NATURAL AND SIMULATED INSECT-SUBSTRATE RELATIONSHIPS IN IDAHO BATHOLITH STREAMS

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MICHAEL F. SANDINE

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Committee members Date
Date

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Department Head Date
College Dean Date

FINAL EXAMINATION: By majority vote of the candidate's Committee at the final examination held on date of Committee approval and acceptance was granted.

Major Professor Date

GRADUATE COUNCIL FINAL APPROVAL AND ACCEPTANCE:

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ABSTRACT

Laboratory and field studies were conducted to determine the effects of sediments on the distribution and abundance of insects in Idaho Batholith streams. Changes in characteristics of substrate, e.g. dominant substrate, imbeddedness of dominant substrate, composition of material surrounding dominant substrate, and water velocities were correlated with changes in benthic insect populations. Multiple regression analysis indicated benthic populations were not responsive to sediment introduction until the dominant substrate became heavily imbedded. Species diversity was found to be directly correlated with water velocities below 0.35 m per sec. Sediment introduction upon riffles in a natural stream, indicated that rocks greater than 6.5 cm in size contributed most to species diversity of the riffle. Riffles composed of cobble recovered more rapidly to the pre-treatment species diversity than riffles without cobble.

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INTRODUCTION

Concern for the protection of man's environment and a quest for additional resources has caused increased intensity in water pollution studies. Expansion of timber harvest, grazing, and mining has intensified watershed disturbances. Investigations have been made in several Idaho watersheds in an effort to understand the components needed for a viable stream environment, leading to sound watershed management techniques.

The Idaho Batholith, encompassing central Idaho, represents a principal problem area (Fig. 1). Geologically, the area is granitic with quartz monsonite predominating (Megahan, 1972). High erosion characteristics coupled with increased logging, road building, and mining has subjected its streams to increased sediment loads. Decomposition of the parent material forms soils having a coarse loamy sand to sandy loam texture. Because of the low clay content, the cohesion of the particles is low. This soil type is subject to high erosion, as demonstrated from studies in Idaho, Oregon, and Northern California (Anderson, 1954; Andre and Anderson, 1961; Megahan, 1972, and others). The topography of the Idaho Batholith is characterized by steep slopes and narrow valleys.

Man-caused activities resulting in deposition of large amounts of sediment into streams have come under increased scrutiny in recent years. It has been shown that large amounts of sediment in streams reduces benthic species diversity and biomass (Chutter, 1970; Buscemi, 1966; Prather, 1971; McClelland, 1972) and reproduction potential of anadromodous fishes (Bjornn, 1969).

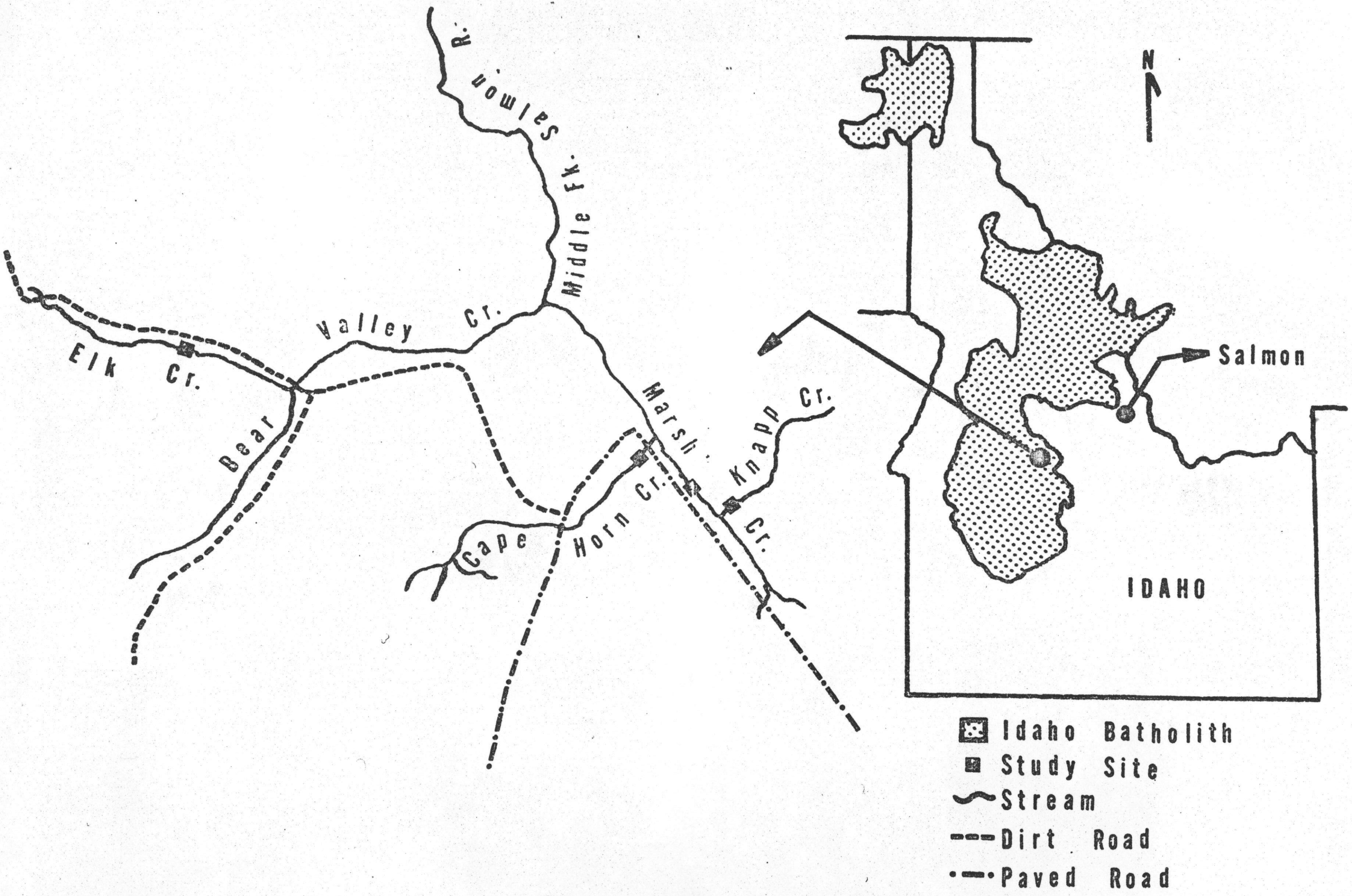

Fig. 1. Map of Idaho batholith, study area streams and sites.

Aquatic insects represent intermediate trophic levels in stream communities. Environment alterations adversely affecting insect populations would have far reaching effects upon other members of the biotic community.

This study represents an interdisciplinary approach by researchers in engineering, fisheries, and entomology to quantify and qualify the effects of stream sedimentation upon insects and fish. Natural and simulated studies provided information for evaluating biotic-substrate interactions. The determination of tolerance levels and ecological impact of different sediment levels on insect populations represented the entomological phase of the study.

The collective results of this study should provide valuable ecological information in formulating watershed management guidelines for Idaho Batholith streams.

METHODS AND MATERIALS

Hayden Creek Laboratory Study

The laboratory phase of this study was conducted at the Hayden Creek Research Hatchery-Steelhead and Salmon Rearing Ponds, 56 km south of Salmon, Idaho. A concrete slab (3.66 x 61 m), covered with a translucent roof served as the laboratory facility. A supply of water was available by diversion of warm spring water and Hayden Creek water into the artificial channels.

Two channels, consisting of four equal reaches (1.21 x 21.3 m), were built on a concrete slab (Plate 1A, Fig. 2). They were constructed from 1.9 cm plywood and fiberglassed with resin and cloth. A headbox was constructed at the upper end of the channels and served as a mixing point for warm spring water and Hayden Creek water and provided a constant discharge into the channels. The two water sources provided relatively uniform temperature control and insured an adequate water supply to the channels.

Aqua Screen Rollers (Steven Aqua Screen Mfgr., Reno, Nevada) were placed at the top and bottom of the four sections, preventing fish migration between reaches within a channel while allowing uninhibited movement and transport of insects and plant material in and out of test sections (Plate 1B).

Insects were introduced into the channels via a 15.2 cm plastic gravity-flow pipe inserted into the main Hayden Creek channel. A funnel apparatus, having a 0.305 x 1.2 m opening, was fitted to the upper end of the pipe and served to collect and concentrate drifting

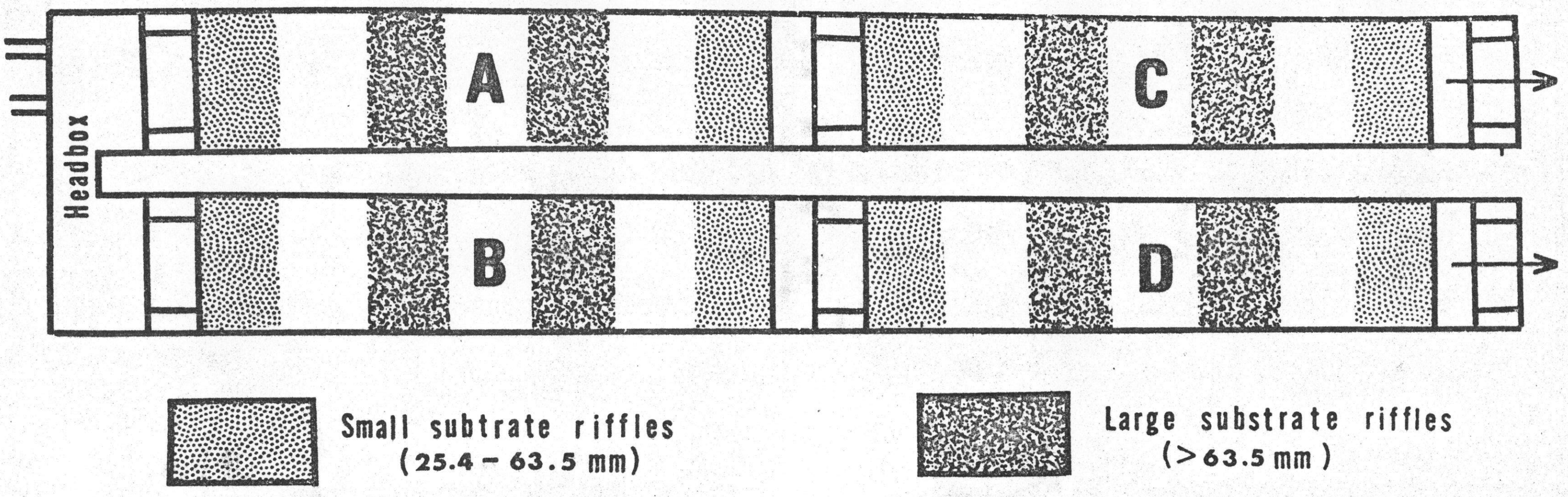

Fig. 2. Experimental stream channel configuration at Hayden Creek. A. Upper control section, no sediment; B. Upper test section, with sediment; C. Lower control section, with fish, no sediment; D. Lower test section, with fish and sediment.

insects and organic matter for transportation to the channels. Spring water also contributed a small number of insects and fresh-water shrimp to the artificial channels. Colonization was generally accomplished in two to three weeks.

The riffle substrate was manually placed in the channels and consisted of "river-run" gravel of two sizes, e.g. 1.9 to 3.7 cm and 6.5 to 12.5 cm in diameter. Each of the four sections had identical pool-riffle configurations (Fig. 2). Riffles were approximately three meters long, 0.45 m deep and 1.22 m. wide. The top and bottom riffle of each section was composed of 1.9 to 3.7 m gravel. The two middle riffles contained rocks 6.5 to 12.5 cm in diameter. Pools separating the riffles contained no gravel, but were covered with a thin layer of fine sediment (less than 1 mm) 0.5 to 2 cm deep.

