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INFLUENCE OF FINE SEDIMENT ON MACROINVERTEBRATE COLONIZATION OF SURFACE AND HYPORHEIC STREAM SUBSTRATES

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ABSTRACT.—Colonization of macroinvertebrates was assessed in a stream impacted by inputs of fine sediments. Colonization was examined at the stream surface and within the hyporheos with Whitlock-Vibert (W-V) boxes. Hyporheic areas accumulated much greater amounts of all size categories of sediment. No significant difference was observed in the amounts of organic matter accumulated at either depth. Only 150-μm sediment had significant effects on macroinvertebrate total numbers and number of taxa. Total numbers of invertebrates at 30 cm were only 20% of those at the surface. Canonical Correspondence Analysis indicated that the strongest influence on macroinvertebrates colonizing W-V boxes at the surface was stream size and secondarily fine sediments. Within the hyporheos, abundance of fine sediment was the dominant influence on macroinvertebrate assemblages. Impacts of sedimentation on hyporheic environments can have significant and persistent impacts on streams.

Key words: stream ecology, hyporheos, sediment, organic matter, macroinvertebrate.

The addition of fine substrates to streams can result in significant changes to stream macroinvertebrate assemblages. Substrate plays an important role in structuring stream macroinvertebrate assemblages. Numerous studies (see Minshall 1984) have demonstrated the importance of both substrate type and size in determining distributions of specific taxa. In general, the number of taxa and productivity of substrates composed of small particle sizes are less than those of larger, more heterogeneous substrates (Pennak and Van Gerpen 1947, Allan 1975, Ward 1975). Reduced invertebrate utilization and production from small substrates may be attributed to a variety of reasons, ranging from the need of some insects for large particles for attachment, to the need for interstitial pore space for movement among substrate particles. Macroinvertebrate responses to variation in substrate size and composition can result in distribution patterns that are observed within streams longitudinally (Allan 1975) and among several streams within a region (Richards et al. 1993).

The addition of fine substrates to streams may also affect macroinvertebrate abundance and distribution in the hyporheos. Taxa within the hyporheic region of streams can be found as deep as 70 cm below the stream bottom (Williams and Hynes 1974). The benthic assemblage within the hyporheic region is associated with overall stream productivity and surface assemblage structure (Strommer and Smock 1989, Ward 1989). Because macroinvertebrates utilize the hyporheos during all seasons, this area can provide a refuge for new colonists following high flows or other disturbance events (Williams 1984, Palmer et al. 1992). Alterations to physical characteristics of the hyporheos could cause significant changes in the dynamics of macroinvertebrate populations that utilize these areas.

This study was undertaken to determine whether fine sediment inputs from both point and nonpoint sources influenced macroinvertebrate assemblages along the length of a stream in central Idaho. We hypothesized that assemblage structure could be related to the proportion of fines in surface and hyporheic substrates.

METHODS

Study Area

The study was conducted in Bear Valley Creek, a headwater tributary to the Middle Fork of the Salmon River watershed in central Idaho. The stream flows through subalpine meadows and lodgepole pine (*Pinus contorta*)

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forests on a granitic batholith. Alluvial deposits of erosive sandy soils typify the region. Historically, the stream had high secondary productivity and supported large populations of anadromous salmonids. Since the 1950s, however, large volumes of fine, inorganic sediments have entered the stream through both point and nonpoint sources along the length of the stream (Konopacky et al. 1986). Consequently, stream substrates have high proportions of fine sediments in many areas, and fish production has declined partly as a result of sediment introduction.

Experimental Method

To examine whether sediment influences macroinvertebrates assemblages, we conducted colonization studies at 19 sites along a 50-km section of Bear Valley Creek. Colonization studies are effective means of examining the dynamics of stream macroinvertebrate assemblages and have been used extensively in many streams and geographic areas (Robinson et al. 1990, Mackay 1992). Study sites were located in riffle habitats at approximately even intervals along the length of the stream. Sites reflected the full range of substrate characteristics found in the stream, including low proportions of fine sediments and high proportions of sediments.

