The influence of highway construction on the macroinvertebrates and epilithic algae of a high mountain stream

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Abstract

The response of a high elevation Rocky Mountain stream to highway construction activities was investigated over a three-year period during the ice-free season. Suspended solids and the proportion of fine sediment in the substrate increased at impacted sites, but rapidly returned to levels similar to reference sites following cessation of construction activities. During snowmelt runoff when suspended solids levels increased, there was little or no sedimentation of fine particles, even in depositional areas. At impacted sites algal species diversity and the organic content of the epilithon were reduced, and the detrital component was increased. The epilithon recovered less rapidly than suspended solids or substrate. The macroinvertebrate community was altered by construction activities at some locations but not others, and was generally less severely affected than anticipated. However, where an alteration occurred, reduction in density, abundance, and diversity were apparent, and the taxonomic composition was modified. The severity of the response was a function of the flow regime and the timing and duration of the impact at a given site. The hydrologic regime and high gradient of the study stream appeared to ameliorate to some extent the potentially adverse effects of short-term perturbations engendered by highway construction activities.

Introduction

An understanding of the responses of biotic communities to perturbation is important not only in assessing man-induced changes, but also may provide insight into the structure and function of natural systems. Several recent volumes treat perturbation theory and processes of ecosystem recovery and restoration (e.g., Holdgate & Woodman 1978; Thorp & Gibbons 1978; Cairns 1980; Barrett & Rosenberg 1981). Virtually no data are available, however, on the responses of high elevation streams to anthropogenic alterations such as highway construction.

Paleolimnological evidence shows that road construction activities have had a demonstrable impact on aquatic organisms at least as long ago as Roman times (Hutchinson *et al.* 1970). Studies of contemporary activities have largely dealt with effects of logging roads on sediment production (e.g., Frederiksen 1970; Megahan & Kidd 1972). Few investigators have addressed the influence of highway construction on stream biota (King & Ball 1964; Burns 1972; Porter *et al.* 1974; Huckabee *et al.* 1975; Barton 1977; Extence 1978; Nixon 1978; Lenat *et al.* 1981), and even some of these studies treated biotic responses only secondarily. We know of no such previous study conducted on a high mountain stream.

In this paper we examine the effects of building a highway over a mountain pass in northern Colorado on the benthic algae and macroinvertebrates of a high elevation stream. It was our contention that the biotic components of such a lotic system would be especially sensitive to perturbation. Data on fishes were also collected, but because of special

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analytical problems related to the high mobility of these organisms, the results will be presented elsewhere.

Study area

Joe Wright Creek, a small tributary of the Cache la Poudre River, drains the east slope of Cameron Pass 113 km southwest of Fort Collins, Colorado. The stream segment studied ranges in elevation from 2 716 to 3 045 m a.s.l. with an average gradient of 3%. Cobble and boulder substrate predominate. Preconstruction riparian vegetation consisted of alder *(Alnus tenuifolia),* willows (*Salix* spp.), englemann spruce *(Picea englemanni),* and various grasses and sedges.

Stream waters were soft, low in total dissolved solids (TDS), and exhibited near neutral pH (Table 1). Waters were at least 90% saturated with oxygen at all locations. These variables, which were not appreciably affected by construction activities, exhibited values typical for headwater Rocky Mountain streams. A more detailed description of physico-chemical conditions is in preparation. The high discharge at Sites 7 and 8 resulted from withdrawal of impounded waters for irrigation during the sampling period.

Methods

Sampling was conducted biweekly over a three-year period (1975–1977) during the ice-free season (May–October). The sampling program was designed to follow the progressive upstream movement of construction activities.

Eight sites were sampled during the study (Fig. 1). Because of the sampling design, most sites were not sampled for the entire three year period. Study sites were located at riffles where sampling was conducted in fast water (erosional) areas. However, based upon results from the first two years, the sampling program was expanded during the third year to also include substrate and macroinvertebrate samples from slow water (depositional) areas at each location.

Construction activities crossed or paralleled Joe

Table 1. Mean values of selected physico-chemical variables during the ice-free season (May–October) for Joe Wright Creek, Colorado.

