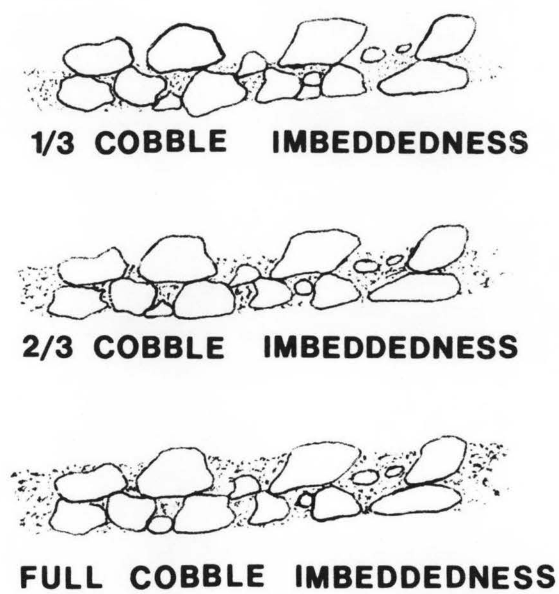

Figure 5. Cross-section of riffle in artificial stream channel with levels of cobble embeddedness with sediment.

I counted aggressive interactions of fish and measured territory size for each fish on the first four days of each run. I observed the fish six hours each day, from the time it was light enough to see the fish until two hours later, from 12:00 P.M. to 2:00 P.M., and the last two hours of the evening in which the fish could be seen. Observations were made through windows in the side of the channels. I divided the pools into foot square areas with white rocks to facilitate accurate location of the fish. I recorded the observations of fish movements and interactions on tape during each two hour period then recorded the date in a logbook and plotted fish territory size on maps of the pools. Interactions per minute were obtained by dividing the number of interactions observed in a section by the minutes of observation time. Average territory size per fish was calculated by summing the areas of territories for fish observed, and then dividing by the number of fish observed.

I took fish length on all fish at the time that they left the stream sections or when I removed them at the end of a run. I took weights for the fish removed at the end of test four to obtain estimates of condition factor.

The fish used in the tests of summer holding capacity were collected with electrofishing gear from Big Springs Creek, a tributary of the Lemhi River, except for the age-0 steelhead trout used in test six which were taken from the raceways at the Hayden Creek Experimental Research Station. The fish for the winter condition tests were taken from the downstream traps at the Lemhi River and Big Springs Creek weirs. All fish were held for one-two days in a tank after collection to insure they were in good condition for the tests.

A typical test was conducted in the following manner after the sediment had been added:

Day 1 - Close traps and add fish to channels for acclimation.

Day 2 - Open traps to permit emigration and start behavior observations.

Days 3, 4, and 5 - Count and remove fish in traps and continue behavior observations.

Day 6 - Count fish in traps and remove all remaining fish from channels with electrofishing gear.

Insect drift was collected during each test at the head and tail end of each channel. Benthos samples were collected at the end of each test from the riffles in each section.

Knapp Creek Study

To test the effects of sediment on the summer holding capacity of a natural stream for juvenile steelhead trout and chinook salmon, the study team added sediment to two pools and two riffles in Knapp Creek.

I evaluated the effects of sediment added to pools and riffles in Knapp Creek on fish by assessing the changes in distribution and abundance of trout and salmon in test and control sections. To determine the effect of reduction of pool area and volume through addition of sediment on fish carrying capacity of pools in summer we calculated fish densities in preferred habitat (pool areas with a depth of over .5 feet).

We selected Knapp Creek as the study stream because it contained all age groups of juvenile steelhead trout and chinook salmon, was small enough that we could cause habitat changes with the sediment we had available, and it was accessible.

The study area on Knapp Creek was divided into a test section and upstream and downstream control sections (Fig. 6). Each section contained at least two pool-riffle series. Physical and biological data collected in Knapp Creek were the same as those in the correlational stream surveys.

In the Knapp Creek study, we measured the physical parameters of the study sections and collected data on the distribution and abundance of fish and insects before sediment was added. We then added sediment to test pools and riffles and then remeasured the physical parameters of the test sections and remeasured the distribution and abundance of fish and insects. We added more sediment to the two test pools and after 60 hours remeasured the distribution and abundance of fish two additional times. We then waited 18

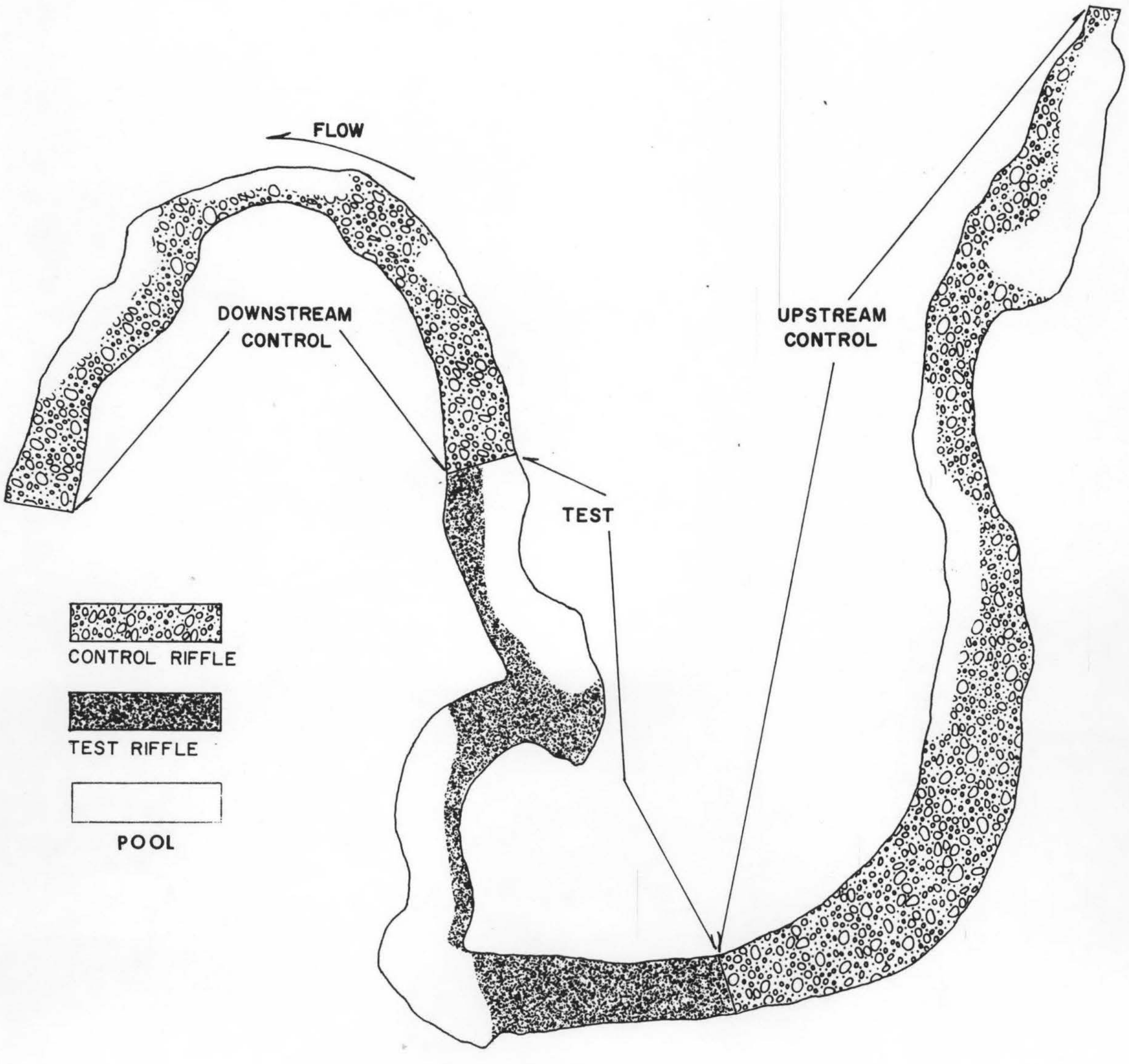

Figure 6. Knapp Creek study area showing test and control sections and pool-riffle configurations.

days after the last addition of sediment and remeasured the physical parameters of the test sections and remeasured the distribution and abundance of fish and insect in the test and control sections (Table 2).

We added sediment to the two test pools in two ways. In the upper pool we placed the sediment on the tail end of the riffle upstream from the pool and allowed the water to wash the sediment into the pool and form a delta in the pool. In the lower pool we spread the sediment over the bottom of the pool and filled the pool up from the bottom. In both pools we wanted to decrease the area and volume of the pools in steps to assess the effects of such reductions on densities and distribution of fish.