At each site, stream width, gradient, and substrate composition were assessed. Substrate was assessed by determining the proportion of surface particles <4 mm in diameter. One hundred points were randomly selected along a transect that bisected the study riffles, and the closest substrate particle to each point was measured. This size class corresponds well to proportions of smaller-sized surface substrate particles in Bear Valley Creek (Konopacky et al. 1986).

We used small basket samplers (Whitlock-Vibert [W-V] boxes; Wesche et al. 1989) for macroinvertebrate colonization. The polypropylene (14 × 6.4 × 8.9-cm-deep) boxes enclosed a known volume of standardized substrate that allowed comparisons among sites. These boxes are typically used to incubate fish eggs in stream gravels (Federation of Fly Fishermen personal communication). The sides, top, and bottom of the boxes are perforated with rectangular slots (3.5 × 13 mm) to allow water circulation. The bottom of each box was covered with duct tape to reduce sediment loss. Boxes were filled with 3/4-inch-grade clean gravel. This readily available substrate approximates the size of clean gravels in Bear Valley Creek. Two boxes were placed at each site: one approximately 30 cm below the surface of the substrate (using a small shovel) and the other flush with the surface directly above the below-surface box. Both boxes were located in the center of the stream channel. Boxes were placed in the substrate the last week of July 1988 and retrieved 10 weeks later. During this period little or no rainfall was received in the area, and the stream was in a baseflow condition.

Colonization was examined in relation to variation in fine sediments that accumulated in the boxes. Fine sediment accumulation in W-V boxes has been shown to be correlated with the amount of fines in surrounding substrates in streams and laboratory channels (Wesche et al. 1989). W-V boxes were removed from the stream as carefully as possible so as to retain any fine substrate materials and macroinvertebrates in the boxes. While still under water, the W-V box was slipped into a plastic bag with minimal disturbance. The lower box was removed in the same way after excavating the substrate material between the upper and lower boxes. Material from the boxes was preserved in 10% formalin. In the lab the 3/4-inch-grade gravel was removed from the samples with a large sieve. Macroinvertebrates were removed from these samples under a dissection microscope, identified to family, and enumerated. The remaining material was divided into portions that collected on 150-μm and 850-μm sieves. These portions were dried at 60°C and then ashed in a muffle furnace to obtain a weight for organic and inorganic (fine sediment) fractions. The 850-μm sieve collected material ≤ 3.5 mm in diameter. Sediment particle sizes <4 mm are frequently implicated in negative impacts on the abundance of stream invertebrates and productivity (Nuttall 1972, Alexander and Hansen 1986). Smaller particle sizes (<850 μm) include clay-sized particles that also decrease invertebrate abundance (Cederholm and Lestelle 1974) and clog interstitial spaces.

Differences in sediment and organic accumulation between surface and below-surface boxes were examined by group comparisons, as were macroinvertebrate assemblage comparisons (species richness, total numbers).

Macroinvertebrate assemblage composition among the sites was examined with multivariate direct gradient analysis (Canonical Correspondence Analysis; ter Braak 1986, 1987). Macroinvertebrate data were log transformed prior to analysis. In CCA, axes are selected to be linear combinations of environmental variables so that taxa are related directly to a set of these variables. This technique is particularly useful for examining the relative strength of various environmental variables on influencing assemblage composition (ter Braak and Prentice 1988, Richards et al. 1993). Environmental variables used in the analysis were sediment and organic accumulations in the boxes, proportion of 4-mm surface sediments in riffles, gradient, and stream width. The latter two variables were included to account for some differences in stream size and channel morphology among the sites.

RESULTS

The width of the study sites ranged from 2.9 to 24 m (mean = 8.57). The proportion of sediments <4 mm in diameter in riffles varied from 0 to 56% (mean = 8.6); all sites had gradients <2% (mean = 0.47).

