BENTHIC INSECT COMMUNITY CHANGES IN RELATION TO IN-STREAM REHABILITATION OF A SILTED STREAM

BY

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ABSTRACT

This study was conducted to evaluate the physical and biological impact of four types of in-stream alterations on Emerald Creek, a silt-polluted stream. Log-drop structures, debris jam removal, [illegible] diversion, and gabion deflectors were used. Cobble factor, embeddedness, sediment size surrounding cobbles, average sediment size, mean channel depth, and benthos were measured at 13 permanent transects (4 control, 9 test) during 1971 and 1972. Various sizes of tagged sediment were used to determine sediment transport phenomena. Field and laboratory studies of insect drift and upstream dispersion were undertaken to yield insight into colonization rates in heavily silted portions of the main stem.

In-stream alterations were found to be effective devices for increasing sediment transport, thereby improving insect and fish habitat. Insect drift and colonization were adversely affected by long, low-gradient, sandy reaches. Insect settle-out rate on sand was found to be a function of current velocity, light conditions and insect species. It was determined that Emerald Creek, by virtue of the natural hydrological cycle, has the ability to cleanse itself of polluting sediments if the source of such sediments could be eliminated.

INTRODUCTION

One of America's greatest natural resources is its abundant supply of freshwater. Until recently, little has been done to protect water from most types of pollution (Warren, 1971). The public, enjoying more leisure time than ever before, is placing increasing demands on quality streams and lakes for recreation. In addition, industrial growth has caused increased needs for water, agriculture requires more water for irrigation and our growing population must have more potable water.

As water resources are being depleted, a concerted effort is being made to preserve our unpolluted waters. Additionally, corrective measures in the form of abatement and rehabilitation are being undertaken to correct the ills of the past. Many studies have been conducted in an effort to determine the effects of different pollutants on stream and lake biotas (Bartsch, 1948; Klein, 1962; Hynes, 1960; Krenkel and Parker, 1969, Wilber, 1969). Silt pollution is a form which has been relatively little studied. It has been shown that streams subjected to abnormally large amounts of silt and sediment are characterized by reduced aquatic insect diversity and biomass (Chutter, 1970; Buscemi, 1966 and Prather, 1971). Aquatic insects are a major component in stream communities, being represented in at least two trophic levels. It follows that any environmental change adversely affecting insects could have far reaching effects on other community members.

Emerald Creek, in northern Idaho, is an example of a silt-polluted stream and served as the site for an intensive study to determine the effects of silt pollution on the distribution and abundance of aquatic insects (Prather, 1971). The present study was conducted in an attempt to evaluate techniques for rehabilitating that stream. The major objectives of this study were: 1) to evaluate the sediment flushing capabilities of different in-stream alterations and 2) to correlate the effectiveness of sediment removal with benthic insect recolonization.

It is believed that information obtained in this study will be useful in managing silt polluted watersheds where rehabilitation is warranted or desired.

STUDY AREA

This study was conducted on the East Fork and main stem of Emerald Creek, a tributary of the St. Maries River in northern Idaho (Fig. 1). The lower reach of Emerald Creek is extremely silt polluted due to private and commercial mining of garnets and garnet sand.

The East Fork of Emerald Creek originates in the Hoodoo Mountains (St. Joe National Forest) in Latah County. It flows northeast until its confluence with the West Fork where it enters a broad valley. The main stem joins the St. Maries River approximately five miles northwest of Clarkia, Idaho.

Emerald Creek is a low gradient stream, dropping approximately 220 feet in the 10-mile section involved in this study. Its width varies from 11-35 feet; average riffle depth is 2-6 inches with pools 2-4 feet deep during midsummer. The current velocity ranges from less than 1.0 to 2.3 ft/sec. Average summer discharge is 15.6 ft^3/ sec for the main stem (Prather, 1971).

The coniferous forest in the Emerald Creek drainage is basically a *Thuja*-*Tsuga*-*Pachistima* association (Daubenmire, 1952). Riparian vegetation consists mainly of alder (*Alnus* sp.), various grasses, sedges and forbes.

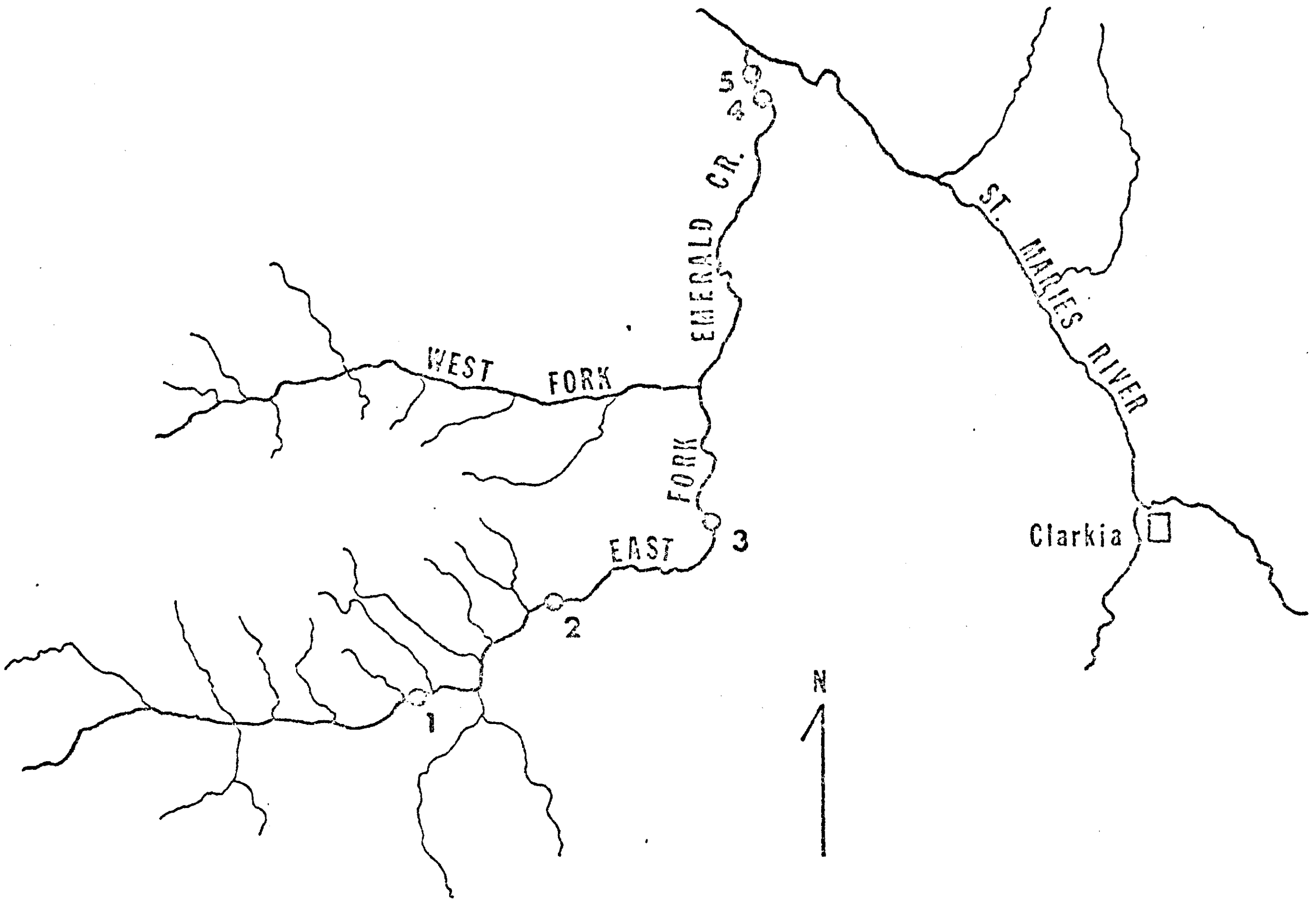

Fig. 1. Emerald Creek and the St. Maries River in northern Idaho with alteration sites identified by number.

Geologically, the East Fork is in the Pre-Cambrian belt series. The stream grades into Columbia River basalt below the confluence of the East and West Forks (Prather, 1971).

The major uses of the Emerald Creek drainage are timber production, mining, summer grazing, and recreation (e.g., rockhounding, fishing, hunting and camping). The East Fork is a major attraction for rockhounds seeking gem-quality garnets. Much digging was done in the banks and beds of the East Fork and its tributaries (Pee Wee, Garnet, No Name gulches, etc.) prior to 1969, with most of the gravel being washed and screened in the streams. During the winter of 1968-1969 the U.S. Forest Service acquired 930 acres along the East Fork through land exchanges with Sunshine Mining Company, Milwaukee Land Company, and Potlatch Forests, Inc. The Forest Service then closed the East Fork and its tributaries to garnet removal except for a 40-acre area which was leased to a private concern.

Sunshine Mining Company now has a dredge site and jig plant located on the main stem immediately downstream from the confluence of the East and West Forks (Fig. 1). As a consequence, the main stem of Emerald Creek, in contrast to the East Fork, is characterized by heavily sedimented runs and pools.

METHODS AND MATERIALS

Laboratory and field techniques were employed to evaluate biological and physical changes of a silt-polluted stream subjected to in-stream alterations.

Physical Analysis of Stream Habitat

Substrate Analysis and Classification

In June, 1971 five sites were selected in Emerald Creek for streambed alteration. Control sites were selected specifically for each test site on the basis of similarity of water velocity, substrate type, depth, and stream width. All sites were surveyed, mapped (stadia survey utilizing standard engineering techniques) and photographically documented before and after alterations.

Permanent transects were established at 1-2 locations (depending on the length of the test reach) for all sites. One-half inch steel rods approximately four feet in length were driven into the stream banks at points opposite each other. A nylon cord, leveled and drawn taut between the rods, served as a transect line from which streambed profiles could be determined by measuring the distance from the cord to the bottom of the stream at 1-foot intervals from bank to bank.

The substrate was described at 1-foot intervals using three criteria: 1) cobble factor (presence of all rock larger than 2.5 inches in diameter), 2) embeddedness of the cobble, and 3) size of the sediment surrounding cobble. The degree of embeddedness was described using a classification scheme similar to that of Prather (1971) consisting of five categories:

<u>Cobble Embeddedness Classification</u>

5.....nearly 100% embedded
4.....75% embedded
3.....50% embedded
2.....25% embedded
1.....nearly 0% embedded

Sediment surrounding cobble was described using a 4-rank classification:

<u>Surrounding Sediment Classification</u>

1.....greater than 1 inch in diameter
2.....1/4-1 inch in diameter
3.....1/8-1/4 inch in diameter
4.....less than 1/8 inch in diameter

The mean substrate sediment size for each site was calculated by averaging 1-foot intercept substrate measurements. Sediment size was described using a 5 rank scheme:

Sediment Size Classification

1.....less than 1/8 inch in diameter

2.....1/8-1/4 inch in diameter

3.....1/4-1 inch in diameter

4.....1-2 1/2 inches in diameter

5.....greater than 2 1/2 inches in diameter

Substrate description was based on visual examination of sediments. Four pre-alteration and five post-alteration sets of transect data were taken during the study.

Sediment Transport

Tagged sediment studies were initiated in the fall of 1971 to determine sediment transport characteristics of Emerald Creek during periods of high flows. Three size classes of sediments were studied at four locations. Sediment obtained from these locations was dried and tagged in the laboratory with fluorescent paint.

In a moderate riffle, three size classes of rocks were positioned along transects on the streambed using a standard engineering transit. Core implants of tagged sediment were used at three other locations. A core sampler designed by the U.S. Forest Service (McNeil, et al, 1960) facilitated placement of the implants (Fig. 2). In a slow run in the upper East Fork, three 6-inch cores of tagged pebble were implanted six inches into the streambed. At the other two locations (lower main stem of Emerald Creek) 3-inch

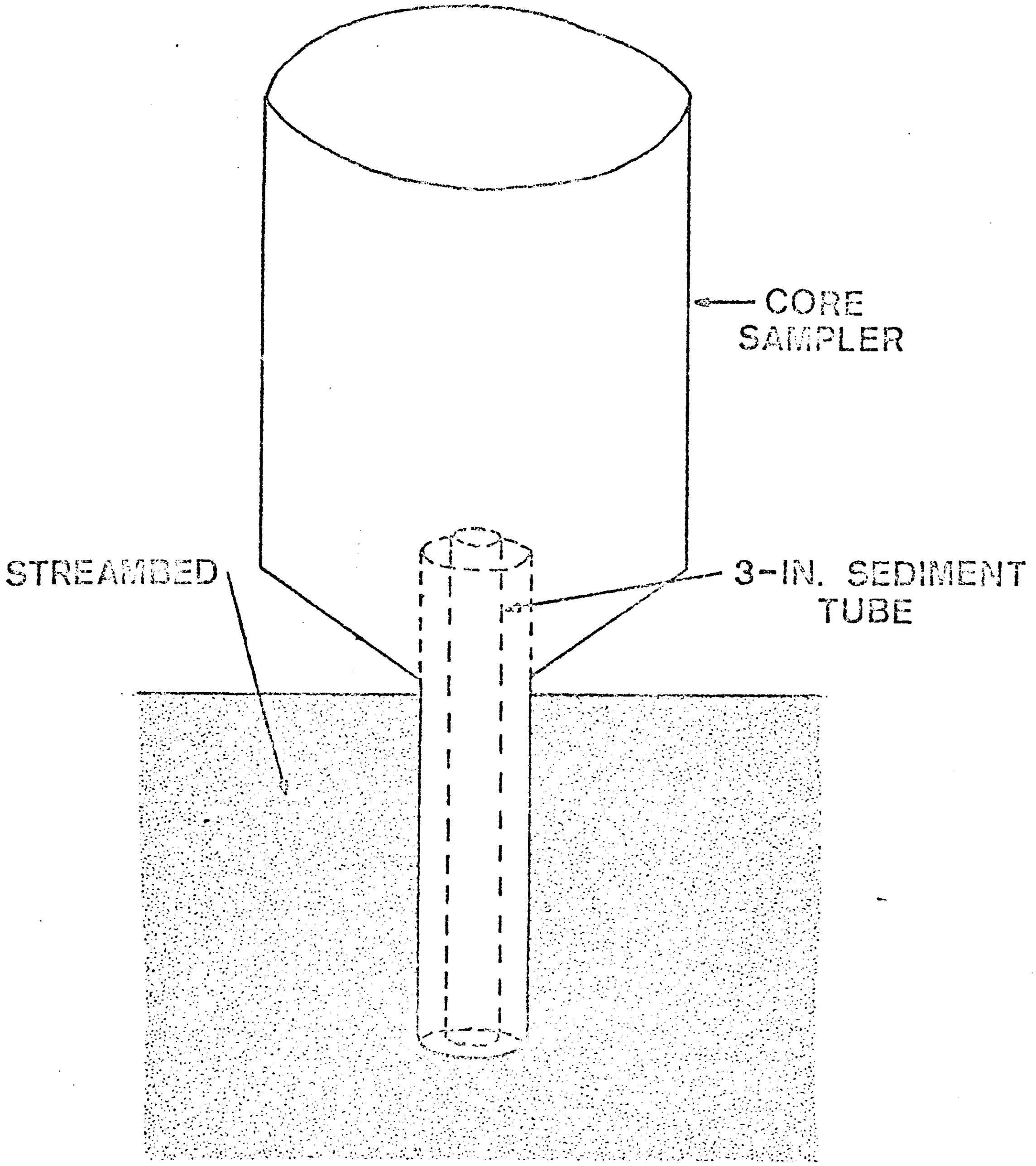

Fig. 2. Streambed core sampler and sediment tube for implanting tagged sediments.

cores of tagged sand were spiked into the bed using a 3-inch aluminum tube placed inside the core (Fig. 2). Unmarked sediments were filled around the tube, which was then removed leaving a vertical column of tagged sediment in the bed. A standard engineering triangulation technique was employed for marking the exact position of each core.

During the spring of 1972, following high water, core implants and tagged cobble were relocated and resampled using the same techniques by which they were placed. Tagged rock displacement distances and core erosion was recorded in an attempt to determine sediment transport phenomena in relation to the hydrologic cycle.

Stream Habitat Rehabilitation

Four types of in-stream alterations were tested in Emerald Creek and included: 1) log-drop structures, 2) debris jam removal, 3) gabion wing deflectors and 4) channel diversion. Stream morphometrics of each test site were determined prior to alteration (Table 1).

Log-drop structure. Two log-drop structures were built in the upper reaches of the East Fork of Emerald Creek to function primarily as pool scouring devices for increasing the pool-riffle ratio (Figs. 3, 4 and Plate 1). The design of the structures is a modification of a design described in

Table 1. Station morphometrics of Emerald Creek in northern Idaho during June-August 1971-1972.

Station	Description	Bottom type	Ave. Depth		Ave. Current vel.	
			Inches	Cm	ft/sec	cm/sec
1	Moderate run	Small rock-pebble; lightly sanded	4.7	11.9	1.4	42.7
2	Slow run	Small cobble; heavily sanded	12.0	30.5	.7	21.3
3	Slow run	Small cobble-pebble; moderately sanded	8.0	20.3	.5	15.24
4	Slow run	Heavy sand burden over large boulders	10.0	25.4	.48	14.63
5	Slow run	Heavy sand burden over large boulders	11.0	27.9	.49	14.94

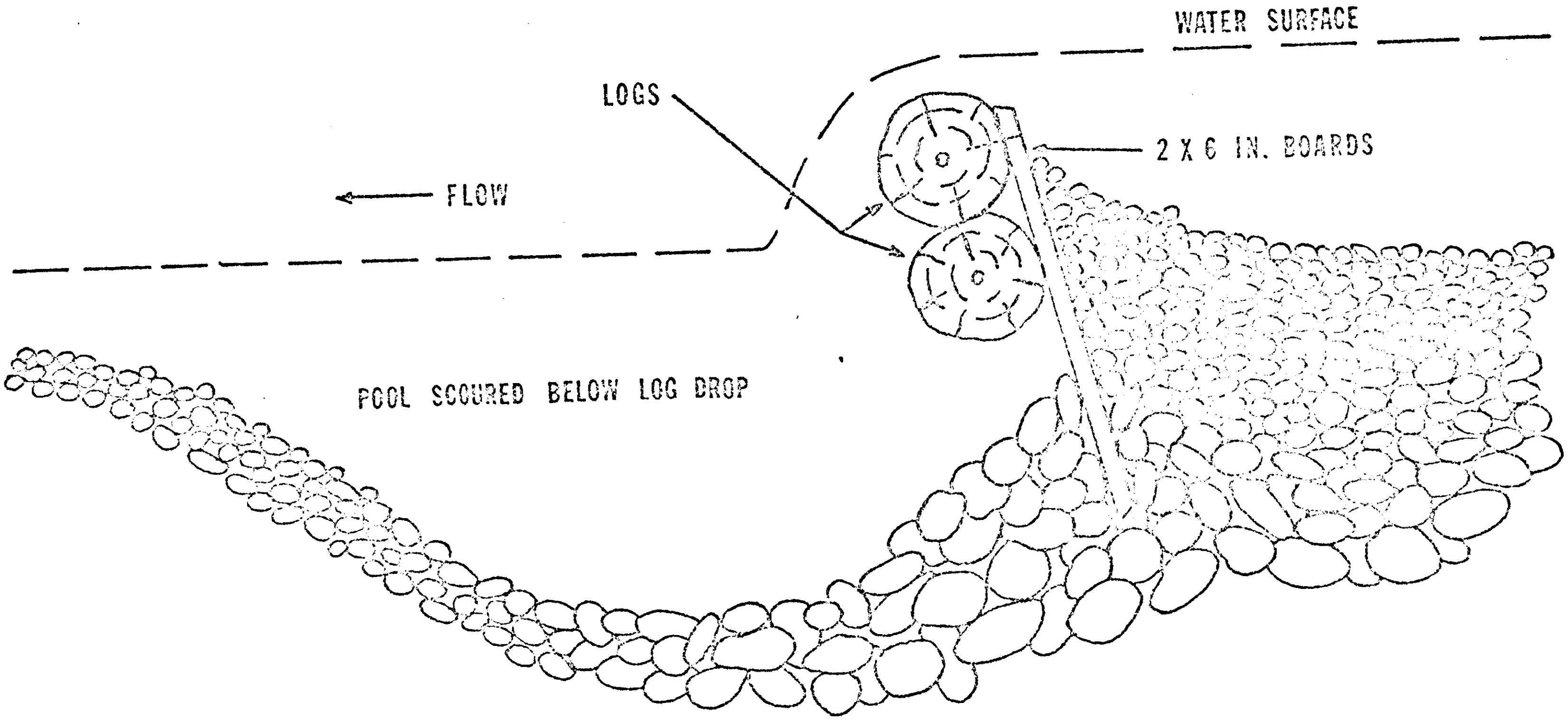

Fig. 3. Cross section of log-drop design employed at transects 1-b and 1-c in Emerald Creek.

