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SEDIMENT IN STREAMS AND ITS EFFECTS ON AQUATIC LIFE

by

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EXECUTIVE SUMMARY

A team of investigators from the disciplines of engineering, entomology and fisheries cooperated in a study to assess the temporal and spatial impact of decomposed granite bedload sediment on insect and fish populations, and on the capability of mountain streams in the Idaho batholith to transport this sediment. This investigation was designed to provide information for resource managers who formulate watershed management guidelines for streams of the Idaho batholith and other areas with granitic baserock.

Three approaches were used in the study:

1. Correlation Surveys - We surveyed natural streams in the Idaho batholith to correlate the amount of sediment in the substrate with sediment movement, standing crop of insects, numbers of drifting insects, and the distribution and abundance of juvenile chinook salmon, Oncorhynchus tshawytscha and steelhead trout, Salmo gairdneri.
2. Experimental Channels - We constructed artificial channels and controlled variables to test experimentally the effects of various levels of riffle sedimentation on the distribution and abundance of insect and fish populations.
3. Addition of Sediment to Natural Streams - We added sediment to both riffles and pools in a study stream during the summer low flow to assess the effects of large amounts of sediment on fish and insects in a stream with small amounts of naturally-occurring sediment

already present. We assessed physical characteristics of the stream and monitored changes in the fish and insect populations before, immediately after and three weeks subsequent to the sediment additions. Both test and control sections were studied.

Data collected from stream surveys, channel experiments and sediment addition to a natural stream indicated that juvenile chinook salmon and steelhead trout were not adversely affected during the summer when there was a large amount of sediment in the riffles. Insect densities (drift and benthos) were smaller in riffles of natural streams with large amounts of sediment, but decreased densities of insects were not reflected in population densities or size of the fish.

Reduction of pool area or volume with sediment in small streams will likely result in reduction in summer capacity of a stream for fish proportional to the percentage of pool area or volume lost.

In our tests with fully sedimented riffles during the winter, fewer age-0 steelhead trout and chinook salmon remained in the channels with sediment than in the ones without sediment because these fish normally entered the crevices in the substrate during winter and were not able to do so in sedimented riffles. Larger juveniles resided in pools during the winter and were not affected by sediment in the riffles.

Insect abundance was not decreased by adding sediment to riffles in the test channels or by adding sediment to a short section of a natural stream. Insect species diversity decreased

temporarily in both test channels and the natural stream after sedimentation of riffles, but there was no measurable effect on the density of benthic or drifting insects one or more days after sedimentation.

Based on the physical characteristics of the streams we studied and a review of bedload discharge formulas, we concluded that the Meyer-Peter, Muller formula appears most applicable to estimate sediment transport capabilities of streams which flow through broad mountain valleys in the Idaho batholith. Additional data is needed, however, to thoroughly test this conclusion. Sediment transport was negligible in the streams we studied during the summer, low-flow period.

These studies are being continued during 1974-1976 to verify some of the findings and include more streams in our studies.

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INTRODUCTION

Most of the streams of the Salmon and Clearwater drainages lie within the central Idaho batholith, a mountainous region of granitic-type base rock. Sediment, mainly coarse sand less than one quarter inch in diameter from decomposed granite, has become a serious problem as expansion of road systems, timber harvest, grazing and mining has increased the frequency of watershed disturbances. Aquatic biologists and hydrologists have not been able to adequately quantify or predict in advance the ability of batholith streams to transport the finer sediments or the impacts of this sediment on aquatic organisms.

The purpose of this study was to assess the temporal and spatial impact of granitic bedload sediment (less than $\frac{1}{4}$ inch in diameter) on insect and fish populations, and on the capability of sinuous streams flowing through broad mountain valleys to transport this sediment. A team of investigators representing the disciplines of engineering, entomology and fisheries cooperated to conduct this study. The study was designed to provide information for resource managers when formulating watershed management guidelines for streams of the Idaho batholith.

Studies were conducted in streams of the Idaho batholith, near Stanley, Idaho, and in experimental channels located at the Hayden Creek Experimental Research Station near Salmon, Idaho (Figure 1).

We conducted the study in three ways:

1. Correlational Surveys - We surveyed natural streams in the Idaho batholith to correlate the amount of sediment

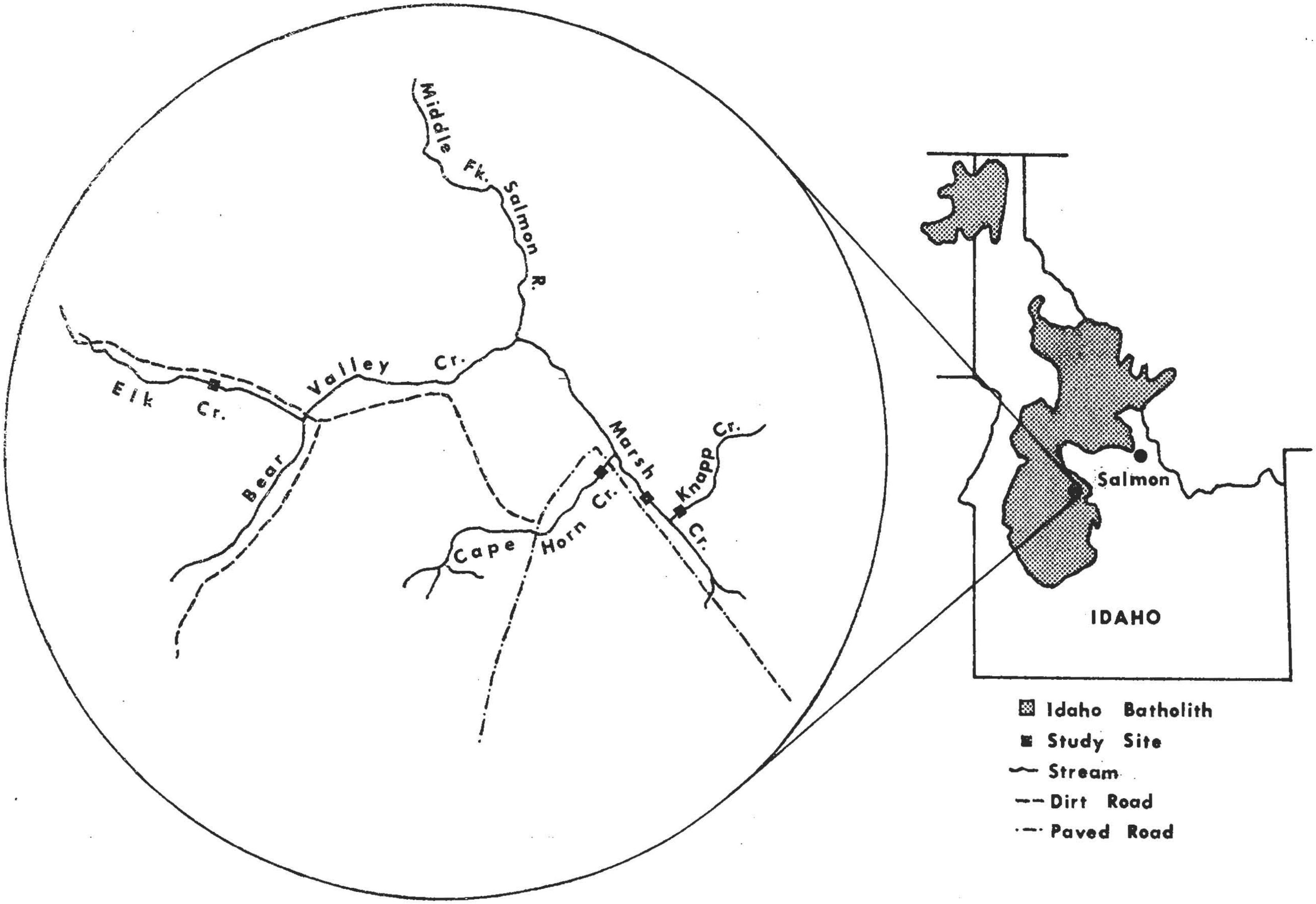


Figure 1

Map of Idaho Batholith, Study Area Stream and Sites in the substrate with sediment movement, standing crop of insects, numbers of drifting insects, and the distribution and abundance of juvenile chinook salmon, Oncorhynchus tshawytscha and steelhead trout, Salmo gairdneri. We also surveyed the streams to establish baseline information for later studies.

2. Experimental Channels - We constructed channels to control variables and test experimentally the effects of various levels of riffle sedimentation on the distribution and abundance of insect and fish populations.

3. Addition of Sediment to Natural Streams - We added sediment to both pools and riffles in a study stream to assess the effects of large amounts of sediment added to a stream with naturally small amounts of sediment. We assessed physical characteristics of the stream and monitored the fish and insect populations before, immediately after and three weeks subsequent to the sediment additions. Both test and control sections were studied.

This report contains the results of the first two years (1972-74) of the study and should be considered preliminary. We plan to verify some of the results and include more streams in the studies conducted during 1974-76.

OBJECTIVES

General Objectives

We attempted to assess: 1) sediment transport and deposition, 2) changes in aquatic habitat, 3) abundance and distribution of aquatic insects, and 4) abundance, distribution, and behavior of fish with varied amounts of sediment, flow and gradient in laboratory and natural stream channels.

Specific Objectives for Each Study Segment

1. Correlational Surveys
    - a) To assess the proportion of sediment (less than ¼ inch in diameter) in riffles of selected streams.
    - b) To estimate the amount of bedload sediment moving in these study streams during the low and high flow period.
    - c) To estimate the abundance of benthic and drifting invertebrates in the selected streams.
    - d) To determine the abundance and distribution of juvenile steelhead trout and chinook salmon in the selected streams.
2. Experimental Channels
    - a) To assess the effects of three levels of riffle sedimentation on the standing crop of benthic invertebrates with and without a fish population present.
    - b) To assess the effects of three levels of riffle sedimentation on the summer and winter holding capacities of streams for juvenile steelhead trout and chinook salmon.
3. Addition of Sediment to a Natural Stream
    - a) To determine the effects of introduced sediment on the physical characteristics of a natural stream.
    - b) To assess the effects of sediment added to pools and riffles on the abundance of benthic and drifting invertebrates.
    - c) To assess the effects of sediment added to pools and riffles on the distribution and abundance of juvenile steelhead trout and chinook salmon.

We also utilized data from correlation surveys, the field sediment addition and other field data collected during the spring run-off period to develop a model to predict the sediment transport capability of streams flowing through broad mountain valleys in the Idaho batholith.

PROCEDURES

1. Correlational Surveys

We selected three streams (Figure 1), Marsh Creek, Cape Horn Creek and Elk Creek to survey based on the following criteria: a) present level of sedimentation; b) suitability to receive an experimental addition of sediment during the following field season; and c) suitable populations of juvenile chinook salmon and/or steelhead trout. Marsh Creek and Cape Horn Creek were visually judged to have low to moderate levels of sedimentation, and Elk Creek appeared to have a moderate to high level of sedimentation. We studied Cape Horn and Elk Creeks in 1972 and 1973 but Marsh Creek only in 1972. These streams represent streams which flow through broad mountain valleys of the Idaho batholith. We did not study the steeper streams found in canyons of the batholith in this segment of the project.

Measurements of the physical characteristics of each stream included detailed mapping of the stream configuration (including water depth, discharge and velocity), composition of streambed material, streambed surface classification and estimates of bed-load sediment (see Neilson, 1974 for detailed descriptions of procedures used to assess the physical features of streams). Standard stadia survey techniques were used for mapping the streams.

A core sampler (McNeil and Ahnell, 1960) was used to collect samples of streambed material to a depth of about 6 inches. The grain size distribution was determined by sieve analysis in the field using a volumetric analyser. Three core samples were taken from a pool on each stream and at least 17 were randomly taken from a riffle on each stream.

Streambed surface classification was determined by three criteria: size of dominant streambed surface material; imbeddedness of dominant material with fines; and the dominant size of the material surrounding the dominant material. The surface of the streambed was visually analyzed according to the procedure outlined by Neilson (1974), which is a modification of the system used by Prather (1971).