Water depth was 10 to 15 cm over the riffles and about 56 cm in the pools. Water velocities over riffles ranged from 0.37 m per sec in the upper riffles of each section to 0.12 m per sec in the low riffles. Water velocities across pools averaged less than 0.04 m per sec. The discharge for the test and control channels were 0.04 and 0.045 m^3 per sec respectively.

Sediment Introduction and Physical Analysis. The physical parameters of substrate type and water velocity were monitored during the course of the study. Velocities were taken during each test at nine points at each riffle and pool with a Gurley Pygmy Current Meter (Model No. 625-F, Gurley Hydrological Instr.). Surface substrate was visually ranked according to three characteristics (Tables 1 and 2): 1) dominant substrate size; 2) imbeddedness of dominant substrate in surrounding sediments; and 3) size of material surrounding the dominant substrate. Ranking was based upon three 0.093 m^2 (1 ft^2) sample areas at each riffle and represented average conditions for the three substrate characteristics mentioned above. A modification of Prather's (1971) ranked sediment scheme was used.

Table 1. Rank classification of dominant substrate and surrounding material.

Rank	
1	less than 1.5 mm in diameter (1/16 in)
2	1.5 - 6.35 mm in diameter (1/16 - 1/4 in)
3	6.35 - 25.4 mm in diameter (1/4 - 1 in)
4	25.4 - 63.5 mm in diameter (1 - 2 1/2 in)
5	greater than 63.5 mm in diameter (2 1/2 in)

Table 2. Rank classification of imbeddedness of dominant substrate.

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

Decomposed granite from the Stanley Lake area was spread on two test section riffles to determine the effects this material had upon aquatic insects. Two test sections (Fig. 2B, D) were treated with four sediment levels, i.e., 1) no sediment, 2) light, 3) moderate, and 4) heavy. The control sections (Fig. 2A, C) contained no introduced sediment during the study.

The study was composed of four phases:

1. Insects introduced into both channels, channels allowed to stabilize for three weeks; no sediment added; benthos, drift, substrate analysis and water velocities taken.
2. Light amounts of sediments added equivalent to providing a 1/3 imbeddedness condition on test sections; fifty steelhead introduced in both lower test and control sections; benthos, drift, substrate analysis and water velocities taken.
3. Moderate level of sediment introduced equivalent to a 2/3 imbeddedness condition; 50 juvenile steelhead introduced in both lower test and control sections; benthos, drift, substrate analysis and water velocities taken.
4. Heavy level of sediment introduced equivalent to a nearly full imbeddedness condition; 50 juvenile steelhead introduced in both lower test and control sections; benthos, drift, substrate analysis and water velocities taken.

Benthos and drift samples were preserved in 75% ethyl alcohol and later sorted and analyzed in the laboratory.

Benthic Community Analysis. Aquatic insect community changes were monitored in relation to different sediment amounts and fish predation. At the end of each testing period (8 - 12 days based upon fish acclimatization period), benthic insects were sampled by means of a cylindrical 0.093 m^2 (1 ft^2) bottom sampler similar to that described by Waters and Knapp (1961). Three random samples per riffle (12 per section) were taken for each test. Samples were stored in pint jars partially filled with 75% ethyl alcohol until analysis. Substrate characteristics (Tables 1 and 2) were evaluated within the perimeter of the benthos sampler at the time of sampling. Insects were sorted and identified in the laboratory, using keys by Usinger (1968), Jensen (1966), Ward and Whipple (1963), and Smith (1968). Questionable specimens were checked with determined specimens in the research collection, Department of Entomology, University of Idaho.

Estimates of community structure were obtained by using Patten's (1962) equations for species diversity. Four values were calculated using the following equations:

1) Diversity per individual (H)

$$H = -\sum_{i=1}^{m} \frac{ni}{N} \mathrm{Log}_2 \frac{ni}{N}$$

2) Maximum diversity (H_{max})

$$H_{max} = \mathrm{Log}_2 N! - m\,\mathrm{Log}_2 \frac{N}{m}!$$

3) Minimum diversity (H_{min})

$$H_{min} = \mathrm{Log}_2 N! - \mathrm{Log}_2 (N-(m-1))!$$

4) Redundancy (R)

$$R = \frac{H_{max} - H}{H_{max} - H_{min}}$$

where (N) is the total number of individuals, (ni) the number of individuals per species, and (m) the number of species in a unit area. Redundancy measures the degree of evenness in the distribution of the numbers within a species, e.g. a value near 0.0 demonstrates a uniform distribution, while a value near 1.0 means a clumped distribution. Because the taxonomy of larval Chironomidae (aquatic midges) has not been resolved, the calculated diversity values are for insects exclusive of Chironomidae.

Drift nets (0.305 x 1.22 m) made of nylon cloth (pore openings 0.8 mm) were positioned across the entire width of each channel, permitting total capture of drifting insects. Nets were placed at the top and bottom of each of the four sections (Fig. 2). One-hour samples were taken at 12 o'clock noon, 30 minutes before sunset, and 2 1/2 hours after sunset. These sampling times were selected to reflect times for measuring predator-prey interaction and high and low periods of behavioral drift by the insects.

Marsh Creek, Cape Horn, and Elk Creek Field Studies

Preliminary surveys were conducted on Marsh, Cape Horn, and Elk Creeks in August, 1972, to establish baseline information of substrate, stream flow characteristics, fish behavior, insect populations, and provide information on field techniques used in later studies.

The entomological phase of this study dealt with establishing the relationship of insect standing crop with substrate on selected riffles. The three creeks were quantitatively and qualitatively compared on the basis of benthic insect populations, substrate, and insect drift.

The test riffles of each stream were divided cross-sectionally into thirds or halves, depending on the length of the riffle. Each section was approximately six to nine meters long. Transect lines were established, and substrate characterized, using the rank scale previously described (Tables 1 and 2). The transect lines consisted of steel rods driven into opposite stream banks and used as reference points. A nylon cord, marked at one-foot intervals was stretched and leveled between the rods. Streambed profiles were measured, and substrate analysis visually made at one-foot intervals using the substrate classification in Tables 1 and 2.

Benthic insects were randomly sampled with a cylindrical, 0.093 m^2 bottom sampler (Plate 1F). Nine to twelve samples were taken per riffle (number of samples varied with the size of the riffle). Insect drift was sampled with three, 0.30 x 0.61 m drift nets (pore size 0.8 mm) equally spaced across each riffle. Sampling was done at four, two-hour intervals over a 24-hour period (0500-0700, 1200-1400, 1930-2130, and 2400-0200 hours).

Commensurate with above methodologies, other members of the research team, i.e. fishery biologists and agricultural engineers, conducted biological studies on fish and determined substrate, channel configuration and discharge characteristics of the streams.

Knapp Creek Field Study

This phase of the field investigation was conducted during August, 1973, in Knapp Creek, a tributary of Marsh Creek. The later is located in the Challis National Forest and is a tributary of the Middle Fork of the Salmon River in central Idaho (Fig. 1). The study site was located in the lower reach of the stream, approximately 500 m above the confluence with Marsh Creek (Fig. 1).

Knapp Creek flows southwesterly becoming a low gradient stream after entering a broad valley. Its width at the study site varied from 3.6 to 5.2 m. Average water depth over the riffles were 10.6 cm; pools were 0.3 to 1.1 m deep. The current velocities range from 0.18

to 0.76 m per sec over the riffles. The average discharge during the study was 0.127 m^3 per sec.

The Knapp Creek drainage is in the Douglas fir zone (Davis, 1952). The riparian vegetation consists of alder (Alnus sp.), various grasses, sedges, and forbes. The valley floor of this batholith stream is largely made up of alluvial deposits.

The study site consisted of four riffles, associated pools and runs. The upper two riffles served as control riffles, the lower two test riffles. The site was selected on the basis of presence of juvenile steelhead and resident trout, an adequate insect population, and vehicle accessibility. The site was surveyed, mapped, and photographically documented, before and after introduction of sediment.

Permanent transects were established at two or three locations on each riffle. The number of transects was determined by the length of the reach. Streambed profiles were measured and substrate analysis made by visual ranking of the substrate at one-foot intervals, using the procedure previously described. Additional substrate analysis was made at each riffle by randomly selecting 30 to 40 points on the riffle and describing the corresponding substrate, using the rank classification (Tables 1 and 2).

Sediment was manually introduced onto the test riffles and associated pools in a manner similar to a natural bank slumpage. Approximately 3.44 cubic meters of decomposed granite (average particle size 0.078 in) was deposited at the head of the main test riffle. The water velocity was sufficient to cause the sediment to be distributed over the full length of the riffle and deposited at the head of the succeeding pool. Human traffic on the riffle was kept at a minimum, allowing undisturbed displacement of sediment over the riffle.

Approximately 18 m^3 of sediment was dumped into the pool immediately below the primary test riffle nearly filling the pool with sediment. Following the same method of sediment introduction, 1.9 m^3 of material was applied to the secondary test riffle. The pool immediately downstream from the secondary test riffle was covered with sediment from 13 to 21 cm deep and occupied one-fourth the original depth of the pool.

Biological and physical samples were taken two days before sediment introduction and 1, 3, 14, and 23 days after introduction. Each entomological testing sequence consisted of: benthos, drift collections, transect and random substrate classification.

Insect populations were sampled with a cylindrical bottom sampler (Plate 1F). Riffles were divided into 4.5 to 6.0 m sections, depending on riffle length. Six (.093 m^2) random benthos samples were taken and analysis made of the associated substrates from each section.

In an attempt to characterize the natural drift rates of insects and to determine the effects of sediment on drift, 0.3 x 0.3 m drift nets (0.8 mm pore size) were positioned at the bottom and center of the control and primary test riffles. During each 24-hour sampling period, three, one-hour samples were taken, corresponding to the sampling times established for the Hayden Creek study. During sediment introduction, drift nets were placed at the bottom of each riffle to analyze the dislodging effect of the sediment upon benthic insects.

RESULTS AND DISCUSSION

Intuitively, excessive streambed sediments may adversely influence aquatic insects. Few qualitative studies have been conducted to determine the degree at which sedimentation effects benthic insects. One of the earliest studies to demonstrate that insects tend to be differentially influenced by varying substrate conditions was by Percival and Whitehead (1929). Since then, it has been shown that substrate is a major factor affecting aquatic insect distribution and abundance (Tarzwell, 1937; Wene, 1940; Linduska, 1942; Smith and Moyle, 1944; Cummins, 1966; Cummins and Lauff, 1969; Chutter, 1969, 1970; Hynes, 1969, 1970; Prather, 1971; McClelland, 1972; and Luedtke, 1973).

Substrate variables of cobble size, spacing, and total substrate composition have been determined to be useful indicators of insect habitat and density (Scott and Rushforth, 1959; Scott, 1960, 1966; and Prather, 1971). In laboratory studies it was shown that many riffle insects prefer cobble over pebble and sand (Cummins, 1961, 1964, 1966; Madsen, 1969; Prather, 1971; McClelland, 1972). Numerous insects inhabit the intersticial spaces between gravel, thus, a decrease in sediment size coupled with increased cobble imbeddedness tends to reduce available microhabitats of many aquatic insects. Prather (1971) and McClelland (1972) demonstrated this effect for non-burrowing insects in the laboratory.