Variable	Study site 1	2	3	4	5	6	7	8
pH (mode)	7.3	7.2	7.2	7.2	7.2	7.2	7.2	7.3
Bound CO_2, mg/l	10.8	9.9	11.8	11.6	11.7	11.6	9.5	10.4
Dissolved O_2, mg/l	11.8	11.1	10.3	10.1	9.3	9.1	8.4	8.4
TDS, mg/l	33.2	30.6	25.4	30.5	27.0	30.9	36.8	31.9
Discharge, m^3/min	10.2	14.4	12.6	12.6	16.5	16.5	144.0	155.5

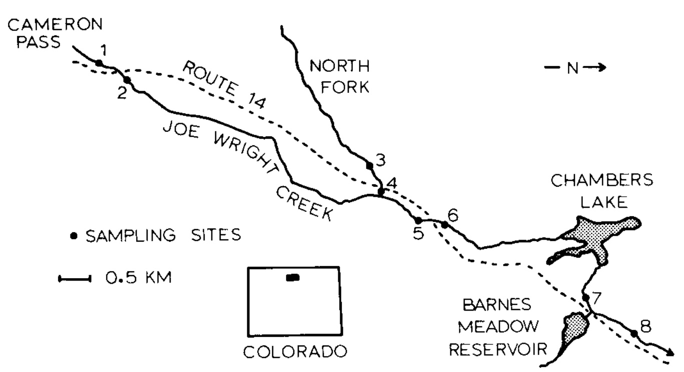

Fig. 1. Joe Wright Creek study area showing sampling sites.

Wright Creek over most of its 22 km length. Site pairs (a reference site and an impacted site) were sampled at locations of major perturbation. Construction activities included culvert installation (between Site pairs 1 and 2; and 3 and 4), bridge construction (between Site pair 5 and 6), channel realignment (between Site pairs 3 and 4; and 7 and 8). Even-numbered sites were affected by construction activities; odd-numbered sites served as reference locations.

Total suspended solids were sampled and analyzed according to *Standard Methods* (APHA *et al.* 1971). Substrate was collected by driving a 28 cm diameter core into the streambed and removing the upper 5 cm of substrate materials, which were dried and separated into size classes in the laboratory.

Epilithon, the attached plants and detritus associated with rock surfaces, was collected using a timed scraping technique (Ward 1974). The upper surfaces of at least ten cobble-sized rocks were scraped during a 5-min period. The percentage composition of the major epilithon components (algae, moss, lichen, detritus) was determined using a square petri dish with a gridded bottom. A Leitz phase contrast microscope, and a Leitz orthoplan microscope equipped with a Normarski phase interference attachment, were utilized for algal identification. Diatoms were cleared with 30% hydrogen peroxide prior to mounting on slides with Hyrax mounting medium. Diatoms, Chrysophyta, and Rhodophyta were identified to species level, or, in some cases, subspecies level; however, it was not always possible to distinguish the number of species within certain genera of Chlorophyta and Cyanophyta from preserved material. Epilithon dry weights were obtained after oven drying at 60 °C for 12 h and desiccating for at least 24 h. Loss on ignition values were determined by ashing the dried samples at 650 °C for 1 h followed by desiccation for at least 24 h prior to weighing.

Macroinvertebrates were collected with a Surber sampler 700 μm mesh) which enclosed 929 cm² of substrate. In 1975 and 1976, six samples were taken in fast water at each site on each date; in 1977 four replicates each were taken in fast and slow water areas. Biomass (wet weight) estimates were obtained by volumetric displacement, assuming a specific gravity of 1.0. No attempt was made to correct for loss of weight during preservation. Shannon diversity ($\bar{d}$) was computed from the formula:

$$\bar{d} = 3.3219/N - (N \log_{10} N - \Sigma N_i \log_{10} N_i),$$

where 3.3219 = conversion factor to base 2 logarithms,
N = total number of individuals,
N_i = total number of individuals of ith taxon.