Table 2. Sequence of events at Knapp Creek and data collected in each phase of the study during 1973.

Event and date	Section of stream	Mapping: Stream boundary	Mapping: Depth and velocity	Mapping: Bottom classification	Mapping: Fish populations	Insects benthos and drift	Sediment added: Riffles	Sediment added: Pools
Pre-dump survey	Control	X	X	X	X	X		
July 27	Test	X	X	X	X	X		
Add sediment August 2	Test						X	X
Post-dump survey	Control				X	X		
August 3	Test		X	X	X	X		
Add sediment August 3	Test							X
Post-dump survey	Control				X			
August 6	Test		X	X	X			
Add sediment August 6	Test							X
Post-dump survey	Control				X			
August 9	Test		X	X	X			
Post-dump survey	Control				X	X		
August 24	Test		X	X	X	X		

RESULTS

Correlational Stream Surveys

Elk Creek had the largest amount of sediment (smaller than 1/4 inch), the lowest average streambed profile (highest cobble embeddedness), and the smallest number of drifting insects; yet the density of juvenile steelhead trout and chinook salmon in the Elk Creek was almost as large as in Marsh and Capehorn Creeks which had less sediment, higher average streambed profiles (less cobble embeddedness), and larger numbers of drifting insects (Tables 3, 4, and 5).

Elk Creek had the largest proportion of bed material finer than 1/4 inch (sediment) in both pools and riffles, based on analysis of core samples (Table 3), and as a result had a larger percentage of cobble embeddedness than did Marsh and Capehorn Creeks. Marsh and Capehorn Creeks had similar amounts of sediment and cobble embeddedness.

In 1972, using macro-habitat techniques, we found that age-0 chinook salmon occurred mostly in water less than 2 feet in depth (Fig. 7), mid-depth water velocities less than 2 fps (Fig. 8), and no correlation with size of streambed material (Fig. 9). Age-1 chinook were found in similar conditions but with more fish in 1-2 feet/second velocities (Fig. 8). We found age-0 steelhead trout mostly in water less than 1 foot in depth (Fig. 10), in mid-depth velocities

Table 3. Volume of flow, sediment discharge, and percentage of sediment in bed material in selected pools and riffles of the three streams in August, 1972.

Study stream	Date Surveyed	Percentage sediment (<1/4 inch)				Water discharge (cfs)	Sediment discharge (pounds per day)
		Pools		Riffles			
		Number of samples	Percentage sediment	Number of samples	Percentage sediment		
Marsh Creek	August 8	3	44	17	34	42.1	7.1
Capehorn Creek	August 12	3	52	17	26	40.8	7.9
Elk Creek	August 15	3	63	17	52	71.9	3.7

Table 4. Number of drifting insects per m^3 of water passing through three drift nets in Marsh, Capehorn, and Elk Creeks from August 8 to 15, 1972.

Location	Time Periods			
	0500-0700	1200-1400	2000-2200	2400-0200
Marsh Creek				
Ephemeroptera	0.780	0.250	1.737	3.994
Plecoptera	0.034	0.044	0.005	0.152
Trichoptera	0.034	0.079	0.059	0.123
Coleoptera	0.093	0.122	0.167	0.501
Diptera	0.074	0.079	0.520	0.623
Totals	1.015	0.535	2.527	5.393
Capehorn Creek				
Ephemeroptera	0.206	0.172	0.319	3.385
Plecoptera	0.098	0.019	0.079	0.864
Trichoptera	0.064	0.108	0.069	0.133
Coleoptera	0.078	0.039	0.054	0.231
Diptera	0.093	0.054	0.093	0.231
Totals	0.539	0.392	0.614	4.844
Elk Creek				
Ephemeroptera	0.113	0.079	0.079	0.731
Plecoptera	0.010	0.005	0.005	0.039
Trichoptera	0.005	0.005	0.044	0.025
Coleoptera	0.019	0.019	0.019	0.152
Diptera	0.049	0.019	0.103	0.137
Totals	0.196	0.127	0.250	1.084

Table 5. Streams surveyed, size of study sections, fish counted and density in August 1972 and 1973.

Stream and year	Size of study area (m^2)	Fish numbers					Fish density/m^2			
		Chinook		Steelhead		Total	Pool #1	Pool #2	Pool #3	Total area
		Age-0	Age-1	Age-0	Age-1					
Marsh Creek										
1972	962	305	67	12	31	415	.693	.726	.916	.432
Capehorn Creek										
1972	1268	427	16	5	0	448	.895	1.350	.497	.360
1973	1268	425	32	3	0	460	-	-	-	.363
Elk Creek										
1972	1131	295	114	6	36	451	1.050	1.090	-	.399
1973	1131	305	97	46	29	477	-	-	-	.422

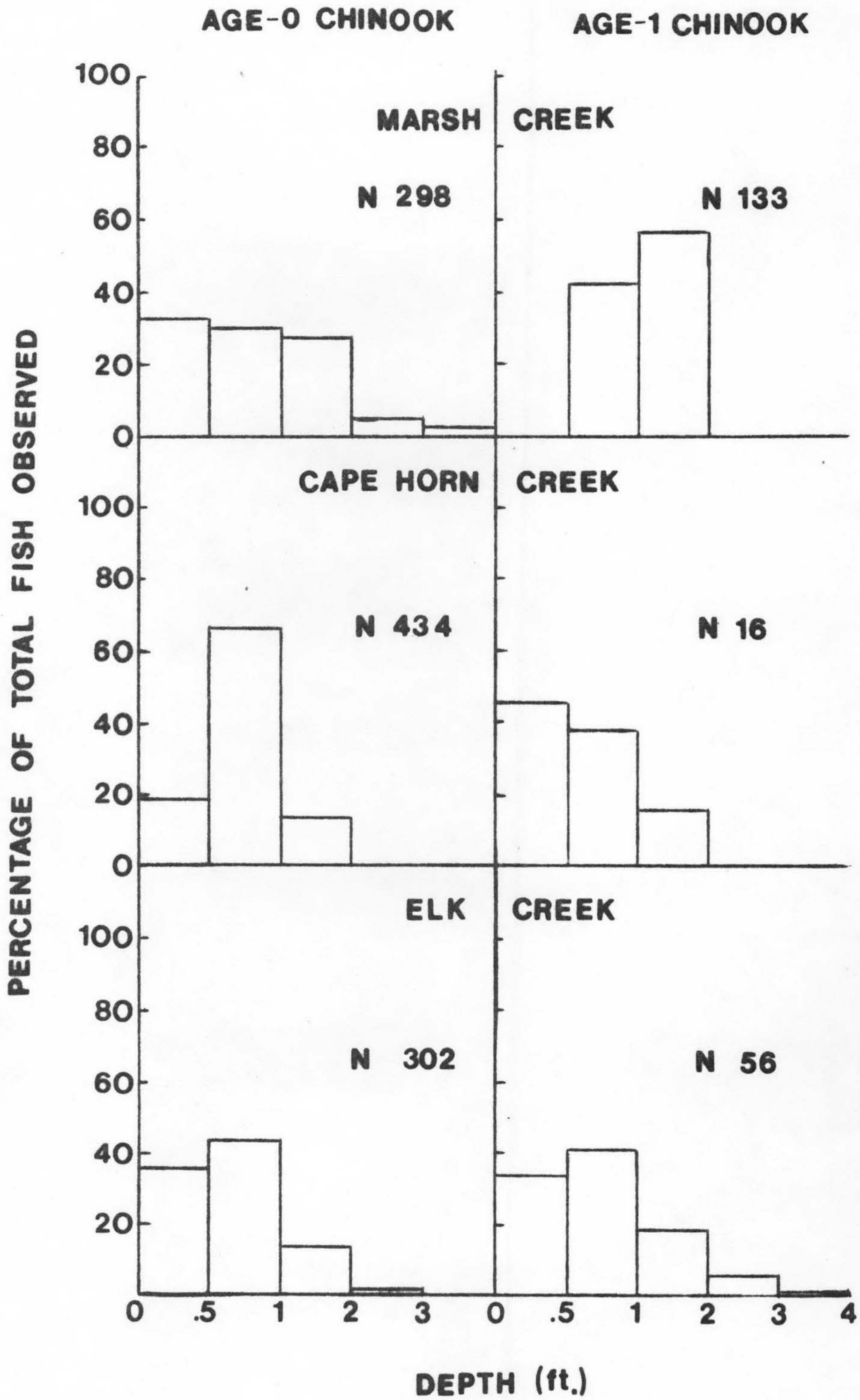

Figure 7. Water depths at which age-0 and age-1 chinook were found in the macro-habitat study.