During the low flows which occurred during the correlational surveys, we used a portable, pressure-differential sampler to estimate the amount of bedload sediment transported in the streams. During the higher flows in the spring of 1974, we used a Helley-Smith sampler to measure the amount of bed material transported (Helley-Smith, 1971).

We used a current meter at low discharges and a dye dilution technique at stream stages above wading depth to determine water discharge (Wilson, 1963). Water depth and velocity were also obtained when the current meter was used. A more complete discussion of these techniques are presented by Neilson (1974).

As described in detail by Sandine (1974), we collected benthos samples from riffles with a modified square-foot Hess bottom sampler. We took 9-12 benthos samples at random per riffle. We collected drift invertebrates from one riffle in each stream with three drift nets (1 foot x 2 foot openings, with 0.8 mm mesh cloth) equally spaced across the stream at 2-hour intervals, 4 times during one 24 hour period.

In 1972, the study of fish distribution and abundance was restricted to macro-habitat analysis of fish location related to water velocity, depth and size of substrate material (see Stuehrenberg, 1974 for detailed descriptions of procedures used to study fish). We located and mapped fish by age-group (except that age-group I and older steelhead were all recorded as age-group I) and species using a wet suit and snorkel (Ellis, 1961). After we mapped the fish population we collected fish from the study area by electro-fishing, measured them and preserved stomach samples for later analysis.

In 1973 we assessed the distribution and abundance of fish in relation to physical features of the stream using micro-habitat techniques. Using a blasting cap gun (Everest and Chapman, 1972) to collect fish, we measured water depth, fish depth, focal velocity and bottom classification at the focal point.

We calculated the density of fish per area of study section and per area of preferred habitat. We defined preferred habitat for fish as pool areas with a depth over 0.5 feet. The contents of fish stomachs were identified to order and counted for each age-group and species of fish. These data were converted to percentages for comparison with percentage composition of insect drift in the study streams.

2. Experimental Channels

We constructed two channels at the Hayden Creek Experimental Research Station. Each channel was divided in half to give four test sections (Figure 2).

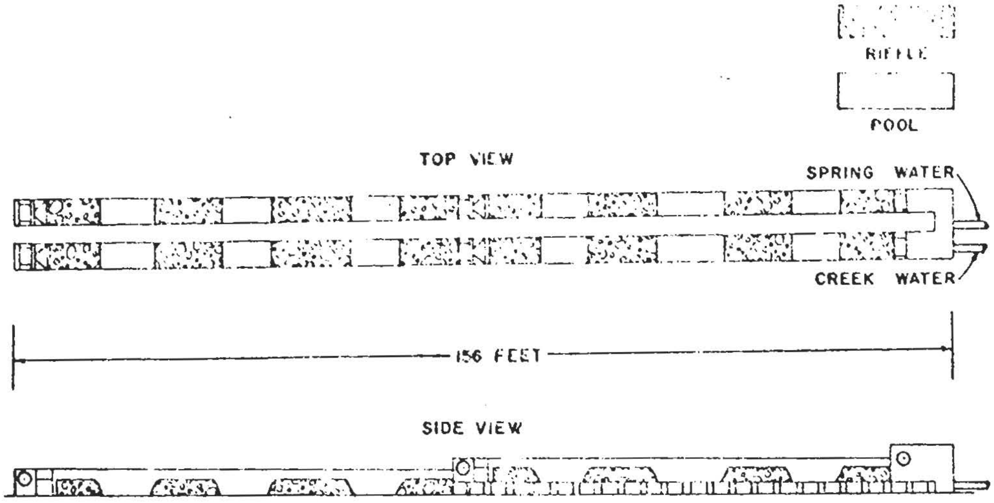


Figure 2
Artificial Stream Channels Showing Dimensions and Pool-Riffle Configurations

Water was supplied by a spring (52-54° F) and by Hayden Creek (natural stream temperatures). Insects drifting in Hayden Creek were collected by a scoop trap, piped to the channels and introduced into the water supply at the headbox. Rotary drum screens were placed at the upstream and downstream ends of each test section to prevent fish from leaving the sections (Figure 3).

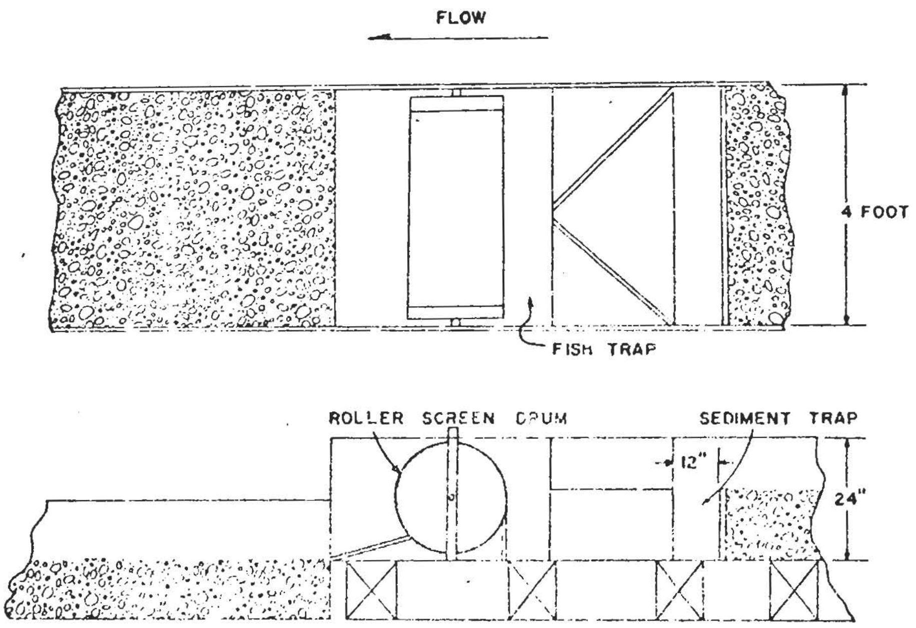
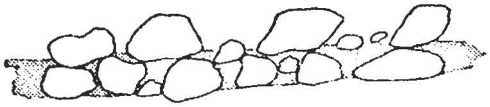


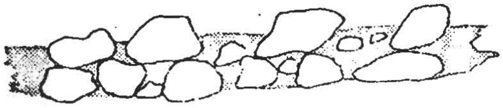
Figure 3
Downstream Ends of Artificial Stream Channels, Rotary Drum Screens, and Sediment Trap

Traps were installed at the downstream end of each section to collect fish that elected to leave the channels. Each test section was composed of four riffles and three pools. For further details of the channels see Sandine (1974).

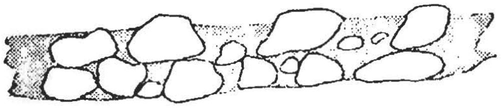
We added sediment to the riffles in two channel sections in three stages: 1) light sedimentation, cobble imbeddedness about 1/3; 2) moderate sedimentation, cobble imbeddedness about 2/3; and 3) heavy sedimentation, full cobble imbeddedness (Figure 4).



1/3 cobble imbeddedness



2/3 cobble imbeddedness



Full cobble imbeddedness

Figure 4

Cross-Section of Riffle in Artificial Stream Channels
With Levels of Cobble Imbeddedness With Sediment

The other two channel sections were controls and received no sediment. Fish were introduced into the lower two sections, one channel with and one without sediment (Figure 5).

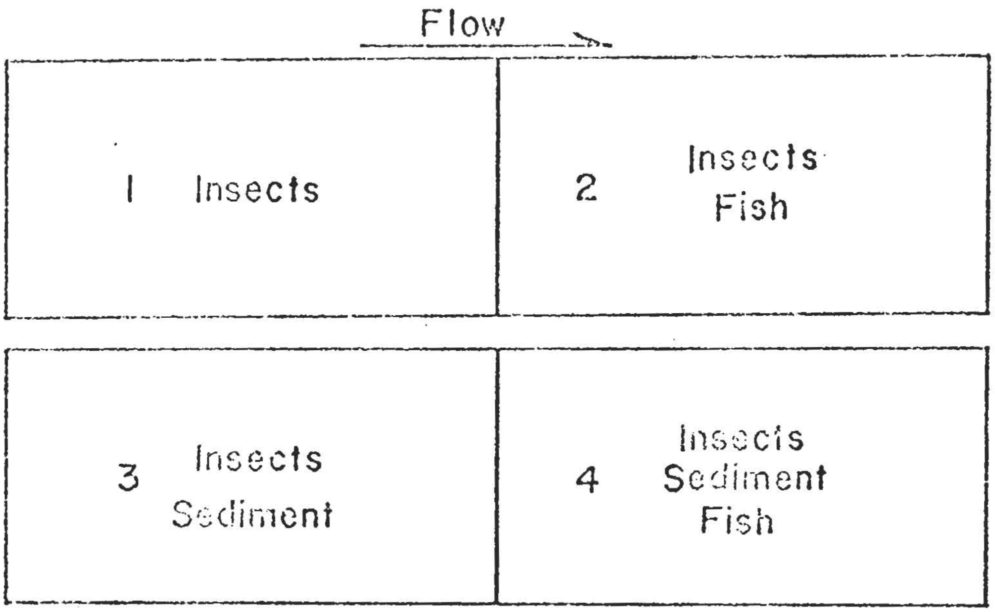


Figure 5
Numbering of Test Channels and Those With Insects, Sediment and/or Fish Added During the Tests

Water velocities, streambed surface classification, benthos and invertebrate drift were monitored throughout the various experiments. Methods and equipment used were similar to those utilized during the correlational survey.

Nine tests were conducted to assess the effects of sedimentation of riffles on insects and/or juvenile steelhead trout and chinook salmon during the summer and winter of 1973 (Table 1). We assessed: 1) the effects of increasing riffle sedimentation on insects and age-1 steelhead trout (tests 1-3); 2) the effects of fully sedimented riffles on insects and age-1 steelhead trout when insect recruitment from outside the channels

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	Cobble embeddedness	Data Collected			
					Insect benthos and drift	Fish density	Fish behavior	Facial depth and velocity
Summer Capacity								
1	Age-1 wild steelhead	6	Pipe	1/3	X	X	X	X
2	Age-1 wild steelhead	6	"	2/3	X	X	X	
3	Age-1 wild steelhead	6	"	Full	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 steelhead	6	"	"		X		
9	Age-1 wild steelhead	6	"	"		X		

was shut off (test 4); 3) the effects of fully sedimented riffles on age-0 steelhead trout from hatchery and wild populations (tests 5 and 6); and 4) the effects of fully sedimented riffles on juvenile steelhead trout and age-0 chinook salmon during the winter (tests 7-9).

We evaluated the effects of riffle sedimentation on juvenile steelhead trout during the summer (tests 1-6) by comparing the differences in fish densities, fish behavior, fish lengths and condition factors between test and control sections. Effects of full riffle sedimentation on steelhead trout and chinook salmon during the winter were evaluated by comparing differences in fish densities between test and control channels. Refer to Stuehrenberg (1974) for more detailed information on how we evaluated the effects of sedimentation on fish populations in the experimental stream channels.

3. Addition of Sediment to a Natural Stream

We added sediment to Knapp Creek, a tributary to Marsh Creek (Figure 1) during August, 1973. We selected Knapp Creek because it contained all age-groups of juvenile steelhead trout and chinook salmon, it was small enough that we could cause significant habitat changes with the available sediment and it was accessible.

The study site consisted of four riffles, associated pools and runs (Figure 6). The upper two riffles and pools served as controls, the middle two riffles and pools as test areas and the lower pools and riffles were utilized as a control area for fish population studies (Figure 3). A further description of Knapp Creek is found in Sandine (1974).