A much larger amount of fine sediment accumulated in the below-surface boxes than in the surface boxes (t test, $p < .05$; Table 1). This was true for both the 850-μm and 150-μm size classes. There was no significant difference in the amounts of organic material that accumulated between treatments for either size class.

Twenty-two macroinvertebrate families were identified from the W-V samplers (Table 2). With the exception of Perlidae, Ceratopogonidae, and Tabanidae, all taxa were found in both surface and below-surface locations. Significantly ($p < .05$) greater numbers of taxa and total numbers of individuals per box were found in the surface samples (Table 2). The most abundant taxa in below-surface samples were Heptageniidae, Leptophlebiidae, Chloroperlidae, and Chironomidae. These taxa also had relatively high abundance in surface samples. Baetidae and Ephemerillidae had relatively high abundance in the surface samples but were not well represented in below-surface samples. No taxa were more abundant in below-surface samples than in surface samples.

Pearson correlation coefficients were calculated between each size class of sediment and taxa richness and total number of individuals to determine whether fine-sediment variables had relationships to macroinvertebrate assemblage characteristics. Separate calculations were made for surface and below-surface samples. No significant correlations ($p < .05$) were found with surface samples. In below-surface samples a significant correlation ($p < .05$) was observed between the 0.15-mm sediment size class and both number of taxa and total numbers of individuals (Fig. 1), but no significant correlations were found with the 0.85-mm size class.

Results of the CCA analysis for surface samples indicated that sediment accounted for a relatively small proportion of the variance in assemblage composition among sites. The first axis, which described the greatest amount of variation in the ordination, was most strongly influenced by gradient and width (Table 3). This axis differentiated the taxa most abundant at sites with high stream gradient and narrow widths from those taxa most abundant at sites with low gradient and wide widths. These data suggest that longitudinal position of the station along the stream course played the greatest role in determining assemblage composition. Nematodes, Ceratopogonidae, Hydropsychidae, and Pteronarcyidae were found in narrow, high-gradient sites, and Rhyacophilidae and Hydracarina were found at

TABLE 1. Macroinvertebrate numbers and sediment and organic material accumulations in experimental colonization boxes. * denotes a significant difference ($p < .05$, t test) between surface and below-surface boxes.

	Surface		Below-surface	
Variable	Mean	Std. dev.	Mean	Std. dev.
850-μm sediment* (gr/box)	11.01	11.22	101.01	51.04
150-μm sediment* (gr/box)	11.44	17.98	79.76	50.74
850-μm organic (gr/box)	0.435	0.460	0.572	0.359
150-μm organic (gr/box)	0.643	0.679	0.706	0.438

Table 2. Macroinvertebrate taxa that colonized surface and below-surface W-V boxes.

Taxa	Surface		Below-surface	
	Mean	Std. dev.	Mean	Std. dev.
Baetidae (BAE)	38.02	50.13	3.84	8.51
Ephemeriliidae (EPH)	35.49	45.53	3.50	5.05
Heptageniidae (HEP)	54.81	60.59	10.96	27.68
Leptophlebiidae (LET)	36.05	37.96	23.80	25.70
Siphlonuridae (SIP)	7.89	20.03	2.96	6.78
Brachycentridae (BRA)	5.81	15.96	0.11	0.48
Hydropsychidae (HYD)	1.75	6.66	0.22	0.66
Hydroptilidae (HYP)	10.03	20.78	0.22	0.66
Lepidostomidae (LEP)	58.28	106.43	2.19	4.52
Limniphilidae (LIM)	12.58	18.95	1.53	3.00
Rhyacophilidae (RHY)	0.66	1.96	0.11	0.48
Chloroperlidae (CHL)	27.35	28.25	12.01	11.75
Perlidae (PED)	0.77	1.88	0.00	0.00
Perlodidae (PER)	5.47	8.27	0.77	1.98
Pteronarcyidae (PTE)	0.77	1.73	0.11	0.48
Ceratopogonidae (CER)	0.55	1.94	0.00	0.00
Chironomidae (CHI)	718.15	868.08	414.84	618.80
Tabanidae (TAB)	3.40	13.82	0.00	0.00
Tipulidae (TIP)	9.65	16.35	5.38	10.08
Elmidae (ELM)	9.75	23.07	2.74	5.24
Annelid (ANN)	10.44	28.29	1.33	2.54
Mollusca (MOL)	11.07	34.45	3.40	7.64
NUMBER TAXA/BOX	11.3	3.24	7.0	2.62
TOTAL NUMBER/BOX	1120.3	1087.5	492.8	641.33