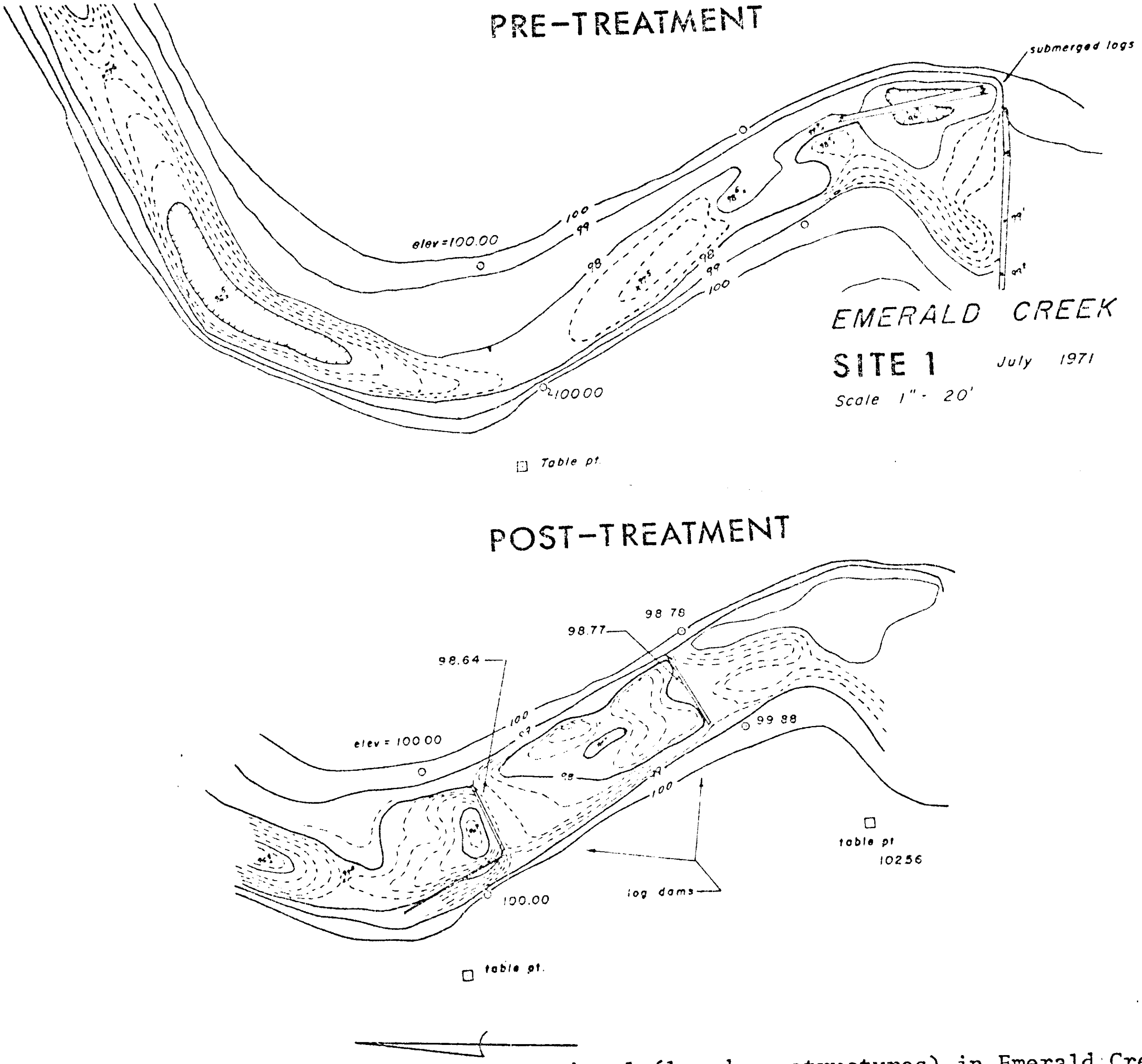

Fig. 4. Pre- and post-alteration conditions at test site 1 (log-drop structures) in Emerald Creek.

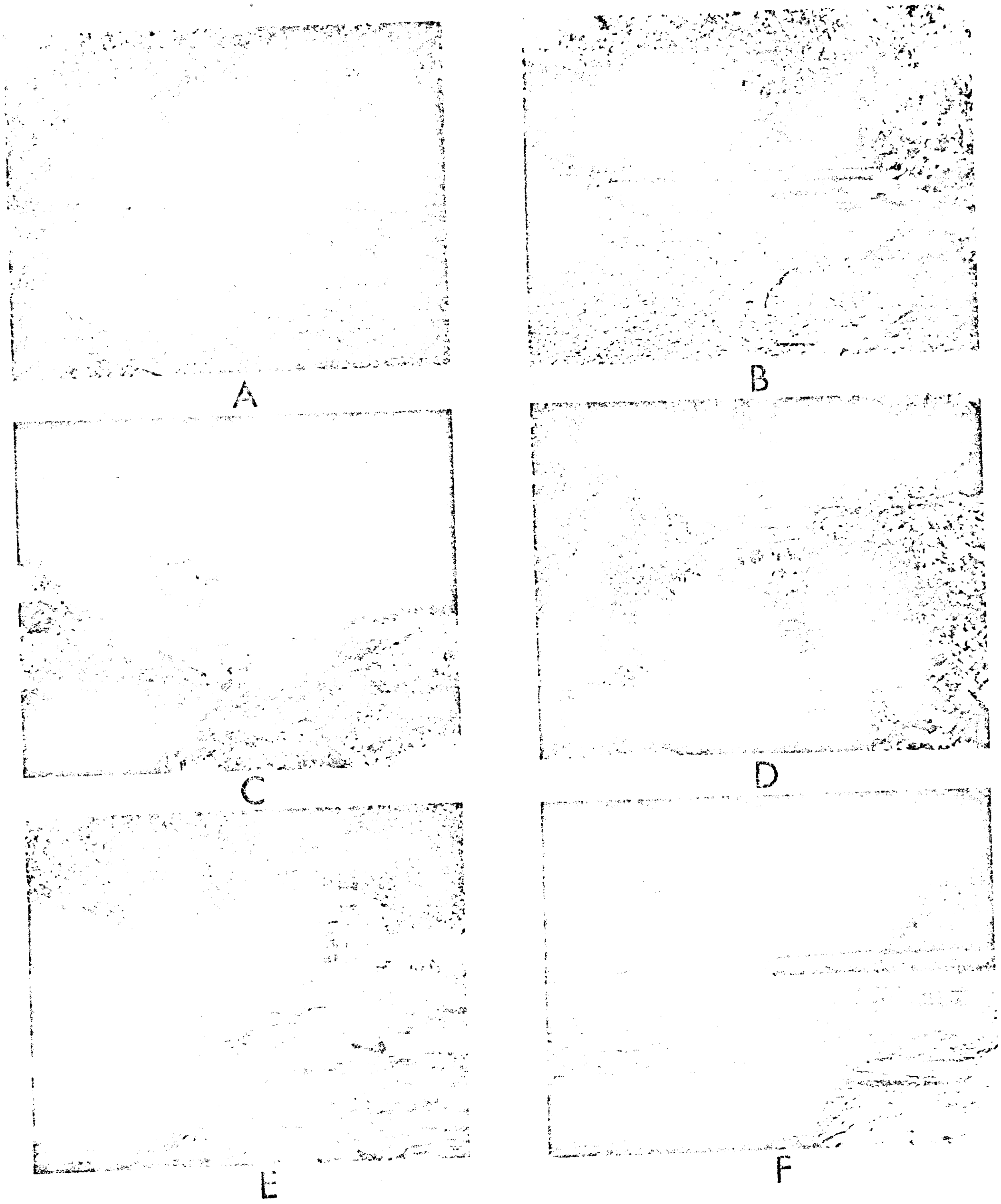

Plate 1. Pre- and post-alteration conditions at three sites in Emerald Creek, 1971-1972. A-B. Log drop structure; C-D. Debris jam removal; and E-F. Gabion deflector.

the USDA Wildlife Habitat Improvement Handbook (1969). Two green cedar logs were positioned transectionally across the streambed. The lower log was embedded into the substrate approximately 6-8 inches. The ends of the logs were set two feet into the banks and shored with large rock. Boards (2 X 6 X 24 inches) were driven into the substrate on the upstream side of the logs and nailed securely to the top log.

Debris-jam removal. A barrier of logs and debris was partially removed with the aid of a chainsaw at site 2 (Fig. 1) to eliminate a potential fish barrier and create a riffle condition. A portion of the jam, which was based on an old railroad tressel (Fig. 5, Plate 1), was removed to permit fish passage and create riffle conditions upstream from the jam.

Channel diversion. A channel blockage structure was built at site 3 (Fig. 1) to divert flow from a bifurcated stream channel into a common channel. It was believed that directing all water through a single channel would increase riffle conditions at the site. Two green cedar logs were laid across one channel; boards (2 X 6 X 24 inches) were driven into the substrate and nailed to the logs as was done with the log-drop structures.

Gabion deflectors. Gabion wing deflectors were built at sites 4 and 5 on the main stem of Emerald Creek

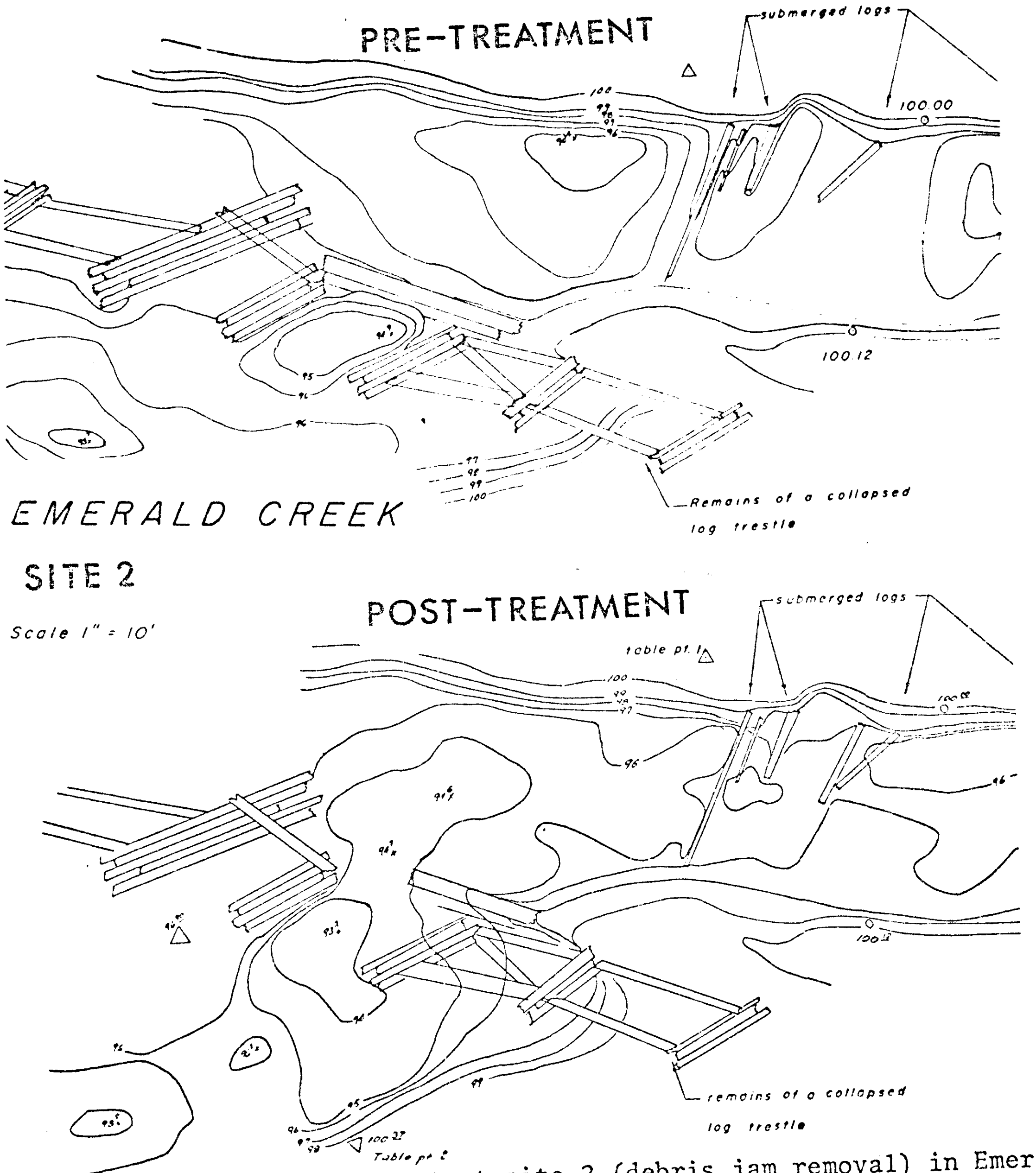

Fig. 5. Pre- and post-alteration conditions at test site 2 (debris jam removal) in Emerald Creek.

(Figs. 1, 6-7). Gabions were made of heavy-gauge chain-link cyclone fencing, cut into 8-foot sections, filled with large rock, interconnected and bound with heavy-gauge wire (Plate 1). The ends of the gabions were set into the stream banks approximately two feet for anchorage. These structures were used to constrict stream flow and increase sediment transport in heavily sanded reaches. In so doing, the "effective" riffle was increased, thereby enhancing insect colonization and productivity.

Insect Population and Community Analysis

Benthic community structure, insect drift and upstream dispersion were analyzed using field and laboratory techniques.

Benthic Community Analysis

Changes in the aquatic insect community were monitored in conjunction with measurement of physical changes of the streambed. At each permanent transect (test and control), the stream was visually divided into sections A, B and C, (e.g., thirds or halves depending on stream width). A modified Hess square-foot sampler (Waters and Knapp, 1961) was used to take two samples from each section. A small hand rake was used to agitate the bottom sediments, causing insects to be washed into the sampler net. Samples were placed in

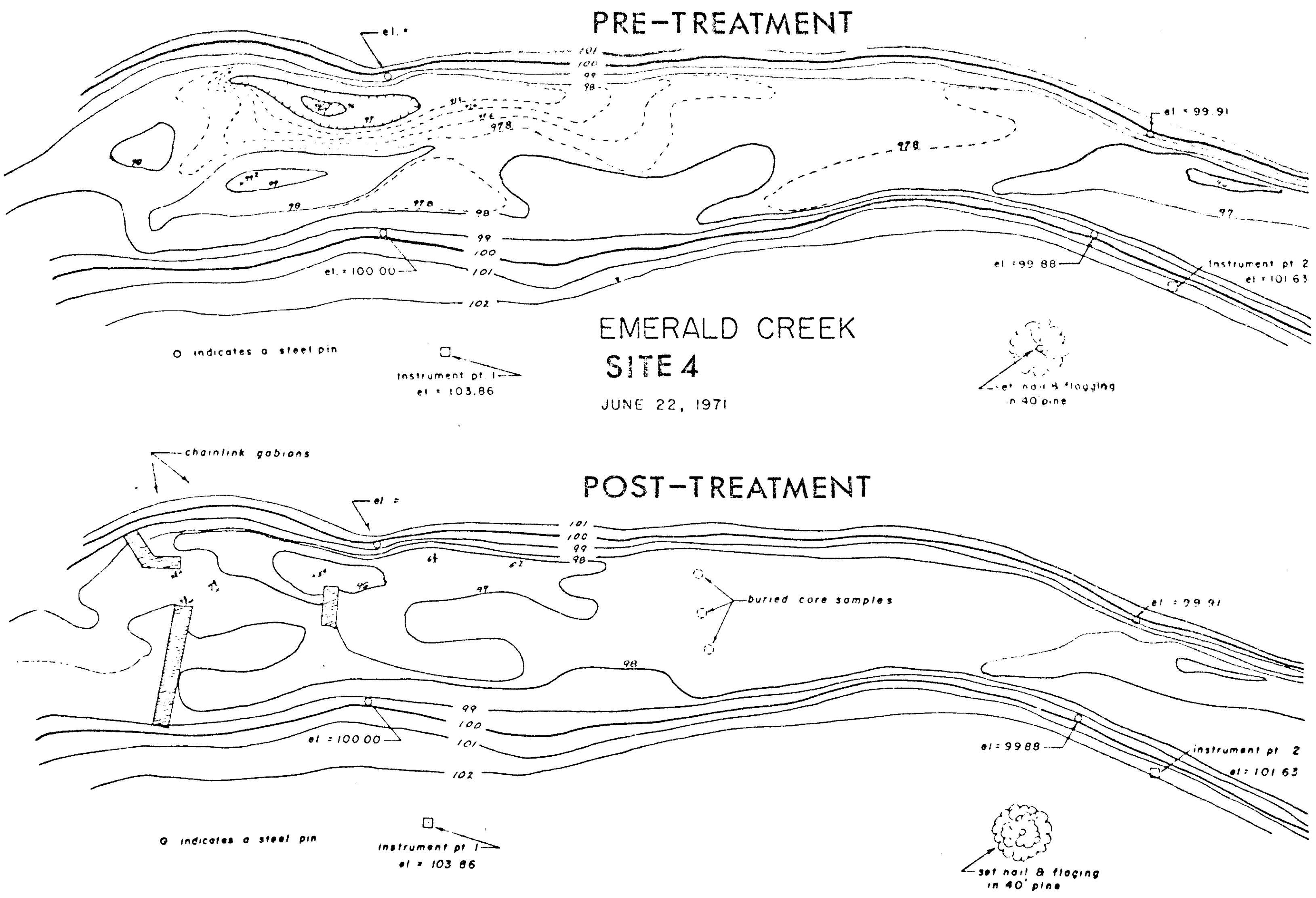

Fig. 6. Pre- and post-alteration conditions at site 4 (gabion deflectors) in Emerald Creek.

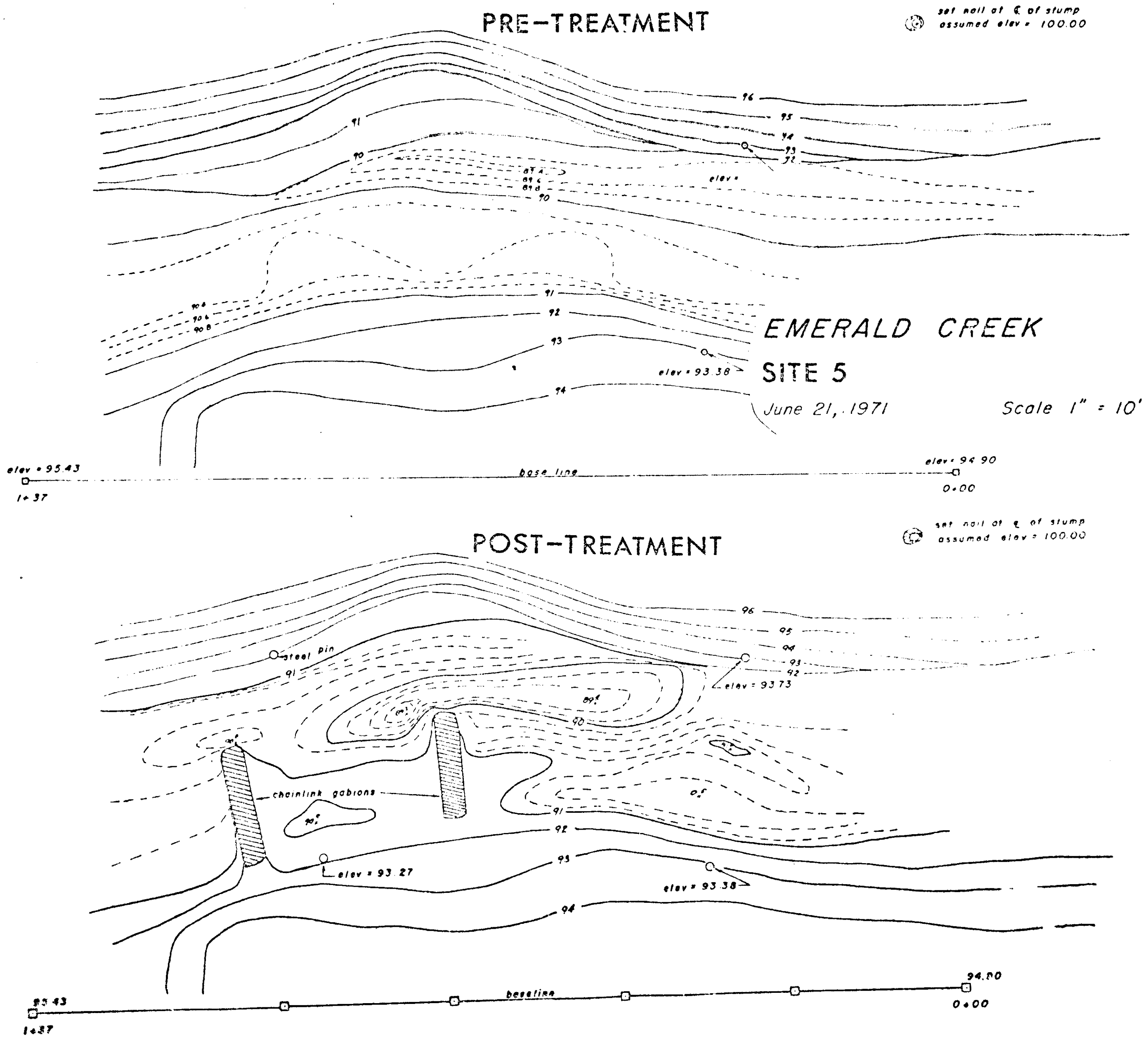

Fig. 7. Pre- and post-alteration conditions at site 5 (gabion deflectors) in Emerald Creek.

museum jars partially filled with 70% ethyl alcohol and stored until analysis. Four pre-construction and five post-construction sets of samples were taken from each transect. In the laboratory, samples were sorted and insects were identified using keys by Usinger (1968), Hynes (1969), Jensen (1966), Peterson (1960) and Smith (1968) in conjunction with identified specimens in the research collections of the Department of Entomology, University of Idaho.