Results

Suspended solids and substrate

Only two physico-chemical variables, suspended solids and substrate composition, were distinctly affected by construction activities. Increased discharge from snowmelt in June appreciably elevated suspended solids, except at Sites 7 and 8 below the storage reservoirs (Figs. 2 and 3). Levels were similar at Site pairs 1–2 and 5–6, but were 40 times higher at Site 4, where construction had already begun, than at reference Site 3. As runoff subsided, suspended solids decreased to less than 10 mg/l at reference Sites 1, 3 and 5; values were from 10 to 100 times greater at impacted Sites 2, 4 and 6. However, values at impacted sites approached reference levels within two weeks following cessation or major reduction of construction activities. Thus, recovery was relatively rapid, and apparently also persistent as exemplified by comparable mean suspended solids values at Sites 5 (23 mg/l) and 6 (17 mg/l) during 1976 when additional construction did not occur at this location. Clear water releases from Barnes Meadow Reservoir (which enters Joe Wright Creek between Sites 7 and 8) resulted in lower suspended solids levels at the impacted site than at the upstream reference location (Fig. 3). After construction ceased, values were again comparable at these two sites and remained so during 1976 when no construction occurred. The variations of suspended solids at impacted sites during construction resulted from the interactions of the flow regime and construction intensity, neither of which are indicated in Figs. 2 and 3.

At locations not regulated by impoundment (Sites 1–6), the proportion of fine sediment (defined as particles ⩽2.0 mm diameter) in the substrate was generally lowest during snowmelt runoff. Site pairs exhibited comparable proportions of fine sediment during runoff and prior to construction. During construction, the relative contribution of fine sedi-

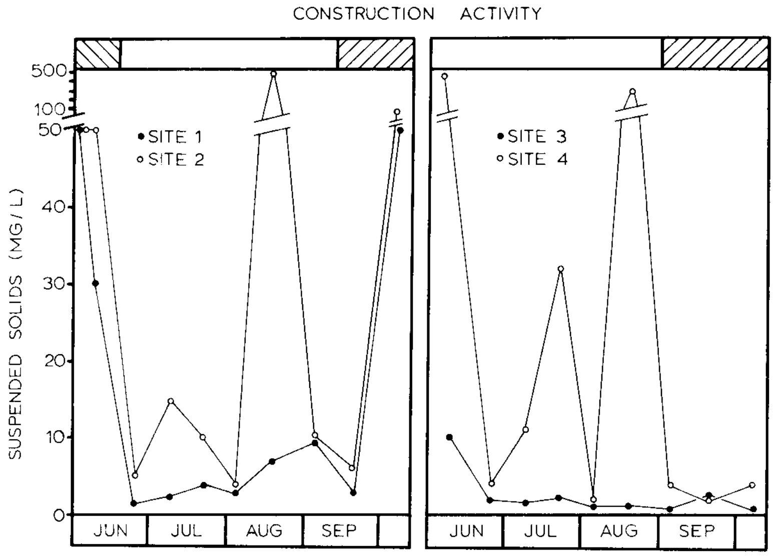

Fig. 2. Total suspended solids (mg/l) at impacted (Sites 2 and 4) and reference (Sites 1 and 3) locations on Joe Wright Creek, Colorado, 1977. Construction activity symbols: ▧ before construction; □ during construction; ▨ after construction.

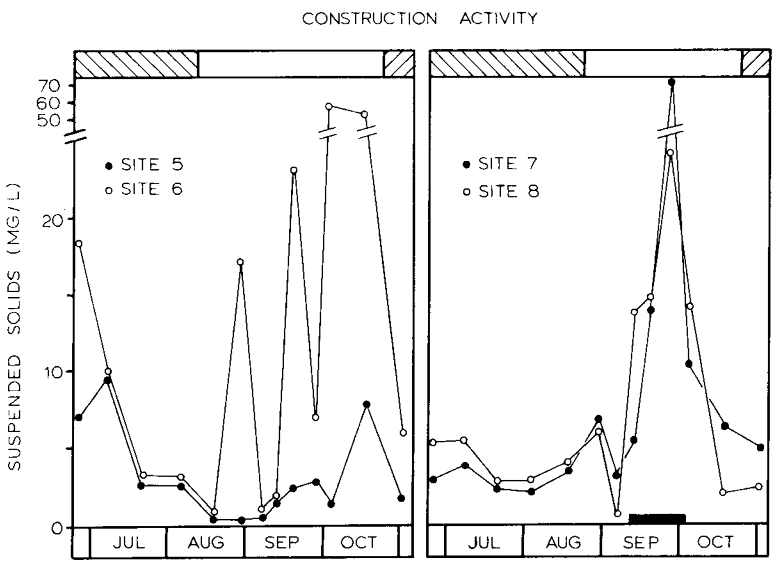

Fig. 3. Total suspended solids (mg/l) at impacted (Sites 6 and 8) and reference (Sites 5 and 7) locations on Joe Wright Creek, Colorado, 1975. (Solid bar on horizontal axis for Sites 7 and 8 indicates period of major discharge from intervening reservoir.) Construction activity symbols same as Fig. 2.