We added sediment in three stages to the test riffles and pools in Knapp Creek. On the first day we added 3.44 m^3 of decomposed granitic sediment (average particle size 0.078 m) at the upper end of the main test riffle, 1.15 m^3 at the head of the secondary test riffle, 8.03 m^3 at the head of the first pool and we spread 3.82 m^3 evenly over the bottom of the second test pool. Water velocity was sufficient to spread the sediment over most of the riffles. Two days later we added about 5.73 m^3 to the first test pool and we spread another 1.49 m^3 over the bottom of the

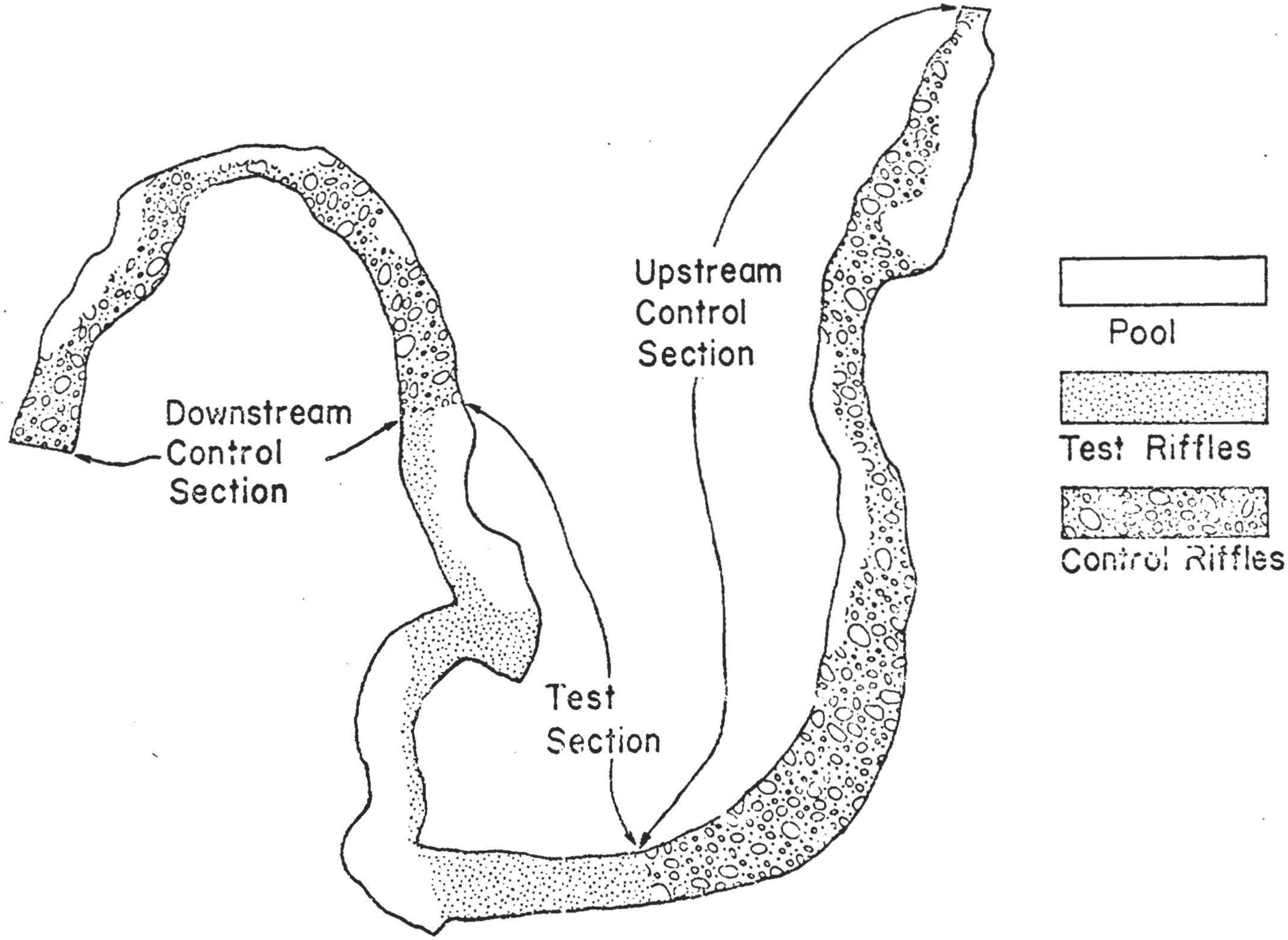


Figure 6

Knapp Creek Study Area Showing Test and Control Sections and Pool-Riffle Configurations second pool. Three days later we added 4.2 m^3 to the first test pool and 1.53 m^3 to the second test pool (Table 2).

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				Insect Benthos and Drift	Sediment added	
		Stream Boundary	Depth and Velocity	Bottom Classification	Fish Populations		Riffles	Pools
Pre-dump survey July 27	Control	X	X	X	X	X		
	Test	X	X	X	X	X		
Add Sediment August 2	Test						X	X
Post-dump survey August 23	Control				X	X		
	Test		X	X	X	X		
Add sediment August 3	Test							X
Post-dump survey August 6	Control				X			
	Test		X	X	X			
Add sediment August 6	Test							X
Post-dump survey August 9	Control				X			
	Test		X	X	X			
Post-dump survey August 24	Control				X	X		
	Test		X	X	X	X		

The same physical and biological measurements taken during the correlational surveys were taken in Knapp Creek before the addition of sediment, after each addition of sediment and 18 days after the last sediment injection. Additional measurements later in the fall did not seem worthwhile because the stream did not move the sediment at the low flows in fall and the chinooks and steelhead started moving downstream in September as part of their normal seasonal movement.

RESULTS

1. Correlational Surveys

Elk Creek had the largest percentage of sediment (smaller than ¼ inch) in riffle substrates, highest degree of cobble imbeddedness, fewest benthic invertebrates, a lower species diversity index and fewest drifting insects of the three streams we studied (Tables 3, 4 and 5). Yet, the density of juvenile steelhead trout and chinook salmon in Elk Creek was as large as in Marsh and Cape Horn Creeks (Table 6).

Table 3. Volume of Flow, Sediment Discharge, Percentage of Sediment (Smaller Than ¼ Inch) in Bed Material in Selected Riffles, and Dominant Streambed Material Imbeddedness Rating of the Three Streams in August, 1972 and 1973.

Study Stream	Date Surveyed	Water Discharge (cfs)	Sediment Discharge (lbs/day)	Sediment in Riffles: Number of Samples	Sediment in Riffles: Percentage Sediment	Dominant Material Imbeddedness Rating
Marsh Creek	August 8, 1972	42.1	7.1	17	35	4.0
Capehorn Creek	August 12, 1972	40.8	7.9	17	27	4.0
	August 8, 1973	28.9	Trace	17	28	4.0
Elk Creek	August 1972	71.9	3.7	17	42	3.0
	August 1973	31.1	Trace	17	52	2.5

Table 4. Numbers of Benthic Invertebrates Per Unit Area and the Average Species Diversity Indices for Benthic Invertebrates from Riffles of Three Study Streams, August, 1972.

Stream and Insect Order	Sample Size	Average Numbers Per 1 sq. ft.	Average Species Diversity (Shannon-Weaver Index)
Marsh Creek	12		3.36
Ephemeroptera		63.6	
Plecoptera		7.8	
Trichoptera		8.7	
Coleoptera		31.3	
Diptera		30.2	
Totals		141.4	
Cape Horn Creek	18		3.13
Ephemeroptera		54.8	
Plecoptera		4.7	
Trichoptera		4.3	
Coleoptera		3.8	
Diptera		6.1	
Totals		73.7	
Elk Creek	18		3.07
Ephemeroptera		34.2	
Plecoptera		6.9	
Trichoptera		8.3	
Coleoptera		15.8	
Diptera		3.6	
Totals		68.8	

Table 5. Number of Drifting Insects per m^3 of Water Passing Through Three Drift Nets in Marsh, Cape Horn, and Elk Creeks from August 8 to 15, 1972.

Stream and Orders of Insects	Time Periods 0500-0700	1200-1400	2000-2200	2400-0200
Marsh Creek				
Ephemeroptera	0.780	0.250	1.737	3.994
Plecoptera	0.034	0.005	0.044	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
Cape Horn Creek				
Ephemeroptera	o.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 6: Streams Surveyed, Area of Surveyed Sections, Fish Counted and Density in Sections in August, 1972 and 1973.

Stream and Year	Study Area Size in m^2	Fish Counted: Chinook Salmon Age 0	Chinook Salmon Age 1	Steelhead Trout Age 0	Steelhead Trout Age 1	Total Fish	Fish Density/m^2: Pool #1	Pool #2	Pool #3	Total
Marsh Creek										
1972	962	305	67	12	31	415	.693	.726	.916	.432
Capehorn Creek										
1972	1268	427	16	5		448	.895	1.35	.497	.360
1973	1268	425	32	3		460	-	-	-	.363
Elk Creek										
1972	1131	295	114	6	36	451	1.05	1.09	-	.399
1973	1131	305	97	46	29	477	-	-	-	.422

Elk Creek had the largest proportion of bed material (sediment) finer than ¼ inch in both pools and riffles, based on analysis of core samples (Table 3), and as a result had a larger degree of cobble imbeddedness (expressed as a smaller imbeddedness rating, Table 3) than did Marsh and Cape Horn Creeks. Marsh and Cape Horn Creeks had similar amounts of sediment and cobble imbeddedness.

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 6). Fish densitites in the entire study sections of Marsh, Cape Horn and Elk Creeks varied between .432 and .360 fish/m^2 (Table 6). The average densities of fish in preferred habitat (pools) of the streams ranged from .497 to 1.350 fish/m^2. We did not include age-0 steelhead in the fish density estimates for pools because we usually found them in water depths less than 1/2 foot, and there were no age-0 steelhead in the study section of Cape Horn Creek.

We compared the mean length of fish from each stream and found no significant difference between streams for each species and age-group (Table 7).

Table 7. Mean Total Length of Chinook Salmon and Steelhead Trout Collected From the Study Streams in 1972.

	Chinook Salmon				Steelhead Trout			
	Age 0		Age 1		Age 0		Age 1+	
Stream	n	length	n	length	n	length	n	length
Marsh Creek	26	62.8	15	104.9	17	32.4	3	145.0
Cape Horn Creek	25	55.1	5	93.0	-	-	2	151.5
Elk Creek	29	61.5	22	93.1	-	-	15	114.6

2. Experimental Channels

Indices of species diversity of benthic insects remained relatively constant in the channels without sediment, decreased in the channel with sediment but no fish and declined initially, but then increased with full imbeddedness in the channel with sediment and fish (Figure 7). The density of benthic insects was also variable, with no response clearly attributable to the addition of sediment (Figure 8). The abundance of drifting insects was not noticeably affected by the addition of sediment to the riffles in the test channels (Figure 9).