A species diversity index, derived from information theory by Brillouin (1956) was used to describe community changes resulting from in-stream alterations. Three values were calculated using equations by Margalef (1957):

Diversity/Individual

$$H=1/N\ \mathrm{Log}_2 N!/N_1!N_2!\ldots N_s! \quad \text{(bits/individual)} \qquad (1)$$

Maximum Diversity

$$H_{max}=1/N\ \mathrm{Log}_2 N!/(m'!)^{s-r}((m'+1)!)^r \quad \text{(total bits)} \qquad (2)$$

Evenness

$$\text{Evenness}=H/H_{max} \qquad (3)$$

where N equals total number of individuals and $N_1, N_2 \ldots N_s$ equals the number of individuals per species. Evenness reflects the degree of equal or even distribution of numbers per species. It is high with nearly uniform distribution, low with a clumped distribution and numerically ranges from 1.0-0.0. All diversity values were calculated on a Digital

PDP - 8 E computer, programmed in Basic.

Insect Drift and Upstream Dispersion--Field Study

Lower reaches of the main stem of Emerald Creek are characterized by long sedimented runs, often 330 ft (100 m) or more long, having a nearly homogeneous substrate of sand. A study was conducted in July and August of 1972 to determine the fate of insects drifting into these highly unfavorable areas.

A long silted run occurring between distinct riffles was investigated. The run was approximately 250 feet (85 m) long and located in the main stem of Emerald Creek about 1 mile (1.61 km) upstream from the Emerald Creek-St. Maries River confluence. Drift nets, similar to those used by McClelland (1972) and wire baskets (12 X 12 X 6 in, made of 2 X 4 in hardware cloth) filled with cobble were used to sample insect drift and colonization rates.

In an attempt to determine how far insects drifted across these sandy areas, nets were positioned at three locations in the sanded reach approximately 75 ft (24 m) apart (Fig. 8). The first net was 17 ft (five m) downstream from a riffle which served as the source for drifting insects. A control net was established in the riffle approximately 75 ft (24 m) upstream from the first test net.

On three successive nights the control net and one test net sampled insect drift. The sampling period began

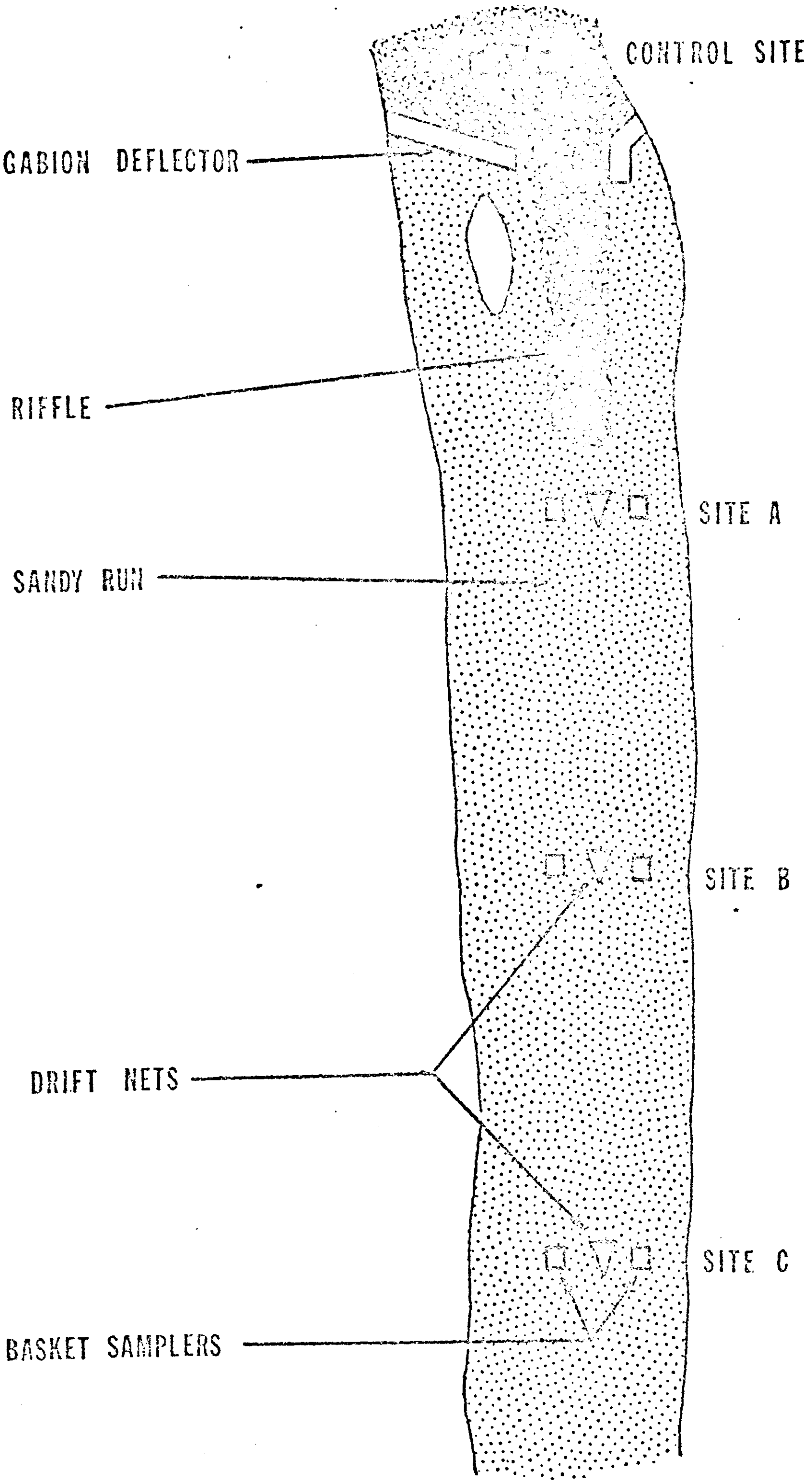

Fig. 8. Field drift and settle-out study design showing net and basket positions in Emerald Creek.

about one hour before dark and ended one hour after sunrise. The nets were emptied every five hours to avoid possible "back-flushing" resulting from net over-loading by debris and insects. The contents were placed in museum jars half-filled with 70% ethyl alcohol, sorted, identified and tabulated in the laboratory. Water velocity was measured using a Gurley Midget Current Meter (Model No. 625-F, Gurley Hydrological Instr.) before each sampling period. Six readings were taken at different positions directly upstream from the mouth of the drift net.

Two basket samplers were placed at the control and each test site. Baskets were positioned near each net at the onset of the drift sampling period and emptied 24 hours later. To prevent loss of insects during sampling, a net was held immediately downstream from the basket to collect insects being washed away while the basket was removed from the water. The basket was quickly put into a 30-gallon plastic container half-filled with water. Cobble were removed and washed clean of insects. Water in the container was strained through a net. The resulting insects and debris were preserved in 70% ethyl alcohol.

In late August, 1972, a study was conducted to determine if insects could successfully move upstream on sand substrates. An open-ended linear channel (4 X 32 feet) was constructed of plywood boards and positioned in the thalweg of a sanded run. Drift nets were positioned at the downstream end of the channel to collect drifting insects. Water velocity in the channel was approximately 0.7 ft/sec, the water depth 7 inches.

Three insect species (Dicosmoecus sp., Pteronarcys sp. and Acroneuria sp.) were used as test organisms. Late-instars were used in order to better facilitate monitoring of movements.

Daylight tests were conducted between 1 and 4 p.m., night tests approximately one hour after sunset to 1 a.m. Each species was individually tested. Ten specimens were used for each test and replicated three times. They were introduced into the middle of the channel and observed continuously for 15 minutes. A fluorescent tagging technique developed by Brusven (1970) was employed; an ultraviolet light enabled visual observations of tagged insects at night.

Insect Drift and Upstream Dispersion--Laboratory Study

In an attempt to better describe insect drift across silted reaches, tests were conducted in a laboratory channel using a drift model by McLay (1970) and Elliott (1971) to describe insect movement and settle-out rates. Insect species, current velocity (0.4, 0.7 and 1.0 ft/sec) and light conditions (light and dark) served as variables.

A regression equation developed by McLay (1970) and Elliott (1971) describes the relationship between numbers of insects caught in a drift sampler and the distance of origin from the net:

$$N_x=N_o e^{-RX}$$

where: N_x is the number of insects in the drift sampler,

N_o is the initial number of drifting insects,

e is the base of natural logarithms (2.718),

R is the "settle-out" rate and

X is the distance upstream from the sampler (e.g., the origin of drifting insects).

Settle-out rates were calculated using a multiple regression program (MULTREGR), on an IBM 360 Model 40 computer data processing system.

The laboratory channel consisted of two sections, eight and 10 feet (2.44 and 3.05 meters) long and 10 inches (25.4 cm) wide, connected by a flexible joint to permit differential slope adjustment. Both sections were of similar construction, having a plywood base, 1/4-inch plexiglass walls and braces and a fiberglass bottom. The channel was divided into eight, 2-foot (61 cm) sections. A net was positioned at the outflow of the channel to collect test specimens drifting out of the system. A small hydraulic jack was used to adjust the gradient of the stream. A 3/4 h.p. centrifical pump (Bell and Gossett, Series 1522-45; maximum discharge 100 gal/minute) was used to circulate water through the stream. Temperature was maintained at approximately 12°C with a thermostatically controlled 3/4 h.p. refrigeration unit. Evaporation was minimized by covering the channel with two mil, clear polyethylene sheeting. Sediments used in the channel were obtained from the field.

Four insect species, *Arcynopteryx* sp., *Brachycentrus* sp., *Ephemerella grandis* (Eaton), and *Pteronarcella* sp., all common to Emerald Creek, were used in laboratory tests. Test specimens were collected in the field and held in a circular laboratory stream described by Brusven (1973). Each replication consisted of 20 insects (1 species) introduced into the middle of the water column at the up-stream end of the channel. After 15 minutes, insects were recovered and recorded for each 2-foot quadrant and outfall net. Three replications were made for each species at each water velocity (0.4, 0.7 and 1.0 ft/sec) under both light and dark conditions. Different specimens were used for each replication.

RESULTS AND DISCUSSION

Rehabilitation of silt-polluted streams requires detailed quantitative and qualitative analysis of streambed sediments since it has been shown that the substrate is one of the primary factors affecting the distribution and abundance of aquatic insects (Chutter, 1969; Cummins, 1966; Cummins and Lauff, 1969; Hynes, 1970; Linduska, 1942; Prather, 1971; McClelland, 1972; Tarzwell, 1937; Thorup, 1966 and Wene, 1940). Heavily silted or sedimented streams generally manifest lower species diversity and productivity than clean unsilted streams (Chutter, 1970; Buscemi, 1966; Ellis, 1936; Herbert, et al, 1961; Bartsch, 1960 and Prather, 1971). Laboratory substrate-preference studies have shown that riffle insects prefer stone and cobble substrates over sand and silt (Cummins, 1961, 1964, 1966; Madsen, 1969; Prather, 1971; McClelland, 1972 and Shelford, 1914).

The substrate criteria of "cobble factor", embeddedness, and surrounding substrate size around cobble used in this study are believed to be useful descriptors of effective insect habitat. Number, size, and spacing of cobble have been shown to be important in determining the density and distribution of aquatic insects (Scott, 1960, 1966; Scott and Rushforth, 1959 and Sprules, 1947). Prather (1971) and McClelland (1972) found many riffle insects preferred unembedded cobble over cobble partially embedded in sand in laboratory streams. Their studies also showed that many riffle insects occupy intersticial areas in coarse, gravelly substrates. Cobble embedded in coarse material (1/2 inch or greater) offers a great number of microhabitats. Cobble embedded in fine sediments are effectively "sealed off" from insect colonization except for burrowing insects.

Substrate data were developed for two purposes: 1) to describe qualitative changes in streambed sediments resulting from rehabilitation and 2) to provide physical criteria for correlation with biotic changes. With few exceptions, benthic changes in Emerald Creek can be predicted after examination of substrate data.

Physical and Biotic Rehabilitation Employing In-Stream Alterations

The main principle of in-stream alteration is to utilize stream flow energy in the rehabilitation process. In low gradient streams, alterations are used to increase or maintain velocity by constricting channel width and removing obstacles to normal flow. In high gradient streams, alterations are used to cause water to plunge and scour pools and runs (White, et al, 1967; U.S.D.A., 1969). In-stream devices can supplement, but never substitute good hydrologic conditions on a watershed. When large quantities of silt and sediments are introduced into a stream many deleterious effects result, e.g., pools are filled, food-producing areas are covered, cover is destroyed, turbidity is increased and spawning areas are blanketed with unproductive fines (USDA, 1969).

Most stream improvements have been historically concerned with fish habitat, with emphasis on improving spawning conditions and increasing shelter. In this study, insects were used as "indicator" organisms to determine effectiveness of in-stream alterations for increasing overall stream production. Both physical and biological changes resulting from the alterations were studied in detail. Insects are the key secondary consumers in most streams and directly affect the distribution and abundance of organisms at higher trophic levels (e.g., fish).

The assumption that natural communities represent meaningful assemblages of organisms that are reflective of environment, has led to numerous analytical methods. Diversity indices are mathematical expressions which describe community structure and permit summarization of large amounts of information about numbers and kinds of organisms (Wilhm and Dorris, 1968). They are useful tools to aquatic ecologists, allowing mathematical evaluation and comparison among communities (Patten, 1962; Pielou, 1966; Wilhm, 1967, 1972).

Indices derived from the field of information theory (e.g., Shannon (1948), Brillouin (1956)) have become widely accepted and are now used by a majority of researchers. In using these equations, diversity and information are considered synonymous and calculations are made directly from numbers of individuals. Diversity is expressed in bits (binary digits), one bit being the amount of information required to specify one of two equally probable states (Margalef, 1957). Diversity values greater than 3.0 are usually considered to be representative of clean water communities while values of 1.5 or less typify grossly polluted situations (Wilhm, 1967).

The diversity indice after Brillouin (1956) was used in this study because the sampling program came closest to meeting the assumptions of the Brillouin. In using this function, samples were treated as entities to be studied for their own sake, and not as random samples of a larger parent population. It has been shown that resultant values from either the Shannon or Brillouin equations are very close and are equally sensitive at higher levels of numbers of species and individuals (Bowman, et al, 1971). All values for diversity per individual, maximum diversity and evenness are given for counts per square meter.

A biological and physical evaluation of in-stream alterations follows. Species diversity was used to analyze community changes. Transect (a) for each of the five sites represents the control; transects (b) and (c) represent test transects.

Log-Drop Structure. Substrate analysis and profile data indicate that streambed conditions at the unaltered transect (1-a) remained relatively constant during the study (Appendix A, Table 2). In contrast, test transects 1-b and 1-c showed substantial increases in average channel depth following construction of log drops (Table 2) as a result of scouring (Fig. 9). Average sediment size did not change noticeably for either test location. The effectiveness of the log drop at 1-b was reduced because of slack-water created by a similar structure at 1-c (Fig. 4). Such interference would have been avoided if the structures were located farther apart.

Diversity per individual, maximum diversity, and evenness remained fairly constant at control transect 1-a during the study (Fig. 10). Numbers of insect species were relatively uniform throughout the 2-year period; total numbers fluctuated greatly during the season, but exhibited similar trends in both 1971 and 1972 (Fig. 11). Diversity and numbers of species at the two altered transects (1-b, 1-c) most closely approximated the control transect (1-a). Total numbers of insects appeared to be the least reliable variable to compare.

Benthos samples were taken immediately above log drop 1-b and below 1-c in order to monitor respective community changes in these two habitats (Fig. 4). Species and maximum

Table 2. Mean channel depth for test and control transects in Emerald Creek in 1971 and 1972. Site 1=log drops; Site 2=debris jam removal; Site 3=channel diversion; and sites 4-5=gabion deflectors.

	Site Number																	
	1-a		1-b		1-c		2-a			2-b			3-a			3-b		
	Section		Section		Section		Section			Section			Section			Section		
Dates	A	B	A	B	A	B	A	B	C	A	B	C	A	B	C	A	B	C
6/24/71	19.8	19.4	-	-	-	-	33.5	43.2	27.0	26.7	33.0	27.5	35.1	37.8	33.8	-	-	-
7/2/71	20.0	19.6	17.2	20.5	21.2	21.2	33.5	43.5	28.4	26.0	32.0	28.9	35.0	38.5	33.8	27.5	37.2	34.4
7/13/71	20.4	19.7	17.2	20.5	21.5	21.2	32.0	44.4	27.6	26.9	32.0	31.2	35.6	38.3	33.9	28.0	36.8	35.1
8/5/71	-	-	-	-	-	-	-	-	-	27.0	31.8	31.0	-	-	-	28.3	36.9	34.2
8/10/71	19.8	19.4	16.9	20.0	21.8	21.6	-	-	-	-	-	-	-	-	-	-	-	-
8/17/71	20.7	19.5	16.5	19.5	21.8	21.5	-	-	-	28.4	32.5	32.1	36.6	38.1	32.9	26.2	36.0	33.5
8/29/71	-	-	-	-	-	-	33.2	44.5	28.1	-	-	-	-	-	-	-	-	-
9/24/71	20.6	19.8	16.5	21.5	21.6	17.9	33.1	44.2	27.9	28.6	33.5	30.7	36.5	38.4	33.1	28.3	37.1	34.1
6/30/72	19.6	18.9	14.9	17.1	27.5	28.8	33.4	44.3	28.5	34.8	41.1	55.0	35.7	37.9	30.8	36.3	31.3	23.9
7/25/72	19.5	19.4	15.1	17.5	27.3	29.1	32.0	43.9	28.2	34.5	41.4	53.3	36.2	38.3	32.2	37.2	31.7	24.4
9/28/72	19.6	19.4	15.1	17.3	27.7	29.3	31.8	42.7	27.9	-	-	-	35.7	38.1	31.1	36.9	31.0	23.7

	Site Number																	
	3-c			4a-5a			4-b			4-c			5-b			5-c		
	Section			Section			Section			Section			Section			Section		
Dates	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
6/24/71	17.5	20.8	27.4	21.5	28.8	34.8	-	-	-	34.8	27.8	25.8	-	-	-	36.3	37.9	38.8
7/2/71	16.7	21.0	27.6	22.4	29.6	35.4	-	-	-	33.8	27.3	25.6	-	-	-	35.3	37.6	39.4
7/13/71	17.1	20.1	27.2	22.2	30.1	35.5	-	-	-	34.1	25.8	25.3	-	-	-	35.1	37.8	39.2
8/5/71	16.0	19.9	26.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8/10/71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8/17/71	17.5	19.9	27.3	-	-	-	24.6	26.4	28.3	35.2	26.2	25.5	24.3	30.4	28.3	36.2	37.1	39.2
8/29/71	-	-	-	21.7	28.6	34.9	24.5	31.7	28.9	34.0	27.5	25.4	25.0	29.2	28.7	36.0	37.8	38.7
9/24/71	26.6	19.0	27.3	21.9	27.9	33.0	24.8	31.4	30.1	32.8	25.7	25.7	24.5	29.1	30.2	36.7	37.5	39.0
6/30/72	26.9	21.3	28.1	33.3	40.6	38.5	25.5	33.5	38.4	43.5	40.0	34.3	25.1	32.8	30.4	36.3	34.8	39.6
7/25/72	27.0	22.7	28.6	32.9	40.4	39.1	26.4	33.9	38.1	43.2	39.7	35.0	25.4	31.8	30.5	35.2	34.6	40.0
9/28/72	27.2	22.3	28.5	33.1	40.2	38.1	27.0	33.7	37.9	43.9	40.0	35.0	24.8	31.1	29.9	35.0	34.3	39.8

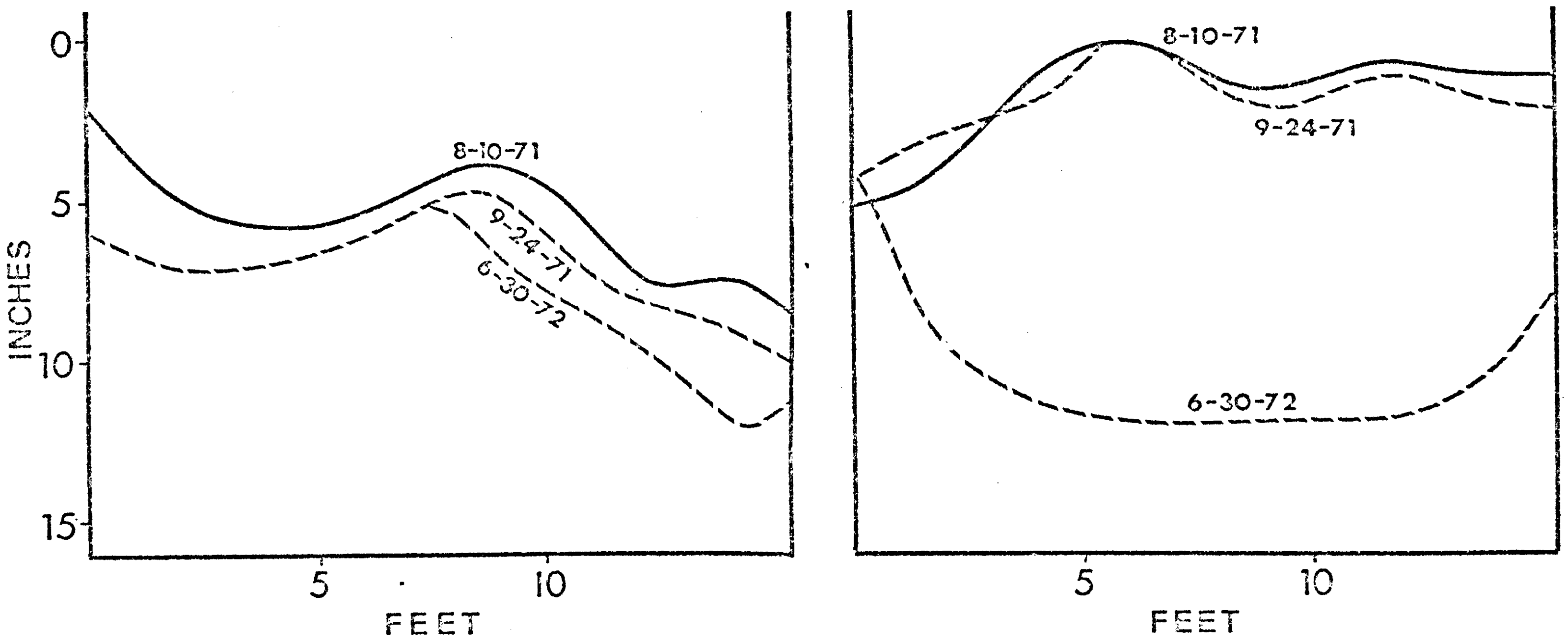

Fig. 9. Streambed profiles of transects 1-b and 1-c in Emerald Creek for pre- (8-10-1971) and post-alteration (9-24-1971 and 6-30-1972) conditions.