ments at impacted Sites 2 and 4 was twice that at reference Sites 1 and 3 (Fig. 4). Even greater disparities occurred between Site pair 5–6 (Fig. 5). However, by October 1976 (see Fig. 5), one year after construction at that location, the substrate of Site pair 5–6 exhibited comparable values indicative of relatively rapid recovery.

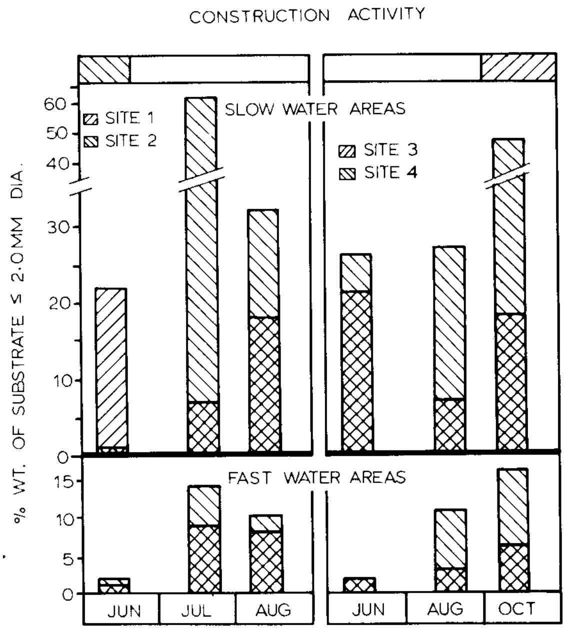

Fig. 4. Percentage dry weight of substrate less than 2.0 mm diameter from slow and fast water areas of Sites 1–4, Joe Wright Creek, Colorado, 1977. Construction activity symbols same as Fig. 2.

At Site pair 7–8 during 1975, the proportion of fine sediment in the substrate was twice as high at the reference location than at the downstream site prior to construction. Commencement of channel realignment reversed this pattern (Fig. 5). Subsequent reservoir releases, however, decreased the proportion of fine sediment at both of these sites. One year later, following a season without construction, the substrate composition was similar at Sites 7 and 8 (see Oct. 1976 on Fig. 5).

Substrate samples from slow water areas (Fig. 4) further elucidated the ameliorative role of current in cleansing the substrate. As discharge subsided during the 1977 season, the proportion of fine sediment in depositional areas at reference Site 1 progressively increased (1% in June, 7% in July, 17% in August). Impacted Site 2 contained 3–10 times more fine sediment than the depositional areas at Site 1; and 3–5 times more fine sediment than the erosional areas of Site 2. A similar relationship was found for Site pair 3–4, which began with comparable substrate in June (Fig. 4).

Therefore, the fine sediments suspended during snowmelt runoff were not deposited within the study reach, even in depositional areas, because of the high discharge at that time. As flow decreased, sedimentation occurred to a limited extent at refer-

