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EFFECTS OF SEDIMENT ADDITION ON MACROBENTHIC INVERTEBRATES IN A NORTHERN CANADIAN RIVER

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Abstract—Two channels built into the Harris River, Northwest Territories were used to study responses of invertebrates to sediment addition. Sediment was added to one channel continuously for approximately 5 h. The other channel was used as a control. In August, 28.27 kg of sediment or 1.38 kg m^{-2} of channel bottom were added. Values for September were 35.88 kg or 1.53 kg m^{-2}.

As a result of sediment addition, numbers of macrobenthos drifting from the sediment addition channel (*S*) increased significantly over those drifting in the control (*C*) in August (= summer) and September (= fall). Total drift from *S* was > 3 times higher in August and > 2 times higher in September than from *C*. Significantly higher numbers of macrobenthos drifted in fall than summer. Numbers of macrobenthos drifting during sediment addition were significantly related to time in September but not in August, indicating a seasonal difference in temporal response to sediment addition. Two explanations are proposed for the response of the September community, as indicated by shape of a polynomial regression curve, to sediment addition. No significant difference existed in standing crops of macrobenthos in the substrate in *C* and *S* after sediment addition.

Sediment addition caused (1) higher numbers of Oligochaeta and Simuliidae to drift in August and September; (2) higher numbers of Plecoptera and Ephemeroptera to drift in September but not in August; and (3) higher numbers of Hydracarina and Chironomidae to drift in August but not September.

We suggest that future work try to relate amounts of settled rather than suspended sediments to quantitative responses of stream macrobenthos. We recommend that highway and pipeline construction undertaken in watersheds of Mackenzie Valley streams during the open-water period, resulting in sediment addition to these streams, should be done during summer rather than spring or fall, providing river discharge is adequate to transport the added sediment.

INTRODUCTION

Construction of pipelines and highways in the Mackenzie River Valley will increase sediment supply to lentic and lotic waters. Surveys of natural and sediment-disturbed systems (Brunskill *et al.*, 1973; Rosenberg & Snow, 1975*a*) proved inadequate to assess and predict responses of macrobenthic invertebrates to increased sedimentation so we turned to experimental field studies.

Our experiments were done on the Harris River, Northwest Territories (61° 52'N, 121° 19'W) during the open-water periods of 1973 (Rosenberg & Snow, 1975*a*) and 1974 (reported here). We used stream drift to indicate the effects of sediment addition on the macrobenthic invertebrate community.

The 1973 experiments indicated a seasonal variation in drift responses of macrobenthos to sediment addition. We estimated that the minimum and maximum per cent values of macrobenthic standing crop drifting due to sediment addition were 0.04 and 2.6%, respectively, in 15 min and that it would take as few as 7 h or as many as 18 days for 50% of the population to leave. The 1974 experiments were meant to verify these estimates, to quantify macrobenthic drift, to investigate the importance of the hyporheic environment in repopulating surface sediments, and to investigate further, seasonal variations in responses of macrobenthos to sediment addition.

METHODS

The riffle area used (described by Rosenberg & Snow, 1975*a*) was partitioned with plywood (buried approx. 5–10 cm deep) into two parallel 1 × 15 m channels to prevent exchange of invertebrates and sediment between the channels. Installation was completed approx. 5 weeks before the first sediment addition to allow recovery.

A 'V'-shaped, 200 μm mesh screen was placed, with its apex upstream and its bottom edge buried, at the upstream end of each channel prior to sediment addition to eliminate incoming drift as a source of variance.

Two sets of equipment for continuous application of a sediment–slurry were equidistantly spaced along the south channel. Four clean 45 gal (205 l) barrels were alternately filled with water by a centrifugal pump [capacity: 4000 gal (18,200 l) h^{-1}]. An ice auger fitted with a metal stirring rod was used to keep the sediment in each barrel in suspension.

When one barrel emptied, its outlet valve was closed and the stirrer was transferred to the second, previously filled barrel. A preweighed amount of dry sediment was added and the outlet valve opened while the first barrel was refilling. This cycle was used for the duration of sediment addition. Activity at the two sets of barrels was synchronized as much as possible. Sediment–slurry from the two sets of barrels was added at a constant rate to ensure even application.

We intended to produce a suspended sediment (*SS*) concentration of 30 mg l^{-1}, a concentration which caused a large increase in drift (Rosenberg & Snow, 1975*a*) but which did not require the addition of large amounts of sediment. The addition rate (g min^{-1}) of sediment required to achieve 30 mg l^{-1} *SS* was calculated using the formula in Rosenberg & Snow (1975*a*) and the weight of sediment to be added to each of the two barrels emptying at the same time was calculated based on addition rate and emptying time of the barrels.

Physical and chemical parameters of water were measured at the downstream end of the control (*C*) and sediment addition (*S*) channels (Brunskill *et al.*, 1973) immediately before sediment addition began and immediately after it ended. Differences in discharge with and without the upstream screens was measured only in the first experiment. Water samples (2 l) for measurement of *SS* concentrations (Campbell & Elliott, 1975) were taken at the downstream end of each channel prior to the start of sediment addition. During sediment addition, 2 l samples were also taken midway throughout each hour at 15 m on *C* and O, 3.75, 7.5, 11.75, and 15 m along *S*.