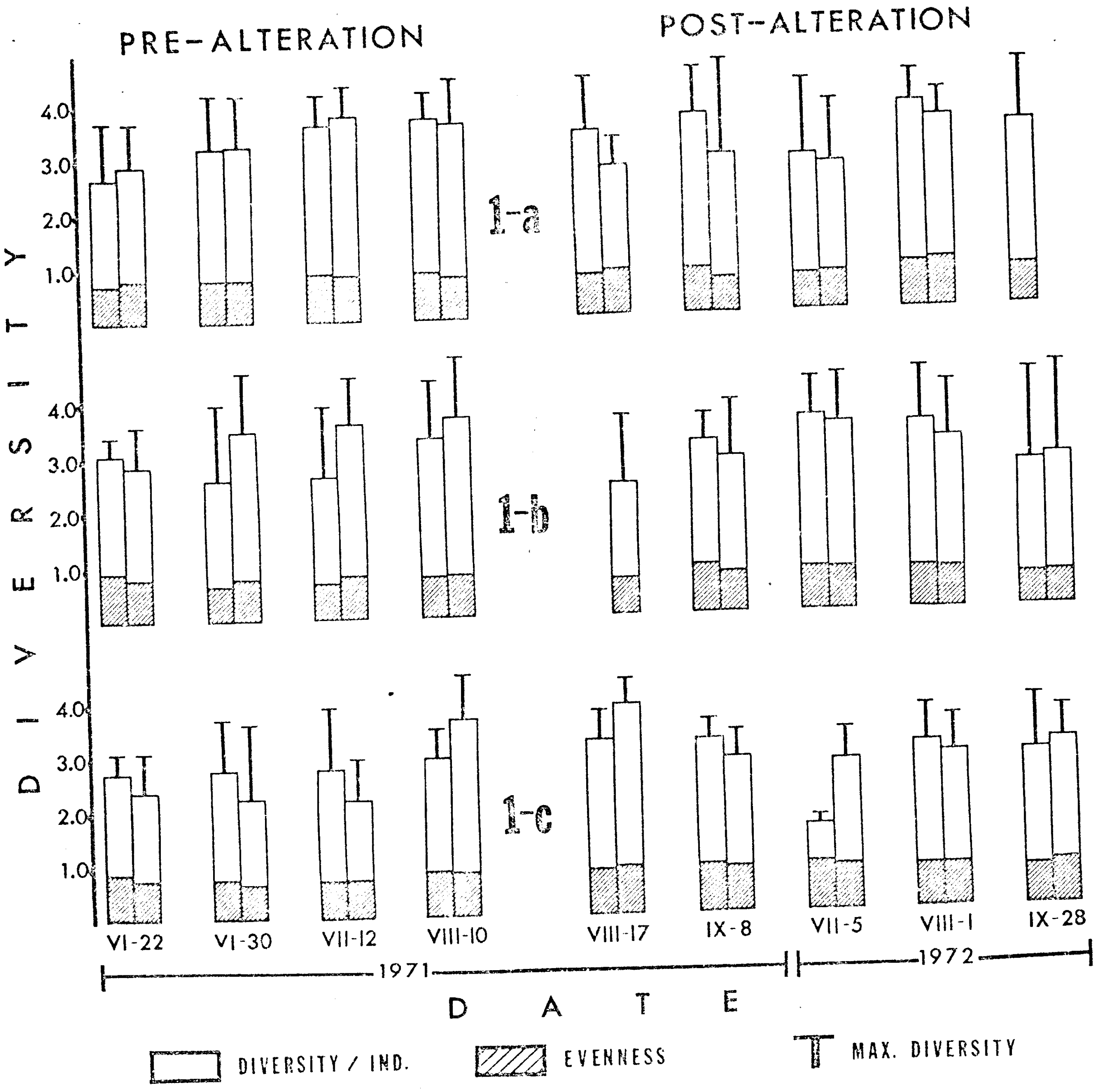

Fig. 10. Diversity per individual, maximum diversity and evenness for pre- and post-alteration samples from transects 1-a, 1-b and 1-c during 1971-1972.

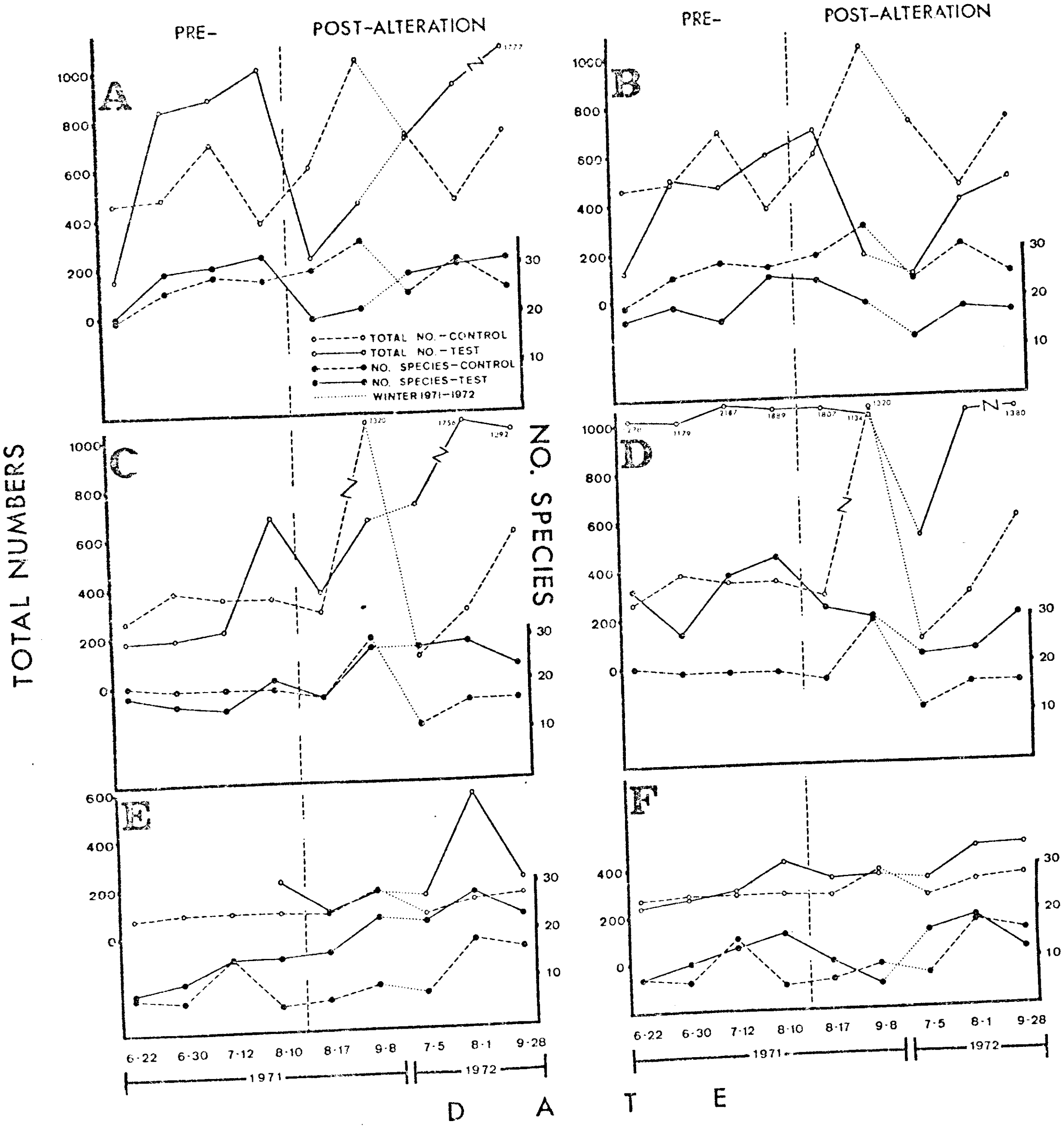

Fig. 11. Numbers of species and total numbers for sites 1, 3, and 4 and associated transects. A. 1-a,1-b; B. 1-a,1-c; C. 3-a,3-b; D. 3-a,3-c; E. 4a-5a,4-b; and F. 4a-5a,4-c. Control transects designated as (-a); test transects (-b) and (-c).

diversities decreased slightly at transect 1-c and remained constant at 1-b after alteration work (Fig. 10). No obvious changes in community structure occurred at either altered transect (1-b, 1-c). Common riffle species were dominant in both pre- and post-alteration samples and included species of Ephememeroptera (*Ephemerella tibialis* McDunnough, *Baetis tricaudatus* Dodds), Plecoptera (e.g., *Alloperla* sp., *Arcynoptera* sp.), Trichoptera (e.g., *Rhyacophila vepulsa* Milne, *Arctopsyche grandis* Banks) and Coleoptera (*Optioservus seriatus* LeConte, *Cleptelmis ornata* Schaeffer). Numbers of species and total numbers decreased substantially at both log drops immediately following completion of alteration work, but returned to pre-alteration levels in 1972 (Fig. 11). Physical disturbance of the streambed during log-drop installation and increased scouring were largely responsible for the immediate decrease in post-alteration numbers.

The overall net effect on aquatic insects at the log-drop transects was a slight reduction in numbers of species and total numbers of individuals. Fish habitat was improved by the formation of pools in a former shallow run. It is concluded that these structures are effective for improving fish habitat and are not extremely detrimental to insect populations. Log drops cause significant scouring in localized areas; however, they are not effective for removing fine sediment from low gradient, long silted riffles and runs. Construction of log drops with decay resistant species (e.g., cedar) assures maximum life of the structure. Such structures are not aesthetically disruptive to the landscape. A log drop of the type built in Emerald Creek required approximately 16 man-hours to construct. It is believed that these structures are sound investments, returning an increased fishery potential for a relatively small input of time, cost and effort.

Debris Jam Removal. A structure believed to be an effective fish barrier was partially removed at site 2, thereby permitting the flushing of fines and passage of fish (Fig. 1). Contrary to popular belief, naturally occurring debris jams do not usually block fish passage (U.S.D.A. 1969). The principal damage caused by debris jams is sediment accumulation behind the jam, resulting in loss of spawning gravels and reduced insect production.

Substrate data for control transect 2-a reveal that little or no change occurred during the 2-year period for values of percent cobble, embeddedness, average sediment size and mean channel depth (Appendix A and Table 2). In contrast, post-alteration analysis indicate sections A, B and C of test transect 2-b showed increases in average sediment size and mean profile depth (Appendix A and Table 2). Removal of the log jam caused an immediate increase in current velocity, changing pool conditions to a free-flowing riffle.

Initially, the main current flowed across section A, flushing the finer sediments (Appendix A). By June 1972, the thalweg had shifted to section C, causing a flush of fines from section C and deposition of same in section A and B.

Species and maximum diversities, numbers of species and total numbers of individuals of control transect 2-a gradually increased during pre-alteration sampling but remained stable during post-alteration samples (Figs. 12 and 13). Species and maximum diversities, evenness and numbers of species did not change appreciably at altered transect 2-b immediately following debris jam removal (Figs. 12 and 13). However, species diversity, evenness and numbers of species dropped noticeably in 1972. Total numbers of individuals increased immediately following alteration and remained at high levels in 1972 (Fig. 13).

It was believed that flushing fine sediments from a reach, thereby exposing underlying cobble, would have a "positive" effect on the benthic community resulting in higher species diversity. Fine sediments were flushed from transect 2-b, leaving a cobble substrate; however, diversity decreased in post-alteration samples. Benthos samples were taken immediately downstream from the transect. This area became a homogeneous riffle after partial removal of the debris jam and produced larger numbers of riffle-type insects (e.g., the mayflies Ephemerella tibialis, Baetis tricaudatus,

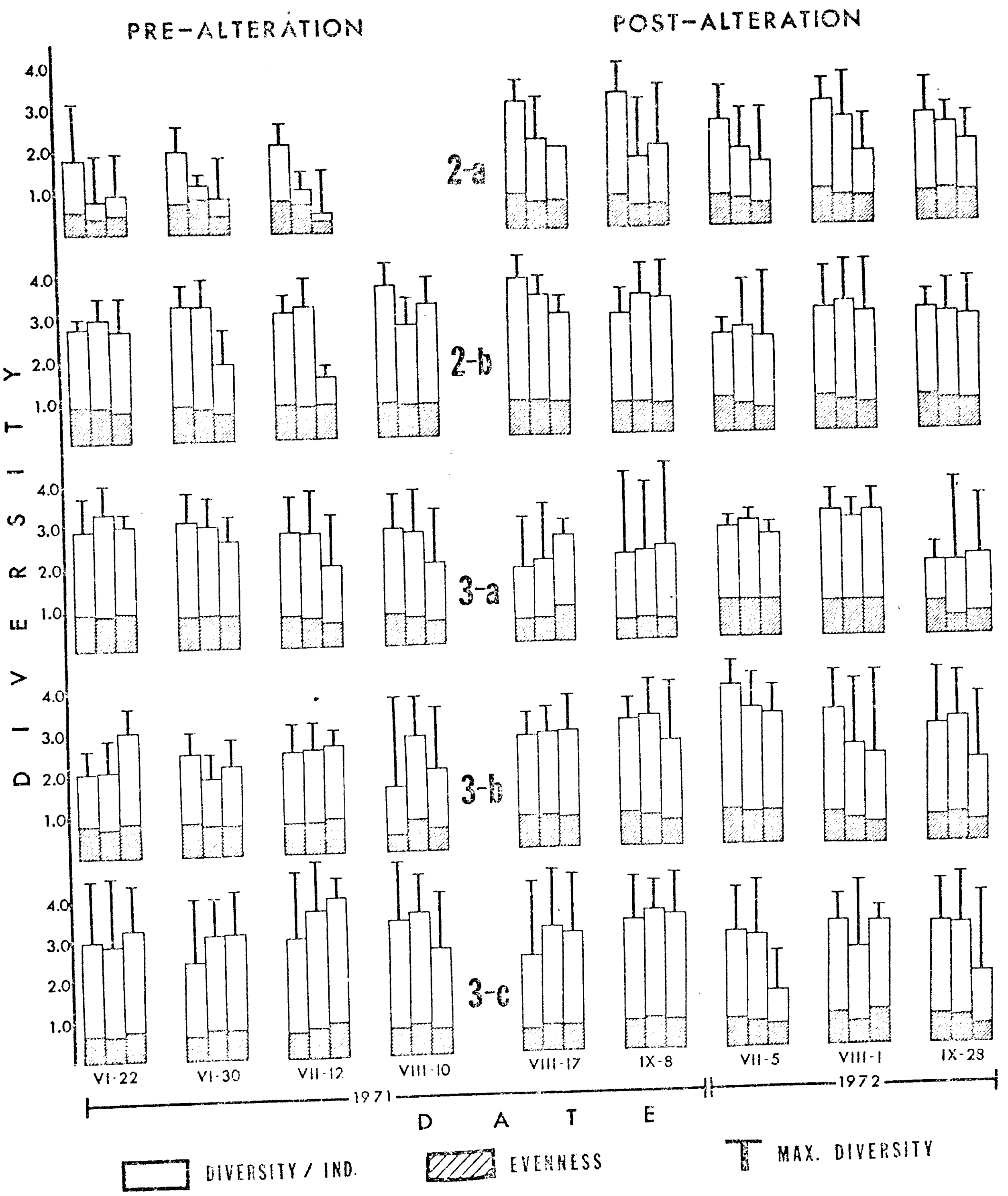

Fig. 12. Diversity per individual, maximum diversity and evenness for pre- and post-alteration samples from transects 2-a, 2-b, 3-a, 3-b and 3-c in Emerald Creek during 1971-1972.

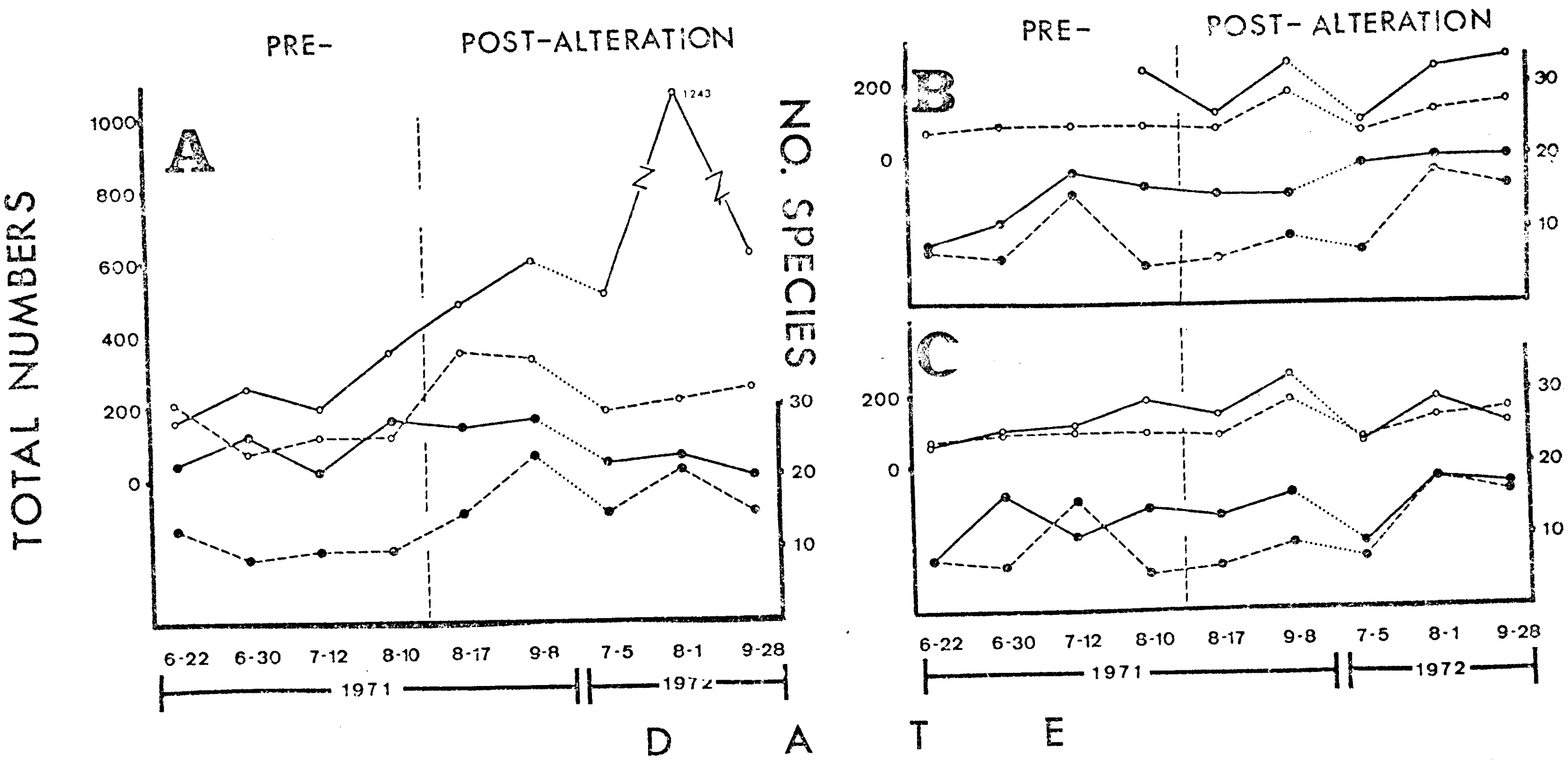

Fig. 13. Numbers of species and total numbers for sites 2 (debris jam removal) and 5 (gabion deflectors) in Emerald Creek during 1971-1972. A. Transects 2-a and 2-b; B. 4a-5a and 5-b; and C. 4a-5a and 5-c.