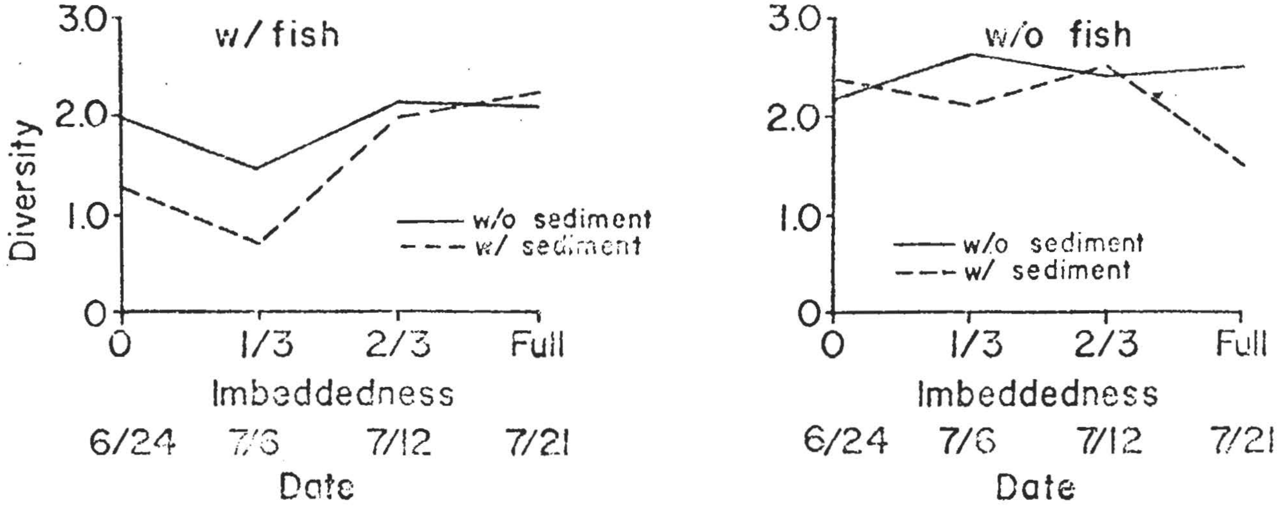


Figure 7

Indices (Shannon-Weaver) of Benthic Insect Species Diversity in Relation to Dominant Substrate Material Imbeddedness in Channels at Hayden Creek

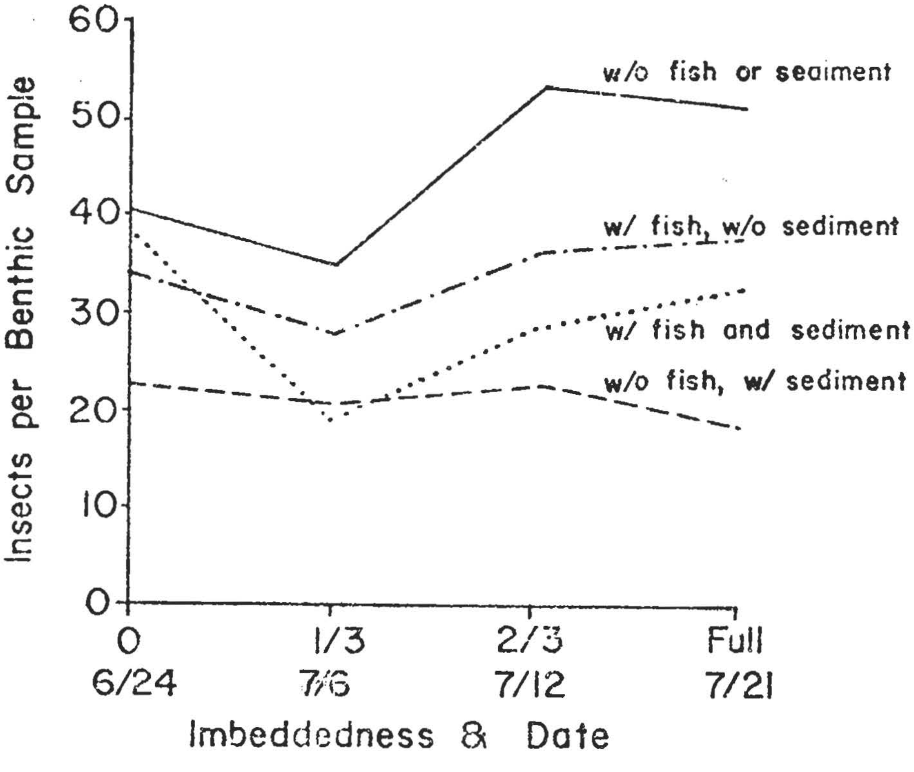


Figure 8

Average Number of Insects Per Benthic Sample ($0.186\ m^2$) From Riffles in Channels at Hayden Creek

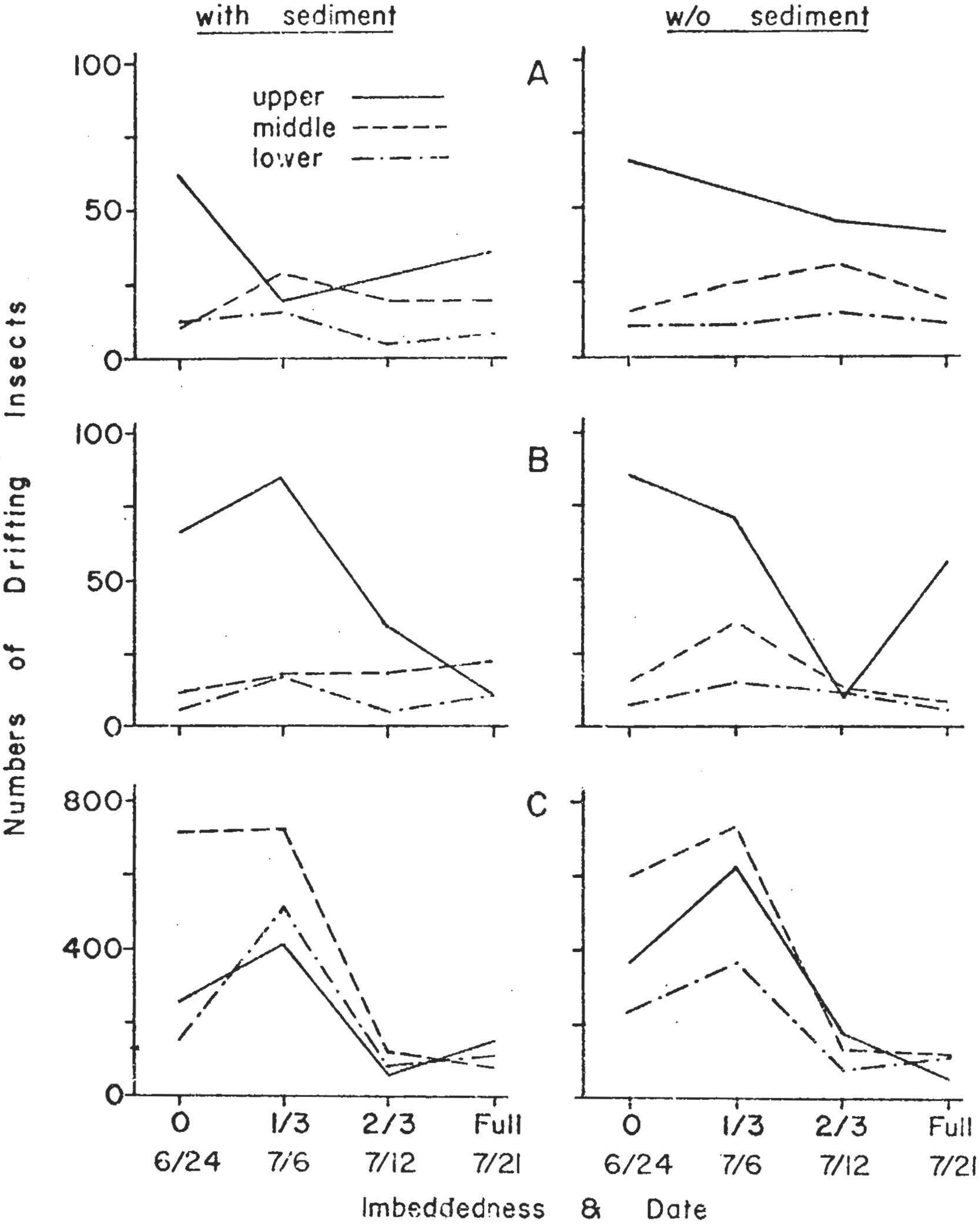


Figure 9

Total Number of Drifting Insects in Channels at Hayden Creek in Relation to Time of Day (A = 1200 - 1300 hours; B = 2030 - 2130 hours; C = 2330 - 0030 hours), Presence and Absence of Fish and Imbeddedness of Substrate. Insects Labeled "Upper" are Those Entering the Upper Channels Through Water and Insect Supply Lines; "Middle" are Those Leaving Upper Channels and Entering Lower Channels; "Lower" are Those Leaving the Lower Channels. The Lower Channels Contained Fish

The presence of fish in the two lower channels reduced the abundance of drifting insects leaving the lower channels and may have reduced the species diversity index and density of benthic insects (Figures 7, 8 and 9).

Fish densities in channels with and without sediment (smaller than ¼ inch) added to the riffles differed little in the tests of summer holding capacity (tests 1-6, Figure 8). End of test densities for age-1 steelhead differed 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 insect supply pipeline the densities were lower than in tests 1-3. In tests 5 and 6 nearly equal numbers of age-0 steelhead remained in the channels with sediment versus those without sediment, but in test 5 with age-0 steelhead trout collected from 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-1 steelhead, used in tests 1-4, set up 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, set up a territorial type behavior in the pools.

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 (tests 7 and 8, Figure 10). Sedimentation of the riffles had no effect on age-1 steelhead trout in the channels during the winter tests (test 9, Figure 10).

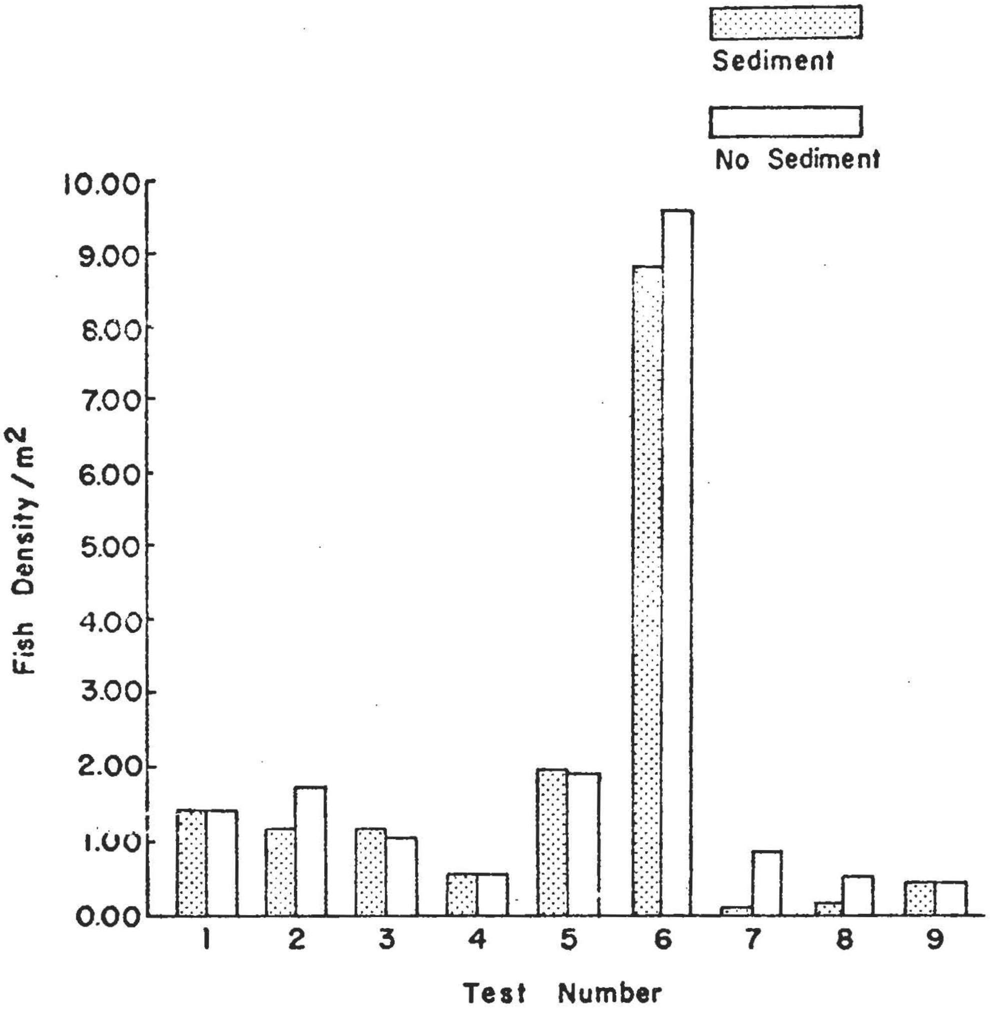


Figure 10

Fish Population Densities Present at the End of the Tests in the Artificial Stream Channels (With and Without Sediment). Refer to Table 1 for Description of Tests

In test 7, 20 times more age-0 steelhead trout 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.

3. Addition of Sediment to Natural Stream

Before the addition of sediment, Knapp Creek contained about as much sediment in the riffles as was found in Marsh and Cape Horn Creeks, had less sediment in the pools, had larger dominant streambed material, but had about the same imbeddedness of dominant material as the other two streams (Tables 3 and 8).

Table 8. The Percentage of Sediment (Smaller Than ¼ Inch) and Imbeddedness of the Dominant Material in Pool and Riffle Substrates of Various Sections of Knapp Creek Before (July 27), Immediately After (August 3) and 21 Days After the Initial Addition of Sediment, July-August, 1973.