Theoretical weight of sediment added per unit area of bottom of *S* (M_A) was calculated using the formula:

$$M_A = \frac{Wt + aQ_c t - bQ_s t}{A_o}.$$

where W = wt of sediment added to *S* per unit time (kg min^{-1}), t = duration of sediment addition (= 277.5 min), a = avg *SS* concn in *C* over t at 15 m (kg m^{-3}) (Table 2), Q_c = avg discharge in C (m^3 min^{-1}) (Table 1), b = avg *SS* concn in *S* over t at 15 m (kg m^{-3}) (Table 2), Q_s = avg discharge in *S* (m^3 min^{-1}) (Table 1), A_o = area of *S* (= 15 m^2).

Particle size distribution (PSD) (Jenning, Thomas & Gardiner, 1922) and organic matter content (Jackson, 1956) of bankside sediment used in the August and September experiments and in 1973 (Rosenberg & Snow, 1975*a*) were similar [sand (2–0.05 mm): approx. 25%; silt (0.05–0.002 mm): approx. 45%; clay (< 0.002 mm): approx. 20%; organic matter: approx. 8%].

Seasonality of effects was tested by doing experiments on August 1 (= summer) and September 9 (= fall). We were unable to do a spring experiment because of normal spring high discharge. Drifting macrobenthic invertebrates were collected with 10 × 10 cm drift nets of 200 μm Nitex mesh. Three nets were placed midway between the water surface and the stream substrate equidistantly across the downstream end of each channel. Macrobenthos were collected for 3 h with no sediment added (to indicate differences between the two channels prior to sediment addition), followed by 5 h during sediment addition. A complete experiment was started at approx 1000 h. Drift net collections on both channels were made for 15 min periods at 0, 30, 60, 90, 120, and 150 min before sediment addition and 0, 22.5, 82.5, 142.5, 202.5, and 262.5 min during sediment addition. Total drift was calculated according to Elliott (1973). Drift samples were taken weekly for 3 consecutive weeks following the August experiment to determine recovery of *S*.

Three Surber samples (200 μm Nitex mesh) were taken randomly from each channel immediately following sediment addition to provide a quantitative estimate of macrobenthic standing crop.

We tested the null hypotheses that (1) there was no difference between *C* and *S* in numbers of macrobenthos drifting during sediment addition; (2) there was no relationship between numbers of macrobenthos drifting and time during sediment addition in *C* or *S*; (3) there was no difference in numbers of zoobenthos drifting between summer and fall; and (4) there was no difference in standing crop of macrobenthos in the substrate between *C* and *S* after sediment addition by using analyses of variance (AOV) (Wang, 1972; Hewlett-Packard, 1974) and polynomial regression (Scott, Freshwater Institute, Winnipeg). Homogeneity of variances for data used in AOV's was checked (Bartlett's test, Hewlett-Packard, 1974) and appropriate transformations (Snedecor & Cochran, 1967) applied when necessary. A significance level of $P \leq 0.10$ was arbitrarily set for AOV's. Orthogonal contrasts (Snedecor & Cochran, 1967) were used to compare numbers of macrobenthos drifting from *C* and *S* for each time period during sediment addition.

RESULTS

Effect of sediment addition on physical and chemical features of the channels

Presence of the upstream nets did not decrease discharge by more than 50% (Table 1). Discharge through drift nets was usually lower and more variable in *S* than *C* (Table 1).

Sediment addition did not change the physical and chemical characteristics of water measured but some seasonal differences were apparent. Water temperatures were higher in August (21°C) than September (6–7.5°C) and dissolved oxygen concentrations were lower in August (approx 7 mg l^{-1}) than September (approx 11 mg l^{-1}). Conductivity was approx 289 μmho cm^{-1} in August and slightly lower in September (266 μmho cm^{-1}). The pH was approx 8 for both experiments. HCO_3^- was approx 2.1 mole m^{-3} in August and slightly higher (approx 3.0 mol m^{-3}) in September. Particulate *C* was approx 28 mmole m^{-3} in August but declined to approx 10 mmole m^{-3} in September. Particulate *N* was approx 3 mmol m^{-3} in August but declined to approx 1.7 in September. Particulate *P* was 0.1 mmole m^{-3} for both experiments. Gammon (1970) also concluded that sediment addition had no significant effect on water quality in the creek he studied.

SS concentrations in *C* varied in August and September, but the mean values for the 2 months were similar (Table 2). *SS* concentrations in *S* tended to

Table 1. Harris River discharge (m^3 s^{-1})*

Date (1974)	Section of river: Control channel Net 1	Control channel 2	Control channel 3	Sediment addition channel Net 1	Sediment addition channel 2	Sediment addition channel 3	Remainder of river	Total
August 1	0.017 0.022	0.020 0.024	0.018 0.023	0.009 0.014	0.016 0.020	0.017 0.035	0.048	0.145
September 9	0.022	0.024	0.025	0.015	0.017	0.029	0.553	0.685

*Numerator = screens in place upstream: denominator = screens removed. All other values are for screens in place.

Table 2. Suspended sediment concentrations (mg l^{-1}) in experimental channels on August 1 and September 9, 1974

Date	Channel	Location of sample along channel (m)		Before	Time of sampling (min from start of run) 30	90	150	210	270	After	X
					Suspended sediment concentration (mg l^{-1})						
August 1	Sediment addition	0		–	0.75	1.23	0.90	1.47	1.27		1.12
		3.75		–	5.95	10.93	4.56	7.52	4.25		6.64
		7.5		–	7.31	14.96	9.33	7.24	4.21		8.61
		11.75		–	13.93	16.41	8.43	10.03	6.63		11.09
		15.0		0.92	16.57*	2.34	9.80*	15.77	12.16*	0.72	11.33
			X	–	8.90	9.17	6.60	8.41	5.70		
	Control	15.0		0.97	0.76	0.84	0.70	1.13	1.05	1.32	0.97
September 9	Sediment addition	0		–	0.72	1.20	0.52	1.32	0.80		0.91
		3.75		–	1.32	7.37	2.42	2.68	0.95		2.95
		7.5		–	1.24	5.78	13.65	5.46	4.43		6.11
		11.75		–	14.63	12.74	11.26	20.94	6.15		13.14
		15.0		0.69	7.34	9.62	16.90	19.38	16.74	1.55	14.00
			X	–	5.05	7.34	8.95	9.96	5.81		
	Control	15.0		0.91	1.22	1.52	1.26	0.49	0.84	0.89	1.02