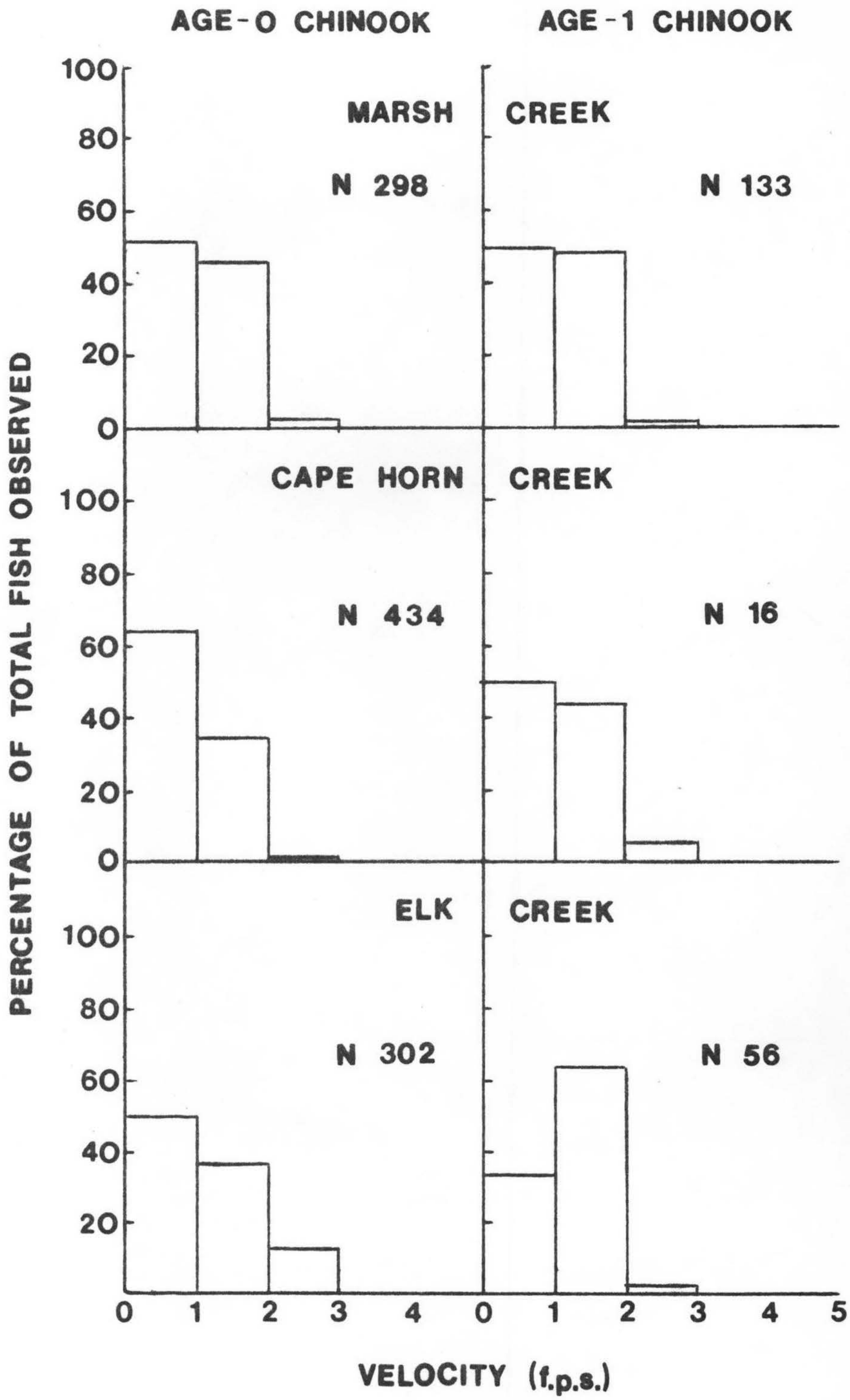

Figure 8. Velocities at mid-depth at which age-0 and age-1 chinook were found in the macro-habitat study.

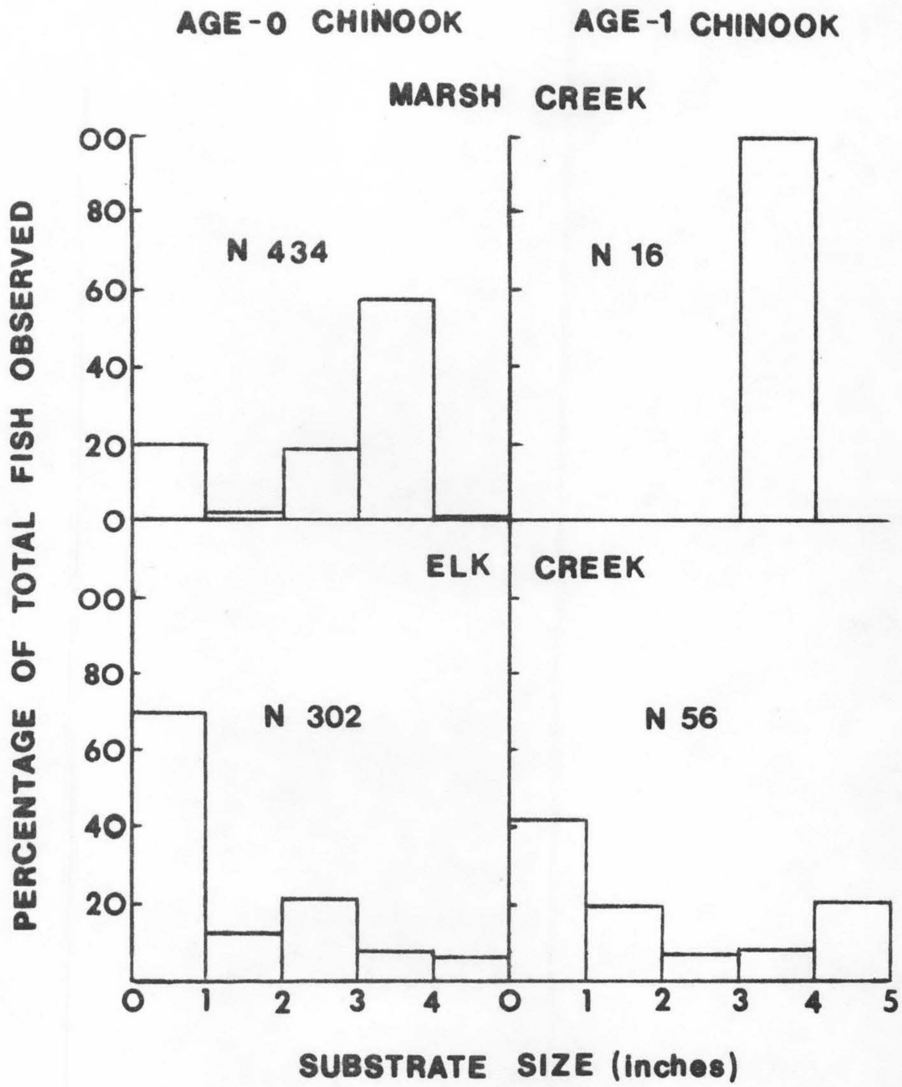

Figure 9. Bottom size in inches of the area where age-0 and age-1 chinook were found in the macro-habitat study.