Study Stream and Section	Date	Percentage Sediment pool	Percentage Sediment riffle	Dominant Material Imbeddedness Rating
Knapp Creek				
test riffle I	July 27	--	31	4.0
	Aug. 3	--	42	2.0
	Aug. 24	--	39	3.0
test riffle II	July 27	--	28	3.0
	Aug. 3	--	46	2.0
	Aug. 24	--	37	3.0
test pool I	July 27	28	--	4.5
	Aug. 3	84	--	1.0
test pool II	July 27	33	--	4.0
upper control riffle	July 27	--	36	4.0
lower control riffle	July 27	--	27	4.0

After the addition of sediment, the percentage of sediment in pool and riffles and the imbeddedness of the dominant substrate material increased.

The species diversity index of benthic insects declined immediately following the addition of sediment to both test riffles (Figure 11). Within two weeks, however, the index for the upper test riffle had recovered to the pre-test level. The index for the lower riffle declined until the last sample in late August.

The density of benthic insects in the test and control riffles changed during the study, but the changes did not seem to be related to the addition of sediment (Table 9).

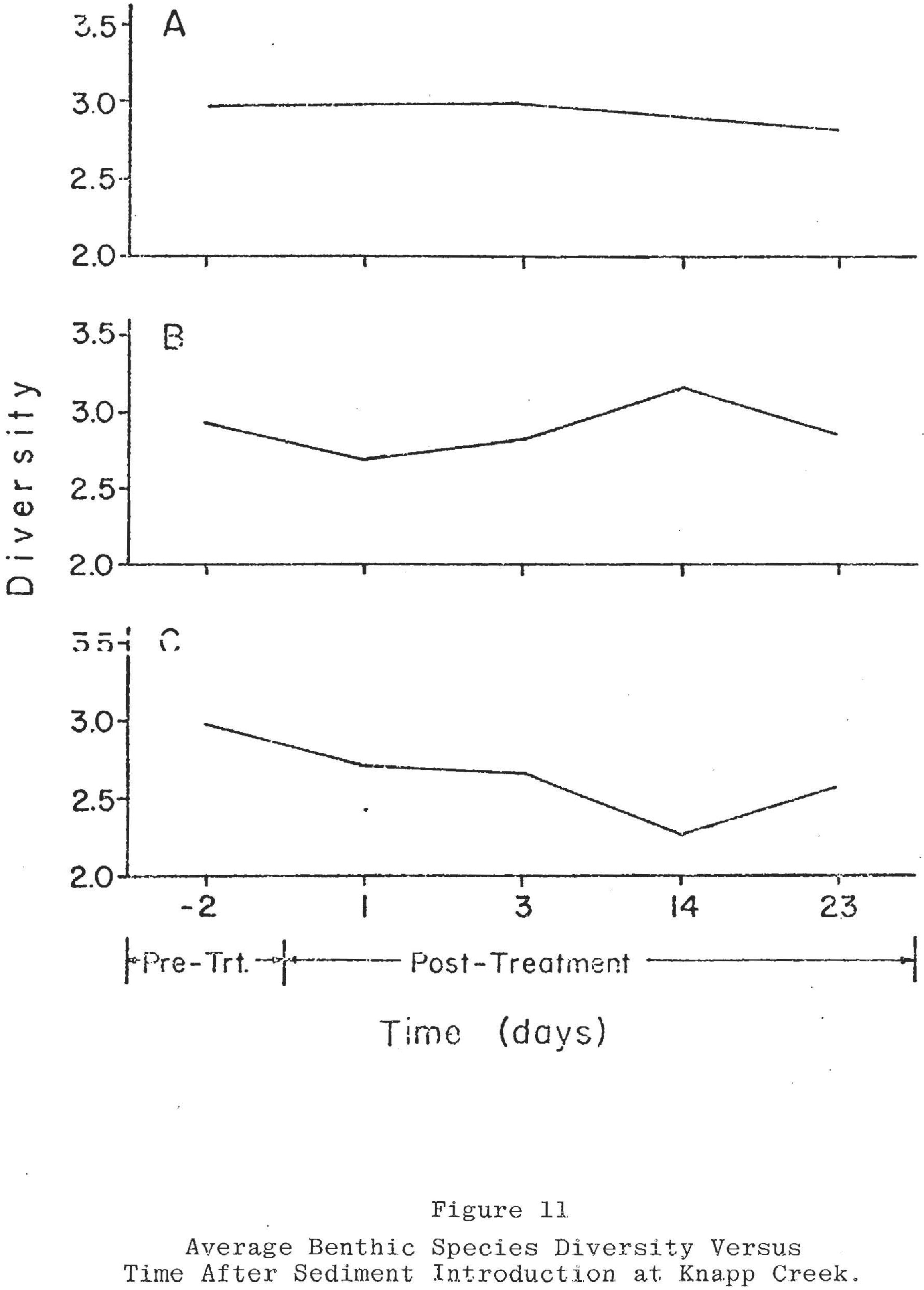


Figure 11

Average Benthic Species Diversity Versus
Time After Sediment Introduction at Knapp Creek.
A - Control Riffle; B - Test Riffle I; C - Test Riffle II.

Table 9. Density of Benthic Insects (per 0.82 m^2) in Riffles Before the Addition of Sediment and 1, 3, 14 and 23 Days After Sedimentation in Knapp Creek, 1973.

	SECTION												
	Control riffle				Test riffle I					Test riffle II			
Insect Order	Before	3	14	23	Before	1	3	14	23	Before	3	14	23
Ephemeroptera	72	42	60	98	132	97	98	301	393	47	85	226	196
Plecoptera	77	37	184	129	51	38	60	154	245	35	69	122	88
Trichoptera	73	33	82	189	309	129	32	117	117	14	23	57	44
Coleoptera	9	3	22	6	16	6	3	44	58	1	3	12	15
Diptera	52	44	89	85	155	42	100	69	98	15	5	17	18
Totals	283	159	437	507	663	312	293	685	911	112	185	434	361

During the addition of sediment on the test riffles, large numbers of insects became dislodged and drifted downstream (Table 10).

Table 10. Number of Drifting Insects Per Cubic Foot of Water Over the Control and Test Riffles Before, During, and 1, 3 and 14 Days After Sediment Addition, Knapp Creek, 1973.

	SECTION										
	Control Riffle					Test Riffle I					Test Riffle II
Insect Order	Before	During	1	3	14	Before	During	1	3	14	During
Ephemeroptera	16	0	9	8	5	16	31	5	5	9	108
Plecoptera	0	0	4	4	0	3	9	1	1	1	14
Trichoptera	4	2	4	4	0	5	87	6	1	2	18
Coleoptera	30	3	15	2	12	12	1	18	14	3	6
Diptera	11	6	5	2	4	8	49	3	2	1	8
Totals	61	11	34	16	21	44	177	33	23	16	154

The case-building trichopteran Brachycentrus sp. and some of the mayflies were most affected by the sediment. Plecopterans and dipterans were also dislodged, but to a lesser extent. The number of drifting insects declined on both the control and test riffles throughout the four weeks of sampling, and the decline on the test riffle was no larger than on the control riffle.

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 11).

Table 11. The Number of Chinook Salmon and Steelhead Trout 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 15
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

The fish density in the Knapp Creek study area before the addition of sediment was .390 fish/m^2 compared with fish densities of .360, .399, and .432 for Cape Horn, Elk and Marsh Creeks, respectively. The fish density of the entire Knapp Creek study area remained near .390 fish/m^2 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 at the beginning of the study to .46 at the end (Figure 12).

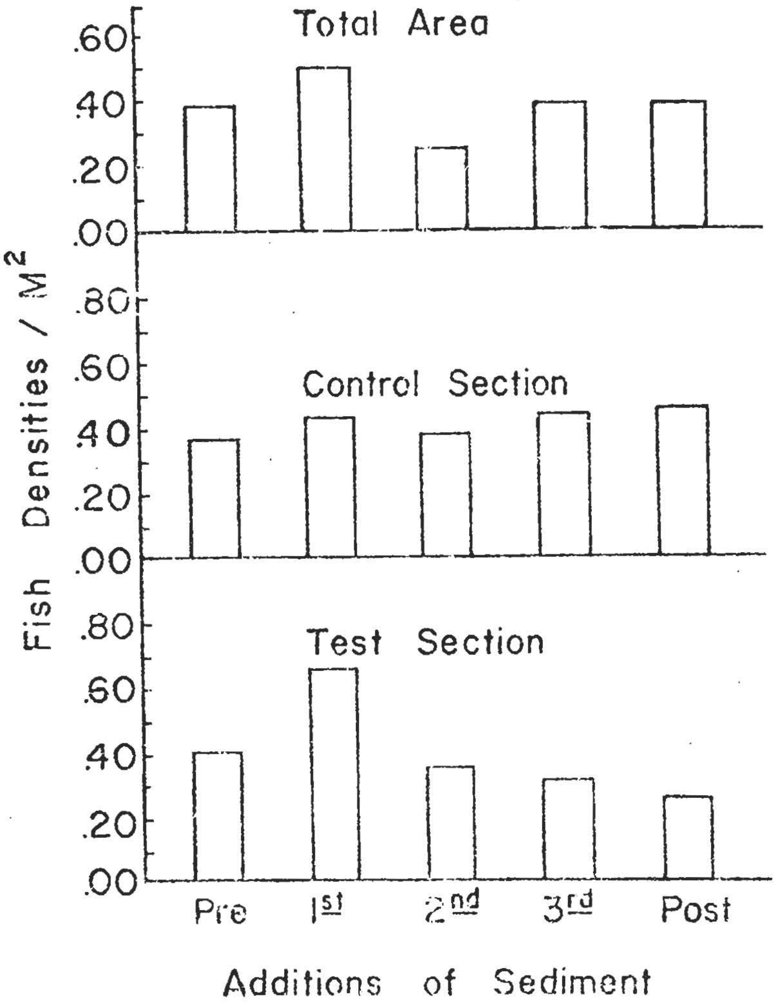


Figure 12

The Change in Fish Densities for the Total, Test and Control Sections in Knapp Creek Before and After the Additions of Sediment. Densities Based on Surface Area Before Sediment Was Added

The density of age-0 chinook salmon and age-0 steelhead trout increased in the control section as it decreased in the test section (Figure 13).