* Mean of 3 samples.

increase through time in September but not in August and were similar in both months (Table 2). *SS* concentrations increased with distance downstream in both months. Overall mean *SS* concentrations (time and distance) were similar for both experiments (7.76 and 7.42 mg l^{-1} for August and September, repectively).

Total weight of sediment added was 28.27 kg in August and 35.88 kg in September. Theoretical weight of sediment added per unit area of bottom of *S* (M_A) was estimated at 1.38 kg m^{-2} for August and 1.53 kg m^{-2} for September.

Drift of the macroinvertebrate community

Numbers of macroinvertebrates drifting from *C* and *S* were similar between the August and September experiments indicating that *S* had recovered from the effects of the August sediment addition.

Total numbers of macroinvertebrates caught in drift nets in *C* and *S* before sediment addition were similar (Table 3; $F_{1,10} = 0.451$; $P > 0.50$). Significantly more invertebrates drifted in September than August before sediment addition (Table 3; $F_{1,10} = 9.953$; $P = 0.010$). Seasonal differences in

Table 3. Numbers of macrobenthic invertebrates drifting during the August 1 and September 9 1974 experiments

Date	Period of experiment	Sampling period*	Control Net 1	Control Net 2	Control Net 3	Sediment addition Net 1	Sediment addition Net 2	Sediment addition Net 3
August 1	Pre-sediment addition†	1	10	11	8	4	18	6
		2	8	8	5	7	6	5
		3	9	10	12	8	6	15
		4	5	9	2	3	6	8
		5	6	11	5	5	2	4
		6	14	17	11	19	15	15
			Σ = 52	66	43	46	53	53
	Sediment addition‡	1	6	12	2	17	13	24
		2	8	10	6	11	5	14
		3	5	8	2	4	10	18
		4	10	3	5	13	11	18
		5	6	3	6	9	5	15
		6	7	3	5	13	10	11
			Σ = 42	39	26	67	54	100
September 9	Pre-sediment addition†	1	11	18	9	22	23	15
		2	14	20	10	10	17	19
		3	14	6	9	9	25	19
		4	11	4	4	4	7	1
		5	19	11	9	12	12	6
		6	7	4	9	9	6	2
			Σ = 76	63	50	66	90	62
	Sediment addition‡	1	8	13	11	30	19	36
		2	11	8	8	10	13	14
		3	10	10	7	13	8	13
		4	16	12	9	14	16	15
		5	19	17	11	23	15	21
		6	23	19	10	19	14	21
			Σ = 87	79	56	109	85	120

* Drift nets were set for 15 min periods. See text for explanation of timing of drift net placement.

† Duration, 3 h.

‡ Duration, 5 h.

Table 4. Total numbers of macrobenthic invertebrates drifting in 5 h from experimental channels in 1 August and 9 September, 1974 sediment additions

Date	Sampling periods	Control channel: Numbers of invertebrates drifting	Control channel: Numbers of invertebrates per m^3 drifting	Sediment addition channel: Numbers of invertebrates drifting	Sediment addition channel: Numbers of invertebrates per m^3 drifting
1 August	1 & 2	146.6	9.8	925.9	61.7
	3 & 4	220.0	14.7	493.2	32.9
	5 & 6	200.0	13.3	420.0	28.0
		Σ = 566.6	37.8	1839.1	122.6
9 September	1 & 2	196.6	13.1	1781.0	118.7
	3 & 4	426.8	28.5	526.8	35.1
	5 & 6	726.8	48.5	753.2	50.2
		Σ = 1350.2	90.1	3061.0	204.0

numbers of macrobenthos drifting are to be expected (e.g. see Elliott, 1973; Modde & Schmulbach, 1973; Cloud & Stewart, 1974). Drift also varied significantly with time ($F_{5,10} = 7.183$; $P = 0.004$), and with net position ($F_{2,10} = 3.356$; $P = 0.077$). Because numbers of macrobenthos caught at various drift net positions were different, the three drift nets were not true replicates. Therefore, either the sum of macrobenthos caught in the three drift nets should be used or the AOV should account for net position as a possible source of variance. We chose the latter approach to allow more flexibility in the AOV's and accounted for the differences in numbers of macrobenthos caught at each position by using a pairing sequence of most similar nets as determined by linear regression analysis (1:2, 2:1, and 3:3, *C*:*S*).

During sediment addition, significantly more macrobenthos drifted from *S* than *C* (Table 3; $F_{1,10} = 55.486$, $P < 0.001$) and in September than August ($F_{1,10} = 56.569$; $P < 0.001$), and numbers varied significantly with time ($F_{5,10} = 6.813$; $P = 0.005$).

Total drift of invertebrates for all but two sets of data were estimated using *mean drift rate* (Elliott, 1970). The sets which did not agree with a Poisson series were from *S* during the first hour of sediment addition in both experiments. For these sets, the χ^2 test for goodness of fit showed that *drift density* was a Poisson variable and total drift was calculated as for mean drift rate (Elliott, 1970). Total drift from *S* was > three times that from *C* in August and > two times in September (Table 4).