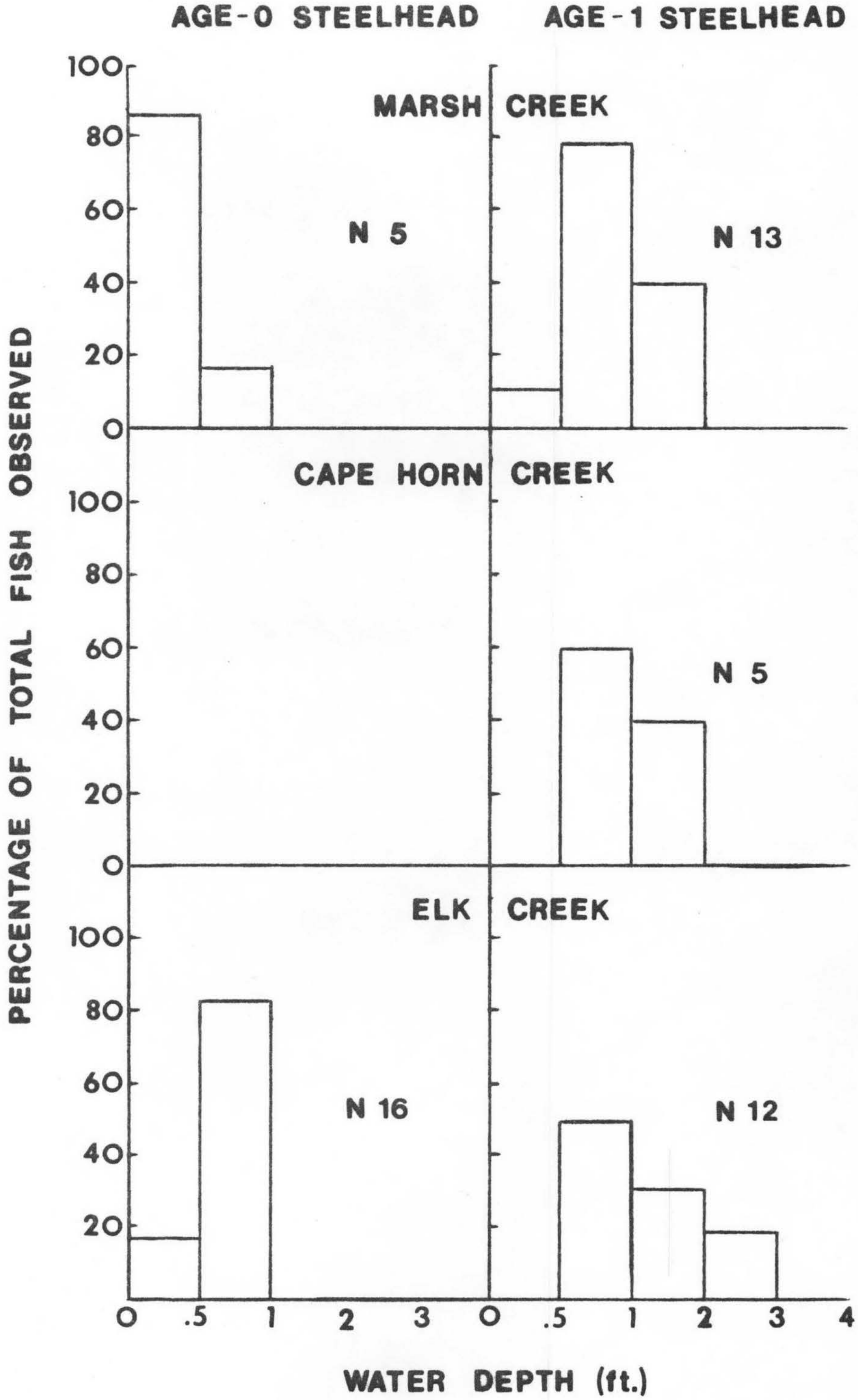

Figure 10. Water depths at which age-0 and age-1 steelhead were found in the macro-habitat study.

less than 2 feet per second (Fig. 11), and over bed material less than 1 inch in diameter. The older age groups of steelhead trout were in areas with mid-depth water velocities of less than 1 fps (Fig. 11) and depth of more than 1/2 foot (Fig. 10), and no correlation with size of bed material.

In 1973, using micro-habitat techniques, we found fish in the same type habitat as in 1972 except for velocities. We measured focal point velocities in 1973 instead of the 1/2 water depth velocities of the macro-habitat studies in 1972. Focal velocities for fish we collected ranged from .10 to .85 fps with an average of .46 fps for age-0 steelhead trout, .15 to 1.2 fps with an average of .52 fps for age-1 steelhead, 0 to .7 fps with an average of .28 fps for age-0 chinook salmon, and .15 to 1.25 fps and an average of .55 fps for age-1 chinook.

In general, age-0 chinook salmon were the most abundant fish in the streams, followed by age-1 chinook salmon, age-0 and age-1 steelhead trout (Table 5). Total fish densities in the entire study section of Marsh, Capehorn, and Elk Creeks varied between .43 and .36 fish per square meter. The average densities of fish in preferred habitat (pools) of the streams ranged from .50 to 1.35 fish per square meter. I did not include age-0 steelhead in the fish density estimates for pools because I usually found them in water depths less than 1/2 foot, and there were

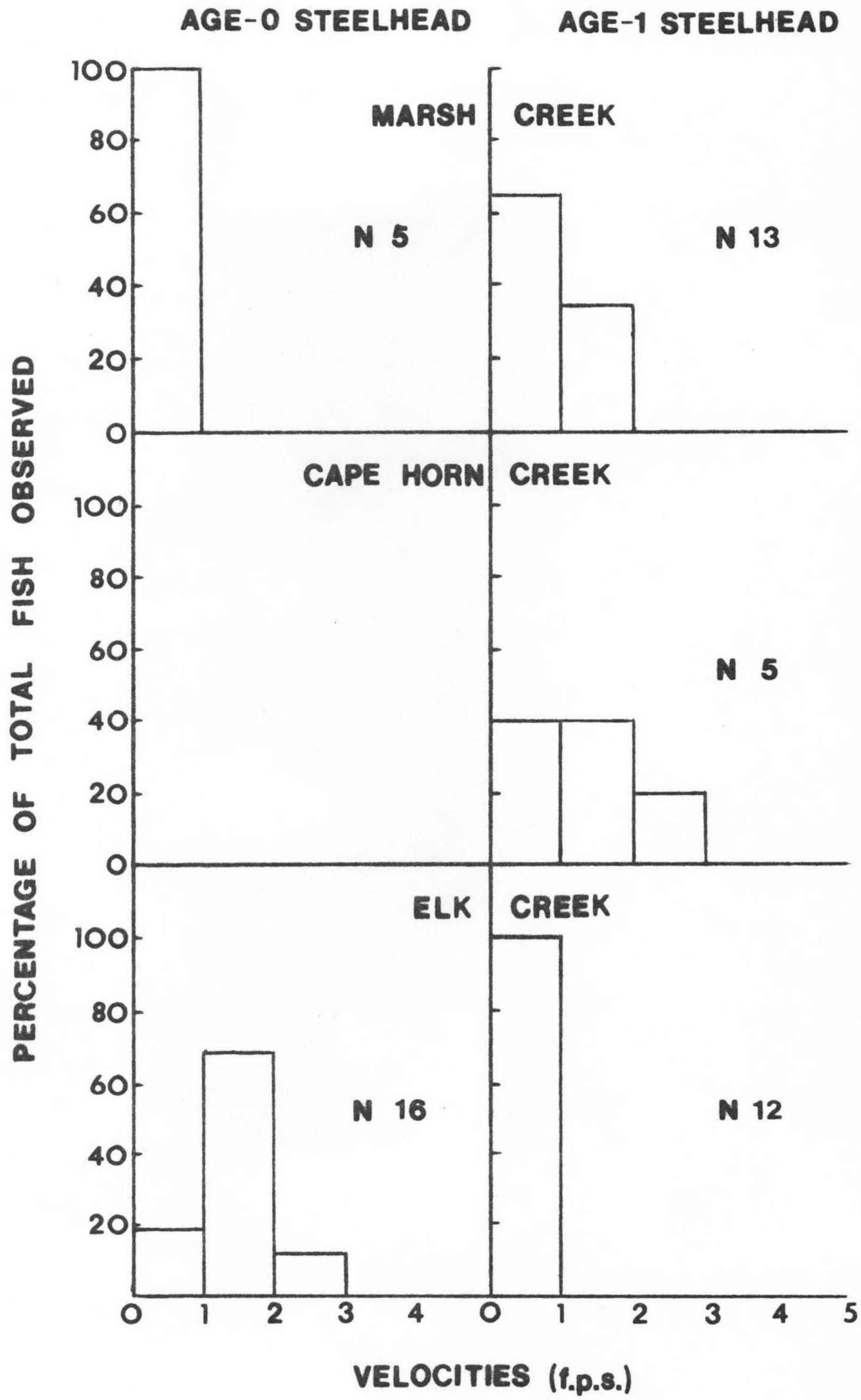

Figure 11. Velocities at mid-depth at which age-0 and age-1 steelhead were found in the macro-habitat study.

no age-0 steelhead in the study section on Capehorn Creek.

I compared the mean length of fish from each stream and found no significant difference between streams for each species and age-group (Table 6).

Insects of the order Diptera were more abundant in the fish stomachs examined than in the drift samples (Table 7). This may have been caused by having too large a mesh size on the drift net, which would have allowed the smaller Diptera to pass through the net. Ephemeroptera were the most abundant group of insects drifting in all three streams and were abundant in the diet of all groups of fish, but proportionately less abundant than in the drift.

Artificial Stream Studies

Fish densities in channels with and without sediment added to the riffles differed little in the tests of summer holding capacity (tests 1-6) (Fig. 12).

End-of-test densities for age-1 steelhead differed very little in tests 1-3 where we added progressively more sediment to the riffles. In test 4, where the fish were left for 28 days without extra insect recruitment via the pipeline the densities were lower than in tests 1-3. In tests 5 and 6 nearly equal number of age-0 steelhead remained in the test section versus the control section, but in test 5 with age-0 steelhead trout collected from

Table 6. Mean total length of chinook salmon and steelhead trout collected from the study stream in 1972.