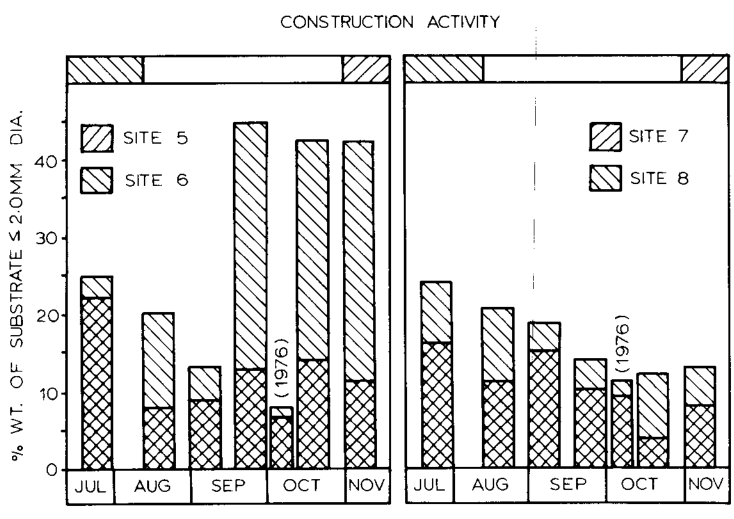

Fig. 5. Percentage dry weight of substrate less than 2.0 mm diameter from fast water areas of Sites 5–8, Joe Wright Creek, Colorado, 1975 and 1976. Construction activity symbols same as Fig. 2.

ence sites and to a greater extent at impacted locations, especially in slow water areas. A similar, but temporally displaced, pattern occurred at Sites 7 and 8 which were influenced by a regulated flow regime.

Epilithon

The living components (algae, moss, lichen) of the epilithon were generally less abundant, and the detrital component more abundant, at impacted sites than at the reference location of a given site pair (Table 2). The epilithon tended to collect fine sediment from the water column. Ash-free dry weight (AFDW), a reflection of the organic content of the epilithon, exhibited a general increase in absolute values downstream, with consistently lower values associated with the impacted location of each site pair (Table 2). The high values at Site 7 below the dam are a function of enhancement from stream regulation (see Ward 1976; Lowe 1979).

During the study 110 algal taxa in 5 divisions were collected. Diatoms (Bacillariophyta) accounted for 85 of the 110 algal taxa. The greatest number of total taxa (63) was collected at Site 1, the most upstream reference location. Fewer taxa were identified from the impacted site than from the reference location of each site pair except one (42 taxa at Site 5, 52 at Site 6).

The epilithon, while showing an effect from construction activities, exhibited a less dramatic response than expected. However, changes detected at impacted sites in 1975 persisted throughout the 1976 season, suggesting that recovery proceeds less rapidly than was the case for suspended solids and substrate.

Macroinvertebrate abundance

The general pattern of abundance exhibited by the total macroinvertebrate community was to begin at a very low density during snowmelt runoff in June, progressively increase through August or September, and subsequently decline (this pattern is undoubtedly partly a function of sampling efficiency as well as a reflection of life cycle phenomena).

Table 2. Summarized percentage compositon of major epilithon components and mean ash-free dry weight (mg) at study sites on Joe Wright Creek, Colorado, during 1975–1977[a]. Because of the sampling program, some sites were sampled in different years than other sites. Values from all site pairs are based on samples from the same years (see text).

		Study site							
		1	2	3	4	5	6	7	8
June	Algae	5	10	24	2	90(40)	50(30)	90(70)	90(25)
	Moss	0	0	0	0	0(50)	0(0)	0(0)	0(0)
	Lichen	0	0	0	0	0(0)	0(0)	0(0)	0(0)
	Detritus	95	90	76	98	10(10)	50(60)	10(30)	10(75)
July	Algae	22	22	15	10	85	30	75	75
	Moss	0	0	0	0	0	0	15	0
	Lichen	0	0	0	0	0	0	0	5
	Detritus	78	78	85	90	15	70	10	20
September	Algae	–	–	–	–	90	90	90	80
	Moss	–	–	–	–	0	0	0	0
	Lichen	–	–	–	–	0	0	0	0
	Detritus	–	–	–		10	10	10	20
October	Algae	85	80	50	85	70	25	–	–
	Moss	0	0	0	0	20	70	–	–
	Lichen	0	0	0	0	0	0	–	–
	Detritus	15	20	50	15	10	5	–	–
Mean AFDW[b]		5.0	3.7	7.7	7.0	9.3 (18.3)	8.1 (9.4)	13.5 (53.2)	7.3 (14.8)

[a] Values in parentheses are based on second year of study at that location.
[b] mg ash free dry weight per 5-min samples.