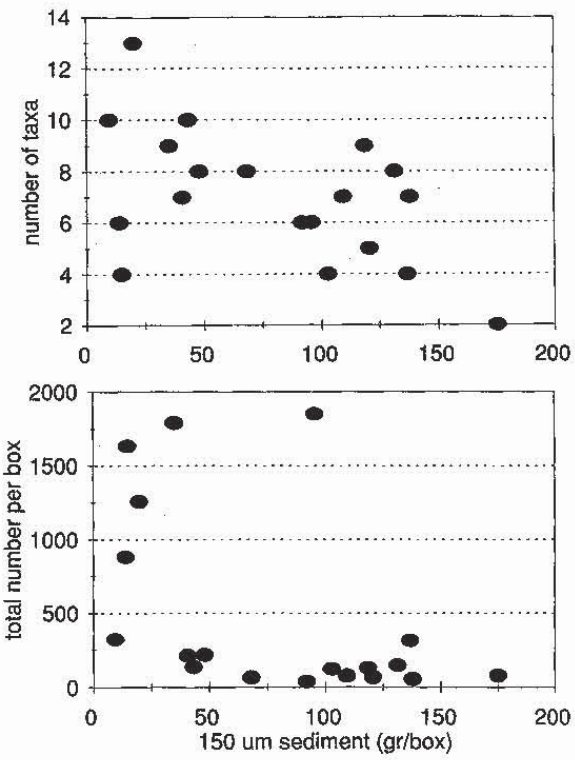

Fig. 1. Correlations between number of taxa ($r = -.52$, $p < .05$) and total numbers of individuals ($r = -.48$, $p < .05$) and the amount of fine sediment that accumulated in W-V boxes within the hyporheos.

low-gradient, wide sites (Fig. 2). The second axis was most strongly influenced by total organic weight and width. No environmental variables had strong ($r < .35$) correlations with the third axis.

Sediment was more important in defining differences in assemblage composition among below-surface samples. The 0.85-mm and 0.15-mm sediment volumes had highest correlations with the first CCA axis (Table 3). These variables acted in an opposite manner. The majority of taxa were associated with decreasing amounts of 0.15-mm sediment; however, Brachycentridae and Hydroptilidae were most abundant at sites with relatively high amounts of 0.15-mm sediment (Fig. 2). Gradient and width had the highest correlations with the second axis. There appeared to be little correspondence between taxa preferring high-gradient, narrow sites or low-gradient, wide sites in below-surface samples and above-surface samples (Fig. 2). Taxa preferring high-gradient sites were Mollusca, Perlodidae, and Tipulidae. Hydracarina, Elmidae, and Siphlonuridae preferred wide, low-gradient sites. As with surface samples, the third axis was difficult to interpret.

TABLE 3. Correlations between environmental variables and CCA axes. Percentages refer to the proportion of variance in species data explained.