Stream	Chinook				Steelhead			
	Age-0		Age-1		Age-0		Age-1	
	N	Length	N	Length	N	Length	N	Length
Marsh Creek	26	62.8	15	104.9	17	32.4	3	145.0
Capehorn Creek	25	55.1	5	93.0	-	-	2	151.5
Elk Creek	29	61.5	22	93.1	-	-	15	114.6

Table 7. A comparison of the percent composition of insects in the drift samples with those in the stomachs of various age-groups of juvenile chinook and steelhead from the three study streams in August, 1972.

		Percent composition				
	Number of fish	Ephemeroptera	Plecoptera	Trichoptera	Coleoptera	Diptera
Marsh Creek						
Drift		70	2	3	9	15
Fish stomachs						
Chinook salmon						
Age-group 0	5	46	0	8	trace	43
Age-group I	39	57	1	2	2	37
Steelhead trout						
Age-group 0	16	31	0	0	trace	67
Age-group III	3	38	9	20	2	31
Capehorn Creek						
Drift		65	15	5	9	7
Fish stomachs						
Chinook salmon						
Age-group 0	11	9	2	2	0	87
Age-group I	30	39	6	2	trace	52
Steelhead trout						
Age-group II	1	92	0	4	0	4
Age-group IV	1	65	0	14	0	9
Elk Creek						
Drift		59	3	3	22	13
Fish stomachs						
Chinook salmon						
Age-group 0	28	9	0	3	0	82
Age-group I	25	19	19	3	17	53
Steelhead trout						
Age-group I	2	9	0	1	6	82
Age-group II	3	21	5	0	0	66
Age-group III	3	3	7	0	0	13

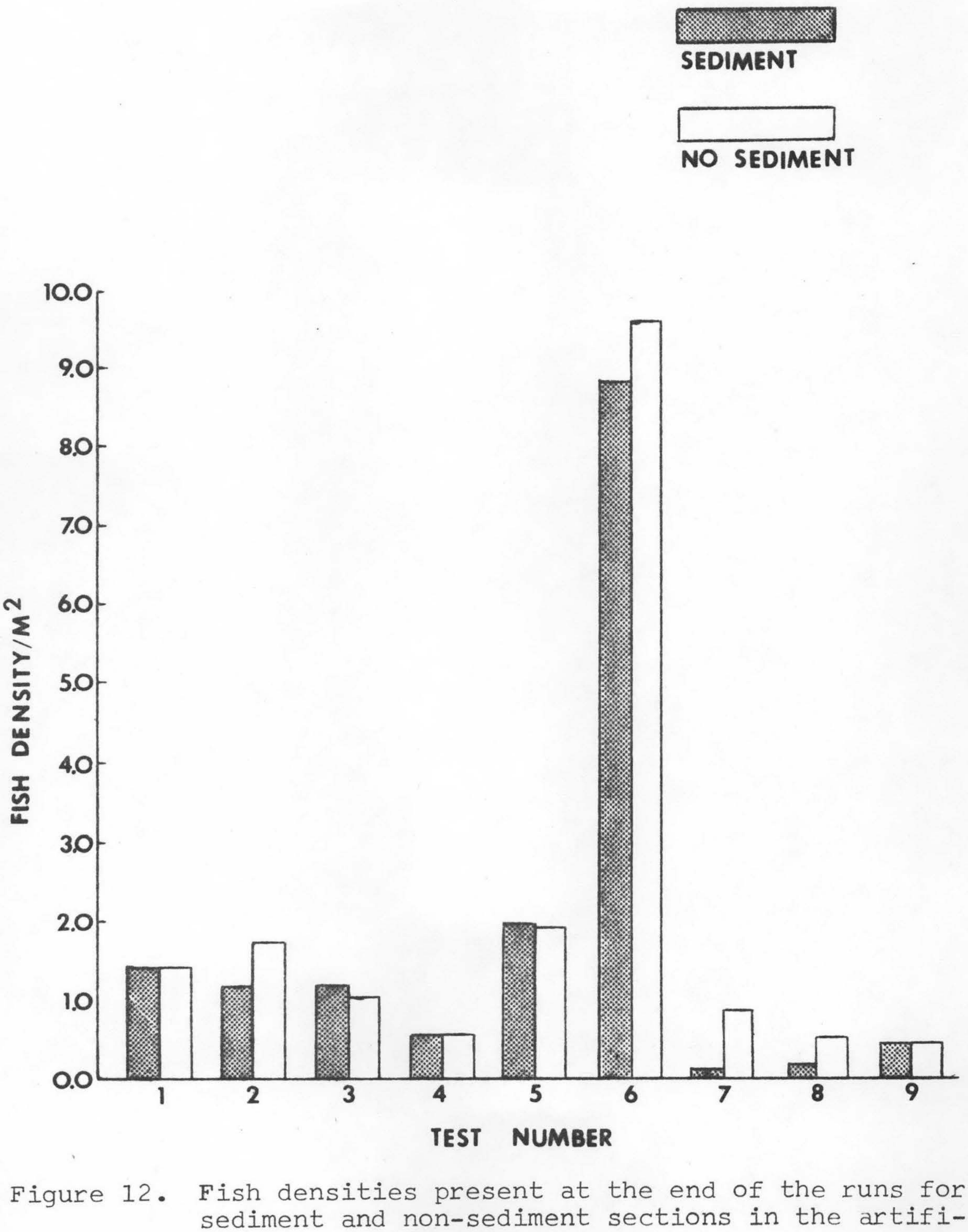

Figure 12. Fish densities present at the end of the runs for sediment and non-sediment sections in the artificial stream channels.

Big Springs Creek, the densities of fish at the end of the test were only a little larger than for age-1 steelhead in tests 1-4. In test 6, with age-0 steelhead trout reared in the hatchery, fish densities at the end of the test were five times larger than in the preceding tests with wild fish. The age-0, hatchery steelhead trout in test 6 had smaller terriroties than the wild fish in test 5 (Table 8).

Fewer age-0 steelhead trout and chinook salmon remained in channels with fully sedimented riffles compared to channels with no sediment during the winter tests. Sedimentation of the riffles had no effect on age-1 steelhead trout in the channels during winter tests (Fig. 12). In test 7, 20 times more age-0 steelhead trout remained in the channel without sediment compared to the one with sediment. In test 8, three times more age-0 chinook salmon remained in the channel without sediment compared to the channel with sediment. Age-1 steelhead trout used the depth of the pools for winter cover, while age-0 steelhead trout and chinook salmon entered the riffle substrate for winter cover.

Aggressive interactions were most frequent on the first day of each test, and dropped off as the density in the channels stabilized (usually within three days). There was no consistent pattern in the frequency of fish interactions between channels with and without sediment (Table 8). This lack of pattern is consistent with the lack of difference in fish densities between channels with and without

Table 8. The amount of time spent observing behavioral interactions, number of fish, agonistic interactions, and size of territories observed in channels, 1973.

	Observation time (minutes)	Time fish observed (minutes)	Number of fish observed	Interactions observed (number)	Interactions observed (number/min)	Territories size fish (ft^2)
Test 1						
with sediment	280	150	15	25	.167	.98
without sediment	321	211	23	14	.066	.66
Test 2						
with sediment	502	437	54	127	.291	1.57
without sediment	494	384	46	74	.193	1.80
Test 3						
with sediment	527	337	38	36	.107	1.69
without sediment	545	429	51	115	.268	1.76
Test 4						
with sediment	457	343	41	73	.213	2.40
without sediment	455	320	33	22	.069	3.00
Test 5						
with sediment	382	347	38	214	.617	2.00
without sediment	364	347	36	185	.580	3.00
Test 6						
with sediment	159	119	13	64	.537	.83
without sediment	161	130	16	100	.769	1.39

sediment. Behavior observations were complicated by muddy water conditions during four of the six summer tests. During tests 1, 2, and 4, I was able to observe the fish on only two days.

The age-1 steelhead, tested in tests 1-4, set up a hierarchical social structure at the downstream end of the pools in both the test and control sections. Age-0 steelhead, used in tests 5 and 6, established a territorial type behavior in the pools, with a resulting interaction rate higher than age-1 steelhead.

Knapp Creek Study

When we added sediment to the pools in Knapp Creek the number of fish decreased. The number of fish in the test section declined with increased sedimentation while the number in the control sections increased (Table 9).

The fish density in the Knapp Creek study area before the addition of sediment was .39 fish per meter square compared with fish densities of .36, .40, and .43 fish per meter square for Capehorn, Elk, and Marsh Creeks, respectively.