The regression relationship between numbers of macroinvertebrates drifting (Y) through time (X) during sediment addition was significant only in September [*C*: $Y = 8.659 + 0.031X$; $r^2 = 0.427$; $F_{1,16} = 11.922$ ($P < 0.005$); *S*: $Y = 25.566 - 0.470X + 4.032 \times 10^{-3} X^2 - 8.979 \times 10^{-6} X^3$; $r^2 = 0.578$; $F_{1,14} = 11.387$ ($P < 0.005$)]. The relationship was linear in *C*, showing a slight increase in numbers drifting in time but was curvilinear in *S* (Fig. 1).

Orthogonal contrasts showed significant differences between numbers of macrobenthos drifting from *C* and *S* in the first, fourth and sixth collection periods during sediment addition in August ($F_{1,24} = 11.54$, $P < 0.005$; $F_{1,24} = 5.75$, $P < 0.025$; and $F_{1,24} = 3.60$, $P < 0.10$ respectively) and the first collection period in September ($F_{1,24} = 27.45$, $P < 0.005$) (Table 3). Differences during the first collection periods were greatest in both months.

Drift of macroinvertebrate taxa

Those taxa drifting in relatively high numbers before sediment addition (Hydracarina, August; Simuliidae, August; Oligochaeta, September; Chironomidae, August and September) indicate that *C* and *S* were similar (Figs. 2 and 3).

Numbers of Chironomidae and Hydracarina drifting during sediment addition increased in August but not in September although low numbers of Hydracarina in September hampered judgement of their response (Figs. 4E, F; 5E, F). Numbers of Plecoptera and Ephemeroptera drifting increased with sediment addition in September but not August but numbers of both taxa were too low in August to adequately judge responses (Figs. 4B, C; 5B, C). Numbers of Simuliidae and Oligochaeta increased in both experiments as a result of sediment addition, although results for Simuliidae in August are equivocal (Figs. 4A, D; 5A, D). Many taxa showed an initial burst of high numbers in response to sediment addition (Figs. 4 and 5).

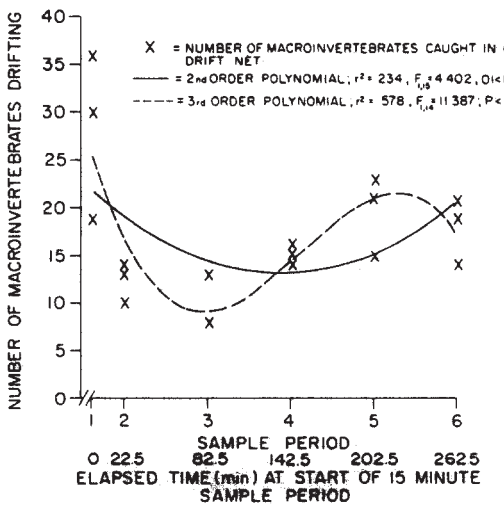

Fig. 1. Numbers of macroinvertebrates drifting in time during the September 1, 1974 sediment addition.

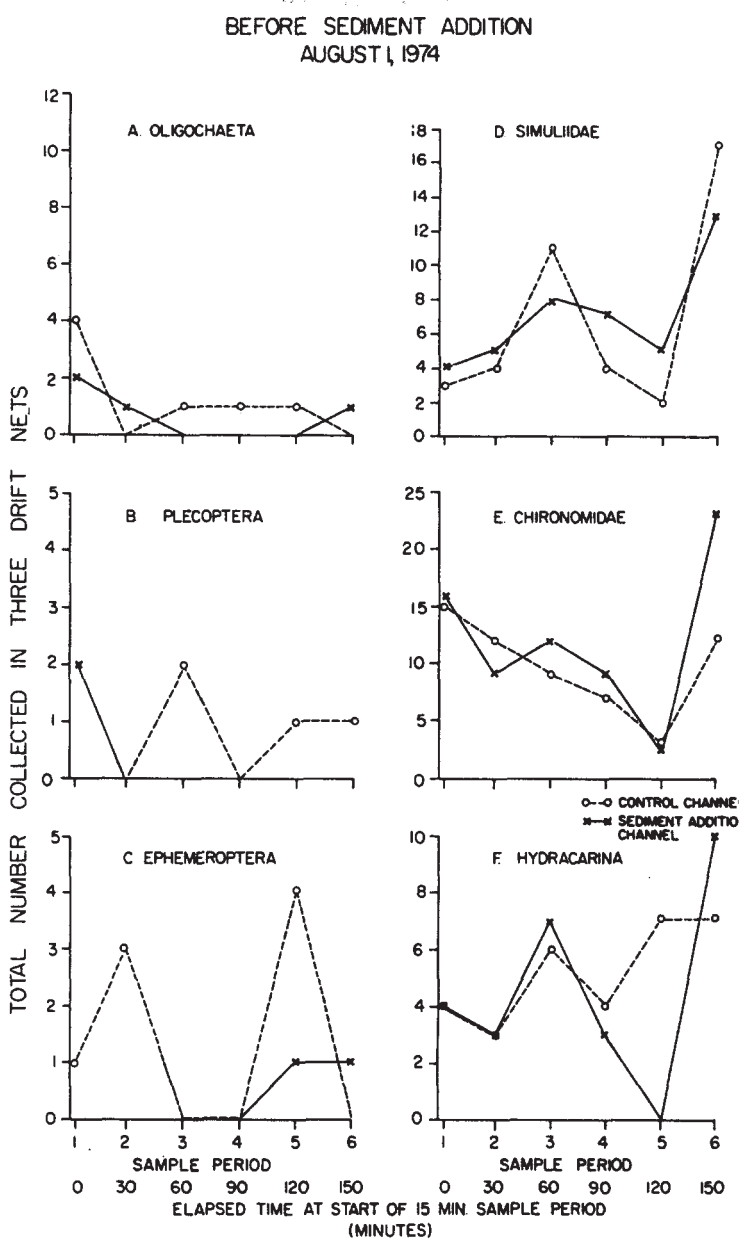

Fig. 2. Numbers of the most common higher taxa of macrionvertebrates drifting in time from experimental channels before the August 1, 1974 sediment addition.