The evidence of relationships between insect abundance and substrate is strong. The development of a mathematical model to express relationships between sediment conditions and productivity in streams is a natural progression to knowledge. Kamler and Riedel (1960) were two of the first to correlate bottom fauna distribution and substrate sizes in the Tatra Mountains of Poland. Insect populations have not been previously modeled for Idaho Batholith streams; therefore, it was of interest to correlate substrate conditions with insect distribution and abundance and attempt to express the relationship mathematically.

Hayden Creek Laboratory Study

Sedimentation was the principal variable tested in relation to insect community structure. Throughout the experiment, two control sections (Fig. 2A, C) contained no artificially introduced sediment. The lower two sections (Fig. 2C, D) contained juvenile steelhead, and provided a possibility for studying predator-prey interactions in relation to varying sediment levels.

Species diversity indexes permit summarization of vast amounts of information on community structure (Shannon, 1948; Brillouin, 1956) and were valuable aids for characterization of insect communities in this study and others (Patten, 1962; Pielou, 1966; Wilhm, 1967). Generally, diversity values greater than 3.0 represent clean water communities, while values less than 1.5 are reflective of polluted waters (Wilhm, 1967). Diversity is expressed as bits (binary digits). A bit is the amount of information required to describe one of two equally probable states (Margalef, 1957). Since diversity is theoretically independent of sample size, all values are comparable.

Prior to the introduction of sediment into the channel, all sections were similar with respect to substrate and pool-riffle configuration. Insects were introduced into the two channels from a common headbox.

Analysis of data indicated the test channel had approximately 30% less recruitment than the control channel (Table 3; Append. A-D), presumably as a result of differential mixing of water and insects. This variation was not similarly reflected in the standing crop diversity between the two channels (Append. E-H). The lower sections in each channel had lower species diversity than the corresponding upper sections at the beginning of the testing period. When insect production (used here to refer to the rate of insect drift out of a reach over a unit time) of each section was compared, production from the upper sections was greater than recruitment into the same sections over the same one-hour time periods. Production from the upper section was equivalent to recruitment into the lower section, however, production from the lower section was less than its recruitment (Append. A-D). This situation suggests the lower sections had not reached the same insect-carrying capacity as the upper sections. Lower benthic species diversity is also found in the lower sections; but after a two week period, the diversity increased and began to stabilize (Fig. 3), indicating the insect-carrying capacity may have been reached.

Upper Test and Control Sections. Species diversity analysis indicated differences among riffles within the respective sections and to some degree between the control and test sections (Append. E-H). In-section differences among riffles was greater than between corresponding riffles in the two channels.

The upper and lower riffles of each section were composed of pebbles approximately four centimeters in diameter, while the middle

Table 3. Number of drifting insects entering and departing Hayden Creek control and test channels during a one-hour sampling period (2330 - 0030 hrs). Test channel sedimentation levels: A - no sediment; B - light; C - moderate; D - heavy. Nets 1, 3, and 5 were positioned in the control channel, nets 2, 4, and 6 in the test channel.

	Orders	Net					
		1	2	3	4	5	6
Test A	Ephemeroptera	306	218	565	682	231	207
	Plecoptera	12	13	8	5	2	7
	Trichoptera	46	16	11	3	1	4
	Diptera	14	8	8	16	6	10
	Coleoptera	0	0	4	4	3	1
	Hemiptera	0	0	0	0	0	0
	Total	378	255	596	710	243	229
Test B	Ephemeroptera	580	365	723	693	339	473
	Plecoptera	17	3	9	9	3	12
	Trichoptera	11	2	1	1	1	2
	Diptera	12	31	8	10	16	9
	Coleoptera	5	7	3	3	8	1
	Hemiptera	0	0	0	1	1	0
	Total	647	409	744	717	368	497
Test C	Ephemeroptera	137	52	108	80	54	77
	Plecoptera	4	1	1	1	0	0
	Trichoptera	4	1	0	1	1	0
	Diptera	9	1	14	17	3	0
	Coleoptera	12	5	6	7	1	2
	Hemiptera	0	0	0	0	0	0
	Total	166	61	129	106	59	79
Test D	Ephemeroptera	154	127	124	85	113	134
	Plecoptera	6	5	1	0	0	0
	Trichoptera	3	3	1	5	1	2
	Diptera	11	17	17	8	6	3
	Coleoptera	14	4	3	1	8	4
	Hemiptera	0	0	0	0	0	0
	Total	188	156	146	99	128	143

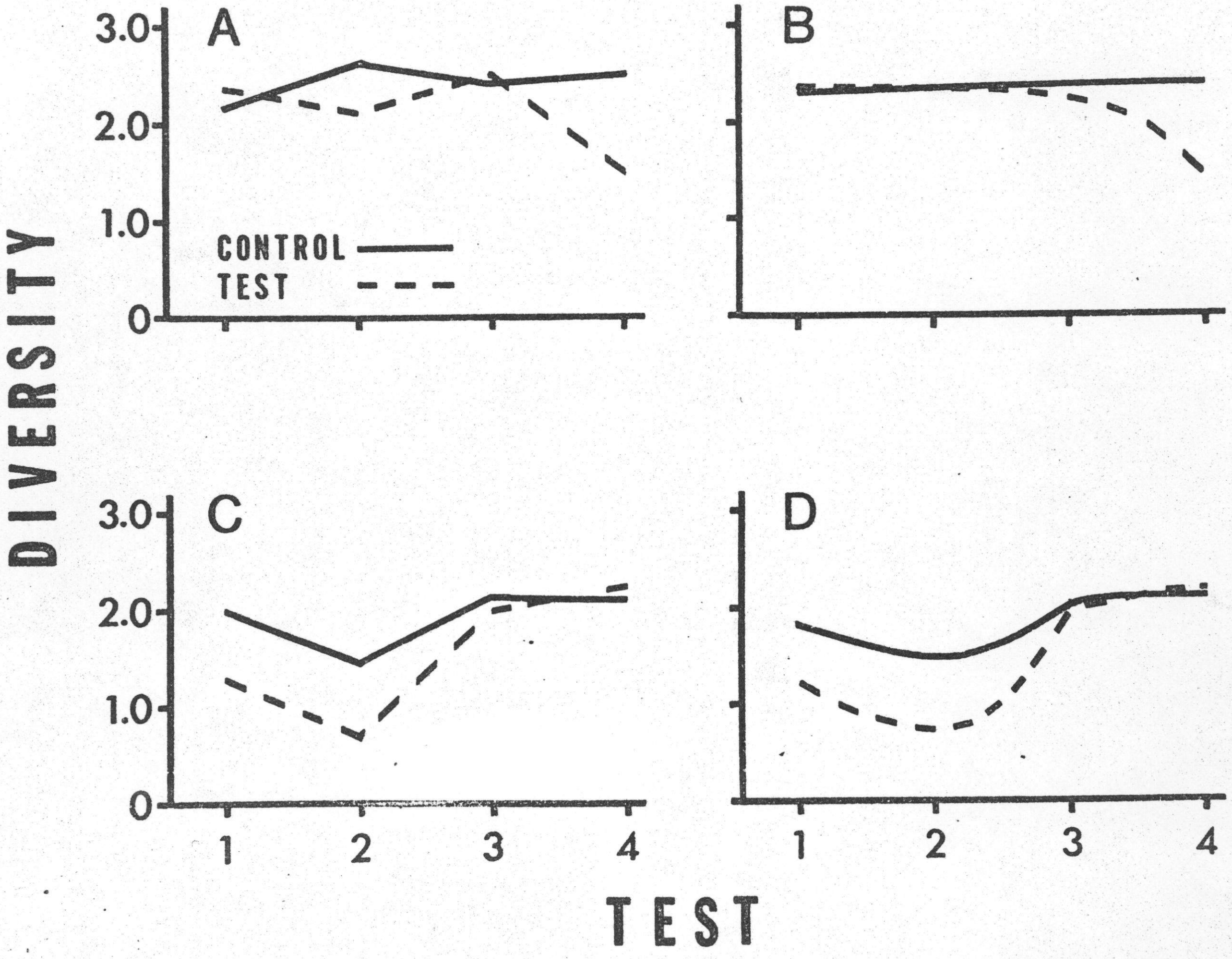

Fig. 3. Average benthic species diversity per test section in relation to dominant substrate imbeddedness at Hayden Creek. A. Upper sections; B. Upper sections, fitted lines; C. Lower sections, fish present; D. Lower sections, fitted lines. 1- no sedimentation; 2- light; 3- moderate; 4- heavy sedimentation.

two riffles had cobble up to 14 cm in diameter. The larger sediment size probably provided a more favorable habitat as reflected by the higher species diversity (Append. E-H).

It is interesting to note that while the second riffle (14 cm cobble) in both the test and control sections supported the highest diversity, the first riffle (composed of pebble) supported a slightly higher diversity than the third riffle which like the second riffle, had large cobble. This suggests that water velocity influenced habitat selection. Water velocity ranged from 0.34 m per sec at the upper end of each section to 0.12 m per sec at the lower riffle.

Another factor influencing diversity is the imbeddedness level of the dominant substrate. After introduction of sediment to a "light" imbeddedness level in the test section, the diversity did not decrease in the upper riffles (Fig. 3). These data indicate that a small amount of sediment (below a 2.2 imbeddedness value) was not detrimental to the insects that had colonized the stream. Similar results were reported by Gammon (1970) where he found no statistical difference in diversity of insects on light and moderately sedimented riffles of Deer Creek in Indiana.

Increasing levels of sedimentation to a heavy imbeddedness value in the test sections, decreased species diversity in a curvilinear fashion. To simplify comparisons between the control and test reaches, a line was fitted to the data. By examining differences of the slopes of these lines, comparisons of the effects of sedimentation upon species diversity may be deduced (Fig. 3). The control section had a slight increase in diversity over time. This indicates the control section probably reached equilibrium at the beginning of the experiment, with an average diversity of approximately 2.5. The test section diversity did not change after addition of sediment until the dominant substrate was nearly fully imbedded (Fig. 3). These data indicate little discrimination by insects at moderate imbeddedness values or less. Redundancy and species diversity responded similarly to increased sedimentation (Append. E - H). Redundancy remained at a low level during light and moderate sedimentation and increased during heavy sedimentation, thus illustrating an increased unevenness in distribution of numbers among the species. A similar trend was noted when comparing average number of individuals present in each benthic sample (Fig. 4). The control increased from 13 to 17 individuals per sample, resulting in only a moderate positive increase of numbers. In the test section, insect density remained stable at unimbedded, light, and moderate imbeddedness levels, but numbers decreased at full imbeddedness, this suggests that the insects became responsive to imbeddedness conditions only when the dominant substrate was highly imbedded.

Insect drift was not noticiably affected by different sediment levels (Fig. 6). Because of variations in drift rates attributable to other factors besides sedimentation (light intensity variations, indigenous behavior patterns, etc.), statistical inferences of the drift-substrate association are not readily interpretable. However, researchers have indicated drift rates may be a function of substrate and a wide range of other factors (Waters, 1962, 1965, 1969; Holt and Waters, 1967; Pearson and Franklin, 1968; Elliott, 1967).