The fish density of the entire Knapp Creek study area remained near .39 fish per meter square throughout the study, but the fish density in the test section declined from .41 at the beginning of the study to .27 at the end. In the control section fish density increased from .38 to .46 from the beginning to the end of the study (Fig. 13). The

Table 9. The number of fish observed in test and control sections of Knapp Creek before the addition of sediment, 20 hours after the first addition, 60 hours after the second and third additions and 9 days after the third addition in 1973.

Stream section	Before sediment July 27	After first addition August 2	After second addition August 6	After third addition August 9	After third addition August 13
Upper control section					
Chinook Age-0	53	77	61	59	61
Age-1	8	12	11	11	9
Steelhead Age-0	46	59	46	81	84
Age-1	2	0	1	1	1
Totals	109	148	119	152	155
Middle test section					
Chinook Age-0	49	78	54	41	37
Age-1	15	30	8	12	3
Steelhead Age-0	26	42	16	19	19
Age-1	1	6	4	1	6
Totals	91	156	82	73	65
Lower control section					
Chinook Age-0	18	22	30	18	23
Age-1	8	8	6	12	8
Steelhead Age-0	15	15	18	11	15
Age-1	4	6	1	5	6
Totals	45	51	55	46	52

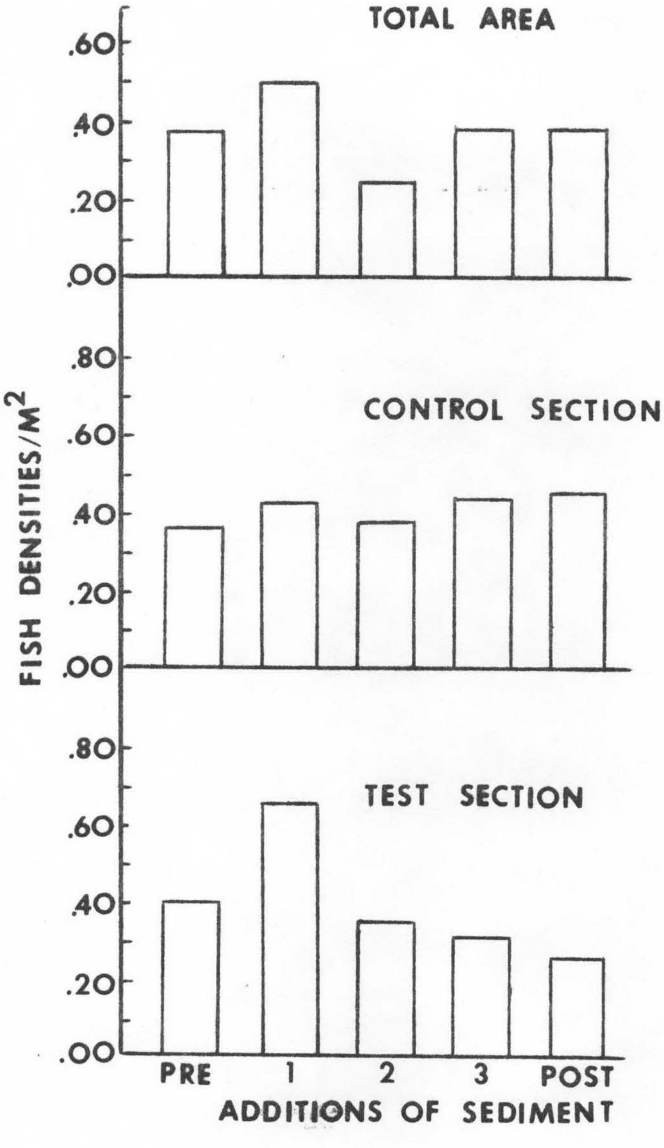

Figure 13. The change in fish densities for total, test, and control study areas in Knapp Creek as sediment was added to the test riffles on the first dump and the test pools on three dumps.

density of age-0 chinook salmon and age-0 steelhead trout increased in the control section as it decreased in the test section (Fig. 14).

Immediately after each sediment dump the fish density in the test section increased temporarily as fish moved into the study area to feed on the increased insect drift caused by the sedimentation, but declined to less than predump densities within 60 hours. In the downstream control section the number of fish present also increased immediately after sediment was added to the test section and then declined but the number of fish present after 60 hours was larger than predump numbers.

Before the addition of sediment to pools in the test section, the upper test pool had a surface area of 64.7 m^2 and the lower pool 42.9 m^2 (Fig. 15). With the first addition of sediment, we decreased the area of the upper pool to 64% (41.7 m^2) of its original area and the lower pool 95% (40.6 m^2) of its original area. After the third addition of sediment to the pools, the area of the upper pool was 36% (23.3 m^2) and the lower pool 45% (19.2 m^2) of their original areas. The volume of the upper test pool before the addition of sediment was 26.1 m^3 and the lower pool 10.9 m^3 (Fig. 15). The first addition of sediment reduced the upper pool to 70% (18.3 m^3) of its original volume and the lower pool to 73% (7.9 m^3). After the third addition of sediment the volume of the upper pool was 16% (4.2 m^3)

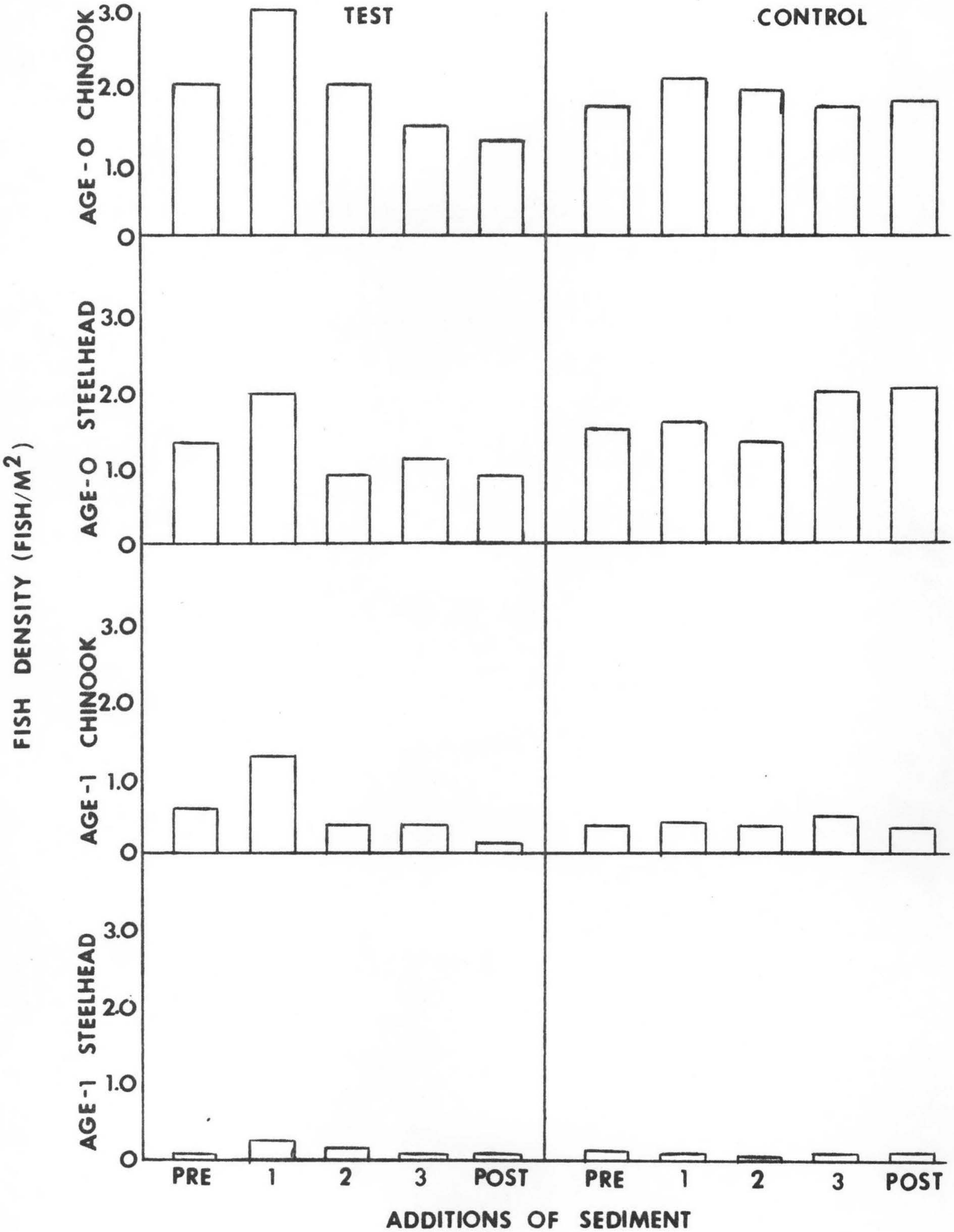

Figure 14. Total fish per square meter for the test and control sections in Knapp Creek as sediment was added to the test section in three dumps.