E. margarita; the stoneflies Alloperla sp., Arcynopteryx sp. and Acroneuria sp.) and several slow-water forms (e.g., the dipterans Hexatoma sp., Rhabdomastix sp., Tabanus sp. Liriope sp. and Palpomyia sp.). It appears that pre-alteration streambed conditions were more diverse, allowing a larger number of species, but fewer total numbers of individuals.

The debris-jam removal work required less than 15 man-hours and no heavy equipment. A large spillway was produced, allowing fish passage and riffle formation upstream and downstream from the jam. An aesthetically attractive spillway also scoured a pool which was inhabited by trout. This type of in-stream alteration, when warranted, is an inexpensive, effective method for increasing sediment transport, thereby improving insect and fish habitat.

Channel Diversion. A channel blockage structure was built at test site 3 for the purpose of improving riffle conditions (Fig. 1). One branch of a bifurcated channel was blocked off, thereby directing all water through a common channel.

Transect 3-a was established as a control for both test transects, 3-b and 3-c. Sections A and C of the control transect (3-a) decreased in percent cobble and average sediment size during 1971, whereas section B increased in same (Appendix A). The thalweg was located in section B, resulting in an accumulation of silt and algae in sections A and C but not B.

Post-alteration data indicated that test transect 3-b exhibited a general increase in percent cobble and average sediment size in 1972 (Appendix A). Mean channel depth at this transect increased in section A and decreased noticeably in sections B and C (Table 3).

Section A of test transect 3-c exhibited a pronounced increase in percent cobble, [illegible] sediment size and mean channel depth in post-alteration analysis (Appendix A, Table 2). In contrast, sections B and C of this same site decreased in average sediment size and mean profile depth following alteration. Section C, located in the blocked channel where water velocity decreased to near zero, accumulated fines and decreased in mean depth as expected.

Increased water velocity from channel diversion at site 3 was apparently concentrated in section A at transects 3-b and 3-c causing scouring in both A sections and deposition of sediment in B and C sections. This was most noticeable following spring run-off in 1972 as profile data indicate (Table 2).

Diversity per individual, maximum diversity and evenness showed extreme seasonal fluctuations at control transect 3-a during 1971 and 1972 (Fig. 12); however, there was a similar trend of decreasing diversity for both years. Late-summer increases of Ephemerella inermis (Eaton) appears to have caused reduced species diversity and evenness (Fig. 12).

Table 3. Core implant and recovery data for three sites in Emerald Creek for Fall 1971 and Spring 1972

Tagged Pebble					
Height of Core Implant				Amount Eroded	
Fall 1971		Spring 1972			
Inches	Cm	Inches	Cm	Inches	Cm
6.8	17.3	6.8	17.3	0	0
6.2	15.8	6.2	15.8	0	0
6.4	16.3	6.4	16.3	0	0
Tagged Sand -- Location 1					
18.0	45.7	0	0	18.0	45.7
24.0	61.0	12.0	30.5	12.0	30.5
22.8	57.9	0	0	22.8	57.9
Tagged Sand -- Location 2					
16.8	42.7	0	0	16.8	42.7
18.0	45.7	0	0	18.0	45.7
12.0	30.5	0	0	12.0	30.5
15.6	39.6	0	0	15.6	39.6
19.2	48.8	0	0	19.2	48.8
20.4	51.8	0	0	20.4	51.8

Post-alteration samples from transect 3-b had higher values of diversity, numbers of species and total numbers of individuals than pre-construction samples (Figs. 11 and 12). Species composition underwent considerable change at this site as a result of streambed alteration. Slack-water species (e.g., *Tricorythodes minutus* Traver, *Centroptilum* sp., *Oreodytes* sp., *Brychius* sp. and *Sigara* sp.) were replaced by common riffle forms (e.g., *Ephemerella tibialis*, *E. margarita* *Ameletus* sp., *Heptagenia criddlei* McDunnough, *Zaitzevia* sp., *Cleptelmis* sp. and *Arcynopteryx* sp.).

In contrast, post-alteration samples from 3-c indicated a net effect of lower numbers of species and total numbers of individuals (Fig. 11); diversity was nearly constant, except in section C where it decreased (Fig. 12). No striking changes in species composition occurred at test transect 3-c. There appeared to be a slight reduction in Diptera (e.g., *Antocha* sp., *Palpomyia* sp.) and a similar increase in Plecoptera (e.g., *Acroneuria* sp., *Arcynopteryx* sp., and *Nemoura* sp.) following alteration work.

Concentration of flow through a single channel at site 3 resulted in increased numbers of species and total numbers at transect 3-b but a decrease in same at transect 3-c; changes in the streambed at transect 3-b are believed to more accurately reflect the post-alteration conditons at this site.

The channel blockage structure is somewhat aesthetically disruptive. Slack-water in the diverted channel proved to be conducive for algal growth. These conditions should have been avoided as this section of Emerald Creek is a high-use area.

Channel diversion has been shown to be an effective means of increasing riffle area. However, prospective diversion sites should be carefully studied to insure that such measures will result in a net increase in insect and fish habitat.

Gabion Deflectors. Gabion deflectors were constructed at sites 4 and 5 in the lower reaches of the main stem of Emerald Creek (Fig. 1). Both test sites were located in heavily silted runs extending over 300 feet (90 m) in length (Table 1). Deflectors were built to constrict channel width, thereby increasing current velocity, riffle length, sediment transport, and insect drift. Two transects were established at each test site. One control site (4-a-5-a) was chosen for both gabion test sites.

The substrate characteristics of sections A and B of control transect 4-a-5-a did not significantly change during the study period (Appendix A). However, section C exhibited increases in percent cobble and average sediment size between 1971 and 1972. Also, less sand deposition was noted during the summer of 1972 than 1971 (Table 2). Since no alterations were made at this site, these observed changes were assumed to be reflective of natural seasonal and yearly flow fluctuations. Spring run-off was extremely high in 1972 and undoubtedly accounted for the scouring and flushing of fine sediments from this section.

At transect 4-b, percent cobble and average sediment size increased in sections A and B and remained constant in C following gabion construction (Appendix A). The most significant substrate changes occurred in section B, where the greatest current velocity was generated (Fig. 6). Profile data for this site indicated a pronounced increase in mean channel depth in sections B and C (Table 2, Fig. 14).

Sections A and C of alteration transect 4-c exhibited marked increases in percent cobble and average sediment size following gabion construction (Appendix A). These changes in section A were not anticipated. High spring run-off completely inundated the gabion; it is believed this caused removal of fine sediments and exposure of large basaltic boulders below the gabions. As water receded, the gabion deflected the water through section C, resulting in little sand deposition in A. Profile data for this transect indicate a massive flushing of sand from all sections between 1971 and 1972 (Table 2; Fig. 15). At gabion site 4, riffle conditions were extended approximately 75 feet (22 m) downstream as a result of the wing deflectors. The majority of stream water was funneled through a narrow opening, creating

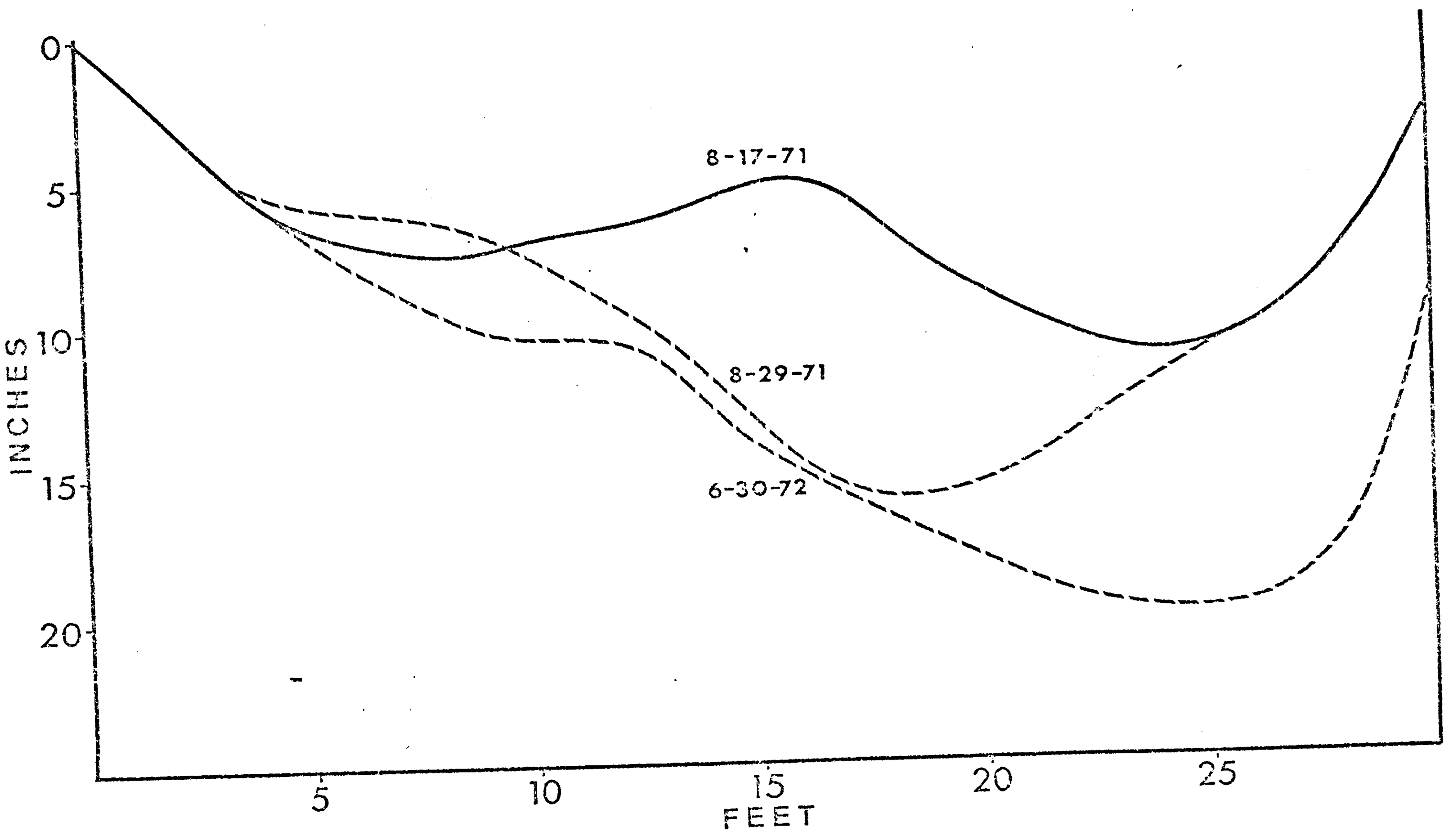

Fig. 14. Streambed profile at transect 4-b in Emerald Creek for pre- (8-17-1971) and post-alteration (8-29-1971 and 6-30-1972) conditions.

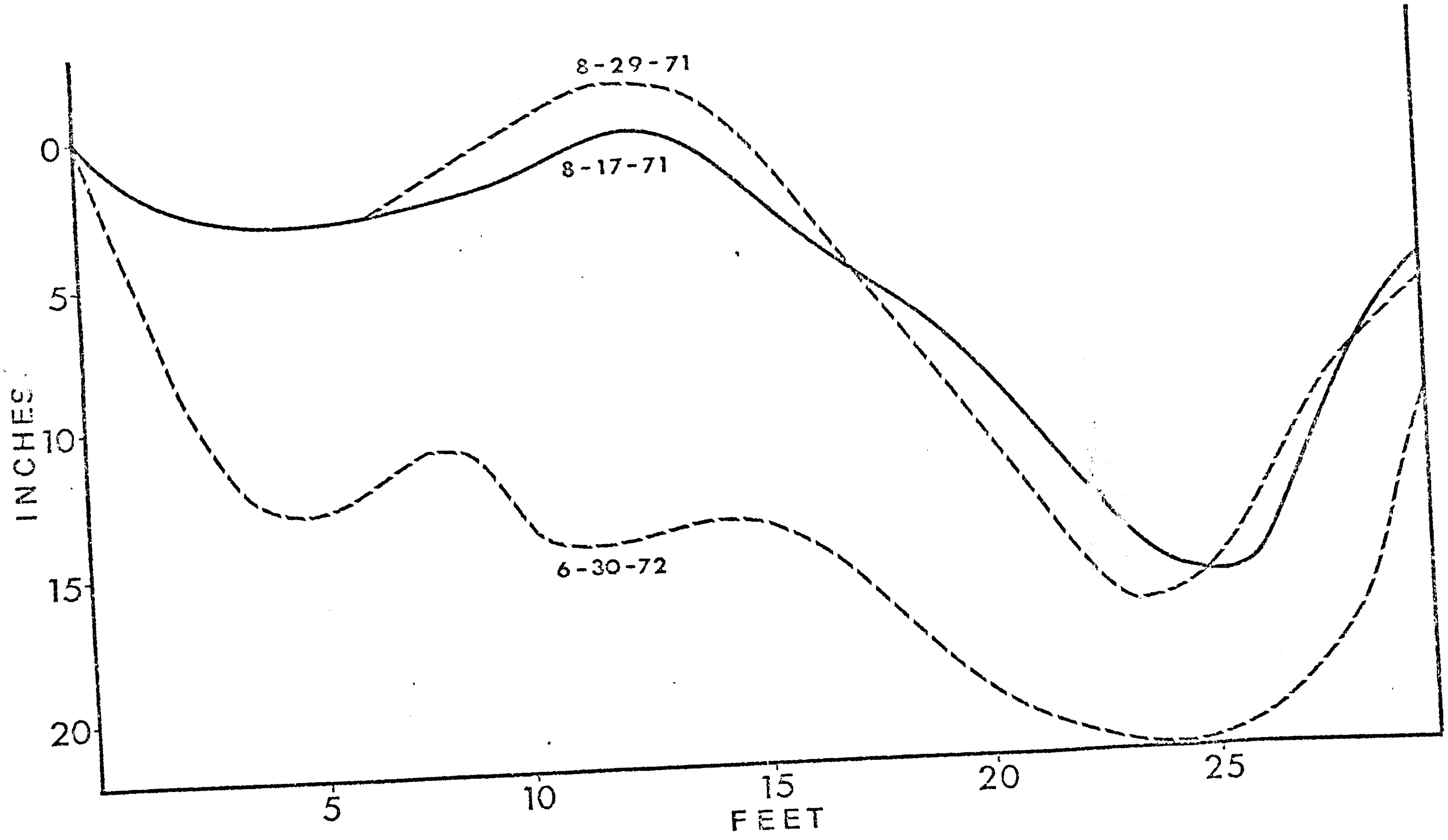

Fig. 15. Streambed profile at transect 4-c in Emerald Creek for pre- (8-17-1971) and post-alteration (8-29-1971 and 6-30-1972) conditions.

greater water velocity and resulting in flushing of fine sediments.

All sections (A-C) of transect 5-b showed increases in percent cobble and average sediment size following gabion construction (Appendix A). Section C, where the greatest change was expected, exhibited a gradual reduction in cobble embeddedness and an increase in the size of sediment around cobble. Substrate changes in sections A and B did not occur until after spring run-off in 1972. As occurred at transect 4-c, high flows inundated the gabions and removed much of the sand burden; sediments were not redeposited as the water receded because of the blocking effect by the gabions (Fig. 7). At transect 5-c, percent cobble and average sediment size increased in section C and remained fairly constant in sections A and B in post-alteration analysis (Appendix A). Average embeddedness decreased and size of sediment around cobble increased in section C, indicating a flush of fine sediments from this area. Profile data for transects 5-b and 5-c show only a slight reduction in mean channel depth following alteration work (Table 2).

Gabions at site 5 did not cause pronounced flushing of fine sediments as occurred at site 4. Apparently the stream constriction was inadequate to generate water velocities capable of transporting sand. Also, the low gradient in this reach reduced the effectiveness of alterations during low flows. However, sediment transport was increased during spring run-off as indicated by 1972 substrate analysis.

At control transect 4-a-5-a, diversity per individual, maximum diversity, evenness, numbers of species and total numbers of individuals were moderately variable during the study period, with 1972 values consistently higher than those from corresponding dates in 1971 (Figs. 16 and 13). Increases in the above values in 1972 correspond with increased percent cobble and average sediment size for this site in 1972 (Appendix A).

Species and maximum diversities, evenness, numbers of species and total numbers were noticeably higher at alteration transect 4-b in 1972 post-alteration samples (Figs. 13 and 16). Species composition of the insect community underwent substantial changes in sections A and B; mayflies and caddisflies increased, while Diptera decreased. Many slow-water forms (e.g., _Sialis_ sp., _Sigara_ sp., _Oreodytes_ sp.) were eliminated and replaced by common riffle species (e.g., _Baetis tricaudatus_, _Ephemerella flavilinea_, _Hydropsyche_ sp., _Cheumatopsyche_ sp., _Pteronarcella_ sp. and _Arcynopteryx_ sp.).

Although diversity and numbers of species decreased slightly at transect 4-c after alteration, there was an obvious shift in species composition (Figs. 13 and 16). This faunal shift, i.e., from slow water forms to riffle species was most pronounced in section C where average sediment size increased following gabion construction (Appendix A).

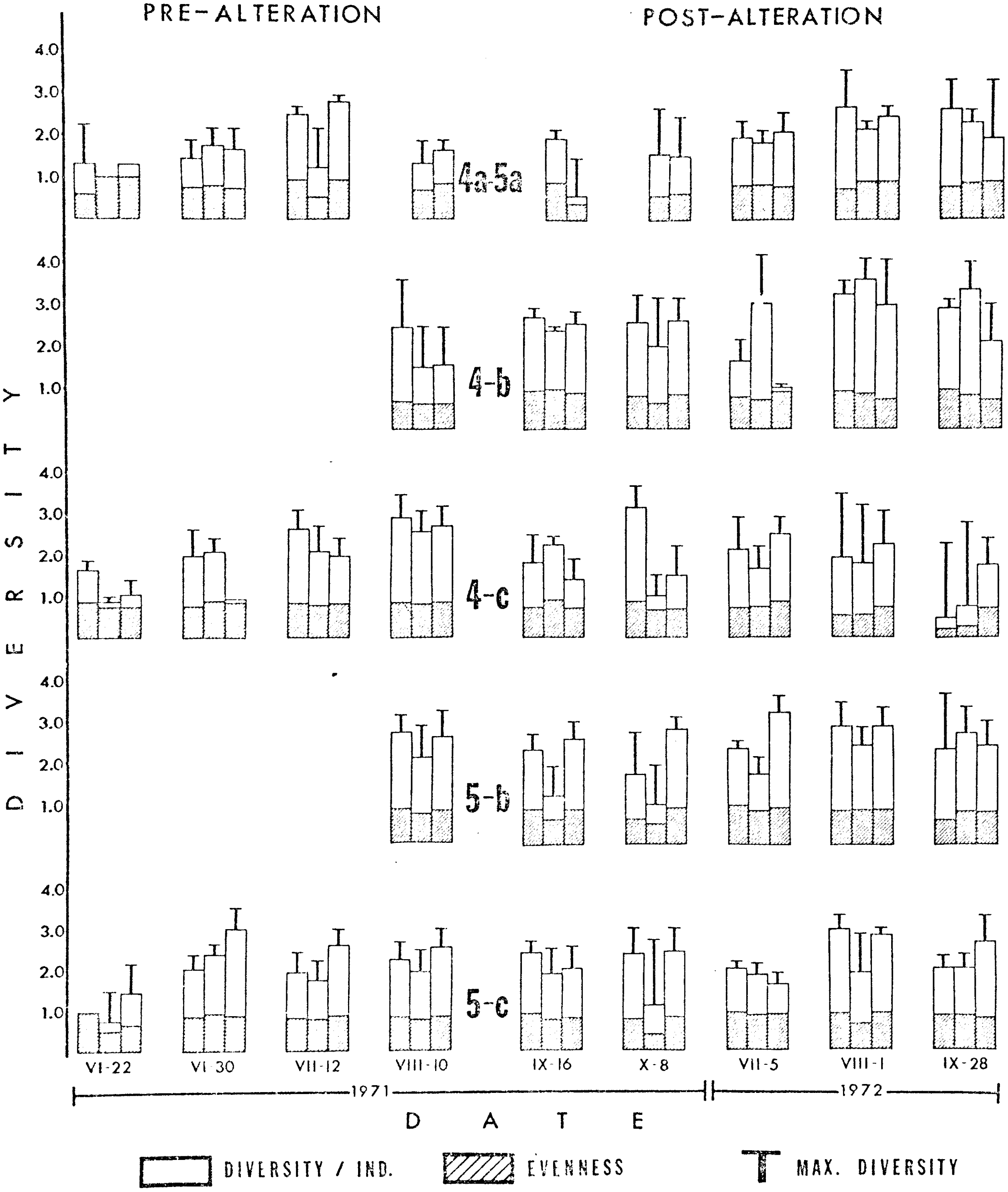

Fig. 16. Diversity per individual, maximum diversity and evenness for gabion deflector sites 4 and 5 in Emerald Creek during 1971-1972.