Lower Test and Control Sections. This portion of the experiment was designed primarily to yield information on fish behavior and insect

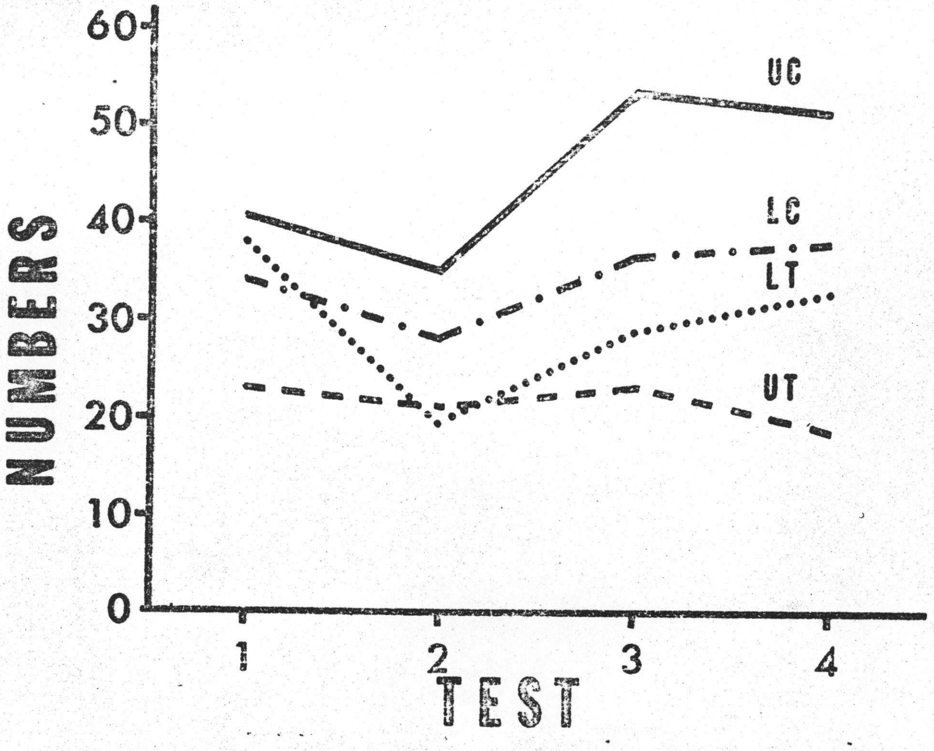

Fig. 4. Average number of insects per benthic sample (0.186 m^2) at Hayden Creek. UC- upper control section; UT- upper test; LC- lower control; LT- lower test. 1- no sedimentation; 2- light; 3- moderate; 4- heavy sedimentation.

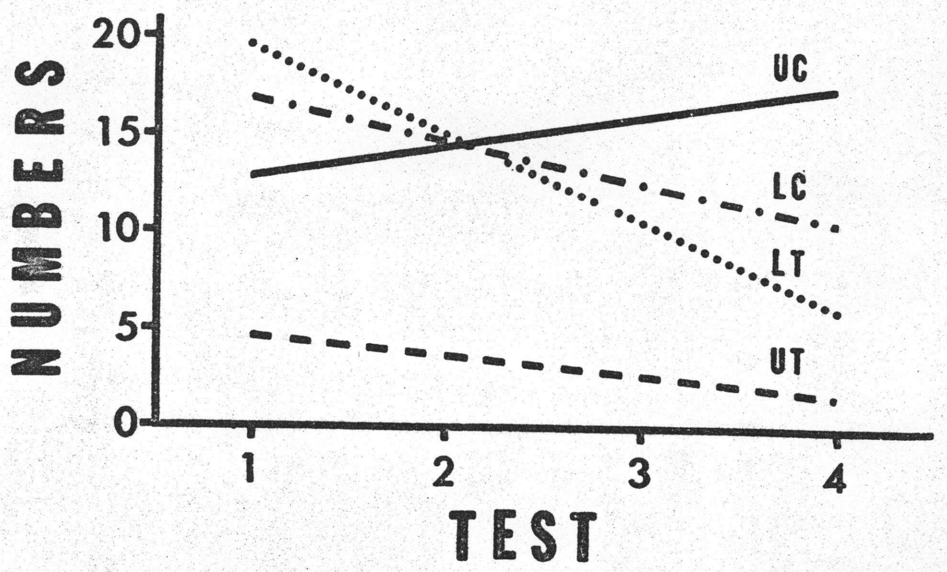

Fig. 5 Fitted lines of the average number of Cinygmula sp. per benthic sample (0.186 m^2) at Hayden Creek; UC- upper control section; UT- upper test; LC- lower control; LT- lower test. 1- no sedimentation; 2- light; 3- moderate; 4- heavy sedimentation.

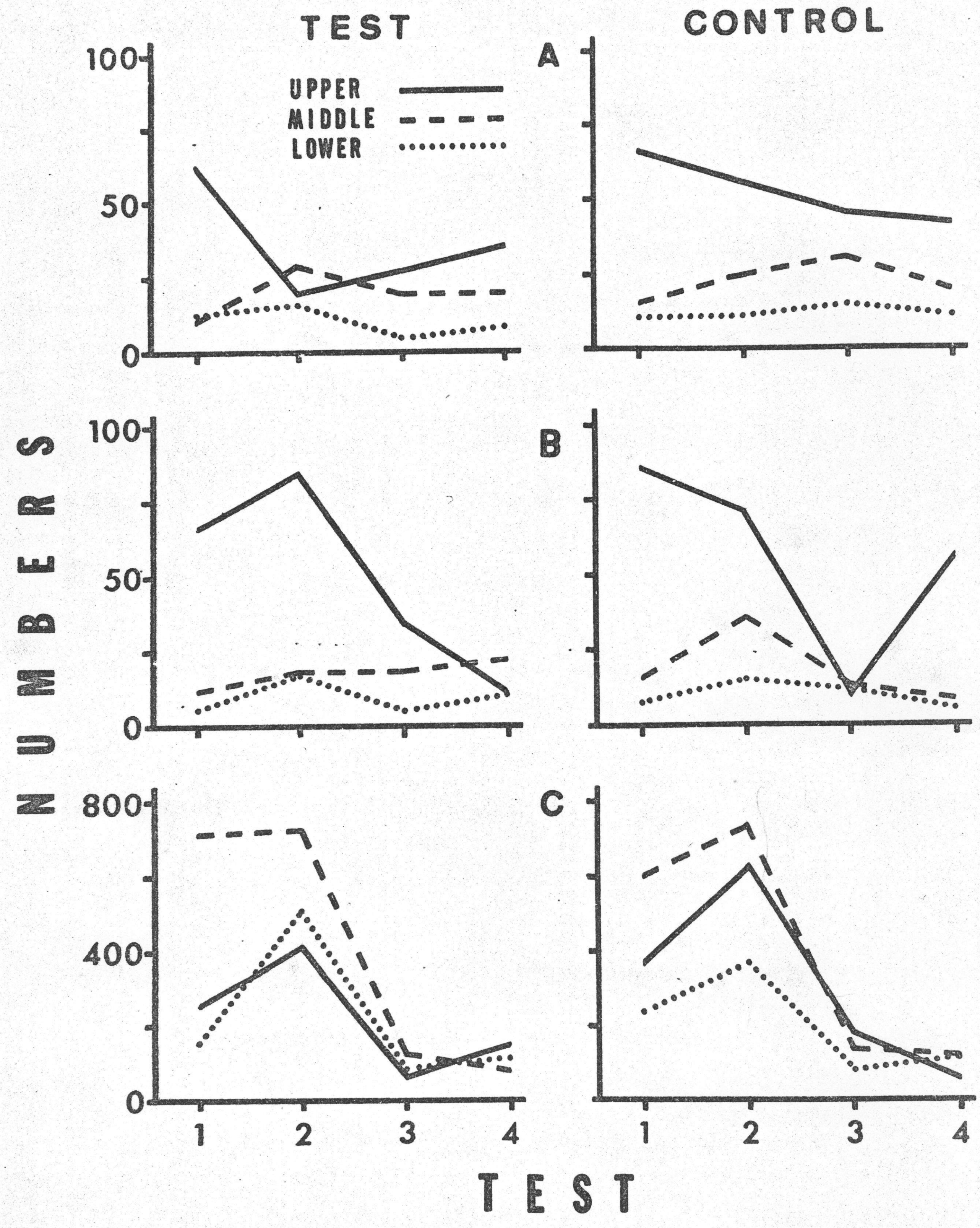

Fig. 6 Total number of drifting insects per test section imbeddedness level for upper (top of channels), middle (between sections), and lower (bottom of channels) nets at Hayden Creek. A- 1200 - 1300 hours; B- 2030 - 2130 hours; C- 2330 - 0030 hours. 1- no sedimentation; 2- light; 3- moderate; 4- heavy.

interactions as a function of different substrate conditions. After a two week stabilization period, fish were introduced into both control and test sections. The test section was subject to three increasing levels of sedimentation, i.e., light, moderate, and high.

With the addition of fish as a biological variable in the lower sections of the channels, benthic diversities were more erratic than the upper test and control sections without fish. Addition of both fish and sediment caused species diversity and average insect density to drop (Fig. 3 and 4). This was probably the result of various factors. Pretreatment diversity in the lower sections was less than that of the upper sections, suggesting the insect population had probably not stabilized prior to the test. When the population was put under stress by introduced sediment, fish predation, and a reduction in flow due to a blocked water intake, a large drop in diversity occurred. Since the population was probably not at its carrying capacity, an increase in species diversity occurred and superseded the effect of sedimentation. In the last test of the experiment, diversity in the lower control section reached values similar to the upper control section indicating a stabilized population had been reached.

Benthic density in both test and control sections was similar prior to introduction of fish. After the initial introduction of sediment, diversity of the control and test sections returned and stabilized to the pre-fish treatment level of the control section (Fig. 3). Differences in species diversity between the sedimented and unsedimented sections were not shown using the Duncan's Multiple Range Test (Table 4). The lower control section was exposed to at least the same quantity of individuals by drift as the upper control (Fig. 6), thus intuitively, in the absence of fish it should have attained the same level of diversity. Species

Table 4. Species diversity comparisons from channel sections at the Hayden Creek experimental channels using Duncan's Multiple Range Test. Test channel sedimentation levels: A = no sediment; B = light; C = moderate; D = heavy. Sections with same identification letters are statistically similar.

Test	Sections	Statistical sets	Average diversity
A	Upper control	A B	2.13
	Upper test	A B	2.35
	Lower control	A	2.07
	Lower test	C	1.34
B	Upper control	B	2.63
	Upper test	A	2.06
	Lower control	C	1.33
	Lower test	D	0.81
C	Upper control	A B	2.39
	Upper test	A B	2.44
	Lower control	A	1.98
	Lower test	A	2.01
D	Upper control	A B	2.49
	Upper test	C	1.41
	Lower control	A B	2.12
	Lower test	A B	2.10

diversity differences of 15-20% occurred between the control sections at the last sampling period may be attributable to fish predation.

Additional insights into the effects of sediment upon insects can be obtained by examining individual species. The mayfly Cinygmula sp. was a good indicator of sediment conditions. It was numerous, comprising 20 to 25% of the total population and was in the early instar stage, consequently, no emergence occurred during the experiment. Cinygmula sp. is a small mayfly occupying the undersurface of rocks and gravel interstices and is probably more sensitive to sedimentation than many other mayflies (Prather, 1971).

If we examine the fitted line of the average Cinygmula sp. density in the upper sections, the control showed a slight increase in average numbers over time (Fig. 5) while the test riffle showed a gradual decrease in numbers. Differences in densities in the upper control and test sections were probably attributed to sedimentation. In the lower sections containing fish, this species showed a similar response in both the control and test section, with the test section numbers decreasing at a faster rate. There was a 30% decrease in density between unsedimented and heavily sedimented substrates in the upper test section and a 48% decrease in the lower test section when subjected to the same sedimented condition but having the presence of predator fish (Fig. 5). Theoretically the 18% difference between the two control sections is attributable to fish predation, substantiating results found when comparing average species diversity.