Macroinvertebrates in the stream substrate

No significant difference in total densities of invertebrates in the substrates existed between the two channels in either of the experiments although mean densities were higher in *S* than *C* after the August experiment and the reverse in September (Table 5). Significantly more ($P < 0.10$) Plecoptera ($F_{1,4} = 6.368$) in August and Nematoda ($F_{1,4} = 4.834$) in September occurred in *C* (Table 5). Both taxa were relatively minor components of the macrobenthic community.

Mean densities in *C* were approximately two to three times the densities used to estimate the minimum and maximum per cent of the population of macrobenthos leaving the substrate due to sediment addition in the 1973 experiment (5000 invertebrates m^{-2}) (Rosenberg & Snow, 1975*a*).

DISCUSSION

SS *and* M_A

Overall mean *SS* concentrations for August and September experiments (7.76 and 7.42 mg l^{-1} respectively) indicate the difficulty in obtaining the desired concentration of 30 mg l^{-1}. A similar problem was reported in the 1973 experiments (Rosenberg & Snow, 1975*a*) and seems to be a common difficulty in experimental work with sediment (Sherk, 1971). Slurry ap-

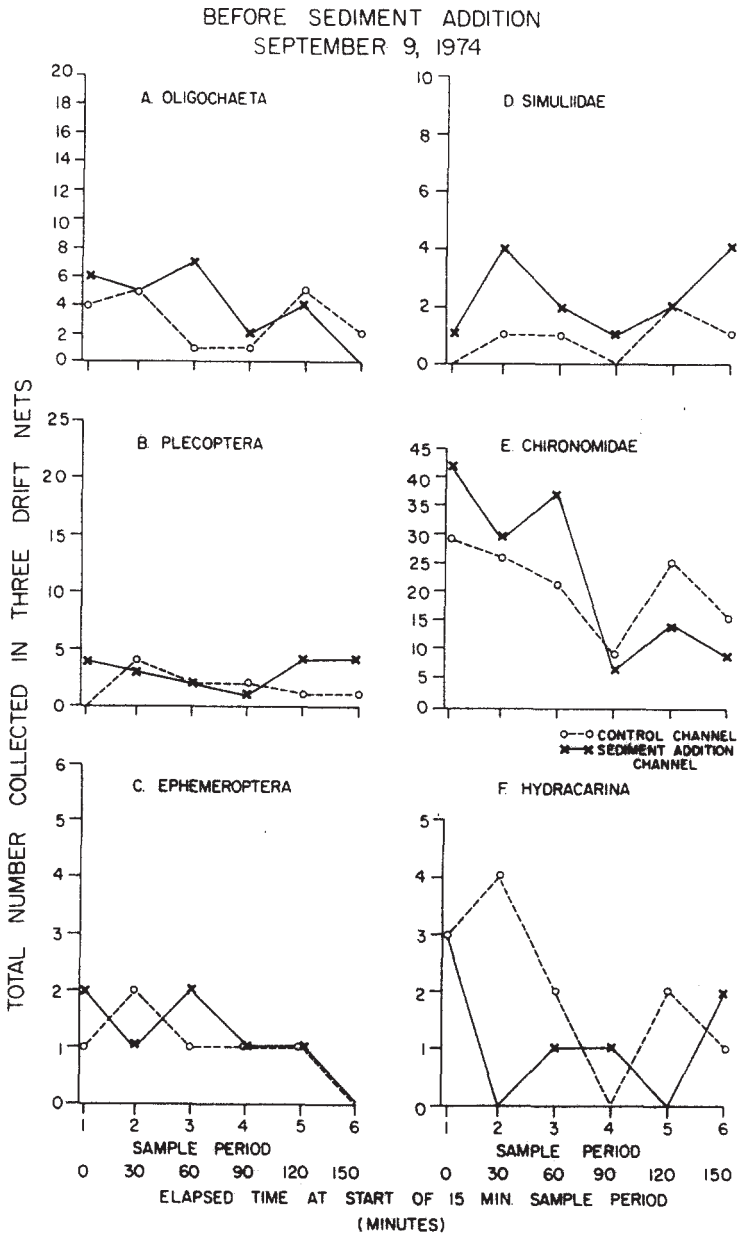

Fig. 3. Numbers of the most common higher taxa of macroinvertebrates drifting in time from experimental channels before the September 9, 1974 sediment addition.

plication over the entire channel yielded reasonably homogeneous *SS* concentrations through time for both experiments but not homogeneous *SS* concentrations along *S*, as originally intended (Rosenberg & Snow, 1975*a*) probably because of progressive, downstream accumulation of *SS*. *SS* concentrations decreased downstream when slurry was added at the head of the channel in the 1973 experiments.

More sediment was added in September than August because September discharge was approx five times higher (Table 1). Higher numbers of macrobenthos drifting in September than August did not result from more sediment being added because (1) the M_A values for August and September were similar; and (2) previous experiments showed that no relationship existed between sediment load and numbers drifting (Rosenberg & Snow, 1975*a*).