The overall net effect of the gabion deflector at site 4 on the aquatic insect community was an increase in numbers of species and total numbers. Certain sections (e.g., B of transect 4-b) showed substantial increases while other sections (e.g., B of transect 4-c) exhibited slight decreases. Mayflies showed greatest increases in number of species and total numbers in post-alteration samples.

Species and maximum diversities, evenness, and number of species were initially reduced at test transect 5-b in 1971 post-alteration samples; however, 1972 data indicated a return to above pre-alteration levels (Figs. 13 and 16). Sections B and C at this site showed the most noticeable changes following gabion installation. Diversity was drastically reduced in section B as a result of deposition of large quantities of sand. In section C, sediment size and percent cobble increased (Table 2) resulting in increased diversity; species composition of the insect community underwent considerable change following gabion construction. Many pool and fine substrate forms (e.g., Tricorythodes minutus, Hexatoma sp., Tabanus sp., Sigara sp., and Brychius sp.) were eliminated or reduced. Riffle species of mayflies (e.g., Ephemerella tibalis, E. flavilinea, and Ameletus sp.) caddisflies (e.g., Hydropsyche sp., Cheumatopsyche sp., and Brachycentrus sp.) and stoneflies (e.g., Arcynopteryx sp. and Alloperla sp.) were commonly collected in post-alteration sampling.

Gabion deflectors built at site 5 had no apparent influence on the insect community at transect 5-c (Figs. 13 and 16). Diversity values, evenness, numbers of species and total numbers remained fairly constant during the 2-year study. The insect community was typified by slow water, sand-substrate species (e.g., Ephemerella hecuba, Centroptilum sp., Tricorythodes minutus, Hexatoma sp., Tabanus sp. and Chironomidae before and after alteration.

The net effect of gabion deflectors at site 5 on the aquatic insect community was an increase in numbers of species and total numbers of individuals. Many common riffle species colonized the area at transect 5-b; in contrast, no changes in fauna were detected at test transect 5-c. These results indicate that current velocity increased considerably at transect 5-b but very little at 5-c. The thalweg was expected to remain along the south bank (Fig. 7); instead, it diverged immediately downstream from the second gabion.

Gabion deflectors were determined to be effective devices for improving fish and insect habitat. Riffle conditions were created as increased current velocity flushed fine sediments producing a cobble substrate. This rehabilitated area was quickly colonized by typical riffle insects. Trout were also found to inhabit the area. It is likely that insect drift rates and distance were significantly increased as a result of this work. Gabion installation required the most time and effort of all in-stream alterations employed in this study. However, it is believed that these structures will prove to be very durable, and will benefit the stream for many years. Immediately after construction gabions are "eye sores" and aesthetically displeasing. Previous rehabilitation studies have shown that gabions are usually colonized by reparian flora shortly after construction, thereby considerably reducing their artificial appearance (U.S.D.A., 1969).

Sediment Transport

Fluorescent tagging techniques were used to determine sediment transport during the winter-spring high flow regime in Emerald Creek. Transport of sand and fine gravel, pebble and cobble was studied at four sites.

Location of tagged sediment cores implanted in the streambed during the fall of 1971 were re-located in the spring of 1972. Recovery data indicates that no tagged pebble material eroded from the three core positions in the East Fork of Emerald Creek (Table 3); however about one inch of new sediment was deposited on top of the implanted cores during spring run-off. No visible changes in the streambed were observed at this site at the time of recovery.

Only one of the three core implants of tagged sand was recovered at the first location on the main stem (Table 3). Because the survey technique used to re-locate core implants was precise, it is assumed that cores A and C were completely eroded during high flow. In contrast, approximately 12 of the 24 inches of tagged sediment was removed from core B by spring flows (Table 3). The gabion wing deflector (Fig. 6) upstream from the core implants may have caused depositions of sediment in the center of the streambed, thereby reducing erosion of core implant B.

The core implants at the second main-stem location were not recovered. During the fall of 1971 when the cores were implanted, this site had a sand substrate over two feet deep. During spring run-off, the sand was completely eroded exposing the armored bottom. Therefore, all material had been swept away.

Results of these studies indicate there is a massive displacement of fine sediments in the lower reaches of the main stem of Emerald Creek during the late winter-spring high water regime. As high flows decrease in late spring, fine sediments are deposited in long, low-gradient, main stem runs and pools.

In the spring of 1972, an attempt was made to recover three sizes of tagged rocks placed on transects in the streambed in 1971. Seven of 11, 6-inch rocks were recovered (Table 4); the average distance travelled was 11.2 feet with a range of 0-32 feet. Nine of 10, 3-inch rocks were recovered; average displacement distance was 18.6 feet (range .5-32.5 feet). Only two of the 10, 1-inch rocks were

Table 4. Sediment transport and recovery for three sizes of tagged rocks in Emerald Creek, 1971-1972.

		6-Inch Rock	
Rock Number	Weight (Grams)	Displacement Distance	
		Feet	Meters
1	2505	-	-
2	2270	-	-
3	1635	24.0	7.32
4	1575	2.0	.61
5	1595	-	-
6	2277	6.0	1.83
7	1218	-	-
8	950	1.5	.46
9	1172	8.0	2.44
10	1256	-	-
11	1178	-	-
*		37.0	11.28
		3-Inch Rock	
12	821	-	-
13	608	1.5	.46
14	519	-	-
15	655	3.0	.92
16	675	29.5	8.99
17	601	3.3	1.01
18	563	-	-
19	616	-	-
20	415	41.5	12.65
21	606	0.5	.15
*		32.5	9.91
*		26.0	7.92
		1-Inch Rock	
22	58	-	-
23	35	-	-
24	39	-	-
25	37	-	-
26	63	-	-
27	34	-	-
28	51	-	-
29	40	-	-
30	27	-	-
*		48.0	14.63
*		0	0

*Rock number unknown

recovered; one at the original transect line, the other 48 feet downstream. These results indicate that small streams such as Emerald Creek have a relatively large capacity for transporting rocks great distances. The transport distance is directly related to diameter and weight of the rock. Small rocks (less than 2 inches in diameter) are apparently moved great distances during high water; medium size rocks (3 - 6 inch diameter) are not displaced long distances even during periods of high flow.

As previously stated, rehabilitation of a silt polluted stream occurs in two major ways: the elimination or "healing" of the source of silt and the ability of the stream to "cleanse" itself of silt through sediment transport. The latter is primarily a function of stream depth, discharge and gradient. Results of tagged sediment studies indicate that Emerald Creek has the capability of transporting large quantities of fine sediments. The U.S. Forest Service reported that the spring run-off for 1972 was extremely high in the St. Maries River and tributaries. This fact may have caused an overestimation of the sediment transport potential for Emerald Creek. However, it is still believed that Emerald Creek does have the capability of flushing fine sediments and could return to near pre-mining conditions if the source of silt were eliminated.

Insect Colonization, Drift and Upstream Dispersion

Downstream drift of aquatic insects is a normal feature of lotic systems (Waters, 1972). Insect drift facilitates recolonization of denuded areas, plays a major role in secondary production and provides a readily available food supply for fish.

Field and laboratory drift and upstream dispersion studies were conducted to determine how drifting insects were affected by long silted reaches, a condition common in the main stem of Emerald Creek. The studies were designed to obtain information on distances travelled by drifting insects, upstream dispersion of insects which had "settled out" in sandy reaches and the capability of different flow rates to effectively transport insects for long distances.

Insect drift has been shown to be one of the major factors in colonizing natural and artificial substrates in streams. Leonard (1942) and Müller (1954) described rapid colonization of newly excavated streambeds by drifting insects. Waters (1964) conducted an experiment to determine if recolonization rates of an insect denuded stream bottom were correlated to drift rates. He found a direct relationship between percent recolonization and drift rates. Prior to this study, it was believed that long silted reaches on the main stem of Emerald Creek were detrimental to drifting insects, thereby reducing colonization potential of the stream. In assessing the importance of insect drift, it is essential to know how far the organisms travel before they return to the bottom. Waters (1965) determined that *Baetis vagans* McDunnough and *Gammarus pseudolimnaeus* Bousfield drifted approximately 50-60 meters. Elliott (1967) found maximum drift was only 10 meters in a stream having dense stands of macrophytes. McLay (1970) reported maximum drift distance in a small stream as 45.7 meters and mean distance as 10.7 meters.

Insect Drift and Settle Out. In the field, basket samplers were used in conjunction with the drift nets to better interpret drift phenomena in low velocity sandy areas. It was believed that organisms not actively drifting in the water column, but crawling on the bottom might not be accurately sampled with a conventional drift net. The basket samplers, therefore, served as colonization sites for drifting and crawling insects in areas otherwise uninhabitable to them.

Most stream insects exhibiting drift periodicity are night active, i.e., they have a high propensity for drift at night (Tanaka, 1960; Waters, 1962, 1965, 1969; Brusven, 1970; Holt and Waters, 1966; Pearson and Franklin, 1968 and Elliott, 1967). Thus, drift studies in Emerald Creek were conducted at night during the time of greatest insect drift. Current velocity and discharge have been shown to directly influence the amplitude of insect drift (Waters, 1972).

Insect drift was conducted in July and August in 1972 to determine the effect of water velocity on insect drift across silted reaches. July drift results exhibited extreme variability during the three-day test period (Table 5). Basket-sample data was much more consistent than drift-net counts (Table 6). Drift counts from the control net were much greater on the second night than the first or third nights. Increases in drift on the second night may be attributed to a late afternoon rain storm that increased the stream flow (Table 5) as also shown by Anderson and Lehmkuhl (1968). Numbers of insect species and total numbers decreased at increasing distances downstream from the riffle at the three net positions (Table 5). Counts from nets A and B are larger than from net C. In contrast, drift rates, enumerated on a volume flow basis, were highest at net C and lowest at A.

Basket sample counts for the control site did not increase on the second night as did the control net counts, but actually decreased (Table 6). It is possible that increased current velocity caused more insects to remain in the water column and not settle out. Site B basket counts were higher than counts from sites A and C (Table 6). Drift net data indicated a significant reduction in drift between B and C. Settle out appears to have been greatest near site

Table 5. Field drift analysis for number of species, total numbers/m^2, and drift rate (numbers/ft^3 and m^3) For Emerald Creek in July and August, 1972.

		8 p.m. - 1 a.m.				1 a.m. - 6 p.m.					
		Number	Total	Rate--Numbers/		Number of	Total	Rate--Numbers/		Current Velocity	
Date		Species	Numbers	ft^3	m^3	Species	Numbers	ft^3	m^3	ft/sec	cm/sec
7/7/72	Control	27	863	2.92	102	24	426	1.44	51	1.97	60.05
	A	23	482	2.57	91	21	245	1.31	46	.63	19.20
7/8/72	Control	28	1293	4.73	167	27	859	3.14	111	2.08	63.40
	B	22	435	2.39	84	19	287	1.58	56	1.0	30.48
7/9/72	Control	19	712	3.00	106	26	550	2.35	83	1.62	49.38
	C	15	214	3.50	124	16	102	1.67	59	0.41	12.5
8/17/72	Control	22	336	2.46	87	22	269	1.97	70	.94	28.65
	A	14	71	1.07	38	16	99	1.49	53	.23	7.01
8/18/72	Control	19	255	1.94	68	16	372	2.83	100	1.02	31.09
	B	16	74	1.03	36	13	117	1.63	58	.40	12.19
8/19/72	Control	16	246	1.92	68	19	296	2.32	82	.99	30.18
	C	6	21	.73	26	12	57	1.98	70	.21	6.4

Table 6. Basket sample counts for number of species and total numbers of individuals from Emerald Creek drift and colonization studies in July and August, 1972.

		Number of Species		Numbers of Individuals	
Date	Basket	Total	Average	Total	Average
7/7/72	Control #1	13	13	40	44
	Control #2	13		48	
	A-1	11	10.5	25	20
	A-2	10		15	
7/8/72	Control #1	10	11	39	51
	Control #2	12		62	
	B-1	11	13	38	48
	B-2	15		57	
7/9/72	Control #1	13	13	50	66
	Control #2	13		81	
	C-1	7	7	15	15
	C-2	7		15	
8/17/72	Control #1	9	10	51	7
	Control #2	11		42	
	A-1	6	9	8	31
	A-2	12		54	
8/18/72	Control #1	9	9	41	72
	Control #2	9		103	
	B-1	7	8.5	18	36
	B-2	10		54	
8/19/72	Control #1	7	8	45	64
	Control #2	9		82	
	C-1	7	8	16	26
	C-2	9		36	

B, resulting in higher basket counts at the same site and lower drift counts at site C.

Results from the August drift study were much less variable than those of July. No significant changes in current velocity occurred during the 3-day study period. The control net produced reasonably consistant data and appears to be more reliable than in July when discharge was variable. Approximately the same number of species and total number of individuals were caught in nets A and B; net C produced fewer numbers of species and total numbers of insects than nets A and B (Table 5). The average drift rate did not appear to be significantly different among the three test nets. As in July, it appeared that many drifting insects settled out downstream from site B before reaching site C. Basket sample averages were higher in August than in July, indicating, again, that insect settle-out rates and average distances drifted are partially dependent on velocity.

Results of the field drift study indicated that low water velocities aided long-distance insect movement (drifting and crawling) over sand substrates. Insect settle-out rates appeared to increase noticeably approximately 175 feet downstream from the riffle (i.e., between nets B and C). A fourth test site should have been established downstream from net C to determine whether or not insect drift and movement ended completely or continued.

Laboratory simulation studies were conducted to more accurately describe insect movement and settle-out patterns by reducing variability of the key parameters of water velocity, light conditions, substrate, and insect species. Behavioral characteristics of different species were described in the laboratory and used in interpreting field drift study results.

A regression equation developed by McLay (1970) and Elliott (1971) was applied to the laboratory drift study. The constant relative rate of return of insects to the substrate (R), i.e., settle-out rate, was reported to vary with insect species, water velocity, bottom type and stream characteristics, but not to vary from day to night or from month to month (Elliott, 1971). Earlier experiments using this model equation were conducted in streams with pebble and cobble substrates. Previous to this study, it was believed that a highly unfavorable sand substrate, on Emerald Creek, might cause lower settle-out rates and longer drift distances than more favorable substrates of pebble and cobble.

When three factors, i.e., species, water velocity and light conditions, were investigated in the laboratory, high settle-out variability was found (Table 7). The mayfly _Ephemerella grandis_ and the stonefly _Pteronarcella_ exhibited similar settle-out patterns for light and dark conditions (Fig. 17). Settle-out rates, R, for _E. grandis_ and _Pteronarcella_ were highest at a water velocity of 0.4 feet per ble 7. Settle-out rates (R) for *Ephemerella* grandis, *Arcynopteryx* sp., *Brachycentrus* sp. and *Pteronarcella* sp. in a laboratory stream at three water velocities in light and dark conditions.

Settle-out Rates (R) for Living Insects									
ter Velocity		E. grandis		Arcynopteryx		Brachycentrus		Pteronarcella	
t/sec	Cm/sec	Light	Dark	Light	Dark	Light	Dark	Light	Dark
0.4	12.19	1.16	.96	1.08	.81	.45	.21	.59	.49
0.7	21.34	.68	.61	1.02	1.08	.60	.44	.43	.46
1.0	30.48	.41	.27	1.13	.78	.59	.16	.22	.26

Settle-out Rates (R) for Dead Insects									
0.4	12.19	.05	-	.41	-	.07	-	.06	-
0.7	21.34	.03	-	.04	-	0.0	-	0.0	-
1.0	30.48	0.0	-	.07	-	0.0	-	.01	-

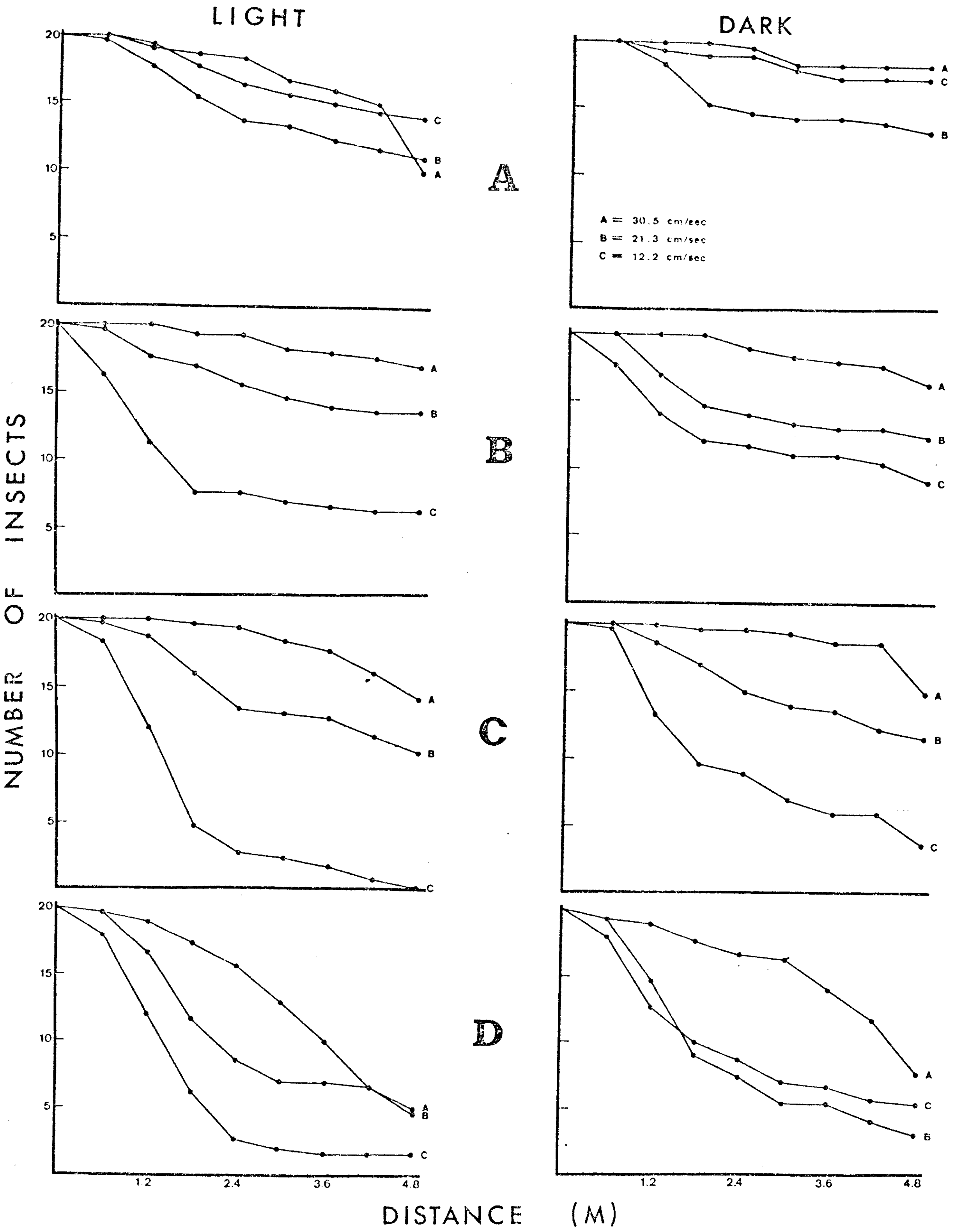

Fig. 17. Settle-out patterns for A. Brachycentrus sp., B. Pteronarcella sp., C. Ephemerella grandis and D. Arcynopteryx sp. at three water velocities under dark and light conditions on a sand substrate.

second and decreased as water velocity increased.