A multiple correlation equation was developed to help summarize data and present it in an interrelatable form. Six factors are present in the equation:

x_1 = dominant substrate size

x_2 = imbeddedness of dominant substrate

x_3 = material surrounding dominant substrate

x_4 = current velocity at sampling point

x_5 = distance from top of section

x_6 = (1) if in upper sections without fish, (0) if in the lower sections with fish

x_7 = (1) if in lower sections with fish, (0) if in upper sections without fish

Transformations of data were not found to significantly decrease the variance of the combined data. The model for predicting species diversity in the Hayden Creek laboratory channels was:

$$Y = 0.189x_1 - 0.038x_2 + 0.154x_3 + 1.03x_4 - 0.06x_5 + 0.71x_6 + 0.243x_7$$

The R^2 value for the equation is 0.91, giving a reasonably good fit of the response plane to the data. The standard error of estimate is 0.63. The variance unaccounted for by regression is 8.9%.

Examination of the magnitude of the equation coefficients reveals several relationships (Table 5). Water velocity contributed most to determining species diversity. A fifteen to twenty percent reduction in diversity in the lower sections may be partially attributed to fish predation, corroborating results obtained from comparisons of average species diversity found in the upper and lower control sections. Larger sizes of dominant substrate contributed substantially to estimating species diversity, accounting for approximately one-fourth of the diversity. In contrast, imbeddedness and distance from top of section contributed very little to predicting species diversity, the only exception being the reaction of insects to fully imbedded dominant substrate, as noted in the sedimented test section without fish (Fig. 3). This effect was not reflected in the composite equation because of higher variability found

Table 5. Percent contribution of each substrate variable and water velocity generated from the Hayden Creek multiple regression model.

Variable		% Contribution	Total Diversity
Dominant substrate	Rank		
	1	7.3	2.59
	2	13.6	2.77
	3	19.1	2.96
	4	24.0	3.15
	5	28.3	3.34
Dominant substrate imbeddedness	Rank		
	1	-1.1	3.46
	2	-2.2	3.42
	3	-3.3	3.38
	4	-4.5	3.34
	5	-5.7	3.31
Surrounding material	Rank		
	1	5.4	2.84
	2	10.2	3.00
	3	14.6	3.15
	4	18.6	3.31
		22.2	3.46
Water velocities	m/sec		
	0.12	17.7	2.63
	0.24	27.9	3.25
	0.30	32.7	3.46
	0.37	36.8	3.67

in the lower sedimented test section with fish offsetting upper section results. Using only the upper sections, the correlation between imbeddedness and diversity is increased by using the transformation $1/(x_2^3)$. This transformation shows that imbeddedness is only important when dominant substrate is nearly completely imbedded. The only significant correlation between equation variables was the distance from the top of each section and velocity (correlation coefficient -0.71), showing that as distance from the top of each section increased, the velocity decreased.

Recapitulating, multiple regression analysis indicated species diversity in the experimental channels was influenced most by water velocity, dominant substrate and to some degree by the presence of fish.

Marsh Creek, Cape Horn and Elk Creek Field Studies

Preliminary surveys were conducted on Marsh, Cape Horn and Elk Creeks for the purpose of establishing baseline information on insect populations and substrate conditions and to develop and test field techniques used in later experimental studies. Selected riffles in each stream were compared on the basis of substrate composition, benthic standing crop, and insect drift rates.

Data gathered from streambed profiles along transect lines provided qualitative and quantitative comparisons of surface substrate conditions on each riffle. The rankings for dominant substrate size, imbeddedness, and surrounding material were averaged and means compared with Duncan's New Multiple Range Test. Although riffles were selected for uniformity, differences appeared between transects on the same riffle (Table 6), suggesting randomization should be used in estimation of substrate conditions over

Table 6. Physical characteristics for each transect at Marsh, Cape Horn, and Elk Creeks. Transect with the same identification letters are statistically similar.

		Average Transect Factors			
Stream Transect	Statistical Sets	Water Depth (cm)	Dominant Substrate rank	Imbeddedness rank	Surrounding Material rank
Marsh Creek 1	A	26.7	3.62	3.77	1.90
Marsh Creek 2	B	12.04	3.38	3.98	2.15
Cape Horn 1	C	22.76	3.33	3.85	1.48
Cape Horn 2	ACD	24.87	3.55	3.28	1.34
Cape Horn 3	D	25.18	3.87	3.74	1.43
Elk Creek 1	E	23.07	2.65	3.33	1.80
Elk Creek 2	F	28.38	3.11	3.97	2.11
Elk Creek 3	H	37.39	2.97	2.64	1.58
Elk Creek 4	HI	45.98	2.66	2.55	1.76
Elk Creek 5	EIJ	22.36	2.88	3.12	1.88
Elk Creek 6	EIJ	20.12	2.67	2.85	1.90

the entire riffle. Elk Creek had a smaller dominant substrate size and the dominant substrate more deeply imbedded than Cape Horn and Marsh Creeks. Surrounding material was similar for all three streams. Marsh Creek and Cape Horn Creek transects were physically similar, based upon the substrate characteristics mentioned above.

In all three streams, mayflies were the most abundant drifting insect (Table 7). These insects have been reported having a high propensity for drift at night (Brusven, 1970; Waters, 1962, 1965, 1969). Insect drift analysis provided ordinal comparisons between streams and reflected the level of insect availability to fish. Comparisons of drifting insects per m^3 of flow in the three streams revealed that Marsh and Cape Horn Creeks had approximately three times more drifting insects than Elk Creek (Table 7). This suggests that the higher drift rates are related to higher standing crop diversities in Marsh and Cape Horn Creeks (Table 8). Drift may be a useful index of production of certain insects, but variation in drift can occur between days and streams because of a wide variety of factors, e.g. indigenous behavioral differences of species, temperature, moonlight, weather, turbidity, drift distances, etc. (Elliott, 1967; McLay, 1970; Waters, 1965). Therefore, between-stream comparisons on the same or different days has varying degrees of reliability.

On the basis of three investigation parameters, i.e. transect substrate analysis, insect drift and benthos, Marsh Creek data indicate higher values for all three criteria (Tables 6, 7 and 8). Elk Creek had the lowest values of the three streams studied. These data suggest a positive correlation between substrate conditions (i.e. dominant substrate, surrounding material, and imbeddedness) and insect standing crop. Although sampling intensity was insufficient during this study to produce con-

Table 7. 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.

	Time Periods			
Location	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
Cape Horn 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
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

Table 8. Species diversity of each benthic sample (0.186 m^2) and composite diversity and redundancy for Marsh, Cape Horn, and Elk Creeks based upon the Shannon-Weaver Diversity index.

Sample	Individual Diversity	Redundancy	Composite Riffle	
			Diversity	Redundancy
Marsh Creek				
1	3.48	0.21		
2	3.22	0.21		
3	3.05	0.24		
4	3.46	0.23		
5	3.62	0.12		
6	3.31	0.22	3.77	0.26
average	3.36	,20		
Cape Horn				
1	2.72	0.32		
2	2.78	0.30		
3	3.02	0.27		
4	3.44	0.25		
5	3.28	0.26		
6	3.48	0.17		
7	3.22	0.13		
8	3.25	0.23		
9	3.19	0.20	3.62	0.30
average	3.13	,23		
Elk Creek				
1	3.07	0.13		
2	2.67	0.31		
3	3.19	0.20		
4	3.09	0.26		
5	3.24	0.20		
6	2.80	0.30		
7	3.32	0.25		
8	3.10	0.16		
9	3.15	0.19	3.60	0.27
average	3.07	.22		

clusive results, the following trends were indicated: 1) no correlation between species diversity and water depth (depths ranged between 15 and 20 cm); 2) a positive correlation between cobble size and species diversity; 3) positive correlation between imbeddedness and species diversity; and 4) weak correlation between diversity and size of the surrounding material. This phase of the study indicated a need for further investigation of species diversity under varying streambed conditions to better define these relationships and determine the interactions involved.

Knapp Creek Field Study

Studies in the Hayden Creek experimental channels and Marsh, Cape Horn and Elk Creek field sites indicated that the distribution of stream insects was influenced by substrate. Substrate is a good indicator of community structure because it is reflective of several ecological factors, e.g. water velocity, water chemistry, geology, surrounding vegetation, etc. By describing the substrate, a qualitative estimate of the fauna may be derived.

Pre-test data showed the physical conditions of the control and secondary test riffle were nearly the same with the dominant substrate averaging four centimeters, and water velocities ranging from 0.2 to 0.75 m per sec. The primary test riffle was composed of larger dominant substrate (greater than 6.3 cm in diameter) than the other two riffles, and a greater variability in water velocities, e.g. 0.2 to 0.9 m per sec. Pre-test analysis indicated all of the riffles studied had dominant substrates less than one-fourth imbedded, surrounding material averaging slightly less than 6.3 mm, and species diversities approximating 2.96

(Fig. 7).

During sediment deposition on the test riffles, large numbers of insects became displaced and drifted (Append. J). The trichopteran Brachycentrus sp. was the major insect affected by this catastrophic event. This caddisfly constructs vegetable cases and clings to the upper surface of rocks and pebbles. It apparently is adversely affected by bedload (sediments tumbling on the stream bottom), causing larvae to be detached from their places of attachment. The mayflies Ephemerella tibialis, Cinygmula, sp. and Centroptilum sp. on the other hand occupy intersticial spaces between rocks and pebbles. Drift rate of these species also increased during sediment introduction (Append. J). This may have been due to the occulsion of the intersticial spaces and the abrasive effect of bedload causing alteration of the microenvironment of these species. Plecopterans and coleopterans were also recovered in the drift samples during the sedimentation process, but to a lesser extent.

The change in benthic composition was reflective of the biotic effects of sediment introduction on the riffles. One day after sedimentation, average species diversity dropped from 2.98 to 2.69 on the primary test riffle and from 2.98 to 2.67 on the secondary test riffle. The control remained the same (Fig. 7).