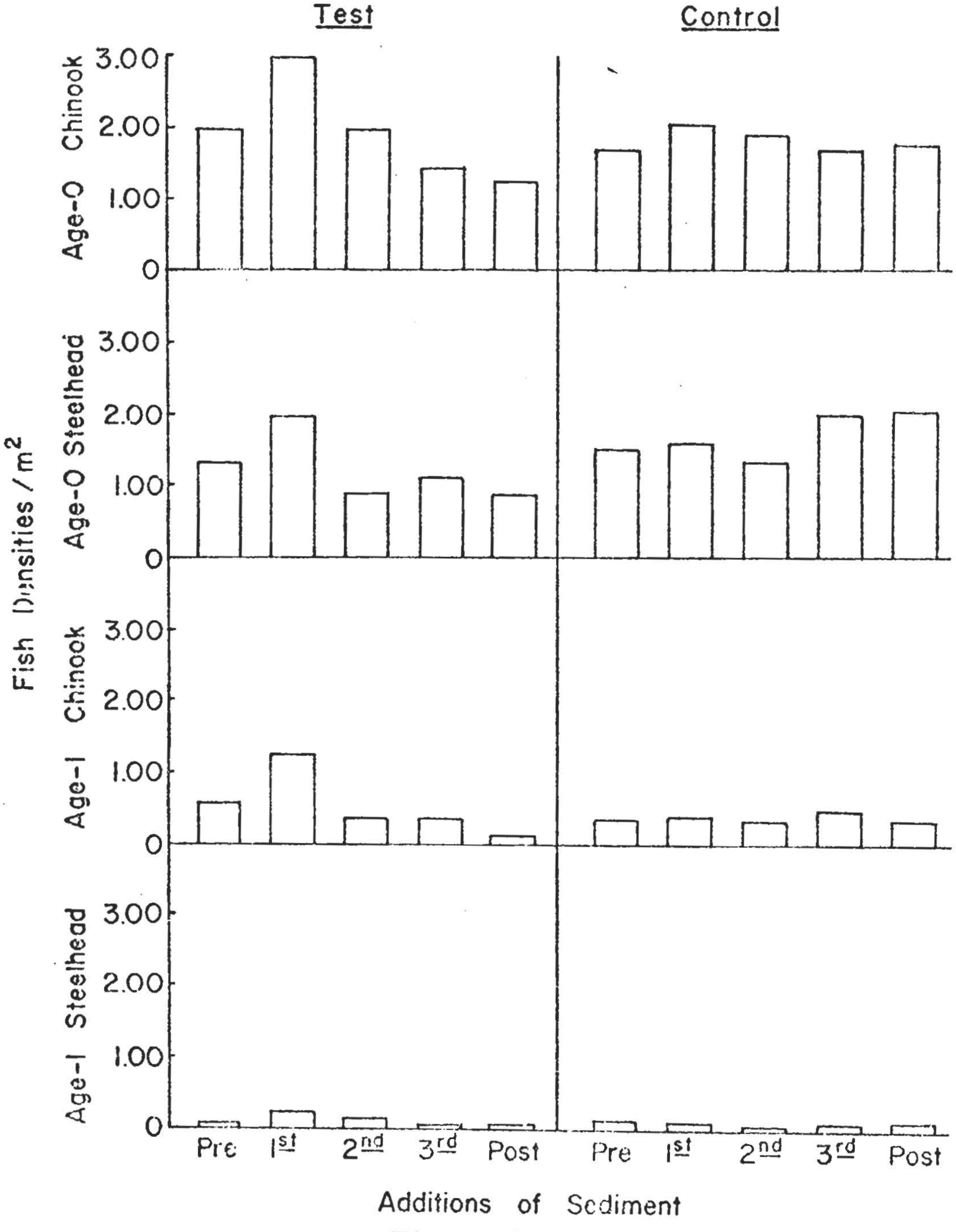


Figure 13

Fish Densities for the Test and Control Sections in Knapp Creek as Sediment Was Added to Test Sections

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.

We believe that fish density was not at maximum in the test and control sections at the beginning of the study. Fish moving up to feed on the increased insect drift and fish displaced from the test section increased the fish density in the control sections.

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 (Figure 14). 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 to 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 (Figure 14). 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) and the lower pool 39% (4.2 m^3) of their original volumes.

The number of age-1 and older steelhead trout and age-0 and

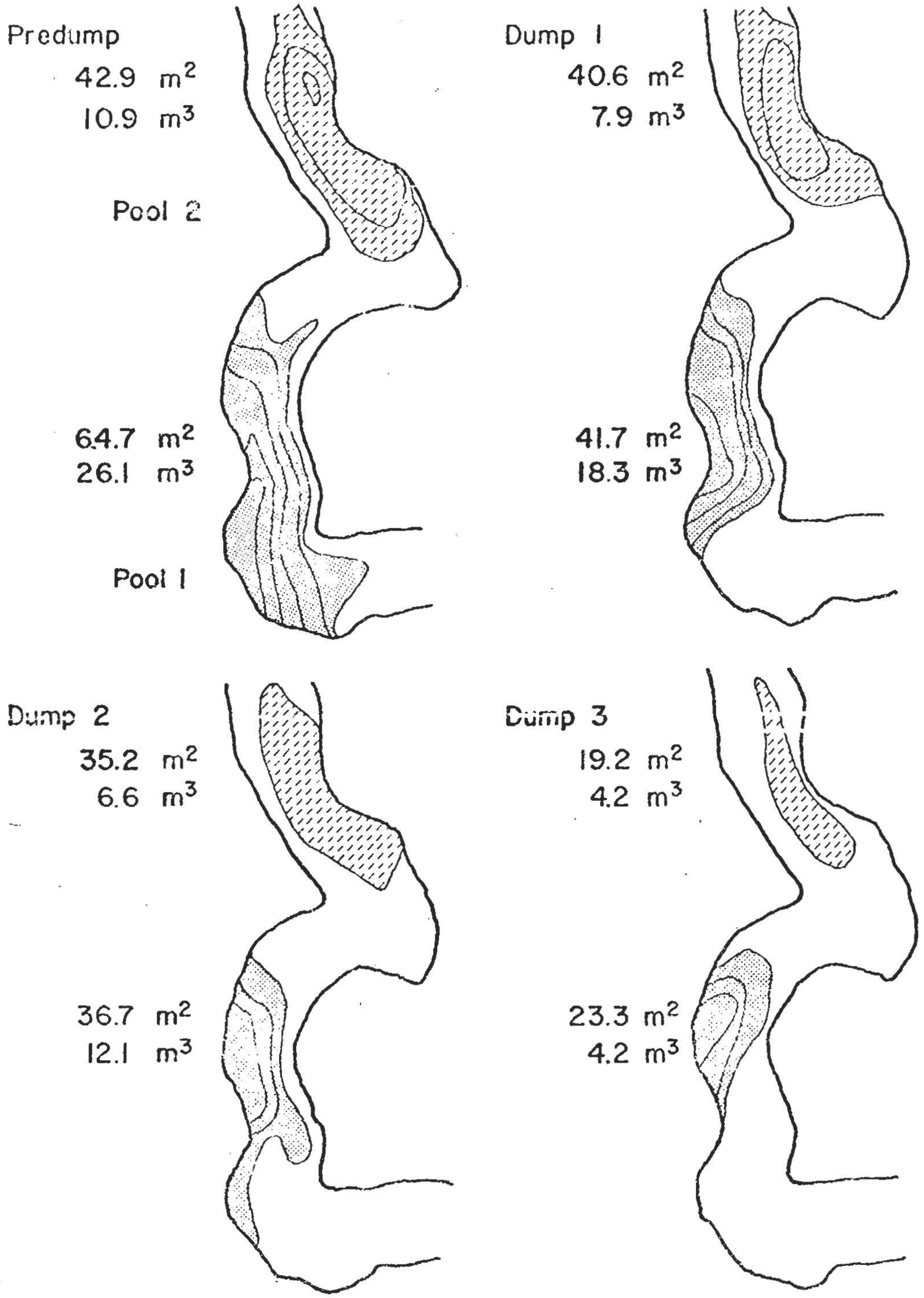


Figure 14

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 age-1 chinook salmon present in the test pools was related to the surface area and volume of the pools (Figure 15).

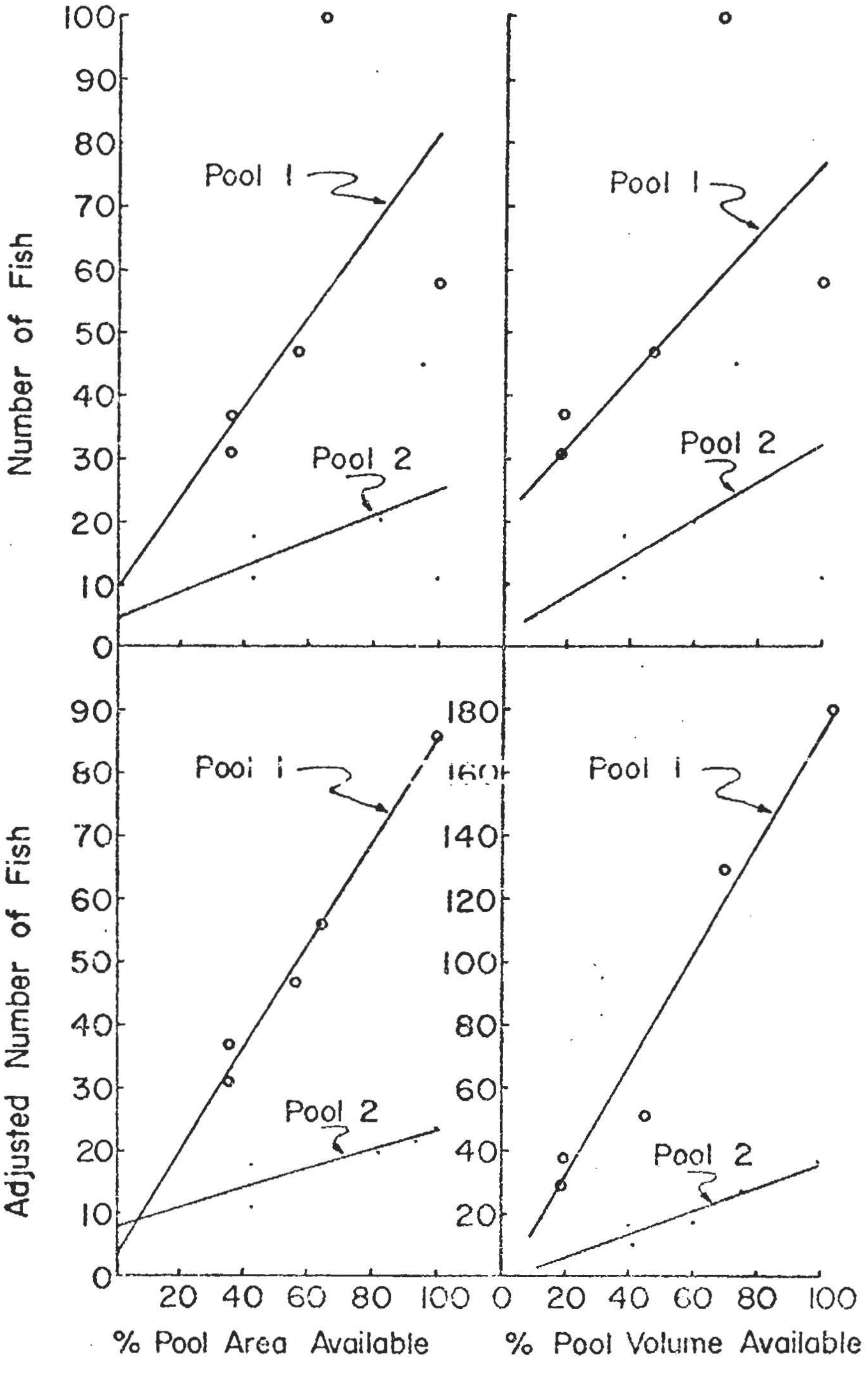


Figure 15

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

As the surface area and volume of the pools decreased the number of fish present decreased. We computed coefficients of determination (r^2) of .47 and .57 for test pools 1 and 2, respectively, for 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 we used the mean fish densities observed after the second and third additions of sediment (Figure 16).

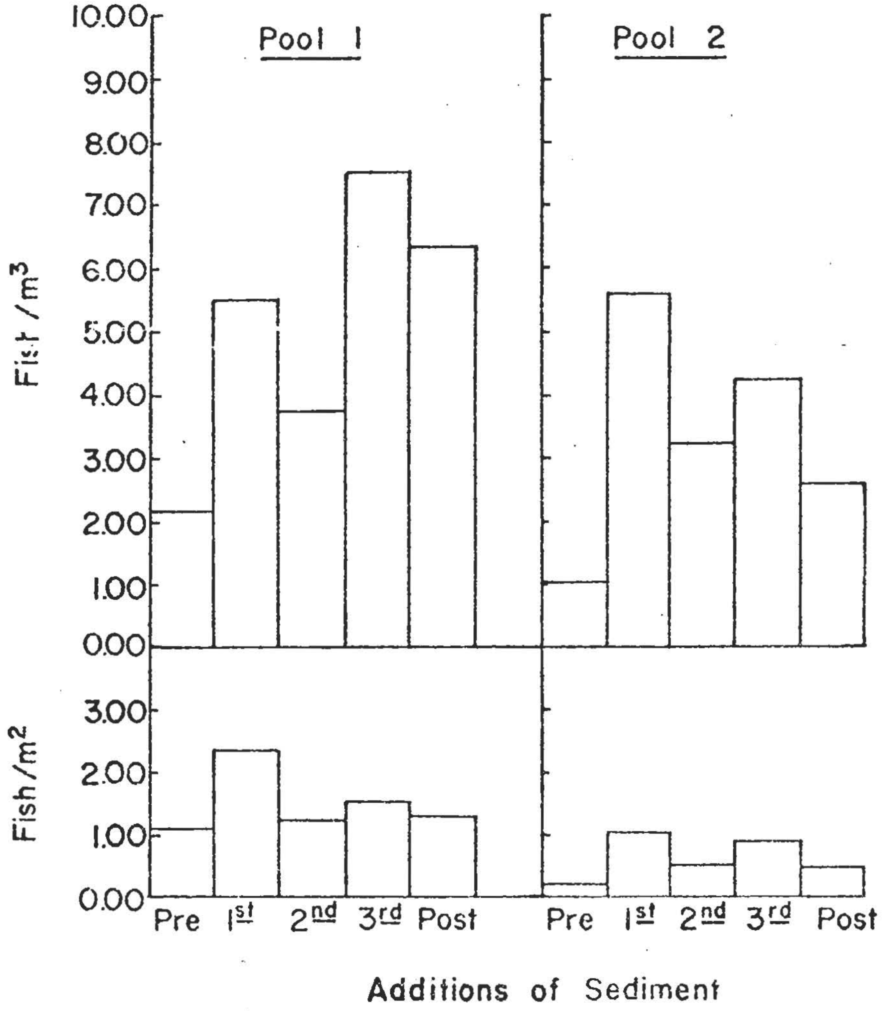


Figure 16

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

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. We 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. We then plotted these calculated numbers of fish per pool with the percentage pool area and volume remaining to obtain an adjusted fish number-pool area and pool volume relationship (Figure 15). If the assumed maximum fish densities we used are close to the true maximum densities, the density of fish (when at maximum initially) will decline in direct proportion as the area or volumes of a pool decline.