The settle-out patterns of another stonefly, Arcynopteryx, and a caddisfly, Brachycentrus, were highly variable (Fig. 17). Both species had highest settle-out rates under lighted conditions (Table 7). The settle-out rates for Arcynopteryx and Brachycentrus did not appear to be strongly correlated to water velocity, as was found with Ephemerella grandis and Pteronarcella.

Passive settle-out rates, i.e., settle out not resulting from physical activity by the insects, were determined for all test species by using dead specimens (Table 7). Settle-out rates were nearly zero for all test species except Arcynopteryx at a water velocity of 0.4 feet per second. From these results it appears that settle out by live specimens was "active" and not "passive". Settle-out rates determined by Elliott (1971) for dead insects in streams with cobble substrates were substantially higher than values obtained in this study.

Most specimens settled out almost immediately after introduction into the laboratory stream, but began drifting and moving downstream after a short pause. Several species displayed mechanisms for reinitiating drift. Ephemerella grandis folded its legs to begin drifting, then extended them to grasp the substrate and stop; Pteronarcella displayed a "tuck and roll" behavior to begin drift, followed after a few seconds by extension of the legs and grasping the substrate. Several <u>Pteronarcella</u> were observed swimming to the surface where they were held by surface tension and usually drifted the full length of stream. It was noted that most <u>Arcynopteryx</u> settled out very quickly; however, some specimens moved head first down the channel, their legs moving in a swimming manner. Others appeared to reinitiate drift by holding their legs in a [illegible]ed, posteriorly directed position.

Prior to this study it was believed that settle-out rates would be lower on sand than on pebble and cobble. However, laboratory settle-out rates were comparable to those reported by Elliott (1971) from a study conducted in a small, cobble-substrate stream. Higher rates obtained in this study can probably be attributed to the shallow water column and short drift interval. All test species made numerous contacts with the substrate as they drifted. In a deeper water column, as in most natural streams, fewer insect contacts with the substrate would be expected. Behavioral observations of the four test species also indicated that all specimens would probably drift or move the full distance of the channel during a longer test period, thus resulting in lower settle-out rates.

<u>Upstream Dispersion on Sand Substrate</u>. Field and laboratory investigations were undertaken to determine if insect upstream migration on a sand substrate was possible

and serve as an off-setting mechanism for downstream drift. Three large species of insects (*Acroneuria* sp., *Dicosmoecus* sp. and *Pteronarcys californica* Newport) were used to enable visual observation of dispersion in a channel erected on a sandy streambed in Emerald Creek. The stoneflies *P. californica* and *Acroneuria* could not move upstream on sand. After several unsuccessful attempts to crawl upstream, most specimens actively swam downstream usually reaching the end of the channel (16 ft., 4.8 m.) within 2-3 minutes after release. Both species appeared to "glide" along the bottom in a swimming motion. In contrast, the caddisfly *Dicosmoecus* sp. moved in a random manner (i.e., upstream, downstream and cross-channel). Many were noted moving upstream, often reaching the end of the channel in 5-10 minutes. It is believed that this species can successfully colonize an upstream habitat when subjected to an unfavorable substrate at a lower reach.

Laboratory simulation studies were conducted to determine the effect of variable current velocity on possible upstream dispersion of four species of aquatic insects (*Arcynopteryx* sp., *Brachycentrus* sp., *Ephemerella grandis*, and *Pteronarcella* sp.). The stonefly *Arcynopteryx* was partially successful at moving upstream against water velocities of 0.4, 0.7 and 1.0 ft/sec. No *Arcynopteryx* moved upstream more than 2 or 3 inches; most drifted downstream 3-4 inches for every inch travelled upstream. Most *Arcynopteryx* attempted to move upstream but lost their "hold" of the substrate when crawling; net movement of all *Arcynopteryx* was downstream. *E. grandis*, *Brachycentrus*, and *Pteronarcella* did not move upstream against any of the three water velocities. These species could not successfully crawl upstream without becoming dislodged and drifting downstream. *Brachycentrus* makes a case of light weight detrital material, whereas *Dicosmoecus* bears a relatively heavy case of sand. This difference in case weight apparently explains why *Dicosmoecus* can successfully maintain itself and move upstream on sand while *Brachycentrus* can not. As with *Arcynopteryx*, net movement for *E. grandis*, *Pteronarcella* and *Brachycentrus* at all water velocities was downstream.

Results of field and laboratory upstream dispersion studies indicated that many riffle insects were unable to effectively move upstream on sand substrates. Larger substrates having pebble or cobble are necessary for upstream movement (crawling) by many insects even at very low water velocities. It has been shown that a layer of water with zero velocity exists at rock-water interfaces (Ambühl, 1959). McClelland (1972) reported that many insects apparently live in this zone and do not experience the direct forces of currents. This zone is probably very thin on fine, loose sediment; therefore, insects settling out on sand are directly exposed to current forces. The combination of exposure to current and instability of fine sand prohibit movement upstream by many insects.

<u>In-Stream Colonization Potential</u>. Insect drift has been shown to be a major factor in colonizing downstream areas in streams. Upstream migration on cobble substrates has been reported to be between 5 and 30 percent of downstream drift, and would therefore seem to be a significant factor in colonizing rehabilitated or insect denuded substrates (Elliott, 1971; Hultin, Svensson, and Ulfstrand, 1969; Bishop and Hynes, 1969). Insect drift and upstream dispersion investigations in long sandy reaches in Emerald Creek indicate that the unfavorable areas are detrimental to "normal" insect movement and colonization. Low water velocities of these reaches are sufficient for aiding insect movement for great distances. However, settle-out rates appear to increase approximately 200 feet downstream from the riffle, resulting in a decrease in drift rates. Results of the upstream dispersion studies indicate that many riffle insects are unable to move upstream after settling out on fine sediments. As a consequence, many insects are forced to move downstream to avoid the unsuitable habitat. The rate of insect movement at water velocities less than 0.4 feet per second was found to be extremely slow. It is likely that prolonged exposure on a fine substrate in absence of cover could result in abnormally high insect predation rates by fish.

It is apparent from these results that insects successfully drift and crawl through long sedimented reaches in Emerald Creek while others are probably lost during the colonization cycle. Thus, colonization potential of Emerald Creek appears to be reduced by long sedimented runs and pools characteristic of portions of this stream.

CONCLUSIONS

Rehabilitation of a silt polluted stream is largely dependent on two factors: 1) elimination of a source of silt and 2) ability of the stream to flush polluting sediments. This study has demonstrated that the sediment transport capability of Emerald Creek is adequate by natural means or in combination with man-made structures for removal of fine sediments from most reaches. These findings are supported by the improvement of streambed conditions in the East Fork of Emerald Creek since cessation of garnet mining in 1969.

Present mining operations on the main stem continue to introduce large amounts of silt and fine sediments. Gabion wing deflectors in key reaches facilitate sediment transport in localized areas. However, all in-stream alterations will only be moderately effective as long as there is a constant input of polluting sediments. The key to rehabilitating Emerald Creek, or any stream or river, is the elimination or healing of the source of sediment. In-stream devices cannot substitute good hydrologic conditions in a watershed; however, they can accellerate the stream's natural cleansing abilities.

Insect life in severely silt-polluted streams is often reduced or eliminated. Insect recruitment following pollution abatement is usually slow. Prather (1971) showed that insect populations in the main stem of Emerald Creek were lower than those in a pristine stream used as a control. However, insect recruitment following silt removal through successive years of normal or above normal runoffs, would be expected to be rapid because of the residual population present.

It is expected that if the source of fine sediments could be eliminated, Emerald Creek would return to near pre-mining conditons within three to four years. Structural in-stream alterations speed sediment removal, benthic recolonization and provide general habitat improvement for all aquatic life.

SUMMARY

This study was conducted on Emerald Creek, a tributary of the St. Maries River in northern Idaho which is extremely silt polluted due to private and commercial extraction of garnet. Log-drop structures, debris jam removal, channel diversion and gabion deflectors were tested as means for physical and biotic rehabilitation.

Pre- and post-alteration measurements were taken for cobble factor, cobble embeddedness, sediment surrounding cobble, average sediment size and mean channel depth from thirteen permanent transects (4 control, 9 test). In-stream alterations were effective means for increasing sediment transport, thereby improving insect and fish habitat. Debris jam removal, channel diversion, and gabion deflectors caused flushing of fine sediment from runs and pools. Log-drop structures scoured pools, thereby increasing the pool-riffle ratio. Post-alteration analysis of test transects yielded higher values of percent cobble, average sediment size and mean channel depth.

Benthos samples, collected from each transect, were taken at monthly intervals during the summers of 1971 and 1972. Community changes resulting from alteration work were analyzed using a species diversity indice derived from information theory. Diversity, numbers of species and total

numbers tended to increase in post-alteration sampling from the test transects. Insect community changes resulting from in-stream alterations were most pronounced at gabion sites and to a lesser extent at debris jam removal, channel diversion and log-drop sites. Slow-water forms (e.g., Hexatoma sp., Sialis sp., Sigara sp., Tricorythodes minutus and Ophiogomphus sp.) were replaced by common riffle species (e.g., Ephemerella tibialis, Baetis tricaudatus, Pteronarcella sp., Arcynopteryx sp., Hydropsyche sp. and Brachycentrus sp.) following stream alteration.

Sediment transport in relation to the hydrologic cycle was studied using various sizes of tagged sediment. Three sizes of rock (1, 3, and 6-inch) were placed on transects in the streambed; 6-inch and 3-inch cores of tagged pebble and sand, respectively were implanted into the streambed. Results of the tagged sediment study indicate that Emerald Creek has the ability to transport small rock and sand substantial distances. Massive quantities of fine sediment are flushed out of the system during spring run-off in the main stem, followed by sediment redeposition as the water recedes. Rock transport distance was directly related to rock diameter and weight, with smaller rocks displaced the farthest.

Insect drift and upstream dispersion studies were conducted in the field and laboratory to yield insight into colonization phenomena of heavily silted portions of the stream. A regression equation describing insect drift and settle-out was applied to simulation studies in a laboratory stream. Results revealed that long, low-gradient sandy reaches in Emerald Creek were detrimental to normal drift and dispersion. Some insects (e.g., *Ephemerella grandis*, *Pteronarcella* sp.) do not successfully cross such areas and are lost to the down-stream colonization cycle. Laboratory studies showed that settle-out rates on sandy substrates were principally a function of current velocity, light conditions, water depth, and insect species. Upstream dispersion studies revealed that some riffle insects (e.g., the stoneflies *Pteronarcella* sp., *Pteronarcys* sp., and *Acroneuria* sp., the mayfly *E. grandis* and the caddisfly *Brachycentrus* sp.) do not successfully move upstream on sand under low water velocities of 0.5-1.0 ft/sec.

Emerald Creek, by virtue of its natural hydrological cycle, has the ability to flush large quantities of fine sediments annually. However, until the source of polluting sediments is eliminated, lower portions of the main stem will continue to be subjected to a heavy sand burden. In-stream alterations are effective for increasing sediment transport, thereby accelerating physical and biological rehabilitation commensurate with retardation of sediment source.

LITERATURE CITED

Ambühl, H. 1959. Die Bedentung der Strömung als ökologischer Factor. Schweig. Z. Hydrol. 21:133-264.

Anderson, N. H., and D. M. Lehmkuhl. 1968. Catastrophic drift of insects in a woodland stream. Ecology. 49:198-206.

Bartsch, A. F. 1948. Biological aspects of stream pollution. Sewage Works Journal. 20:292-302.

________. 1960. Settleable solids, turbidity and light penetration as factors affecting water quality. Second Seminar on Biological Problems in Water Pollution, Public Health Service, R. A. Taft San. Eng. Cent. Cincinnati, Ohio. p. 118-127.

Bishop, J. E. and H. B. N. Hynes. 1969. Upstream movements of the benthic invertebrates in the Speed River, Ontario. J. Fish. Res. Bd. Canada. 26:279-298.

Bowman, K. O., K. Hutcheson, E. P. Odum and L. R. Shenton. 1971. Comments on the distribution of indices of diversity. In: Statistical Ecol. 1:315-366.

Brillouin, L. 1956. Science and information theory. Academic Press, New York. 320 p.

Brusven, M. A. 1970. Drift periodicity and upstream dispersion of stream insects. J. Entomol. Soc. Brit. Columbia. 67:48-59.

________. 1970. Fluorescent pigments as marking agents for aquatic insects. Northwest. Sci. 44:202-237.

________. (In Press.) A closed system Plexiglas stream for studying insect-fish-substrate relationships. Prog. Fish Cult., Bur. Sp. Fish. and Wildlife.

Buscemi, P. A. 1966. The importance of sedimentary organics in the distribution of benthic organisms. p. 79-86. In Cummins, K. W., C. A. Tryon, and R. T. Hartman (eds). Organism-substrate relationships in streams. Spec. Publ. Pymatuning Lab. of Ecology, U. of Pittsburgh 4:1-145.

Chutter, F. M. 1969. The effects of silt and sand on the invertebrate fauna of streams and rivers. Hydrobiol. 34:57-76.

________. 1970. Hydrobiological studies in the catchment of Vaal Dam, South Africa. Part 1. River zonation and the benthic fauna. Hydrobiol. 55:445-494.

Cummins, K. W. 1961. The micro-distribution of the caddisfly larvae *Pycnopsyche lepida* (Hagen) and *Pycnopsyche guttifer* (Walker) in a restriced portion of a small Michigan stream. Unpubl. Ph.D. dissertation, University of Michigan, Ann Arbor. 158 p.

________. 1964. Factors limiting the micro-distribution of larvae of the caddisflies *Pynopsyche lepida* (Hagen) and *Pycnopsyche guttifer* in a Michigan Stream. Ecol. Monogr. 34:271-295.

________. 1966. A review of stream ecology with special emphasis on organism-substrate relationships. p. 2-51. In Cummins, K. W., C. A. Tryon, and R. T. Hartman (eds). Organism-substrate relationships in streams. Spec. Publ. Pymatuning Lab. of Ecology, University of Pittsburgh. 4:1-145.

Cummins, K. W. and G. H. Lauff. 1969. The influence of substrate particle size on the micro-distribution of stream macrobenthos. Hydrobiol. 34-145-181.

Daubenmire, R. F. 1952. Forest vegetation of northern Idaho and adjacent Washington, and its bearing on concepts of vegetation classification. Ecol. Monogr. 22: 301-330.

Elliott, J. M. 1967. Invertebrate drift in a Dartmoor stream. Arch. Hydrobiol. 63:202-237.

________. 1971. The distances travelled by drifting invertebrates in a Lake District stream. Oecologia 6:350-379.

________. 1971. Upstream movements of benthic invertebrates in a Lake District stream. J. Anim. Ecol. 40:235-252.

Ellis, M. M. 1936. Erosion silt as a factor in aquatic environments. Ecology 17:29-42.

Herbert, D. W. M., J. S. Alabaster, M. C. Dort and R. Lloyd. 1961. The effect of china-clay wastes on trout streams. Int. J. Air Water Pollut. 5:56-74.

Holt, C. S. and T. F. Waters. 1967. Effect of light intensity on the drift of stream invertebrates. Ecology 48:225-234.

Hultin, L., B. Svensson and S. Ulfstrand. 1969. Upstream movements of insects in a South Swedish small stream. Oikos. 20:553-557.

Hynes, C. D. 1969. The immature stages of the genus Rhabdomastix (Diptera:Tipulidae). Pan-Pacific Entomol. 45:229-237.

Hynes, H. B. N. 1960. The biology of polluted waters. Liverpool University Press, Liverpool. 202 p.

Jensen, S. L. 1966. The mayflies of Idaho. Unpubl. Master's thesis, University of Utah, Salt Lake City. 367 p.

Klein, L. 1962. River pollution, II. Causes and effects. Butterworths, London. 456 p.

Krenkel, P. A. and F. L. Parker. 1969. Biological aspects of thermal pollution. Vanderbuilt University Press. 407 p.

Leonard, J. W. 1942. Some observations on the winter feeding habits of brook trout in relation to natural food organisms present. Trans. Amer. Fish. Soc. 71: 219-227.

Linduska, J. P. 1942. Bottom types as a factor influencing the local distribution of mayfly nymphs. Can. Entomol. 74:26-30.

Madsen, B. L. 1969. Reactions of Brachyptera risi (Morton) (Plecoptera) nymphs to water current. Oikos 20:95-100.

Margalef, R. 1957. Information theory in ecology. Gen. Syst. 3:37-71.

McClelland, W. T. 1972. The effects of introduced sediment on the ecology and behavior of stream insects. Unpubl. Ph.D. dissertation, University of Idaho, Moscow. 167 p.

McLay, C. 1970. A theory concerning the distance travelled by animals entering the drift of a stream. J. Fish. Res. Bd. Canada. 27:359-390.

McNeil, W. J. and W. H. Ahnell. 1960. Circular No. 20. Fish. Res. Inst. University of Washington, Seattle.

Müller, K. 1954. Investigations on the organic drift in North Swedish streams. Rep. Inst. Freshwater Res. Drottningholm. 35:133-148.

Patten, B. C. 1962. Species diversity in net phytoplankton of Raritan Bay. J. Mar. Res. 20:57-75.

Pearson, W. D. and D. R. Franklin. 1968. Some factors affecting drift rates of Baetis and Simuliidae in a large river. Ecology 49:75-78.

Peterson, B. V. 1960. Simuliidae of Utah, Part 1. Great Basin Nt. 20.

Pielou, E. C. 1966. Species diversity and pattern diversity in the study of ecological succession. J. Theor. Biol. 10:370-383.

Prather, K. V. 1971. The effects of stream substrates on the distribution and abundance of aquatic insects. Unpubl. Master's thesis, University of Idaho, Moscow. 62 p.

Scott, D. 1960. Cover on river bottoms. Nature 188:76-77.

________. 1966. The substrate cover-fraction concept, p. 75-78. In K. W. Cummins, C. A. Tryon, and R. T. Hartman (eds). Pymatuning Laboratory of Ecology, University of Pittsburgh. 4:1-145.

________, and J. M. Rushforth. 1959. Cover on river bottoms. Nature. 184:836-837.

Shannon, C. E. 1948. A mathematical theory of communication. Bell Syst. Tech. J. 27:379-423.

Shelford, V. E. 1914. An experimental study of the behavior agreement among animals of an animal community. Biol. Bull. 26:294-315.

Smith, D. S. 1968. The Rhyacophila of the Salmon River drainage of Idaho with special reference to larvae. Ann. Entomol. Soc. Am. 61:655-574.

Sprules, W. M. 1947. An ecological investigation of stream insects in Algonquin Park, Ontario. University of Toronto Studies, Biol. Ser. 56:1-81.

Tanaka, H. 1960. On the daily change of the drifting of benthic animals in streams, especially on the types of daily change observed in taxonomic groups of insects. Bull. Freshwater Fish. Res. Lab. 9:13-24.

Tarzwell, C. M. 1937. Experimental evidence on the value of trout stream improvement in Michigan. Trans. Amer. Fish. Soc. 66:177-187.

Thorup, J. 1966. Substrate type and its value as a basis for the delimitation of bottom fauna communities in running waters, p. 59-74. In K. W. Cummins, C. A. Tryon, and R. T. Hartman (eds). Organism-substrate relationships in streams. Spec. Publ. Pymatuning Laboratory of Ecology, University of Pittsburgh 4: 1-145.

Usinger, Robert L. (ed.). 1968. Aquatic insects of California. University of California Press, Berkeley. 508 p.

U.S.D.A. 1969. Wildlife habitat improvement. Forest Service Handbook 2609.11. U.S.D.A., Forest Service. 146 p.

Warren, C. E. 1971. Biology and water pollution control. W. B. Saunders Co., Philadelphia. 434 p.

Waters, T. F. 1962. Diurnal periodicity in the drift of stream invertebrates. Ecology 43:316-320.

________. 1964. Recolonization of denuded stream bottom areas by drift. Trans. Am. Fish. Soc. 93:311-315.

________. 1965. Interpretation of invertebrate drift in streams. Ecology 46:327-334.

________. 1969. Invertebrate drift--ecology and significance to stream fishes. In Symposium on Salmon and Trout in Streams, ed. T. G. Northcote, 121-134. H. R. MacMillan Lectures in Fisheries, Vancouver; Univ. British Columbia.

________. 1972. The drift of stream insects. Ann. Rev. Entomol. 17:253-272.

________, and R. J. Knapp. 1961. An improved stream bottom fauna sampler. Trans. Amer. Fish. Soc. 90:225-226.

Wene, G. 1940. The soil as an ecological factor in the abundance of aquatic chironomid larvae. Ohio J. Sci. 40:193-199.

White, R. J. and O. M. Brynildson. 1967. Guidelines for management of trout stream habitat in Wisconsin. Dept. of Nat. Resources, Div. of Con. Tech. Bull. 39. 65 p.

Wilbur, C. G. 1969. Biological aspects of water pollution. C. C. Thomas, Publisher. 296 p.