Benthic insects most affected by the sediment correspond to those recovered in drift during sediment introduction. The mayfly, Ameletus sp. showed a 100% reduction in the primary test riffle following sedimentation (Append. L). A 75% reduction was noted for the mayfly Centroptilum, sp. stonefly Acroneuria californica, the beetle Heterlimnius corpulentus, and the free-living trichopteran Rhyacophila acropedes. Leech and Chandler (1956) and Prather (1971) indicated H. corpulentus may be rare

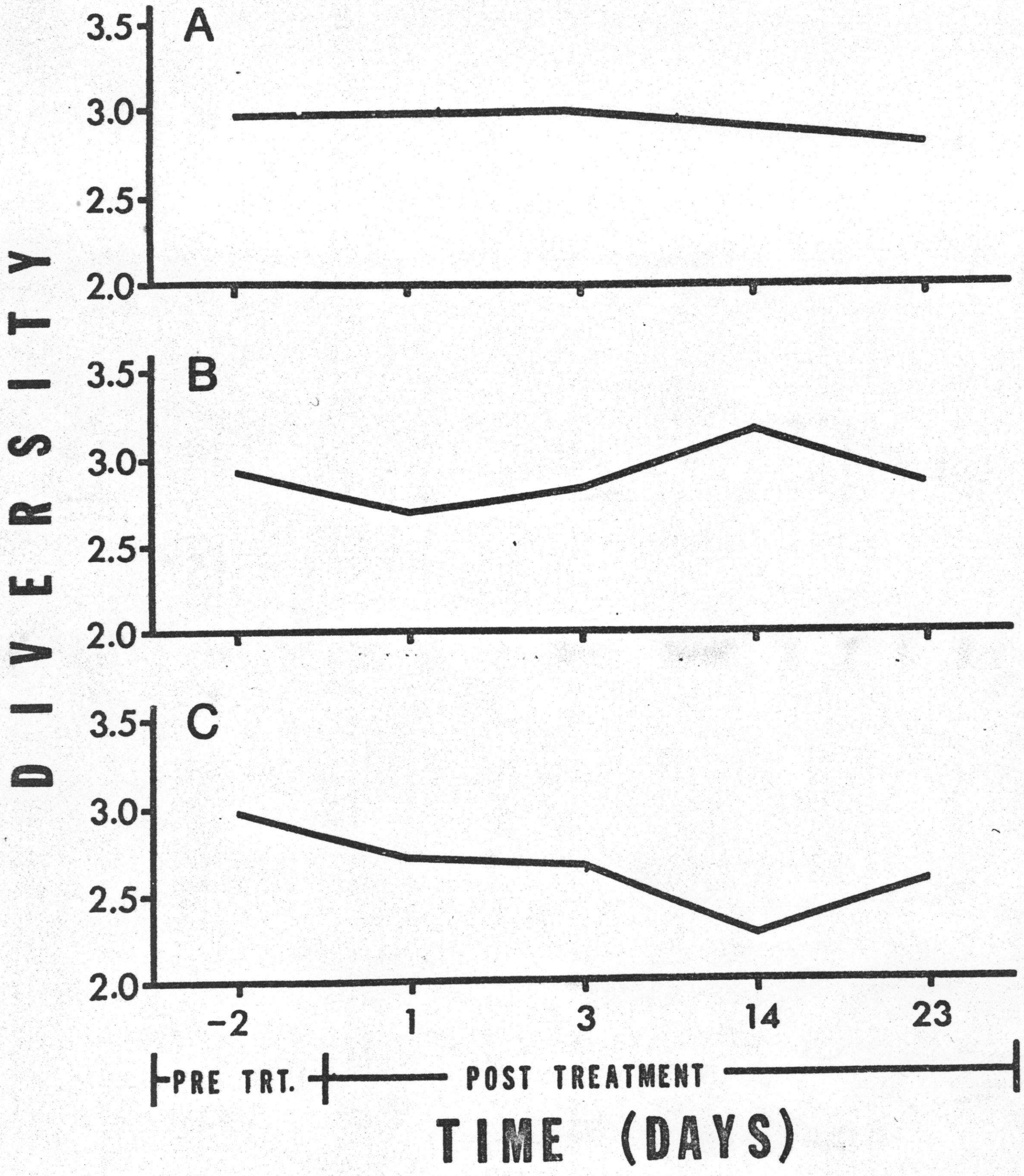

Fig. 7. Average benthic species diversity versus time after sediment introduction at Knapp Creek. A- control riffle; B- primary test riffle; C- secondary test riffle.

in streams having heavy sediment loads. Trichopterans are usually associated with unsandy, well-cobbled habitats (Smith, 1968). Their reduction in numbers, therefore was expected. The decrease of Brachycentrus sp. was probably due to bedload. This decrease may have been lessened if sediment had been introduced by a more gradual means, thus reducing the catastrophic event and permitting greater chance of inhabitation of the upper surfaces or rocks and pebbles. Other species showing various tolerance levels to sedimentation, include the mayfly Ameletus sp. which had little tolerance for fine sediments. However, Cinygmula sp., E. grandis, E. tibialis, Paraleptophlebia heteronea, in spite of reduced numbers, indicated some tolerance (Append. L).

Species diversity declined in the secondary test riffle during the first two weeks after sediment introduction. However, a slight recovery was noted during the subsequent nine-day period (Fig. 7). The imbeddedness level of the cobble in both test reaches showed only a slight improvement after three weeks. Low current velocities across the impacted riffles did not effectively clean the riffles of sediment.

The primary riffle exhibited a greater recolonization potential than the secondary test riffle. The primary test riffle regained or slightly exceeded pre-test diversity values within two weeks after sediment was added (Fig. 7). Similar findings were reported by Scott (1960) in a New Zealand river.

Because natural riffles are not uniform in the distribution of substrate and water velocities, an analysis of the entire riffle by a few samples may be misleading. For this reason, a multiple correlation model was developed for the Knapp Creek study to illustrate the relationships between diversity and physical characteristics of the stream.

The parameters of this equation were dominant substrate material size, imbeddedness of dominant substrate, surrounding material, and water velocities. Data transformations were performed to obtain a good fit. The model for predicting species diversity on the Knapp Creek study area is:

$$Y = 1.23\ x_1\ -0.032/x_2\ +0.04x_3\ +1.01\sin(.2x_4)$$

x_1 = dominant substrate size

x_2 = imbeddedness of dominant substrate

x_3 = material surrounding dominant substrate

x_4 = current velocity

The R^2 value for the equation is 0.98, giving a good fit of the response plane to the data. The standard error of estimate was 0.41; the variance unaccounted for by regression was 2.1%.

Data in Table 9 show variations in species diversity when varying one factor at a time while holding the other factors constant. It is evident that dominant substrate contributes most to species diversity and water velocity to a lesser degree. Surrounding material is significant only when particle sizes are larger than 6.3 mm. Lightly and moderately imbedded dominant substrate contributed only 2 - 4% of the predictive response. A higher imbeddedness level in this study may, however, have had a substantial effect as was demonstrated in the simulation channels at Hayden Creek. In a similar manner, the higher diversities on cobble riffles at Knapp Creek, having velocities greater than 0.73 m per sec, agrees with findings at Hayden Creek.

Table 9. Percent contribution of each substrate variable and water velocity generated from the Knapp Creek multiple regression model.

Variable		% Contribution	Total Diversity
Dominant substrate	Rank		
	1	77.2	1.59
	2	83.0	2.09
	3	85.7	2.48
	4	87.3	2.81
	5	88.5	3.10
Dominant substrate imbeddedness	Rank		
	1	0.4	3.09
	2	0.2	3.10
	3	0.2	3.10
	4	0.2	3.10
	5	0.2	3.10
Surrounding material	Rank		
	1	1.3	2.98
	2	2.6	3.02
	3	3.9	3.06
	4	5.2	3.10
	5	7.5	3.14
Water velocities	m/sec		
	0.18	2.4	3.06
	0.30	5.4	3.14
	0.49	8.9	3.26
	0.61	11.0	3.34
	0.79	13.6	3.44

SUMMARY

This interdisciplinary study was conducted at Hayden Creek experimental channels and Knapp, Marsh, Cape Horn, and Elk Creek field study streams. The latter streams are tributaties of the Middle Fork of the Salmon River and are located in the Idaho Batholith region. The entomological objectives were to determine of the tolerance levels and ecological impact of sediment on insect populations.

The Hayden Creek experimental channels consisted of four sections; each section had two large-cobble and two small-cobble riffles. One section served as a control, the remaining sections were treated with combinations of increasing sediment levels and an introduced fish population. Insect populations were monitored by benthic and drift samples at each test period and correlated with substrate conditions. Substrate was visually ranked based on characteristics of dominant substrate, imbeddedness of dominant substrate and surrounding material. Water velocity measurements were also taken in each section.

At Hayden Creek, insect species diversity was unaffected by increased sedimentation until the dominant substrate reached a moderate (2/3) imbeddedness level. Comparisons between the control without fish and the control with fish, suggested that fish predation possibly reduced the insect population 15 - 20%. A multiple regression equation fitted to the data showed that dominant substrate size and velocity contributed most toward predicting species diversity in relation to varying substrate conditions.

Marsh, Cape Horn, and Elk Creek field studies provided insights into insect-substrate relationships under natural conditions. Elk Creek,

having greater amounts of fine sediment than the other two creeks also manifested a lower benthic species diversity and insect drift.

The Knapp Creek field site was intensely studied by subjecting test riffles to artificially-introduced sediment simulating a natural slumpage. Insect populations were sampled before and after sediment introduction by random bottom samples and three, one-hour drift samples two days before and 1, 3, 14, and 23 days after sediment introduction. Drift substantially increased during sedimentation of riffles, but returned to normal pre-test rates in less than 24 hours. The caddisfly, *Brachycentrus* sp. mayflies, *Ameletus* sp. and *Centroptilum* sp., stonefly, *A. californica*, and beetle *H. corpulentus* were most affected by abnormally high sediment loads as reflected by decreases in benthic density and higher drift. Post-treatment analysis indicated benthic insect populations recovered faster on the primary test riffle which had larger substrate (6 - 12 cm) than the secondary test riffle, composed largely of pebble (2 - 4 cm). A multiple regression equation was fitted to the data and revealed that dominant substrate size contributed most to predicting diversity and surrounding material, imbeddedness and water velocity to a lesser extent.

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APPENDICES

Append. A. Number of drifting insects entering and departing Hayden Creek control and test channels during a one-hour sampling period (2330 - 0030 hrs) when the test channel did not have introduced sediment. Nets 1,3,5 were positioned in the control channel, nets 2,4,6 in the test channel.

Species	Net					
	1	2	3	4	5	6
EPHEMEROPTERA						
Ameletus sp.		1	4			
Baetis bicaudatus Dodds	220	145	412	330	144	65
Baetis parvus Dodds	2	1				
Baetis tricaudatus Dodds						
Centroptilum sp.	2	2				
Cinygmula sp.	6	23	70	200	22	39
Epeorus longimanus Eaton	22	5	8	16	17	13
Ephemerella doddsi Needham	2	3	3			
Ephemerella flavilinea McDunnough	2					
Ephemerella grandis Eaton	2					
Ephemerella infrequens McDunnough	10	18	32	53	26	70
Ephemerella spinifera Needham		1		15		
Ephemerella tibialis McDunnough						
Paraleptophlebia heteronea McDunnough		1				
Rithrogena hageni Eaton	34	18	36	68	21	17
Rithrogena robusta Dodds	4				1	3
Siphlonurus sp.						
Total	306	218	565	682	231	207
PLECOPTERA						
Alloperla sp.	6	4	4			4
Chloroperla sp.	4	7		4	2	3
Isogenus sp.	2	1	4			
Nemoura sp.						
Pteronarcys californica Newport		1		1		
Total	12	13	8	5	2	7
TRICHOPTERA						
Agraylea sp.						
Arctopsyche grandis (Banks)	27	14	8	3	1	4
Brachycentrus sp.						
Glossosoma sp.						
Limnephilidae (sp. 1)						
(sp. 2)						
Micrasema sp. 1						
sp. 2	4		3			
Rhyacophila acropedes Banks	15	2				
Rhyacophila hyalinata Banks						
Rhyacophila tucula Ross						
Total	46	16	11	3	1	4

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Append. A. Continued

Species	Net					
	1	2	3	4	5	6
DIPTERA						
Chironomidae spp.		1		4		2
Dicranota sp.						
Empididae (sp.)						
Hexatoma sp.	4	2				
Limnophila sp.						
Liriope sp.						
Psychodidae (sp.)						
Simulium sp.	10	5	8	12	6	8
Total	14	8	8	16	6	10
COLEOPTERA						
Dytiscidae (sp.)						
Heterlimnius corpulentus (LeConte)			4	4	2	1
Lara sp.					1	
Optioservus seriatus (LeConte)						
Total			4	4	3	1
HEMIPTERA						
Corixidae (sp.)						
Total	378	255	596	710	243	229

Append. B. Number of drifting insects entering and departing Hayden Creek control and test channels during a one-hour sampling period (2330 - 0030 hrs) when the test channel had a low introduced sediment. Nets 1,3,5 were positioned in the control channel, nets 2,4,6 in the test channel.