4. Sediment Transport Capacity Calculation

From a review of available bedload discharge formulas and actual stream data, the Meyer-Peter, Muller formula appears to be the one most applicable to streams flowing through broad mountain valleys of the Idaho batholith. This formula is the only one that includes a separate term considering the armor layer. Also, the Meyer-Peter, Muller incipient motion relationship seems reasonable when compared with shear stress and armor particle diameter we measured in two of the study streams (Figure 17). The four circled points came from an area where channel alterations had occurred and the existing armor may not have been the result of the channel configuration which existed in 1972-73.

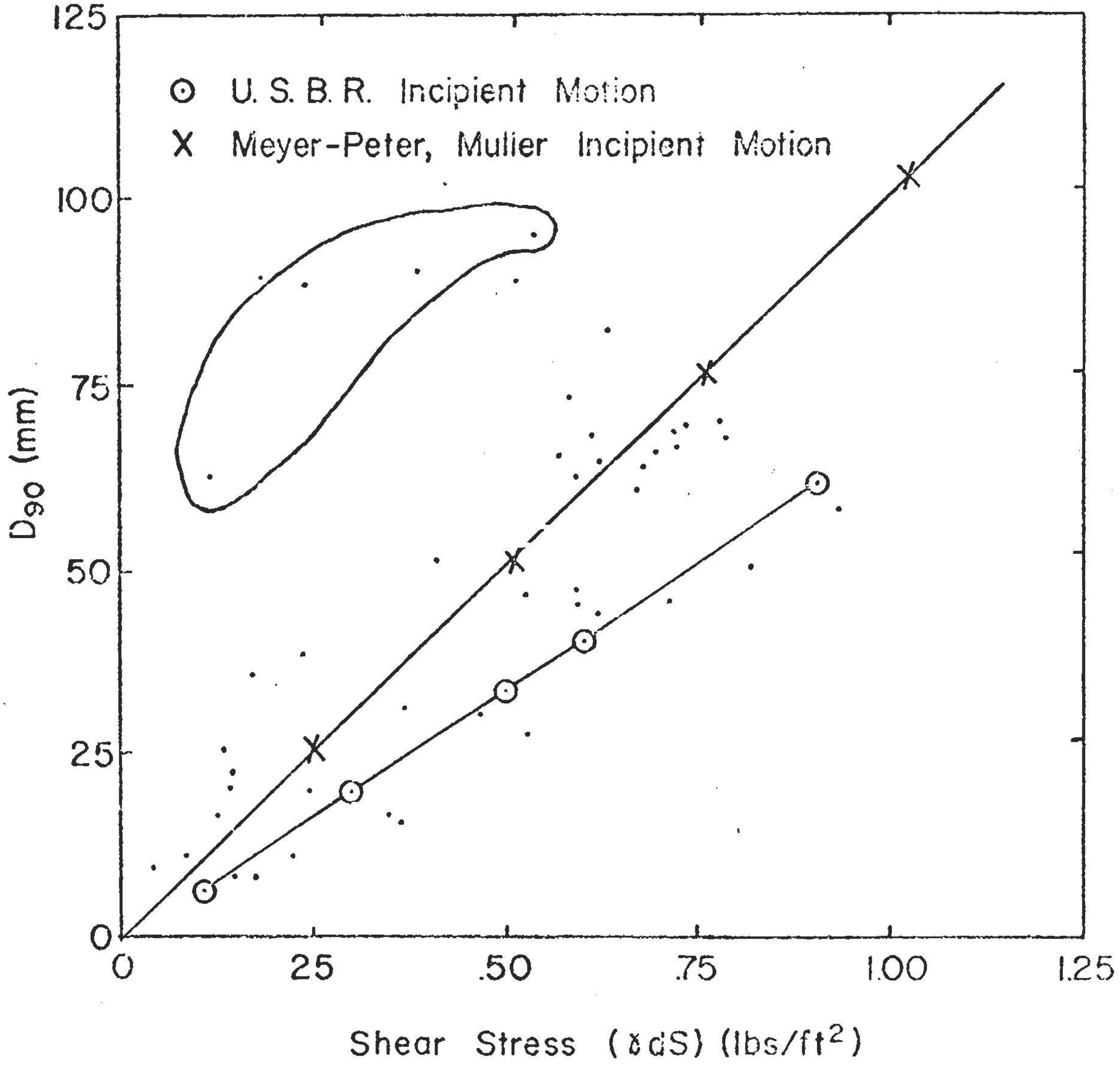


Figure 17

D_{90} Versus Shear Stress as Measured in Cape Horn and Knapp Creeks.

The Meyer-Peter, Muller bedload formula was converted to the English system and generalized for the specific weight of water and quartz particles by the Bureau of Reclamation in 1960. The equation is as follows:

$$g_s = 1.606 \left[3.306 \left(\frac{Qs}{Q}\right) \left(\frac{D90^{1/6}}{n_s}\right)^{3/2} dS - 0.627 D_m \right]^{3/2} \quad \text{where}$$

g_s = Bedload transport (tons/day/foot width)

Q_s = Discharge quantity determining bedload transport (cfs) function of n_w and n_m, where

n_w = Side wall roughness value

n_m = Total channel roughness

Q = Total water discharge quantity (cfs)

D_{90} = Armor size (mm) as approximated by the size of sediment for which 90% of the material is finer than that size

n_s = Weighted Manning's "n" value for the streambed

d = Depth of flow (feet)

S = Slope energy grade line (feet/foot)

D_m = Effective size of bed material

$$D_m = \frac{(D_{mi} P_i)}{100} \text{ (mm), where}$$

D_{mi} = Mean diameter of a selected portion of the size-distribution curve.

P_i = Percent of material within a selected portion of the size-distribution curve

For the condition at which bed material just begins to move, D_m in the original formula is replaced by the individual particle size, D, and

$$dS = 0.0001624\ D.$$

then shear stress equals $\gamma dS = 0.0001624\ D\gamma$, where γ = specific weight of water (62.4 pounds/cubic foot).

The Meyer-Peter, Muller formula is divided into static variables, those not changing during the sediment transport period, and dynamic variables, those which do change. The static variables are Q_s/Q, D_{90}, S, and D_m. For Batholith streams, where the width is at least twenty times the depth in riffle areas, the Q_s/Q ranges from 0.90 to 1.00 when $n_w/n_s = 1.0$. Therefore, a constant value of 0.95 was chosen for this term. Although the slope, S, varies with discharge it changes very little during the transport period (Neilson, 1974), and approaches the overall channel slope of that section. The mean diameter, D_m, and 90% diameter, D_{90}, which are computed from bed material samples, are assumed constant during the transport period. This would not be true when large amounts of fine sediments (smaller than ¼ inch) are entering the stream during the transport period. An adjustment in the D_m can be made by using a relationship developed between D_m and the volume of fines in cubic feet per one hundred square feet of streambed surface to a depth of six inches (Neilson, 1974). The relationship is used when known amounts of fine sediments are entering the stream and combined with the prior D_m level, the figure can be used to vary the D_m appropriately.

The dynamic variables of depth, d, and Meyer-Peter, Muller "n_s" vary with stream discharge and are therefore related to the stream hydrograph and discharge frequency relations. The depth is related to discharge by a rating curve or depth-discharge relation for the riffle areas.

The Meyer-Peter, Muller "n_s" is a factor to relate the Manning's "n" value variation for the total channel roughness and sidewall roughness as related to the channel depth-width ratio into a single function. The relative roughness, resistance to flow or Manning's "n" is assumed constant across the riffle section. Measurements on Cape Horn Creek supported this assumption.

The Meyer-Peter, Muller formula can be rearranged by grouping the static and dynamic variables into a generalized equation for batholith streams. Since it is a tractive force type equation, it contains a theoretical transport level minus a critical transport level or beginning-of-transport term.

$$g_s = 1.606(3.306 \frac{Q_s}{Q} (D_{90}{}^{1/6})^{3/2} dS - 0.627d_m)^{3/2},$$ can be rearranged to

$$g_s = 1.606(3.306 \frac{Q_s}{Q}(D_{90})^{\frac{1}{4}} S \frac{d}{n_s{}^{3/2}} - 0.627D_m)^{3/2}$$

This equation can be reduced to

$$g_s = 1.606 (T - T_{cr})^{3/2}$$

or

$$1.606 (C_T \cdot d/n_s{}^{3/2} - T_{cr})^{3/2},$$

where $3.306 (Q_s/Q)(D_{90})^{\frac{1}{4}} S$ is a coefficient of sediment transport, C_T, so that the theoretical transport level, T_{cr}, is then $0.627 D_m$.

The $d/n_s{}^{3/2}$ term changes continually with discharge, so the theoretical transport level, T, also varies. Sediment is only transported when T is greater than T_{cr}. Negative values indicate zero transport rate and equal values indicate the point of incipient motion. The daily sediment transport rates are calculated by raising the $T - T_{cr}$ to the three halves power and multiplying by 1.606.

The total yearly sediment transport is calculated by summing the daily sediment transport amounts for the year. The result of the calculations is expressed in tons per year per foot width which must then be multiplied by the average width of the riffle during the transport period. Since the transport rate is determined from the bed material present, it will vary as the bed composition changes. Changes can occur when fine sediments enter or leave the stream section. If known amounts of fine sediments are entering the stream, D_m should be varied and the transport rate will vary accordingly.

Since aquatic biologists are often concerned with the material finer than 0.25 inches, the total transport of that size material or finer is determined by multiplying the transport rate by the fraction of bed material finer than 0.25 inches. The relation of the portion of material finer than 0.25 inches and the sum of three components of streambed surface classification can be used to determine the amount of fines present in the streambed (Figure 18).