In fast water areas of Sites 1–4, density values were lower (but not invariably so) at impacted compared to reference sites, during and following construction (Figs. 6 and 7). For example, peak density at Site 1 (1 395 org/ m²), was nearly three times higher than at Site 2 (500 org/ m²), and mean density was double that at Site 2. In contrast, values at impacted and reference locations were similar for Site pairs 5–6 and 7–8 during 1975. Although Sites 7 and 8 were influenced by abrupt fluctuations in the regulated flow regime, the pattern and absolute density values responded similarly at both locations. Nor did macroinvertebrate abundance at Sites 5–8 exhibit any discernible effects of a longer term nature. One year after cessation of construction, values were comparable or even higher at previously impacted locations than at reference sites.

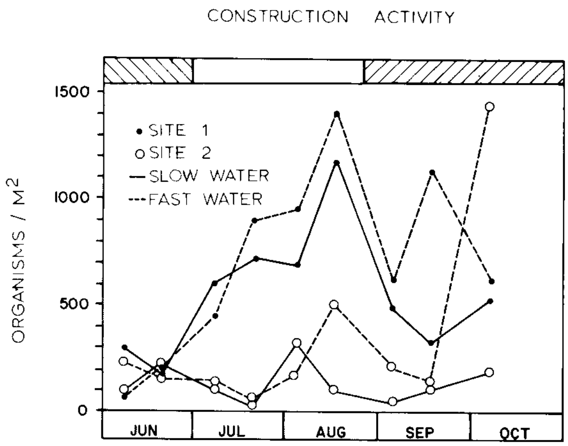

Fig. 6. Macroinvertebrate density (organisms/ m²) in slow and fast water areas of Sites 1 and 2, Joe Wright Creek, Colorado, 1977. Construction activity symbols same as Fig. 2.

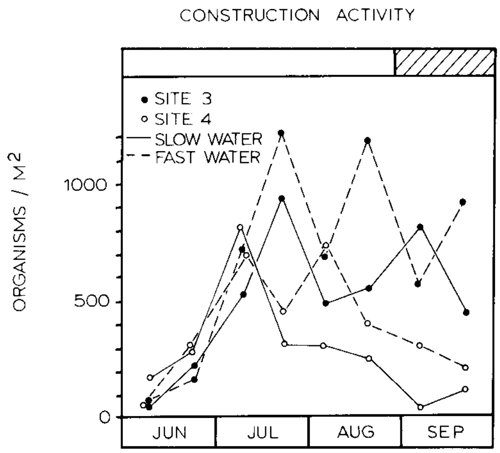

Fig. 7. Macroinvertebrate density (organisms/ m²) in slow and fast water areas of Sites 3 and 4, Joe Wright Creek, Colorado, 1977. Construction activity symbols same as Fig. 2.

The effects of construction on macroinvertebrate abundance were sometimes more apparent in slow than fast water areas, despite the generally lower densities in the former habitat (Figs. 6 and 7).

Total macroinvertebrate biomass values (Table 3) support the results based on density. During 1975

Table 3. Mean total macroinvertebrate biomass (g/ m² wet wt) and percentage composition by biomass of major macroinvertebrate groups, Joe Wright Creek, 1975–77.

	Fast water areas												Slow water areas			
	1975				1976				1977				1977			
Site:	5	6	7	8	5	6	7	8	1	2	3	4	1	2	3	4
Mean biomass (g/ m²)	4.1	5.2	2.5	3.4	2.4	2.7	1.0	1.5	4.3	1.1	2.7	1.5	3.9	0.7	1.6	0.9
Percentage composition																
Ephemeroptera	55	41	25	24	49	38	18	24	41	55	48	51	26	43	42	43
Plecoptera	11	16	35	52	12	25	10	28	9	13	19	4	8	4	27	25
Trichoptera	20	26	12	7	13	11	7	3	4	8	11	11	2	4	13	3
Diptera	13	16	24	14	19	20	41	21	31	16	18	22	52	31	10	16
Other[a]	1	1	4	3	7	6	23[b]	24[b]	15[b]	8	4	12	12	18[c]	8	13

[a] Oligochaeta, Coleoptera, Turbellaria, Nematoda, and Hydracarina.
[b] Oligochaeta 19%.
[c] Coleoptera 9%.

and 1976, when density was unaffected by construction activities, mean biomass values at impacted Sites 6 and 8 were comparable or even higher than at reference locations (Sites 5 and 7). In 1977 total mean biomass values were two to four times higher at reference Sites 1 and 3 than at Sites 2 and 4 which were affected by construction activities.