Species	Net					
	1	2	3	4	5	6
EPHEMEROPTERA						
Ameletus sp.	1			1		
Baetis bicaudatus Dodds	520	272	616	600	305	418
Baetis parvus Dodds	15	12	8		12	
Baetis tricaudatus Dodds						
Centroptilum sp.						
Cinygmula sp.	3	63	19	20	20	
Epeorus longimanus Eaton	8		27	12		10
Ephemerella doddsi Needham	3		2	2		2
Ephemerella flavilinea McDunnough		5	3	2		
Ephemerella grandis Eaton						
Ephemerella infrequens McDunnough	7	3	16	33	1	14
Ephemerella spinifera Needham	1			2		1
Emphemerella tibialis McDunnough			1			
Paraleptophlebia heteronea McDunnough					1	
Rithrogena hageni Eaton	22	10	17	20		28
Rithrogena robusta Dodds			14	1		
Siphlonurus sp.						
Total	580	365	723	693	339	473
PLECOPTERA						
Alloperla sp.	5		1	2		2
Chloroperla sp.	11	3	8	7	3	10
Isogenus sp.	1					
Nemoura sp.						
Pteronarcys californica Newport						
Total	17	3	9	9	3	12
TRICHOPTERA						
Agraylea sp.						
Arctopsyche grandis (Banks)	6	1	1		1	2
Brachycentrus sp.						
Glossosoma sp.						
Limnephilidae (sp. 1)						
(sp. 2)						
Macrasema sp. 1						
sp. 2	1	1				
Rhyacophila acropedes Banks	4			1		
Rhyacophila hyalinata Banks						
Rhyacophila tucula Ross						
Total	11	2	1	1	1	2

Append. B. Continued

Species	Net 1	2	3	4	5	6
DIPTERA						
Chironomidae spp.	1	25	4	3	10	
Dicranota sp.						
Empididae (sp.)						
Hexatoma sp.	1	1		1		1
Limnophila sp.						
Liriope sp.						
Psychodidae (sp.)	3					
Simulium sp.	7	5	4	6	6	8
Total	12	31	8	10	16	9
COLEOPTERA						
Dytiscidae (sp.)						
Heterlimnius corpulentus (LeConte)	4	3	2	3	5	1
Lara sp.	1					
Optioservus seriatus (LeConte)					3	
Total	5	7	3	3	8	1
HEMIPTERA						
Corixidae (sp.)		1		1	1	
Total	647	409	744	717	368	497

Append. C. Number of drifting insects entering and departing Hayden Creek control and test channels during a one-hour sampling period (2330 - 0030 hrs) when the test channel had a moderate introduced sediment. Nets 1,3,5 were positioned in the control channel, nets 2,4,6 in the test channel.

Species	Net 1	2	3	4	5	6
EPHEMEROPTERA						
Ameletus sp.						
Baetis bicaudatus Dodds	111	40	90	63	38	73
Baetis parvus Dodds	2	1	3	1	1	1
Baetis tricaudatus Dodds						
Centroptilum sp.						
Cinygmula sp.	4		6	4		
Epeorus longimanus Eaton	6	2	7	9	4	2
Ephemerella doddsi Needham	3	4	2			
Ephemerella flavilinea McDunnough				1		
Ephemerella grandis Eaton						
Ephemerella infrequens McDunnough	10	4				
Ephemerella spinifera Needham						
Ephemerella tibialis McDunnough	1	1				
Paraleptophlebia heteronea McDunnough						
Rithrogena hageni Eaton						
Rithrogena robusta Dodds						
Siphlonurus sp.				2	11	1
Total	137	52	108	80	54	77
PLECOPTERA						
Alloperla sp.	1	1		1		
Chloroperla sp.	3		1			
Isogenus sp.						
Nemoura sp.						
Pteronarcys californica Newport						
Total	4	1	1	1	0	0
TRICHOPTERA						
Agraylea sp.						
Arctopsyche grandis (Banks)	2	1		1		
Brachycentrus sp.						
Glossosoma sp.						
Limnephilidae (sp. 1)						
(sp. 2)						
Micrasema sp. 1						
sp. 2	1				1	
Rhyacophila acropedes Banks						
Rhyacophila hyalinata Banks						
Rhyacophila tucula Ross	1			1		
Total	4	1	0	1	1	0

Appendix C. Continued.

Species	Net					
	1	2	3	4	5	6
DIPTERA						
Chironomidae spp.						
Dicranota sp.						
Empididae (sp.)				1	1	
Hexatoma sp.			2	2		
Limnophila sp.						
Liriope sp.						
Psychodidae (sp.)					1	
Simulium sp.	9	1	12	14	1	
Total	9	1	14	17	3	0
COLEOPTERA						
Dytiscidae (sp.)	1	1	1	3	1	1
Heterlimnius *corpulentus* (LeConte)	1	1	4			
Lara sp.	8	3		1		
Optioservus *seriatus* (LeConte)	2		1	3		1
Total	12	5	6	7	1	2
HEMIPTERA						
Corixidae (sp.)						
Total	166	61	129	106	59	79

Append. D. Number of drifting insects entering and departing Hayden Creek control and test channels during a one-hour sampling period (2330 - 0030 hrs) when the test channel had a high introduced sediment. Nets 1,3,5 were positioned in the control channel, nets 2,4,6 in the test channel.

Species	Net 1	2	3	4	5	6
EPHEMEROPTERA						
Ameletus sp.		1		1		1
Baetis bicaudatus Dodds	91	61	70	46	54	40
Baetis parvus Dodds	16	9	4	6	3	10
Baetis tricaudatus Dodds						
Centroptilum sp.						
Cinygmula sp.	4	8	5	8	1	2
Epeorus longimanus Eaton	27	31	31	13		32
Ephemerella doddsi Needham						
Ephemerella flavilinea McDunnough	1					1
Ephemerella grandis Eaton						
Ephemerella infrequens McDunnough	10	7	1	1	1	
Ephemerella spinifera Needham						
Ephemerella tibialis McDunnough	4	2	4	3		3
Paraleptophlebia heteronea McDunnough						
Rithrogena hageni Eaton	1	8	3	3	42	3
Rithrogena robusta Dodds						
Siphlonurus sp.			4	4	12	42
Total	154	127	124	85	113	134
PLECOPTERA						
Alloperla sp.	3	2	1			
Chloroperla sp.	1	1				
Isogenus sp.		1				
Nemoura sp.	2	1				
Pteronarcys californica Newport						
Total	6	5	1	0	0	0
TRICHOPTERA						
Agraylea sp.						
Arctopsyche grandis (Banks)			1	2	1	2
Brachycentrus sp.				1		
Glossosoma sp.	1					
Limnephilidae (sp. 1)						
(sp. 2)						
Micrasema sp. 1						
sp. 2	2					
Rhyacophila acropedes Banks		1		1		
Rhyacophila hyalinata Banks		2				
Rhyacophila tucula Ross				1		
Total	3	3	1	5	1	2

Append. D. Continued.

Species	Net 1	2	3	4	5	6
DIPTERA						
Chironomidae spp.	6	8	3	3	3	3
Dicranota sp.						
Empididae (sp.)						
Hexatoma sp.		1				
Limnophila sp.						
Liriope sp.						
Psychodidae (sp.)						
Simulium sp.	5	8	14	5	3	
Total	11	17	17	8	6	3
COLEOPTERA						
Dytiscidae (sp.)			1		1	
Heterlimnius corpulentus (LeConte)	14	4	2	1	5	
Lara sp.					1	2
Optioservus seriatus (LeConte)					1	2
Total	14	4	3	1	8	4
HEMIPTERA						
Corixidae (sp.)						
Total	188	156	146	99	128	143

Append. E. Average ranked substrate characteristics of dominant substrate, imbeddedness, surrounding material, species diversity, and redundancy (R) at Hayden Creek experimental channels before introduction of sediment into the test channel. A- upper control section; B- upper test; C- lower control; D- lower test.

SECTION	Riffle	Dominant substrate	Imbeddedness	Surrounding material	Average diversity	R
A	1	3	3	3	2.2	0.43
	2	4.5	4.5	4	2.73	0.25
	3	4.5	4.5	4	1.92	0.43
	4	3	3	3	1.66	0.27
B	1	3	3	3	2.34	0.21
	2	4.5	4.5	4	2.96	0.26
	3	4.5	4.5	4	2.29	0.27
	4	3	3	3	1.80	0.06
C	1	3	3	3	1.95	0.53
	2	4.5	4.5	4	2.41	0.15
	3	4.5	4.5	4	2.08	0.19
	4	3	3	3	1.85	0.21
D	1	3	3	3	1.5	0.62
	2	4.5	4.5	4	2.05	0.26
	3	4.5	4.5	4	.83	0.01
	4	3	3	3	1.0	0.01

Append. F. Average ranked substrate characteristics of dominant substrate, imbeddedness, surrounding material, species diversity, and redundancy (R) at Hayden Creek experimental channels with light level of sediment introduction in the test channel. A- upper control section; B- upper test; C- lower control; D- lower test.

SECTION	Riffle	Dominant substrate	Imbeddedness	Surrounding material	Average diversity	R
A	1	3	3	3	2.1	0.46
	2	4.5	4.5	4	2.36	0.12
	3	4.5	4.5	4	2.88	0.14
	4	3	3	3	2.36	0.22
B	1	3	2.2	1	2.55	0.22
	2	4.5	3	1	2.50	0.42
	3	4.5	3	1	2.32	0.21
	4	3	2.2	1	.87	0.13
C	1	3	3	3	2.12	0.44
	2	4.5	4.5	4	1.72	0.46
	3	4.5	4.5	4	1.22	0.50
	4	3	3	3	.72	0.19
D	1	3	3.2	1	1.60	0.46
	2	4.5	3	1	.89	0.31
	3	4.5	3	1	.01	0.01
	4	3	2.2	1	.37	0.20

Append. G. Average ranked substrate characteristics of dominant substrate, imbeddedness, surrounding material, species channels with a moderate level of sediment introduction in the test channel. A- upper control section; B- upper test; C- lower control; D- lower test.

SECTION	Riffle	Dominant substrate	Imbeddedness	Surrounding material	Average diversity	R
A	1	3	3	3	2.63	0.31
	2	4.5	4.5	4	2.2	0.42
	3	4.5	4.5	4	2.55	0.31
	4	3	3	3	2.15	0.34
B	1	3	2	1	2.27	0.14
	2	4.5	3	1	2.54	0.28
	3	4.5	3	1	2.82	0.20
	4	3	2	1	2.14	0.16
C	1	3	3	3	2.24	0.41
	2	4.5	4.5	4	2.21	0.31
	3	4.5	4.5	4	1.83	0.49
	4	3	3	3	1.64	0.50
D	1	3	2	1	2.15	0.46
	2	4.5	3	1	2.65	0.20
	3	4.5	3	1	1.6	0.41
	4	3	2	1	1.66	0.27

Append. H. Average ranked substrate characteristics of dominant substrate, imbeddedness, surrounding material, species diversity, and redundancy (R) at Hayden Creek experimental channels with a high level of sediment introduction in the test channel. A- upper control section; B- upper test; C- lower control; D- lower test.