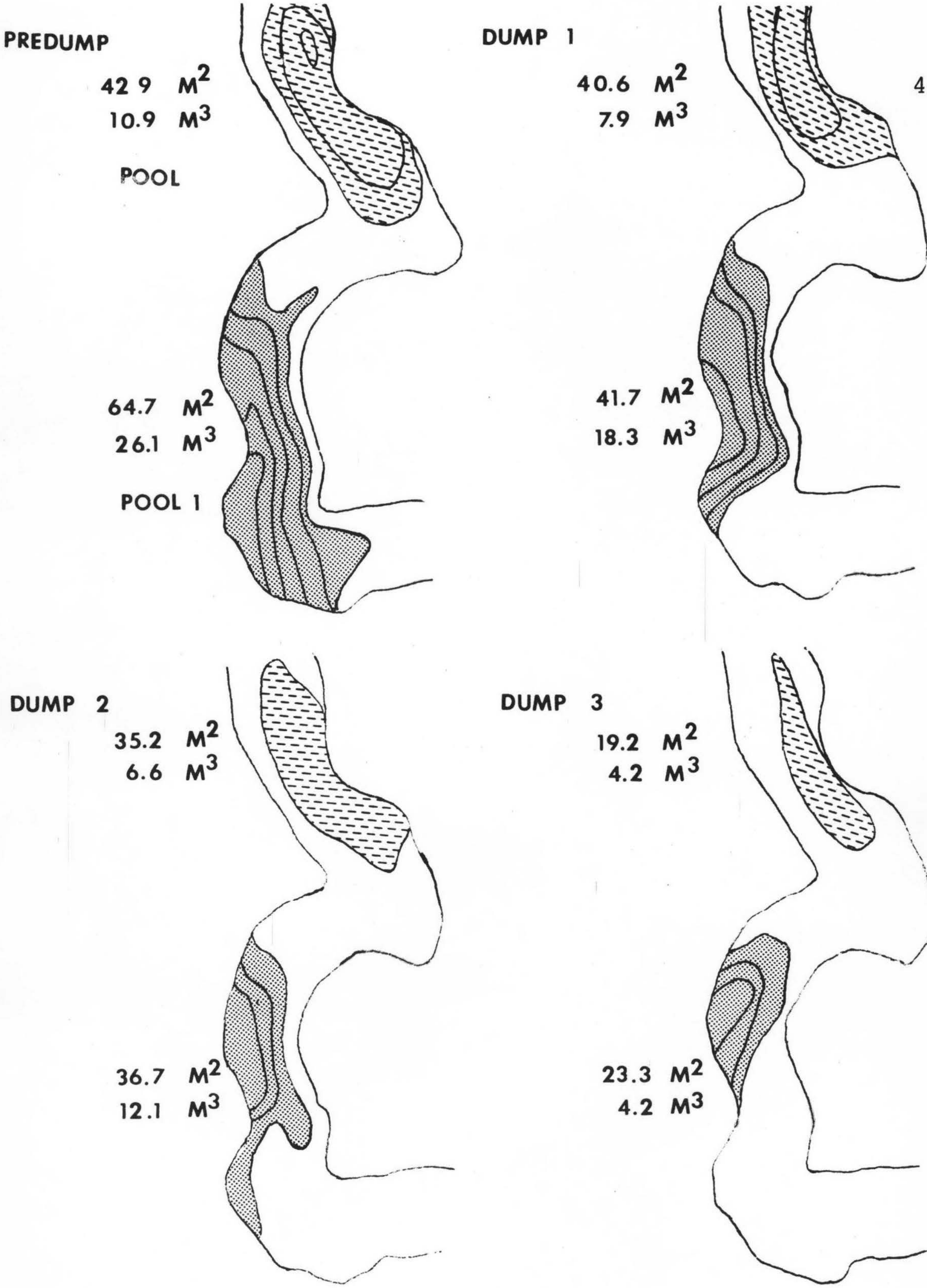

Figure 15. Pool areas (m^2, depicted by shaded areas on maps) and volumes (m^3) present in the test pools in Knapp Creek before and after each addition of sediment

and the lower pool 39% (4.2 m^3) of their original volumes.

The number of age-1 and older juvenile steelhead trout and age-0 and age-1 chinook salmon present in the test pools was related to the surface area and volume of the pools (Fig. 16). As the surface area and volume of the pools decreased the number of fish present decreased. I computed coefficients of determination of .47 and .57 for test pools 1 and 2, respectively, for fish/surface area and .46 and .17 for test pools 1 and 2, respectively, for pool volume. Pool area or volume accounted for nearly half the variation in number of fish in the pools.

To estimate the "maximum density" for each test pool I used the mean fish densities observed after the second and third additions of sediment (Fig. 17). The pre-dump density in each test pool was smaller than after we added sediment. The fish density after the first addition of sediment was probably too large because we counted the fish before the fish had time to readjust fully to the altered habitat. I assumed that 1.5 fish/m^2 and 7.0 fish/m^3 for test pool 1 and 0.6 fish/m^2 and 3.5 fish/m^3 for test pool 2 were maximum densities for those pools and calculated the number of fish that would have been present in each pool with their respective areas and volumes of pool available before and after the first addition of sediment. I then plotted these calculated numbers of fish per pool with the percentage pool area and volume remaining to obtain

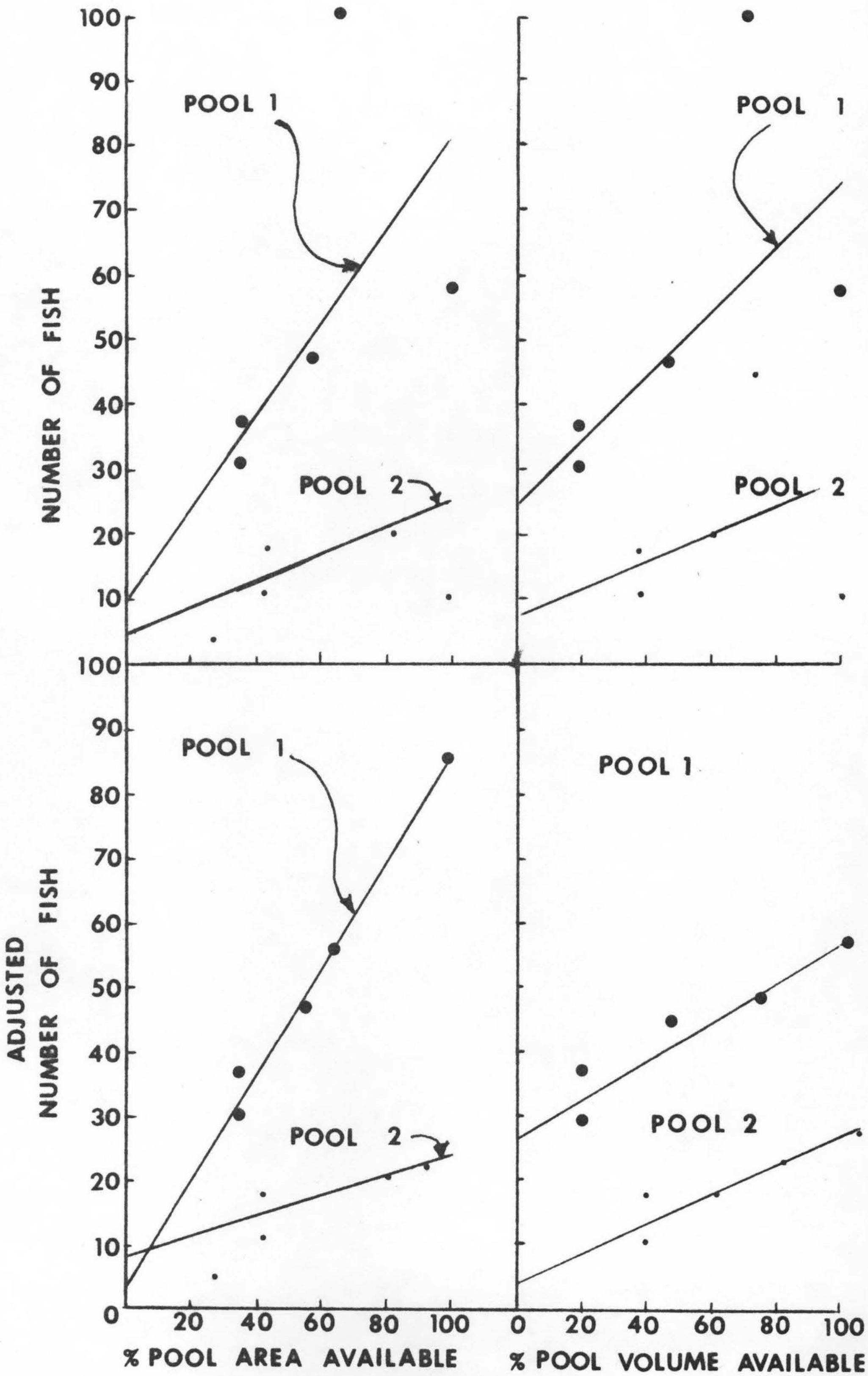

Figure 16. The number of fish observed in test pools of Knapp Creek with given amounts of the original pool areas or volumes remaining before and after each addition of sediment. The adjusted number of fish - area or volume relationship based on assumed maximum densities, see text for explanation.