Above surface	Axis 1 (17.3%)	Axis 2 (9.6%)	Axis 3 (8.0%)
Surface sediment (<4 mm)	0.01	0.32	0.17
Box sediment (850 μm)	0.14	0.29	–0.13
Box sediment (150 μm)	–0.28	0.19	0.06
Total organic weight	0.03	0.64	0.13
Gradient	0.51	–0.47	–0.28
Width	–0.53	0.53	–0.32
Below surface	**Axis 1 (9.3%)**	**Axis 2 (7.5%)**	**Axis 3 (6.0%)**
Surface sediment (<4 mm)	–0.10	0.17	0.30
Box sediment (850 μm)	0.40	0.34	–0.03
Box sediment (150 μm)	–0.60	–0.01	0.17
Total organic weight	0.28	0.38	0.38
Gradient	0.02	0.60	–0.18
Width	–0.10	–0.61	0.42

DISCUSSION

Colonization patterns on the stream surface were most strongly influenced by variation among sites with respect to stream size and gradient and not fine-sediment abundance. Several other studies within the Middle Fork of the Salmon River basin also found that macroinvertebrate assemblages exhibit predictable changes with increasing stream size (Bruns et al. 1982, 1987, Bruns and Minshall 1985). In our study the available pool of colonists probably shifted within the study area and masked our ability to examine fine-sediment impacts. Within the 60-km study region on Bear Valley, the stream increases from a first- to a fourth-order stream and exhibits longitudinal changes in channel morphology and riparian characteristics along this gradient that influence macroinvertebrate assemblage composition (Bruns et al. 1982, 1987). Surface substrate characteristics played a secondary role to other stream features in influencing macroinvertebrate abundance. However, this does not mean that substrates do not influence macroinvertebrate distributions on surface substrates. Other studies of sediment effects in the Bear Valley watershed found that biomass of macroinvertebrate drift from sand substrates was less than that from larger substrates (Konopacky 1984) and that macroinvertebrate densities were greater in riffles with low amounts of fines than riffles with higher proportions (Bjornn et al. 1977). Both studies were conducted within relatively small areas that did not encompass longitudinal variation in stream characteristics.

Fine-sediment abundance did have distinct effects on macroinvertebrate colonization within the hyporheos. The greatest effect was with the smallest sediment size class (<1.50 mm). Sediment particles in this size range may have the most potential for clogging interstitial spaces within gravel. Although most sediment studies have not explicitly assessed impacts of sediments in this size range on macroinvertebrates, at least one study (Cederholm and Lestelle 1974) noted that particles <0.84 mm in diameter had strong negative correlations with total number of stream invertebrates. In addition, particles <1 mm in diameter are known to reduce availability of dissolved oxygen in stream gravels (Tagart 1984), and clay-sized silt impairs periphyton production in riffles (Graham 1990).

Our results suggest that macroinvertebrate habitat in Bear Valley Creek is impaired because of fine-sediment abundance in the hyporheos. Cobble and gravel bed streams without high proportions of sediment in the hyporheos typically exhibit much less difference in macroinvertebrate composition and abundance between surface and hyporheic zones than we observed in this study. For example, Coleman and Hynes (1970) found little differentiation in macroinvertebrate numbers in the upper 30 cm of substrate. Williams and Hynes (1974) reported differences among near-surface and below-surface macroinvertebrate assemblages; however, they found total numbers at 30-cm depth were typically at least 50% of those near the surface. In Bear Valley, total numbers at 30 cm were only 22% of those near the surface. Bear Valley