SECTION	Riffle	Dominant substrate	Imbeddedness	Surrounding material	Average diversity	R
A	1	3	3	3	2.30	0.47
	2	4.5	4.5	4	2.70	0.16
	3	4.5	4.5	4	2.69	0.20
	4	3	3	3	2.27	0.26
B	1	3	1	1	.66	0.61
	2	4.5	2	1	1.95	0.37
	3	4.5	2	1	1.62	0.14
	4	3	1	1	1.44	0.44
C	1	3	3	3	2.53	0.41
	2	4.5	4.5	4	2.61	0.25
	3	4.5	4.5	4	1.72	0.50
	4	3	3	3	1.62	0.36
D	1	3	1	1	2.53	0.29
	2	4.5	2	1	2.47	0.18
	3	4.5	2	1	2.04	0.36
	4	3	1	1	1.39	0.56

Append. I. Number of benthic insects per 1.12 m^2 per section per treatment at Hayden Creek experimental channels. A- upper control; B- upper test; C- lower control; D- lower test. Treatment 1- no sediment; 2- low sediment; 3- moderate sediment; 4- high sediment in test sections.

Section	A				B				C				D			
Treatment (Sediment level)	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
EPHEMEROPTERA																
Ameletus sp.	19	58	93	76	27	103	84	72	27	58	93	76	15	104	84	72
Baetis bicaudatus Dodds	47	17	14	4	33	6	13	7	46	17	14	4	94	6	13	7
Baetis parvus Dodds	7	10	35	71	6	12	14	22	20	10	35	71	17	12	14	22
Baetis tricaudatus Dodds																
Centroptilum sp.																
Cinygmula sp.	179	147	165	233	66	33	42	20	220	147	165	233	283	33	42	20
Epeorus longimanus Eaton	8	3	11	10		1	8	4	7	3	11	10	4	1	8	4
Ephemerella doddsi Needham		2			2	2	1		1	2				2	1	
Ephemerella flavilinea McDunnough						2								2		
Ephemerella grandis Eaton		5	3	2	1	1	1			5	3	2	1	1	1	
Ephemerella infrequens McDunnough		10	17	20	51	8	8	3	32	10	17	20	13	8	8	3
Ephemerella spinifera Needham		1								1						
Ephemerella tibialis McDunnough	64	9	3	29	1	4	1	1	2	9	3	29	5	4	1	1
Paraleptophlebia heteronea McDunnough		3	1	1						3	1	1				
Rithrogena hageni Eaton	1					1							7	1		
Rithrogena robusta Dodds		4								2				1		
Siphlonurus sp.				52				27				52				27
PLECOPTERA																
Alloperla sp.	19	40	83	61	7	30	44	59	11	40	83	61	9	30	44	59
Chloroperla sp.									1							
Isogenus sp.	3		3	3	1		1	1	4		3	3	1		1	1
Nemoura sp.	2		1						1		1		1			
Pteronarcys californica Newport																

Append. I. Continued.

Section	A				B				C				D			
Treatment (Sediment level)	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
TRICHOPTERA																
Agraylea sp.		8	4				4	4		8	4		1	4	4	
Arctopsyche grandis (Banks)	26	19	6		7	7	10			19	6			7	10	
Brachycentrus sp.						1	3							1	3	
Glossosoma sp.																
Limnephilidae (sp. 1)												1				
(sp. 2)	1	6	6	9	1	2	5	1		6	6	9		2	5	1
Micrasema sp. 1		1								1						
sp. 2		4	13	4	5	1	6		1	4	13	4		1	6	
Rhyacophila acropedes Banks	72	21	12	5	4	6	10	1		21	12	5	1	6	10	1
Rhyacophila hyalinata Banks																
Rhyacophila tucula Ross												2				
DIPTERA																
Chironomidae spp.	181	303	431	368	409	398	549	264	967	303	431	368	715	398	549	264
Dicranota sp.					17	10	6	2	3	5	10	8	2	10	6	2
Empididae (sp.)	5	5	10	8		1								1		
Hexatoma sp.	6	8	5	7	2	4	2			8	5	7		4	2	
Limnophila sp.			1		1		10				1				10	
Liriope sp.			1			1					1			1		
Psychodidae sp.	5	8	3	2	18	2	2	1		8	3	2		2	2	
Simulium sp.	3	2	7	5		2	3		7	2	7	4		2	3	1
COLEOPTERA																
Dytiscidae (sp.)												1				
Heterlimnius corpulentus (LeConte)	6	5	5	6	8	3	2	1	2	5	5	6		3	2	1
Lara sp.																
Optioservus seriatus (LeConte)				1								1				1
HEMIPTERA																
Corixidae (sp.)																

Append. J. Number of drifting insects per net during the two hour introduction of sediment upon test riffles at Knapp Creek.

	Control	Test Riffle 1	Test Riffle 2
EPHEMEROPTERA			
Ameletus sp.		1	7
Baetis bicaudatus Dodds			
Baetis parvus Dodds			
Baetis tricaudatus Dodds			
Centroptilum sp.		21	43
Cinygmula sp.			29
Epeorus longimanus Eaton			
Ephemerella doddsi Needham			
Ephemerella flavilinea McDunnough			
Ephemerella grandis Eaton		3	1
Ephemerella infrequens McDunnough			
Ephemerella spinifera Needham			
Ephemerella tibialis McDunnough		6	27
Paraleptophlebia heteronea McDunnough			1
PLECOPTERA			
Acroneuria californica Banks		8	10
Alloperla sp.		1	3
Isogenus sp.			1
Nemoura sp.			
Pteronarcys californica Newport			
TRICHOPTERA			
Agraylea sp.	2	3	5
Arctopsyche grandis (Banks)		4	4
Brachycentrus sp.		78	
Glossosoma sp.			
Limnephilidae sp.			3
Micrasema sp. 1			
sp. 2			2
Rhyacophila acropedes Banks		2	4
Rhyacophila hyalinata Banks			
Rhyacophila tucula Ross			

Append. J. Continued.

	Control	Test Riffle 1	Test Riffle 2
DIPTERA			
Chironomidae spp.	2	42	3
Ceratopogonidae (sp.)			
Dicranota sp.			
Hexatoma sp.			3
Psychodidae (sp.)	4	7	2
Simulium sp.			
Tipula sp.			
COLEOPTERA			
Dytiscidae (sp.)			1
Heterlimnius corpulentus (LeConte)	3	1	4
Lara sp.			1
Optioservus seriatus (LeConte)			
HEMIPTERA			
Corixidae (sp.)			
Total	9	137	155

Append. K. Number of drifting insects per riffle per test date taken from 2300 - 0030 hours, numbers adjusted for equal volumes (1 cfs).

Riffle	Control				Test Riffle 1			
Days after sediment introduction	pre	1	3	14	pre	1	3	14
EMPHEMEROPTERA								
Ameletus sp.	5	2	1			2	1	1
Baetis bicaudatus Dodds		1	2	4	4	2		
Baetis parvus Dodds	1		1		5			2
Baetis tricaudatus Dodds								
Centroptilum sp.	5	3	2		4		3	
Cinygmula sp.	3	2		1				4
Epeorus longimanus Eaton	1		1		2			
Ephemerella doddsi Needham								
Ephemerella flavilinea McDunnough								
Ephemerella grandis Eaton								1
Ephemerella infrequens McDunnough							1	
Ephemerella spinifera Needham								
Ephemerella tibialis McDunnough		1						
Paraleptophlebia heteronea McDunnough	1		1		1	1		1
PLECOPTERA								
Acroneuria californica Banks					1	1		
Alloperla sp.		1			1		1	1
Isogenus sp.					1			
Nemoura sp.								
Pteronarcys californica Newport								
TRICHOPTERA								
Agraylea sp.		3				2		
Arctopsyche grandis (Banks)	1					1		
Brachycentrus sp.	3				5			
Glossosoma sp.								
Limnephilidae (sp.)								
Micrasema sp. 1						3		2
sp. 2		1					1	
Rhyacophila acropedes Banks								
Rhyacophila hyalinata Banks								
Rhyacophila tucula Ross								

Append. K. Continued.

Riffle	Control				Test Riffle I			
Days after sediment introduction	pre	1	3	14	pre	1	3	14
DIPTERA								
Chironomidae spp.								
Certaopogonidae (sp.)								
Dicranota sp.								
Hexatoma sp.	1						1	
Psychodidae (sp.)								
Simulium sp.	10	5	2	4	8	3	1	1
Tipula sp.								
COLEOPTERA								
Dytiscidae (sp.)								
Heterlimnius corpulentus (LeConte)	29	15	2	12	12	18	14	3
Lara sp.								
Optioservus seriatus (LeConte)	1							
HEMIPTERA								
Corixidae (sp.)				1	1			2

Append. L. Number of benthic insects per $0.82 m^2$ per riffle per test date, at Knapp Creek study area.

Riffle	Control Riffle				Test Riffle 1					Test Riffle 2			
Days after sediment introduction	Pre	3	14	23	Pre	1	3	14	23	Pre	3	14	23
EPHEMEROPTERA													
Ameletus sp.	3	11	13	28	15				1	1	1	1	
Baetis bicaudatus Dodds				3				6	5	1		1	7
Baetis parvus Dodds		5	2			2	6	7	8		1	1	1
Baetis tricaudatus Dodds									1	1			
Centroptilum sp.	27	8		3	29	4	12	6		22	3	1	2
Cinygmula sp.	22	11	27	23	31	42	42	136	257	2	61	181	146
Epeorus longimanus Eaton													1
Ephemerella doddsi Needham									1			1	2
Ephemerella flavilinea McDunnough													1
Ephemerella grandis Eaton	10	3	2	19	14	19	7	68	39	3	11	26	23
Ephemerella infrequens McDunnough		1			2	1		3		1		2	1
Ephemerella spinifera Needham													
Ephemerella tibialis McDunnough	3	2	2		9	2	9	3	4	15	8	4	
Paraleptophlebia heteronea McDunnough	7	1	14	22	32	27	22	72	77	1		8	12
PLECOPTERA													
Acroneuria californica Banks		1		1	12	2	18	24	21	10	7	10	22
Alloperla sp.	71	31	176	116	26	27	37	122	216	17	55	107	61
Isogenus sp.	6	5	8	12	11	9	5	8	8	8	6	5	5
Nemoura sp.					2						1		
Pteronarcys californica Newport													
TRICHOPTERA													
Agraylea sp.	7			5	1	1		1	8				1
Arctopsyche grandis (Banks)	5		10	9	23	4	3	4	14	1	3	5	1
Brachycentrus sp.	10	5	5	78	214	28	10	31	26	6	3	1	2
Glossosoma sp.	1	2			2	2		2					
Limnephilidae sp.	1												

Append. L. Continued.

Riffle	Control Riffle				Test Riffle 1					Test Riffle 2			
Days after sediment introduction	Pre	3	14	23	Pre	1	3	14	23	Pre	3	14	23
Micrasema sp. 1					13	71	1	20	10	2			
sp.2	48	26	66	95	30	18	14	49	53	5	12	49	36
Rhyacophila acropedes Banks	1		1		22	5	4	9	6		5	2	2
Rhyacophila hyalinata Banks				2	4								2
Rhyacophila tucula Ross								1					
DIPTERA													
Chironomidae (spp.)	27	24	55	38	118	31	74	33	45				
Ceratopogonidae (sp.)	3		1	3		2	7		5				
Dicranota sp.		1		1									
Hexatoma sp.	15	14	11	28	25	8	13	18	32	5	3	8	10
Psychodidae (sp.)			3	3	3	1	5	9	11	10	2	9	
Simulium sp.	1				9		1	9	4				7
Tipula sp.	6	5	19	12					1				1
COLEOPTERA													
Dytiscidae (sp.)	1		2										
Heterlimnius corpulentus (LeConte)	6	3	20	6	16	5	3	44	58	1	3	12	15
Lara sp.						1							
Optioservus seriatus (LeConte)	2												
HEMIPTERA													
Corixidae (sp.)													
Total	283	160	450	510	668	239	227	685	917	155	186	433	361