Macroinvertebrate composition

Ephemeroptera, Plecoptera, Trichoptera, and Diptera (especially Chironomidae, Simuliidae, and Blephariceridae) generally contributed the majority of total macroinvertebrate density and biomass (Tables 3 and 4), although stream regulation altered the composition at Sites 7 and 8 (see Ward & Short 1978; Ward & Stanford 1979). During 1975 and 1976, when there were no indications that total density or biomass values were influenced by construction activities, neither were there consistent differences in the composition of major groups between site pairs which could be attributed to construction. However, during 1977 Ephemeroptera and Diptera accounted for a greater proportion and Plecoptera a smaller proportion, of total density at impacted Sites 2 and 4 than at their corresponding reference locations. These differences were slightly greater in slow water than in fast water areas. Ephemeropterans contributed a larger proportion of total biomass at impacted sites during 1977, while other major groups did not exhibit consistent trends.

There were no discernible effects of construction activities on the abundance of individual macroinvertebrate taxa during the first two years of study. However, in 1977 when total density and biomass were affected by construction impacts, 16 taxa indicated an intolerance (consistently lower densities at impacted sites of each site pair) to the alterations engendered by construction (Table 5). Many taxa occurred in numbers too low to accurately assess their responses to perturbation. While the identification of taxa sensitive to construction activities is a significant finding, we do not know whether these results are applicable throughout the geographical range of the species, or even whether populations at lower elevations respond in a similar manner. In addition, the lack of suitable identification keys for the immature stages of many aquatic insects limits the value of these data.

Table 5. Macroinvertebrate taxa intolerant of the effects of construction activities on Joe Wright Creek, Colorado (see text).

Ephemeroptera	**Trichoptera**
Ameletus sparsatus	*Arctopsyche grandis*
Cinygmula sp.	*Glossosoma* sp.
Ephemerella coloradensis	*Oligophlebodes* sp.
E. doddsi	*Rhyacophila angelita*
Rhithrogena robusta	
Plecoptera	**Diptera**
Alloperla (s.l.) spp.	*Micropsectra* sp.
Capnia sp.	*Palpomyia* sp.
Zapada oregonensis	*Tipula* sp.
Coleoptera	
Heterlimnius corpulentus	

Table 4. Percentage composition by density of major macroinvertebrate groups, Joe Wright Creek, 1975–1977.

	Percentage composition by density during and after highway construction															
	Fast water areas												Slow water areas			
	1975				1976				1977				1977			
Site:	5	6	7	8	5	6	7	8	1	2	3	4	1	2	3	4
Ephemeroptera	59	53	44	38	49	46	15	17	65	70	72	78	48	68	66	75
Plecoptera	15	15	14	27	10	13	11	13	11	10	11	4	16	5	14	9
Trichoptera	14	11	3	1	21	10	3	2	5	4	8	5	4	4	7	4
Diptera	10	19	37	33	15	27	47	58	4	6	7	9	6	12	9	10
Other[a]	2	2	2	1	5	4	24[b]	10	15	10	2	4	26[c]	11	4	2

[a] Oligochaeta, Coleoptera, Turbellaria, Nematoda, and Hydracarina.
[b] Oligochaeta 23.5%.
[c] Coleoptera 18%.

Macroinvertebrate diversity

Shannon diversity index values further support the macroinvertebrate response to construction previously indicated at impacted Sites 2 and 4, and the lack of a negative response at Sites 6 and 8. Prior to construction at Site 2, diversity values were higher than at reference Site 1, a pattern which reversed when construction activities commenced, and did so sooner and to a greater extent in slow water than fast water areas (Fig. 8). However, at Site pair 3–4, where commencement of construction preceded initial sampling, differences in diversity were apparent only for slow water areas (Fig. 9). Site pairs 5–6 and 7–8 displayed a similar range of Shannon diversity values as sites 1–4, but did not exhibit differences indicative of a construction impact at sites 6 and 8.