Settled sediment probably creates most changes in macrobenthic communities in rivers. Isolated, unrelated measurements of *SS* concentrations do not provide direct reference to the amount of sediment that settles. Future field research should try to relate quantitative measurements of sedimentation such as M_A or the *SSR* of Brunskill *et al.* (1975; equation 6) to quantitative responses by the stream biota.

General effects of sediment addition on drift of macroinvertebrates

Numbers of macrobenthos in the drift usually increase with increasing discharge (Elliott, 1970) so the

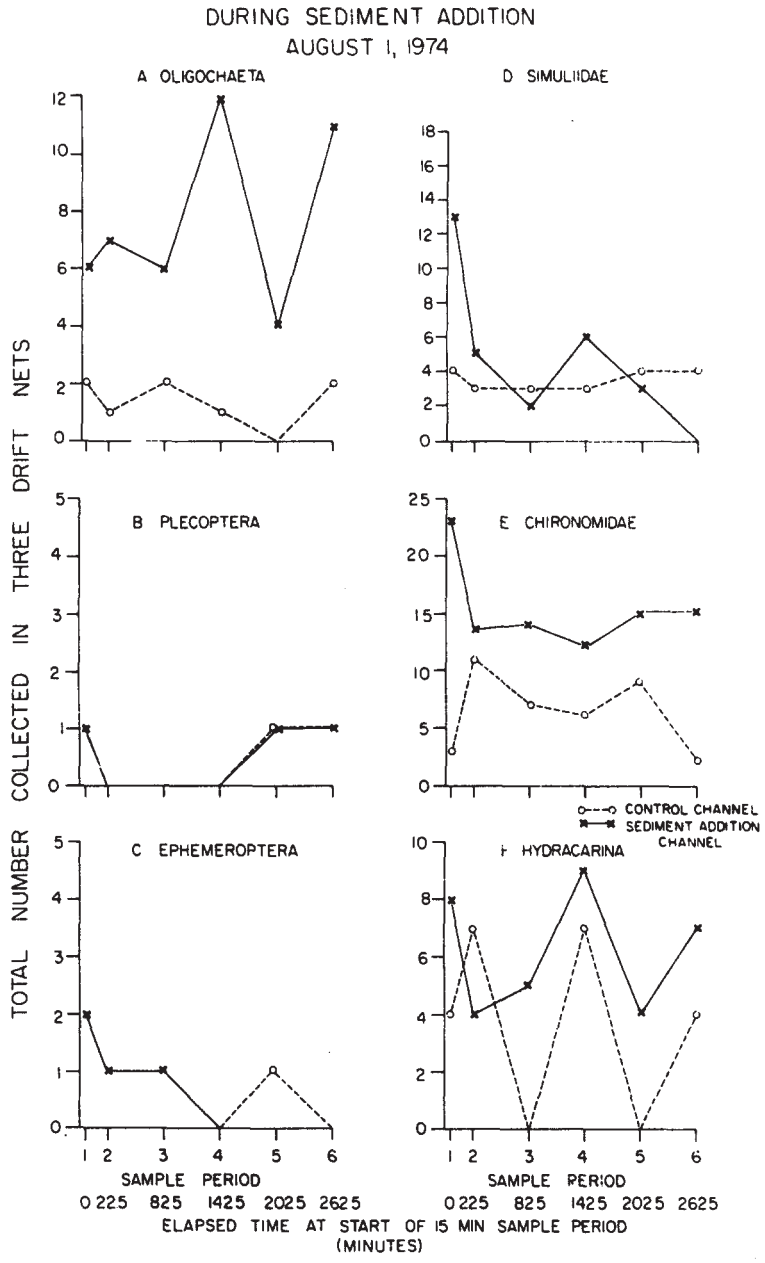

Fig. 4. Numbers of the most common higher taxa of macroinvertebrates drifting in time from experimental channels during the August 1, 1974 sediment addition.

higher numbers drifting from *S* than *C* during sediment addition (Tables 3 and 4). despite a lower discharge in *S* (Table 1), emphasize the effect of sediment addition. Experimental sediment additions by Gammon (1970) in Indiana & Müller (1970) in Sweden and stream dredging operations in England (Pearson & Jones, 1975) also produced increases in drift of macrobenthos, indicating a universal response to sediment addition and to other environmental perturbations (e.g. Elliott, 1967; Anderson & Lehmkuhl, 1968; Minshall & Winger, 1968; Hynes, 1970; Waters, 1972).

Effect of sediment addition on standing crop

Per cent of standing crop drifting in *C** was similar in August (0.39%) and September (0.53%). Increase in per cent of standing crop drifting due to sediment addition† was 0.36% in August and 1.84% in September. (Seasonal differences in response of macrobenthos to sediment addition are discussed below.)

Reduction of the standing crop of macrobenthos in the Harris River by 50% after 5 h of continuous

*Numbers drifting m^{-2} in 5 h divided by mean total number of macrobenthos m^{-2}.

† Numbers drifting m^{-2} in 5 h in *S* divided by mean total number of macrobenthos m^{-2} in *S* minus mean control % (= 0.46%).