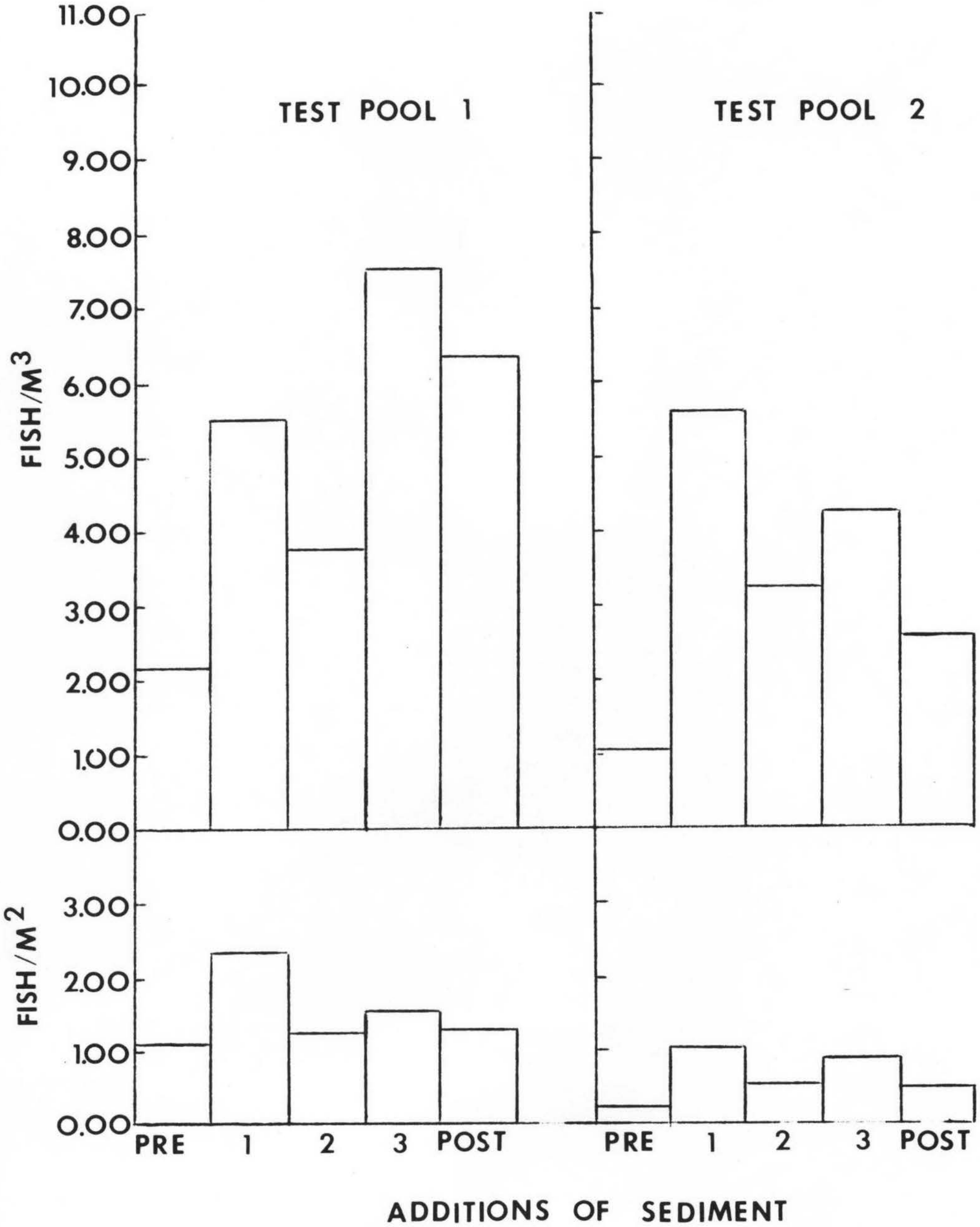

Figure 17. The density of fish in test pools of Knapp Creek before and after the additions of sediment. Densities based on area or volume remaining after each addition of sediment.

an adjusted fish number-pool area and pool volume relationship (Fig. 16). If the assumed fish densities I used are close to the true maximum density, the density of fish (when at maximum initially) will decline in direct proportion as the area or volumes of a pool decline.

We are not sure how the fish number-pool area relationship looks when only a small percentage of the original pool is left, but suspect it is linear as in Figure 16.

DISCUSSION

In my observations and tests I did not find that juvenile steelhead trout or chinook salmon were adversely affected when there was a large amount of sediment in the riffles during the summer. Capehorn, Marsh, and Elk Creeks had riffle substrates with sediment levels that ranged from 52% in Elk Creek to 26% in Capehorn Creek, yet the densities of juvenile steelhead trout and chinook salmon in the study areas of these streams were nearly the same (Table 5). I found no differences in fish densities between control and test sections when I tested three levels of riffle sedimentation in the artificial stream channels on age-0 and age-1 steelhead trout. At the time I added sediment to the riffles in Knapp Creek the age-0 steelhead trout which inhabited those riffles left the riffle, but within 60 hours they had returned.

In general, insect densities (drift and benthos) were smaller in riffles with large amounts of sediment, but the decreased densities of insects was not reflected in the densities or size of the fish. Although Elk Creek had more sediment in its riffles and fewer insects drifting per cubic foot of flow than Capehorn and Marsh Creeks, the fish were not smaller or less abundant in Elk Creek (Table 5). In test 4 in the artificial stream channels where I shutoff the addition of insects to the channels, the fish had to rely on insects produced in the channels but there was no difference in fish densities or fish size between test and control sections after 28 days. The large number of Gammarus sp. in the channels may have confounded any effect of reduced abundance of riffle insects caused by the sediment.

Reduction of pool area or volume in small streams will likely result in a reduction in summer capacity of a stream for fish proportional to the percentage of pool area or volume lost. In Capehorn, Marsh, Elk, and Knapp Creeks, age-0 and age-1 chinook salmon and age-1 and older steelhead trout primarily occupied the pool areas with depths in excess of .5 feet. When we added sediment to the test pools in Knapp Creek the number of fish declined in those pools. Density of fish increased as pool size decreased, but we believe the density increased only because the stream was not stocked to capacity when we started our test. Additional evidence that fish density was not at maximum in the stream at the beginning of the study was the increase in number of fish in the control section. Fish moving up to the increased insect drift and fish displaced from the test section increased the fish density in the control section.

In my tests with fully sedimented riffles during the winter, at Hayden Creek, fewer age-0 steelhead trout and chinook salmon remained in the channels with sediment than in the ones without sediment because the fish normally enter the crevices in the substrate during winter and were not able to do so in the sedimented riffles. Age-1 steelhead trout resided in the pools in my channels during the winter and were not affected by sediment in the riffles.

My observations and tests cover only a part of the conditions that need to be tested. The study team found that sediment added to a limited number of riffles had no measurable effect on fish although there was some reduction in abundance of insects. We did not evaluate the situation where an entire drainage is sedimented and/or where fish density was at maximum. In those situations, the reduction in fish food supply may be of sufficient magnitude to cause reductions in fish densities or growth. I found that when there was sufficient sediment in a stream to fill or partially fill the pools a reduction can be expected in the number of fish that will rear in that stream during the summer (and probably the winter, too). I did not test or observe the effect of sediment on winter or summer fish holding capacity in sections of streams classed as runs, with large rock substrates and larger velocities than pools.

Although the study team needs additional study to verify some of our findings and test additional conditions, we believe the following guidelines will prove valid and can be used in the interim by resource managers to protect the aquatic habitat.

(1) In small streams, where most fish reside in the pools, activities which put sufficient sediment in a stream to deposit sediments in the pools will reduce the summer, and probably winter, capacity of the stream for fish.

(2) A level of sedimentation which fills the interstitial spaces between larger substrate materials will reduce the winter capacity of the stream for fish.

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