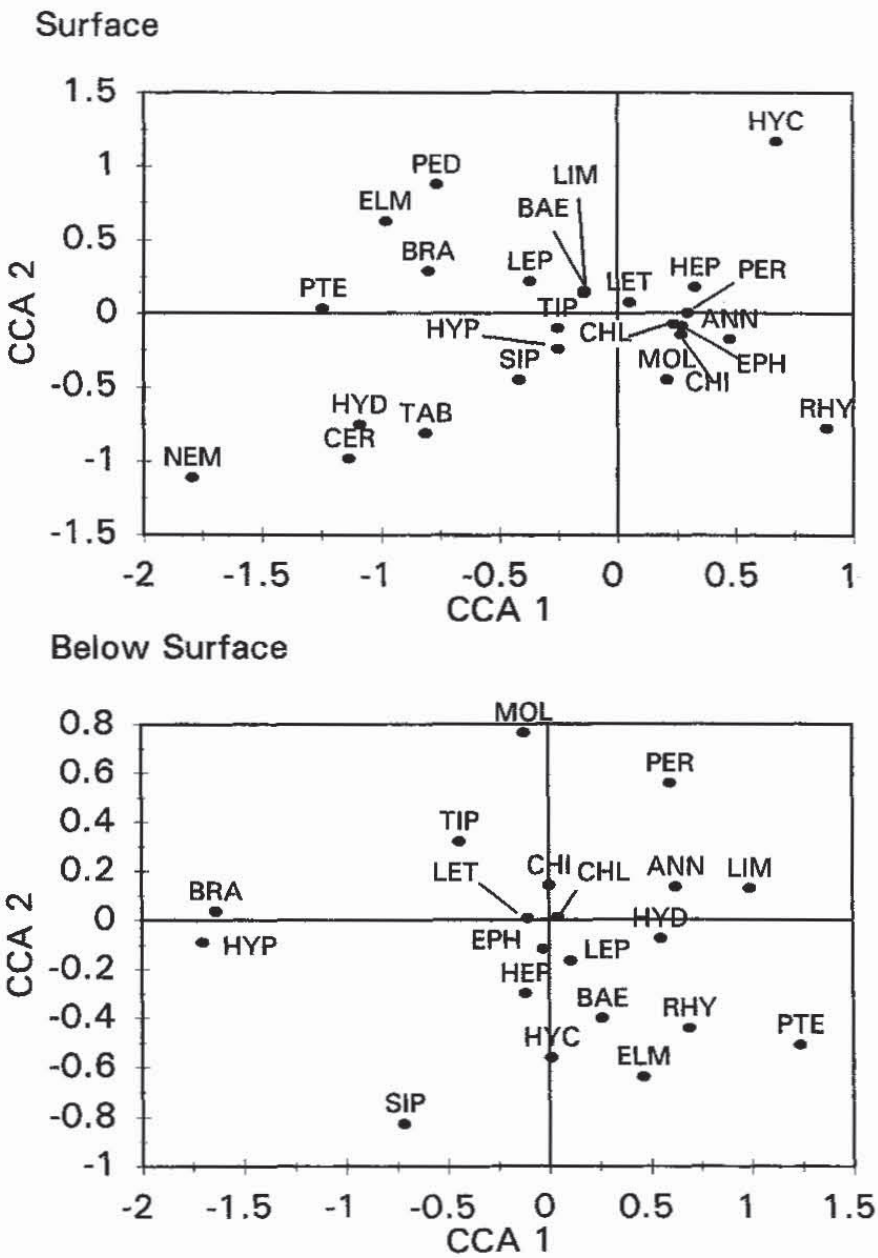

Fig. 2. Ordination of macroinvertebrate taxa with respect to environmental variables in surface and hyporheic areas.

results are more similar to those reported from streams with high proportions of fine sediment in the hyporheos, such as those examined by Poole and Stewart (1976) and Strommer and Smock (1989), who found that total numbers at approximately 30-cm depth were at least 80% less than those near the surface. Both studies attributed these differences to high proportions of fines in the hyporheos that altered physical habitat and subsurface water flow.

High proportions of fine sediment within the hyporheos of Bear Valley Creek may significantly decrease available habitat for macroinvertebrates and therefore limit potential secondary production in the stream. Our study suggests that the hyporheos should be included when assessing impacts of sediment additions to stream ecosystems. Since macroinvertebrate assemblages exhibit consistent long-term changes to watershed activities that influence substrate characteristics

(Richards and Minshall 1992), dramatic and potentially persistent effects can be initiated through the introduction of fine sediments into the hyporheos.

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