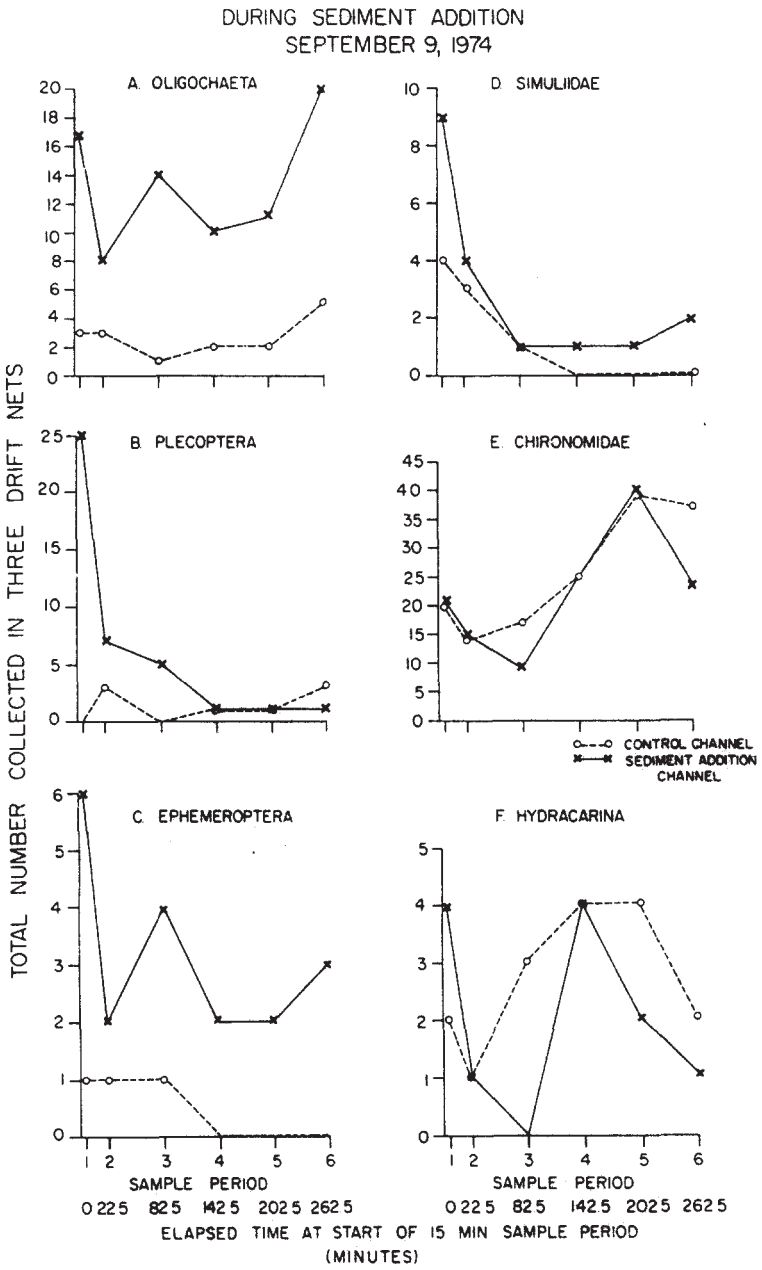

Fig. 5. Numbers of the most common higher taxa of macroinvertebrates drifting in time from experimental channels during the September 9, 1974 sediment addition.

sediment addition is uncertain because of the inadequate estimates of standing crop obtained (e.g. see Needham & Usinger, 1956; Chutter, 1972). Gammon (1970) reported that differences in standing crops could not always be detected using Surber samples when the creak of his study received relatively light suspended sediment addition (approx. two times normal, i.e. 15 to 40 mg l^{-1} during summer) but when suspended sediment rose to four times normal, standing crop decreases were easily detected. Concentrations of *SS* in the Harris River were increased 12–14 times (Table 2) but Deer Creek usually received quantities of sediment far in excess of the Harris River and over much longer periods of time. However, it is unlikely that we succeeded because (1) the statistical analyses of the Surber data do not support this conclusion; (2) numbers of macrobenthos drifting as a result of sediment addition did not exceed approx 2% of the standing crop in 5 h of sediment addition; and (3) the 1973 estimate of the time required to achieve 50% depletion (Rosenberg & Snow, 1975*a*) was far faster than for 1974.

Temporal effects of sediment addition

We examined the possibility that macrobenthic community response to sediment addition in the fall (Fig. 1) was a simple rate function, i.e. sediment addition initially 'strips' high numbers of macrobenthos from the substrate resulting in increased drift followed

Table 5. Densities (numbers m^{-2}) of major invertebrate taxa in Surber samples taken from experimental channels after the 1 August and 9 September, 1974 experiments

Date	Taxon	Channel: Control Sample no. 1	2	3	x	Channel: Sediment addition Sample no. 1	2	3	x
1 August	Plecoptera	75.4	53.8	64.6	64.6	10.8	53.8	10.8	24.8
	Ephemeroptera	430.6	527.4	366.0	441.3	602.8	355.2	559.7	505.9
	Trichoptera	150.7	301.4	0	153.9	118.4	247.6	150.7	172.2
	Chironomidae	9709.1	7341.2	4036.5	7028.9	8277.5	18406.4	9364.7	12015.9
	Simuliidae	0	279.9	0	93.7	10.8	53.8	0	21.5
	Hydracarina	183.0	53.8	322.9	186.2	75.4	462.9	387.5	308.9
	Oligochaeta	2701.8	624.3	1550.0	1625.4	775.0	2798.6	1765.3	1779.3
	Nematoda	107.6	21.5	107.6	78.6	43.1	75.4	366.0	161.5
	Total	13422.7	9310.9	6479.9	9738.2	9924.4	22507.5	12647.7	15026.5
9 September	Plecoptera	75.4	204.5	107.6	129.2	64.6	129.2	96.9	96.9
	Ephemeroptera	53.8	129.2	204.5	129.2	64.6	0	64.6	43.1
	Trichoptera	107.6	710.4	613.6	476.9	269.1	107.6	53.8	143.2
	Chironomidae	4015.0	19913.4	16199.8	13379.7	5091.4	7287.2	6393.8	6257.1
	Simuliidae	10.8	0	0	3.2	0	0	32.3	10.8
	Hydracarina	183.0	678.1	355.2	405.8	96.9	96.9	96.9	96.9
	Oligochaeta	602.8	4488.6	1840.6	2311.0	1711.5	2917.0	1786.8	2138.8
	Nematoda	21.5	204.5	279.9	204.5	0	0	0	0
	Total	5091.4	26328.7	19816.5	17082.5	7341.1	10634.8	8665.0	8880.3