Wilhm, J. L. 1967. Comparison of some diversity indices applied to populations of benthic macroinvertebrates in streams receiving organic wastes. J. Water Pollut. Contr. Fed. 39:1673-2252.

________. 1972. Graphic and mathematical analyses of biotic communities in polluted streams. Ann. Rev. Entomol. 17:223-252.

________, and T. C. Dorris. 1968. Biological parameters for water quality criteria. Bioscience 18:477-481.

APPENDICES

Appendix A. Substrate Analysis of Test and Control Transects for Characteristics of Percent Cobble, Average Embeddedness, Average Material Surrounding Cobble and Average Sediment Size in Emerald Creek.

		Site 1-a							
		Section A				Section B			
Dates		% Cobble	Ave. Embed.	Ave. Surr.	Ave.Sed. Size	% Cobble	Ave. Embed.	Ave. Surr.	Ave.Sed. Size
Pre-Alteration	6/24/71	0	-	-	2.75	0	-	-	2.79
	7/2/71	0	-	-	3.13	0	-	-	2.67
	7/13/71	0	-	-	3.63	0	-	-	3.08
	8/10/71	0	-	-	3.63	0	-	-	2.75
Post-Alteration	8/17/71	0	-	-	4.00	0	-	-	2.38
	9/24/71	0	-	-	4.00	0	-	-	2.38
	6/30/72	0	-	-	3.90	0	-	-	3.07
	7/25/72	0	-	-	3.88	0	-	-	2.71
	9/28/72	0	-	-	3.88	0	-	-	1.00

Appendix A. Continued.

				Site 1-b					
		Section A				Section B			
Dates		% Cobble	Ave. Embed.	Ave. Surr.	Ave.Sed. Size	% Cobble	Ave. Embed.	Ave. Surr.	Ave.Sed. Size
Pre-Alteration	7/2/71	0	-	-	3.30	0	-	-	3.50
	7/13/71	0	-	-	3.00	0	-	-	3.75
	8/10/71	0	-	-	3.50	0	-	-	3.00
Post-Alteration	8/17/71	0	-	-	3.00	0	-	-	3.50
	9/24/71	0	-	-	2.67	0	-	-	3.75
	6.30/72	0	-	-	3.33	0	-	-	3.00
	7/25/72	0	-	-	3.42	0	-	-	3.75
	9/28/72	0	-	-	3.17	0	-	-	3.75
				Site 1-c					
Pre-Alteration	7/2/71	0	-	-	2.50	0	-	-	3.17
	7/13/71	0	-	-	2.10	0	-	-	2.83
	8/10/71	0	-	-	3.50	0	-	-	3.00
Post-Alteration	8/17/71	0	-	-	3.50	0	-	-	3.14
	9/24/71	0	-	-	3.07	0	-	-	3.57
	6/30/72	0	-	-	3.25	0	-	-	3.43
	7/25/72	0	-	-	2.58	0	-	-	2.86
	9/28/72	0	-	-	2.67	0	-	-	3.29

Appendix A. Continued.

		Site 2-a											
		Section A				Section B				Section C			
Dates		% Cobble	Ave. Embed.	Ave. Surr.	Ave.Sed. Size	% Cobble	Ave. Embed.	Ave. Surr.	Ave.Sed. Size	% Cobble	Ave. Embed.	Ave. Surr.	Ave.Sed. Size
Pre-Alteration	6/24/71	0	-	-	1.00	0	-	-	1.06	0	-	-	1.00
	7/2/71	0	-	-	1.71	0	-	-	2.29	0	-	-	1.38
	7/13/71	0	-	-	1.19	0	-	-	2.11	0	-	-	1.00
Post-Alteration	8/29/71	0	-	-	1.00	0	-	-	1.00	0	-	-	1.00
	9/24/71	0	-	-	1.00	0	-	-	1.00	0	-	-	1.00
	6/30/72	0	-	-	1.88	0	-	-	2.00	0	-	-	1.00
	7/25/72	0	-	-	1.50	0	-	-	1.22	0	-	-	1.00
	7/28/72	0	-	-	1.00	0	-	-	1.00	0	-	-	1.00
		Site 2-b											
Pre-Alteration	6/24/71	0	-	-	1.00	0	-	-	1.00	0	-	-	2.86
	7/2/71	0	-	-	2.25	0	-	-	2.64	0	-	-	3.08
	7/13/71	0	-	-	2.67	0	-	-	1.71	0	-	-	2.50
	8/3/71	0	-	-	1.50	0	-	-	1.71	0	-	-	1.50
Post-Alteration	8/17/71	17	-	-	3.58	0	-	-	2.00	0	-	-	1.75
	9/24/71	14	-	-	3.29	0	-	-	2.60	0	-	-	1.60
	6/30/72	0	-	-	1.00	0	-	-	2.00	83	2.40	2.40	4.33
	7/25/72	0	-	-	1.00	0	-	-	1.50	67	2.25	2.00	3.67
	9/28/72	0	-	-	1.00	0	-	-	1.00	80	2.25	2.50	4.80

Appendix A. Continued.

		Site 3-a											
		Section A				Section B				Section C			
Dates		% Cobble	Ave. Embed.	Ave. Surr.	Ave.Sed. Size	% Cobble	Ave. Embed.	Ave. Surr.	Ave.Sed. Size	% Cobble	Ave. Embed.	Ave. Surr.	Ave.Sed. Size
Pre-Alteration	6/24/71	16	-	-	3.50	29	2.50	2.25	3.39	0	-	-	2.25
	7/2/71	14	-	-	3.29	14	-	-	4.14	13	-	-	2.63
	7/13/71	12.5	-	-	4.00	14	-	-	3.71	14	-	-	1.86
Post-Alteration	8/18/71	0	-	-	1.43	14	-	-	2.86	14	-	-	1.57
	9/24/71	0	-	-	1.00	25	2.50	1.00	2.00	0	-	-	1.00
	6/30/72	13	-	-	1.50	43	3.00	1.00	3.14	14	-	-	1.57
	7/25/72	0	-	-	1.00	29	2.50	1.00	2.57	0	-	-	1.75
	9/28/72	0	-	-	1.00	25	2.50	1.00	3.13	0	-	-	1.38
		Site 3-b											
Pre-Alteration	6/24/71	0	-	-	1.00	0	-	-	1.06	0	-	-	2.00
	7/2/71	0	-	-	3.00	14	-	-	3.43	50	1.30	1.00	4.00
	7/13/71	0	-	-	3.00	14	-	-	2.00	40	1.00	1.00	2.80
	8/5/71	0	-	-	1.33	14	-	-	1.57	33	1.00	1.00	2.33
Post-Alteration	8/18/71	0	-	-	2.14	14	-	-	1.57	50	2.00	1.00	3.00
	9/24/71	0	-	-	1.00	14	-	-	1.57	17	-	-	2.17
	6/30/72	67	1.17	3.17	4.33	0	-	-	3.88	0	-	-	3.50
	7/25/72	83	1.20	3.60	4.22	0	-	-	2.75	0	-	-	3.00
	9/28/72	40	2.00	1.00	3.80	17	-	-	3.17	0	-	-	1.00

Appendix A. Continued

		Site 3-c											
		Section A				Section B				Section C			
Dates		% Cobble	Ave. Embed.	Ave. Surr.	Ave.Sed. Size	% Cobble	Ave. Embed.	Ave. Surr.	Ave.Sed. Size	% Cobble	Ave. Embed.	Ave. Surr.	Ave.Sed. Size
Pre-Alteration	6/24/71	0	-	-	2.13	0	-	-	2.50	0	-	-	3.39
	7/2/71	0	-	-	2.67	0	-	-	2.81	22	1.00	4.00	4.22
	7/13/71	0	-	-	2.67	0	-	-	2.44	11	-	-	3.78
	8/5/71	0	-	-	3.05	0	-	-	2.75	0	-	-	3.89
Post-Alteration	8/18/71	0	-	-	2.19	17	-	-	3.00	0	-	-	4.00
	9/24/71	33	1.33	3.17	4.33	0	-	-	2.07	0	-	-	1.00
	6/30/72	30	1.00	3.67	4.20	0	-	-	1.22	0	-	-	1.00
	7/25/72	22	1.50	4.00	3.67	0	-	-	1.90	0	-	-	1.00
	9/28/72	11	-	-	3.44	0	-	-	2.89	0	-	-	1.00

		Site 4a-5a											
Pre-Alteration	6/24/71	0	-	-	1.75	0	-	-	1.56	0	-	-	1.11
	7/2/71	0	-	-	1.06	0	-	-	1.44	11	-	-	1.61
	7/13/71	0	-	-	1.00	0	-	-	1.00	11	-	-	1.44
Post-Alteration	8/29/71	0	-	-	1.00	0	-	-	1.17	11	-	-	1.29
	9/24/71	0	-	-	1.00	0	-	-	1.00	11	-	-	1.14
	6/30/72	0	-	-	1.00	0	-	-	1.00	56	2.80	1.00	3.56
	7/25/72	0	-	-	1.00	11	-	-	1.56	44	3.75	1.00	2.78
	9/28/72	0	-	-	1.00	10	-	-	1.40	22	3.00	1.00	1.89

Appendix [illegible]

						Site 4-b							
		Section A				Section B				Section C			
	Date	% Cobble	Ave. Embed.	Ave. Surr.	Ave.Sed. Size	% Cobble	Ave. Embed.	Ave. Surr.	Ave.Sed. Size	% Cobble	Ave. Embed.	Ave. Surr.	Ave.Sed. Size
Pre-Alteration	[illegible]	[illegible]	-	-	1.33	11	-	-	1.44	0	-	-	1.00
Post-Alteration	[illegible]	0	-	-	1.33	22	2.00	2.00	2.56	0	-	-	1.00
	9/24/71	0	-	-	1.00	22	2.00	1.25	3.22	0	-	-	1.00
	[illegible]	[illegible]	2.00	2.25	2.70	90	2.00	3.33	4.60	0	-	-	1.00
	[illegible]	33	2.67	[illegible]	2.67	80	1.50	3.50	[illegible]	0	-	-	1.11
	9/28/72	[illegible]	3.00	1.00	2.56	67	1.83	3.50	[illegible]	[illegible]	-	-	1.23

						Site 4-c							
Pre-Alteration	6/24/71	0	-	-	1.65	0	-	-	1.60	0	-	-	1.56
	7/2/71	0	-	-	1.17	0	-	-	1.27	0	-	-	1.36
	7/13/71	0	-	-	1.00	0	-	-	1.00	0	-	-	1.14
	8/17/71	0	-	-	1.00	0	-	-	1.00	0	-	-	1.00
Post-Alteration	8/29/71	0	-	-	1.00	0	-	-	1.00	0	-	-	1.00
	9/24/71	0	-	-	1.00	0	-	-	1.00	0	-	-	1.00
	6/30/72	27	2.67	1.00	2.09	0	-	-	1.09	55	3.00	3.67	3.50
	7/25/72	18	2.50	1.00	1.73	9	-	-	1.77	36	2.75	3.25	3.27
	9/28/72	18	2.50	1.00	1.73	0	-	-	1.00	27	3.33	1.33	2.23

Appendix A. Continued.

		Site 5-b											
		Section A				Section B				Section C			
Dates		% Cobble	Ave. Embed.	Ave. Surr.	Ave.Sed. Size	% Cobble	Ave. Embed.	Ave. Surr.	Ave.Sed. Size	% Cobble	Ave. Embed.	Ave. Surr.	Ave.Sed. Size
Pre-Alteration	8/19/71	0	-	-	1.00	11	-	-	1.44	33	3.67	1.00	2.33
Post-Alteration	8/29/71	0	-	-	1.00	0	-	-	1.33	56	2.80	1.00	3.23
	9/24/71	0	-	-	1.00	13	-	-	1.50	56	2.60	1.00	3.22
	6/30/72	40	2.50	1.00	2.90	20	1.50	1.00	2.45	78	2.14	1.00	4.39
	7/25/72	30	2.00	1.00	2.50	25	1.50	1.50	2.50	70	2.57	2.29	4.40
	9/28/72	22	2.00	1.00	2.89	10	-	-	2.00	40	2.00	1.75	3.50
		Site 5-c											
Pre-Alteration	6/24/71	0	-	-	1.00	29	3.50	1.00	2.14	29	2.50	1.00	3.00
	7/2/71	0	-	-	1.00	0	-	-	1.00	50	2.50	1.00	3.39
	7/13/71	0	-	-	1.00	0	-	-	1.00	50	2.75	1.00	3.75
	8/19/71	0	-	-	1.00	13	-	-	1.50	43	2.33	1.00	3.14
Post-Alteration	8/29/71	0	-	-	1.00	13	-	-	1.50	50	2.25	1.00	4.13
	9/24/71	0	-	-	1.00	0	-	-	1.00	38	2.30	1.00	3.25
	6/30/72	0	-	-	1.00	0	-	-	1.00	100	2.00	1.75	5.00
	7/25/72	0	-	-	1.00	9	-	-	1.00	75	1.60	2.80	4.63
	9/28/72	0	-	-	1.00	0	-	-	1.00	50	2.00	1.00	3.75

Appendix B. Checklist and relative abundance* of insect species from 5 sites (13 transects) in Emerald Creek before (A) and after (B) in-stream alteration.

Species	Transects 1-a		1-b		1-c		2-a		2-b		3-a		3-b		3-c		4a-5a		4-b		4-c		5-b		5-c	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
EPHEMEROPTERA																										
Ameletus sp.	r	r	r	c	r	c	r	r	r	c	r	r		r	r	c	r	r				r		r	r	
Baetis bicaudatus Dodds	r	r	r		r					r					c	r				r						
Baetis tricaudatus Dodds	c	c	c	c	c	r	r	r	r	c					c	r				r				r	r	
Centroptilum sp.	r	r	r	r	r	r	r	r	r	r	c	c	r	r	r	c	r	r	r	r	r	c	c	r	r	r
Cinygmula sp.	r	c	r	r	r	c				r				r	r	c				r						
Epeorus albertae (McDunnough)	r									r				r	c	c				c				r		
Epeorus longimanus (Eaton)		r								r										r						
Ephemerella coloradensis (Dodds)														r												
Ephemerella doddsi Needham																				r		r				
Ephemerella edmundsi Allen	r	r	r		r																					
Ephemerella flavilinea McDunnough	r	r			r				r	c	r	r	r	r	c					c		r		r		
Ephemerella grandis Eaton	r	r	r	c	r	r			r	r	r	r	r	c	r	c				r				r		
Ephemerella hecuba Eaton			r	r				r	r	r	r	r	r	c	r	r	r	r	r	r	r	r		r	r	r
Ephemerella hystrix Traver																				r		r				
Ephemerella inermis Eaton	r	r	r	r	r	r	r	r	r	r	a	a		a		r	r			r				r		
Ephemerella margarita Needham				r			r	r	r		r	r	r	c	r	c	r			r	r	r		r	r	r
Ephemerella spinifera Needham	r	r	r																							
Ephemerella teresa Traver	c	c	c	c	r	r	c	c	r	c	r	r	r	c					r	r			r		r	
Ephemerella tibialis McDunnough	a	c	c	c	c	r	r	r	r	a			r	c	a	c				r		r		r		
Heptagenia criddlei McDunnough	r	r	r		r	r				r	r		r	r	c	c	r			r		r	r	r		
Paraleptophlebia bicornuta (McDunnough)			r	r			r	r	r		c	c	c	c		r		r	r	r		r	r	r	r	r
Paraleptophlebia debilis (Walker)		r	r	r	r		r	r	r		r	r	r	r		r		r		r			r	r		

Appendix B. Continued.

Species	Transects																									
	1-a		1-b		1-c		2-a		2-b		3-a		3-b		3-c		4a-5a		4-b		4-c		5-b		5-c	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Paraleptophlebia heteronea	r	r	c	c	r	r		r	r		r	r	r	r	c	r				r						
(McDunnough)																			r							
Pseudocloeon sp.		r		r																		r				
Rhithrogena robusta Dodds							r	r																		
Tricorythodes minutus Traver											c	c	c	r	r	r	r	r	r	r	r	r	r	r	r	r
ODONATA																										
Ophiogomphus sp.													r		r						r			r		r
PLECOPTERA																										
Acroneuria sp.	r	r	r	r	r	r				r				r	r	r	r									
Alloperla sp.	c	c	c	c	c	c	r	r	r	c	r	r	r	c	c	c				r	r	r	r	r	r	
Arcynopteryx sp.	r	r	r	c	r	r		r	r	r				r	r	r		r		r		r		r	r	r
Isogenus sp.	r	r	r		r																					
Leuctra sp.		r	r	r			r	r	r	r																
Nemoura sp.	r	r	r	r	r	r			r	r		r		r	r	r										
Paraperla sp.	r	r												r		r				r						
Pteronarcella sp.										r					r					r						
Pteronarcys californica Newport															r	r										
HEMIPTERA																										
Gerris sp.													r		r		r									
Sigara sp.							r	r	r	r	r	r	r		c	r	r	c	r	r	r	c	r	r	r	r
NEUROPTERA																										
Sialis sp.							r	r	r		r	r	r	r	r	r		r	r			r		r	r	
COLEOPTERA																										
Brychius sp.							r	r		r	r	r	r	r			r	r	r	r			r	r	r	
Cleptelmis ornata (Schaeffer)	r	r	r		r	r	r		r	r				r	r	r						r				

Appendix B. Continued.

Species	Transects																									
	1-a		1-b		1-c		2-a		2-b		3-a		3-b		3-c		4a-5a		4-b		4-c		5-b		5-c	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Dubiraphia sp.											r								r		r	r		r	r	
Heterlimnius *corpulentus* (LeConte)	c	r	r	c	r	r			r	r		r			r				r	r						
Lara sp.	r							r																		
Narpus *concolor* LeConte	r	r	r	r	r	r			r																	
Optioservus *seriatus* (LeConte)	c	c	c	c	r	r	r	r	r	r	r	r	r	c	a	a	r	r		c	r	r	r	r	r	r
Oreodytes sp.	r	r	r	r	r	r	r	r	r		r	r	r	r	r	r		r	r	r	r	r	r	r	r	r
Zaitzevia *parvula* Horn	r	r	r	r	r		r	r	r	r	r	r	r	r	r	r				r					r	r
TRICHOPTERA																										
Agraylea sp.				r		r		r			r	r		r	r	r										r
Arctopsyche *grandis* (Banks)		r	r			r				r																
Athripsodes sp.																	r	r		r	r	r		r		r
Brachycentrus sp.																	r		r	r	r	r	r	r		
Cheumatopsyche sp.											r	r	r	r	r	r				r	r			r		
Dicosmoecus sp.				r										r	r	r				r					r	
Glossosoma sp.	r	r													r	r				r		r				
Hydropsyche sp.	r									r	r		r		r	r				r				r	r	
Lepidostoma sp.		r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r		r	r	r
Micrasema sp.	r	r	r	r	r	r			r						r			r		r						
Neophylax sp.	r	r	r	r		r			r						r										r	
Neothremma sp.								r						r		r										
Parapsyche sp.																				r				r		
Polycentropus sp.				r	r					r																
Psychomyia sp.											r	r		r		r										r
Phryganeidae												r				r						r		r		
Rhyacophila *acropedes* Banks	r	r	r	r																						
Rhyacophila *angelita* Banks																r				r						
Rhyacophila *vepulsa* Milne	r	r	r	c	r	r																				

Appendix B. Continued.

	Transects																									
Species	1-a		1-b		1-c		2-a		2-b		3-a		3-b		3-c		4a-5a		4-b		4-c		5-b		5-c	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Wormaldia sp.	r	r	r							r	r		r	r	r											
DIPTERA																										
Antocha monticola Alexander		r									r	r	r	r	r											
Atherix variegata Walker			r	r	r			r	r	r	r	r	r	r	r	r				r						r
Chironomidae	c	c	c	c	r	r	c	c	c	r	c	c	c	c	c	r	c	c	a	c	c	c	a	c	c	a
Dicranota	r	r	r	r	r	r	r	r	r	r	r	r	r		r											
Empididae	r	r	r	r	r				r																	
Forcipomyia sp.							r	r			r	r														
Hexatoma sp.	r	r	r	r	r	r	c		r	r	c	c	c	c	r	r	c	c	c	r	c	r	c	r	c	r
Limnophila sp.				r			r	r		r		r		r						r				r		r
Liriope sp.				r			r	r	r						r											
Palpomyia sp.		r	r				r	r	r		r	r	r	r	r							r	r		r	r
Prosimulium sp.	r	r	r	r	r				r						r											
Rhabdomastix sp.	r		r	r	r		r		r	r	r	r														
Simulium sp.	r	r	r	r	r	r			r	r	r			r	r			r								
Tabanus sp.	r						r		r		r		r		r	r	r	r	c		r	r	r	r	r	r
Tipula sp.	r	r	r	r		r											r									

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* Relative abundance based on average pre- and post-alteration densities. a = abundant (>50 insects); c = common (10-50 insects); and r = rare (<10 insects).