Discussion

Suspended solids at all impacted sites at times exceeded levels reported as being detrimental to aquatic biota (Cordone & Kelley 1961; European Inland Fisheries Advisory Committee 1965; Einstein 1972; Sorensen *et al.* 1977; Iwamoto *et al.* 1978). Why then were macroinvertebrates adversely affected only in 1977 when construction occurred at upstream locations? The answer appears related to the timing and duration of construction activities, and the lower discharge at upper sites which received less tributary inflow and did not derive flow supplements from impoundments (Table 1). Clear water releases from the reservoirs and tributary inflow, somewhat ameliorated high levels of suspended solids and reduced sedimentation at these downstream sites, especially Site 8. Barton

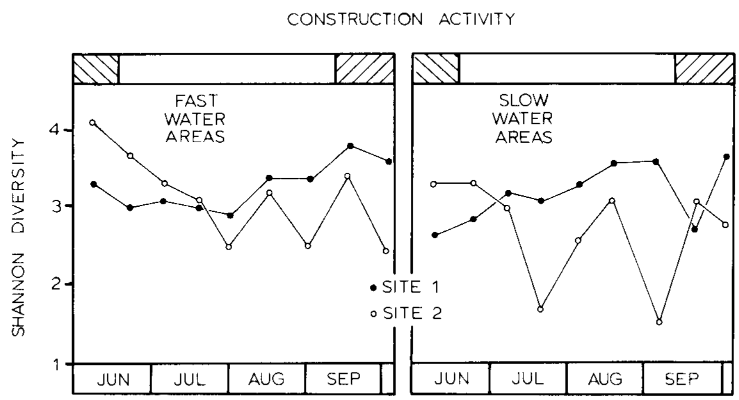

Fig. 8. Shannon-Weaver diversity index ($\bar{d}$) values for macroinvertebrate macroinvertebrate samples from slow and fast water areas of Sites 1 and 2, Joe Wright Creek, Colorado, 1977. Construction activity symbols same as Fig. 2.

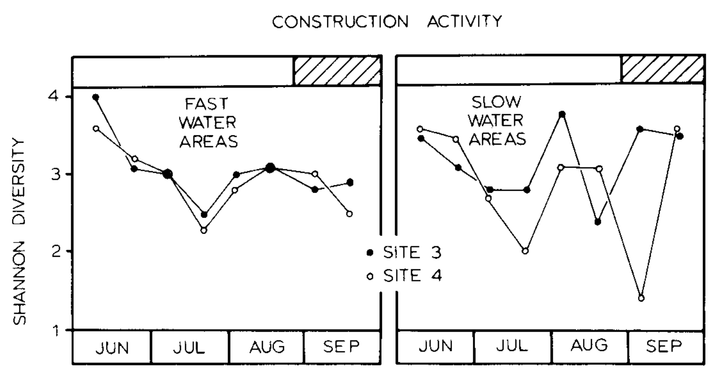

Fig. 9. Shannon-Weaver diversity index ($\bar{d}$) values for macroinvertebrate samples from slow and fast water areas of Sites 3 and 4, Joe Wright Creek, Colorado, 1977. Construction activity symbols same as Fig. 2.

(1977) and Hamilton (1961) concluded that severe and persistent sedimentation is required to induce distinct faunal changes. Impacts from stream-crossing during pipeline construction in British Columbia had only short-term, non-residual affects on macroinvertebrates (Tsui & McCart 1981). The extremely high snowmelt discharge which characterizes high mountain streams such as Joe Wright Creek, removes fine sediments which are not redeposited, even in depositional areas of high gradient reaches. Thus, snowmelt runoff (or high discharge from the reservoirs) cleanses the sediment and only increases suspended solids for a relatively short period. Deposition occurs in lentic water bodies or in low gradient lotic reaches father downstream.

At Sites 2 and 4 construction activities began earlier and continued about one month longer than at impacted locations downstream. This resulted in considerably higher levels of suspended solids over a longer period, and a greater proportion of fine sediment in the substrate of both erosional and especially depositional areas.

In conclusion, our original premise that the biota of high elevation streams would be sensitive to short-term perturbation from construction activities must be modified. Although distinct responses occurred at sites located in upper reaches, the effects were not nearly as severe as anticipated. The hydrologic characteristics and high gradient appeared to ameliorate the effects of construction activities. In addition, direct perturbations were of relatively short duration at all locations and were not annual events.

Acknowledgments

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