The amount of fine sediment that should be allowed to enter a stream before detrimental effects will occur on the aquatic habitat will depend on the amount of fines already contained within the stream channel section. Bjornn (1969) indicated that when fines comprised more than 20 to 30% of the riffle material they become detrimental to the survival of pre-emergent steelhead trout and chinook salmon. The amount that can enter the stream is the difference between the present level and the allowable level plus the amount transported as determined by summing the yearly values for the period of concern. For example, if sediments enter the stream during the period of three years, three runoff events of some chosen frequency can be used to obtain a three year sediment transport

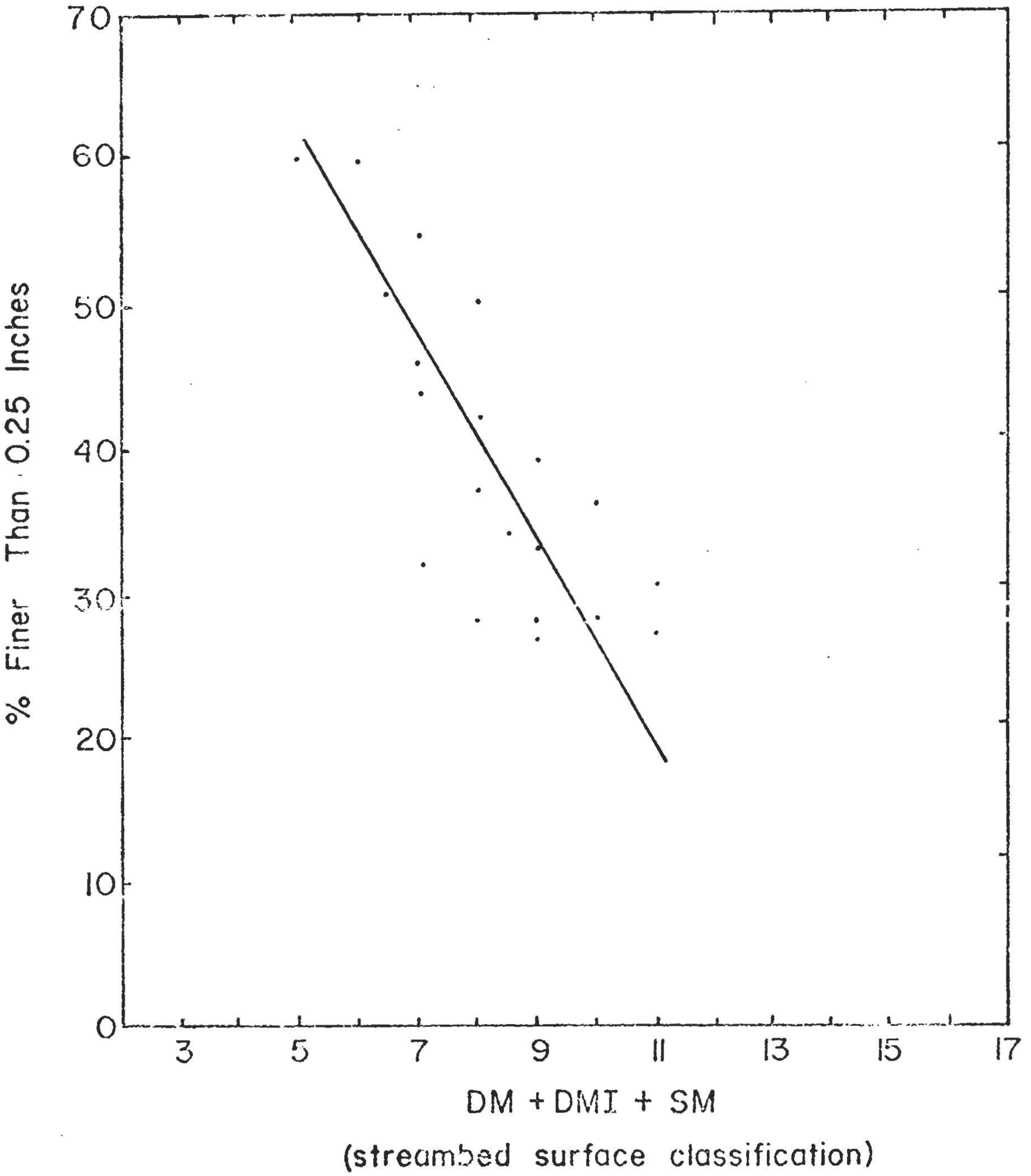


Figure 18

Percent of Material Finer than 0.25 Inches
Versus Streambed Surface Classification
of Three Idaho Batholith Streams

amount for that stream. By varying the return interval of a runoff event and the streambed composition and repeating the transport calculations, a relationship such as Figure 19 can be developed. It should be emphasized that this procedure was developed with a minimum of sediment transport data to verify the model. Data collected in the June-July runoff period of 1974 will be used to verify and/or modify this model to enhance its usefulness to the resource manager. The entire procedure to determine the transport of sediment through a stream section is found in Neilson (1974).

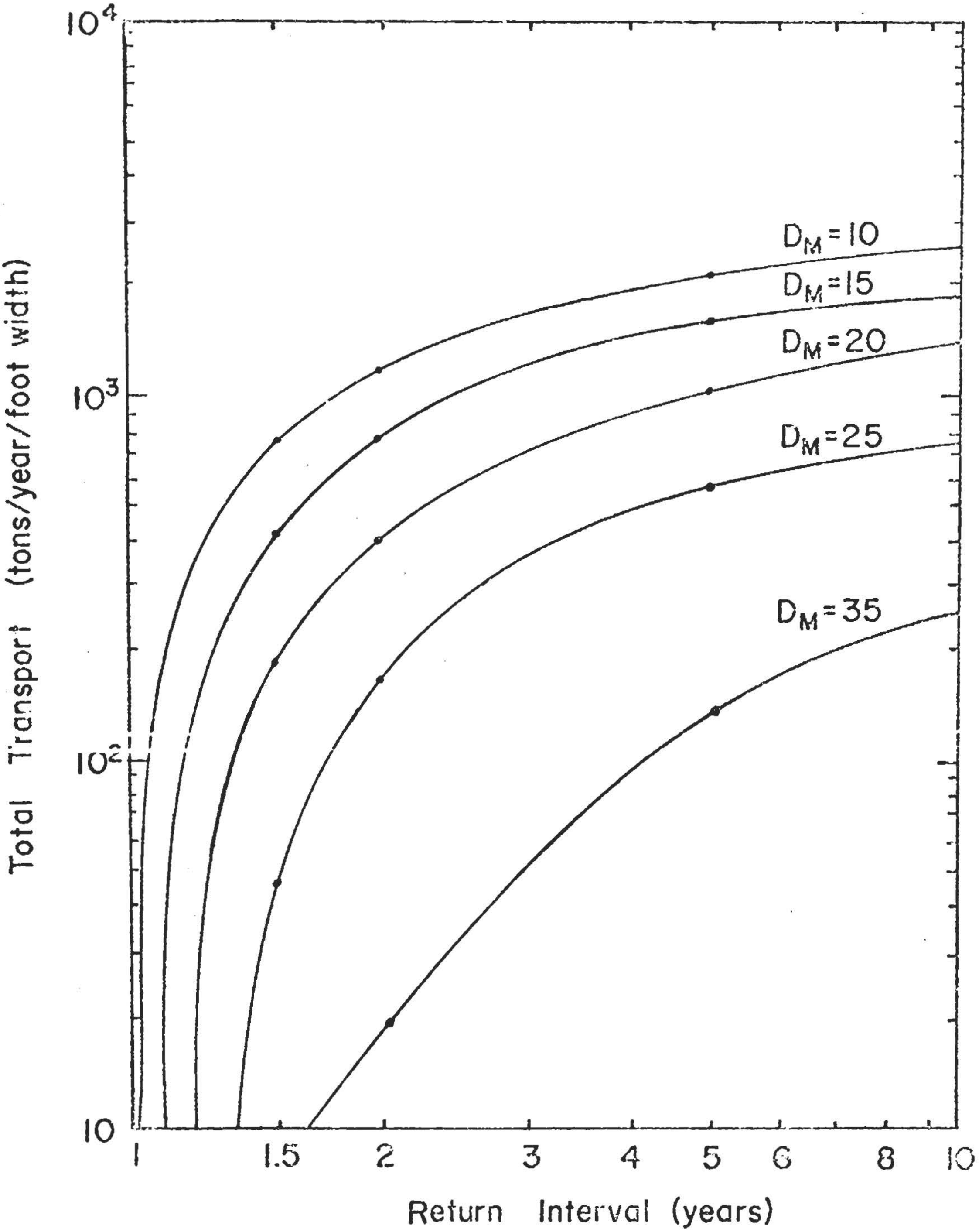


Figure 19

Total Transport Versus Return Interval for Cape Horn Creek as Determined from the Meyer-Peter, Muller Bedload Formula

DISCUSSION

In our observations and tests we did not find that juvenile steelhead trout or chinook salmon were adversely affected during the the summer when there was a large amount of sediment in the riffles. Cape Horn, Marsh, and Elk Creeks had riffle substrates with sediment levels that ranged from 52% in Elk Creek to 26% in Cape Horn Creek yet the densities of juvenile steelhead trout and chinook salmon in the study areas of these streams were nearly the same (Table 5). We found no differences in fish densities between channels with or without sediment when we tested three levels of riffle sedimentation on age-0 and age-1 steelhead trout. At the time we 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 were not reflected in the densities or size of the fish. Although Elk Creek had a larger proportion of sediment in its riffles and fewer insects drifting per m^3 of flow than Cape Horn and Marsh Creeks, the fish were not smaller or less abundant in Elk Creek. In test 4 in the artificial stream channels, where we shut off 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 the effect of sediment placed on riffles but the channels with sediment had as many drifting insects (exclusive of Gammarus) as channels without 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 Cape Horn, Marsh, Elk and Knapp Creeks, age-0 and age-1 chinook salmon and age-1 and older steelhead trout occupied primarily 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 which resided in those pools declined. The density of fish increased as the pools became smaller, but we believe the density increased only because the stream was not stocked to capacity when we started our test.

In our tests with fully sedimented riffles during the winter, fewer age-0 steelhead trout and chinook salmon remained in the channels with sediment than in the ones without sediment because those 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 our channels during winter and were not affected by sediment in the riffles.

Although the stream (Elk Creek) which had the most sediment also had the smallest density of benthic insects, fewest drifting insects and the lowest diversity index of the streams we surveyed, we could not cause decreased insect abundance in the test channels or Knapp Creek by adding sediment. When we added sediment to the riffles in the channels at Hayden Creek, we noted a temporary decline in the diversity index but no measurable effect on benthic or drifting insects. In Knapp Creek, the abundance of drifting insects increased while we were adding the sediment to the riffles but there was no measurable effect on the density of benthic or drifting insects 1 or more days after adding the sediment. Perhaps the insects drifting downstream from unsedimented portions of the stream rapidly recolonized the sedimented riffles and many insects drifted through pools without being eaten.

Based on the physical characteristics of the streams we studied and a review of bedload discharge formulas, we concluded that the Meyer-Peter, Muller formula appears to be the most applicable to estimate sediment transport capabilities of streams flowing through broad mountain valleys in the Idaho batholith (Neilson, 1974). Preliminary data required to calculate sediment transport rates include stream flow records, depth-discharge relationships, streambed composition, tons of sediment supplied to the section, and channel slope and width. Using this formula, we estimated that the sediment transport capability of Cape Horn Creek, just below our study site was 1730 tons of sediment material or 1280 m^3 per year with mean annual discharge (Neilson, 1974).

Sediment transport was negligible during the summer, low flow period. Because of a small runoff during the spring of 1973, sediment transport during the spring runoff was also negligible, and we were unable to test our hypothesis that the Meyer-Peter, Muller formula was most applicable for mountain meadow type streams. Sediment transport data was collected during the spring runoff, 1974, but was not analyzed in time to include in this report.

Our observations and tests cover only a part of the conditions that need to be tested. We found that sediment added to a limited number of riffles had no measurable effect on the abundance of fish or 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 reduction in fish densities or growth. In our studies, insects from unsedimented portions of streams may have compensated for losses in the riffles where we added sediment.

We found that when we added sufficient sediment to a stream to fill or partially fill the pools a reduction in the number of fish that reside in that stream during the summer (and probably the winter, too) will occur. We 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.

Small, localized, one-time additions of sediment to a stream (such as in Knapp Creek) appear to have limited spacial or temporal impact on fish or insects. Most streams can transport substantial amounts of sediment during the spring runoff and thus flush small amounts of sediment from their channels.

Although we need 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:

1) In small streams, where most fish reside in the pools, activities which add sufficient sediment to a stream so that pool area or volume is reduced, 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.

3) Small amounts of sediment added to limited areas of a stream during a short summer period will cause only limited, temporary impacts on aquatic life.

We will continue studies of the effects of sediment in streams during 1974 and 1975 to verify results of these studies, to evaluate previously untested conditions and to test our model for predicting transport capabilities of streams.

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