by a logarithmic decrease through time as the substrate becomes progressively depleted of macrobenthos.

Increased numbers of Chironomidae drifting during the fifth drift net period (Fig. 5) probably caused the peak during the fifth period in the third order polynomial (Fig. 1). Drift of Chironomidae was similar between *C* and *S* (Fig. 5) so we removed Chironomidae from the total number of macrobenthos drifting, redid the polynomial regression, and found that the third order polynomial was no longer significant. Best fit to the data was a second order polynomial ($y = 16.733 - 0.152X + 4.910 \times 10^{-4}X^2$; $r^2 = 0.475$; $F_{1,15} = 8.866$; $P < 0.01$) which resembled the second order polynomial in Fig. 1 ($y = 21.758 - 0.127X + 4.684 \times 10^{-4}\ X^2$). Next we arbitrarily made the increased numbers of Oligochaeta drifting during period 6 (the only taxon whose numbers increased significantly at the end of the September experiment, Fig. 5) equal to the number drifting during period 5 and redid the polynomial regression. Best fit to the data remained a second order polynomial ($Y = 16.462 - 0.134X + 3.916 \times 10^{-4}\ X^2$; $r^2 = 0.469$; $F_{1,15} = 5.414$; $P < 0.05$). We could not equate this final curve with a simple rate function, so a modified explanation of the observed response of macrobenthos to sediment addition is required. Two possibilities are:

(1) Initiation of sediment addition causes an immediate avoidance reaction by surface dwelling macrobenthos, shown by an increase in drift. A lag period follows while the surface sediments are repopulated by macrobenthos from the hyporheic. (The lag period could also result from macrobenthos moving down into the hyporheic to avoid sedimentation.) Drift rate again increases after 2–2½ h as the newly recruited macrobenthos drift to avoid sediment addition. Macrobenthos are capable of vertical migrations within the hyporheic (Hynes, 1970; Williams & Hynes, 1974) which can serve to recolonize disturbed areas of a stream (Williams & Hynes, 1976). Rates of vertical migration in the hyporheic have not been measured although Hynes (1970, 1974) and Williams & Hynes (1974) have suggested that the movements are rapid, possibly within 1–2 h (e.g. observations on the Speed River, Ontario; Wallace, Northern Forest Research Center, Edmonton; personal communication). Duration of the lag period in our study was ½–2 h so it is possible that recruitment in the Harris River could have occurred during this time.

(2) Species of invertebrates most sensitive or most exposed to sediment addition begin leaving immediately after initiation of sediment addition (e.g. Simuliidae, Plecoptera, Ephemeroptera; Fig. 5). A lag period follows during which time sufficient sediment settles to cause more tolerant species or those deeper in the substrate to leave as well (e.g. Oligochaeta; Fig. 5) (cf. Rosenberg & Wiens, 1976).

Seasonal effects of sediment addition

The polynomial regressions indicated a different temporal response to sediment addition in the fall than the summer; the increase in per cent of standing crop drifting due to sediment addition was five times greater in September (1.84%) than August (0.36%); and four of the six major taxa examined showed different seasonal responses to sediment addition (see above). Seasonal differences in responses of invertebrates to environmental pollutants have been reported (e.g. Crapp, 1971; Tagatz, Borthwick & Forester, 1975).

Normal seasonal differences in undisturbed temperate stream macrobenthic communities (Hynes, 1970) could explain our observations in the Harris River. Zoobenthos in late summer are characterized by high emergence and egg-laying (resulting in lower numbers of invertebrates present in the substrate to respond to sediment addition), many species in resting stages to avoid high water temperatures (and therefore, unresponsive to sediment addition), and species occur-

ring deeper in the substrate to avoid drought (and hence less affected by sediment addition).

Temperate streams in autumn are characterized by eggs hatching, an increase in numbers and growth of invertebrates, and emergence of insects from resting states. Thus, more invertebrates in active life history stages are present to respond to sediment addition.

Spring communities are composed of species of insects which emerge early, hatching of eggs of species which grow in spring and summer, and species which begin renewed growth after the winter slowdown. Therefore, this is also an active time in the life of a stream and, in the absence of actual experimentation, we infer that the invertebrate community would also be sensitive to sediment addition in spring.

Relevance to terrain disturbance in the Mackenzie Valley

Although our conclusions should be tested on a variety of stream types in the Mackenzie Valley, we believe that stream watershed disturbances (e.g. road or pipeline construction) undertaken during the open-water period and likely to yield additions of sediment to streams would have less effect on the invertebrate community during the summer months than during spring or fall.

However, since it is important that a river be able to quickly clear its substrate of settled sediment to prevent damage to the macrobenthic community (Rosenberg & Snow, 1975*b*), verification of adequate river discharge should accompany our recommendation of a summer 'safe' period.

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