

Research Technical Completion Report

**EFFECTS OF SUSPENDED SEDIMENTS
ON STREAM INVERTEBRATE DETRITAL
PROCESSING AND BIOENERGETICS**

Co-Investigators:

M.A. Brusven

and

C.E. Hornig

Department of Plant, Soil and Entomological Sciences



Idaho Water and Energy Resources Research Institute

University of Idaho

Moscow, Idaho 83843

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University of Idaho
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ABSTRACT

The effects of suspended sediments on stream invertebrate detrital processing and bioenergetic parameters were investigated in replicated, light and temperature-controlled chambers in the laboratory. The leaf-shredding insects Pteronarcys californica and Hesperophylax occidentalis were studied. Mean daily ingestion rates were less among test insects than control insects for seven of the eight trials. In five of the eight trials, mean ingestion rates were suppressed by $\geq 41\%$ when compared to insects held in 0.0 g/l suspended sediment environments. Feeding inhibition was typically greater at the end of the feeding trials (14 days) than at the beginning (0-4 days). Growth of the immature feeding stage of the insects studied in both test and control environments for all trials combined was negligible when compared to their ingestion rates. Mean daily growth rates ranged from -1.2% to 1.6% of the mean daily ingestion rates. The mean assimilation efficiencies of second-year naiads of P. californica were 17.4% and 21.3% when subjected to 3.0 g/l and 0.0 g/l suspended sediment concentrations, respectively.

Processing of coarse particulate organic matter in streams is of major importance not only to the shredding insect component, but to collectors which feed on fine particulate organic matter. Much of the fine particulate organic matter is the undigested residue of shredding insects. Vertebrate predators on the other hand benefit by feeding on invertebrates, thus facilitating productivity of their own trophic level.

INTRODUCTION

Inorganic sediment introduction is a common and ubiquitous cause of water quality deterioration in lakes and streams (Iwamoto et al., 1978). Agriculture, forestry, road construction, mining, and urban development all contribute to increased sediment loads of streams. The effects of bottom sedimentation on the community structure of benthic insects have been well documented (Cordone and Kelley, 1961; Cummins and Lauff, 1969; Brusven and Prather, 1974; Lemly, 1982). Bjornn et al. (1977) found that sediment in streams caused a major impact on invertebrate population and community dynamics; further, the degree to which cobbles were imbedded in fines resulted in conspicuous species-specific responses.

Sedimentation may also affect the productivity of insect populations through burial of their food resources. Reice (1980) reported that leaf litter decomposition was less in silt than on coarser sediments. Herbst (1980) reported decreased insect consumption of previously buried leaves.

Suspended sediment effects on stream insects are poorly understood. To date, studies have been limited primarily to field investigations which have found that increased insect drift occurs during times of high suspended sediment loads (Rosenberg and Wiens, 1975; White and Gammon, 1977; O'Hop and Wallace, 1983). In a laboratory study, Brusven and Hornig (1984) found no significant mortality when selected insect species were subjected to suspended volcanic ash levels of 2 g/liter concentration. Although suspended solids are not actually toxic to aquatic life (Wilber, 1969), stressful responses

(catastrophic drift) to suspended sediments prompted us to study the sublethal effects of these materials. Our studies were designed to apply bioassay techniques to investigate the effects of suspended inorganics on the functional processing of leaves by invertebrates, and to assess changes in energy budget parameters of selected invertebrates under different suspended sediment conditions.

MATERIALS AND METHODS

The suspended sediment experiments were conducted in 10, 1-liter glass beakers filled with 0.9 liter of unchlorinated tap water. These vessels were placed in a temperature bath held at 5°C-10°C. A magnetic stirrer was positioned beneath each vessel in order to maintain water circulation and oxygen saturation within the vessels. A 1.2 mm mesh screen was used to divide the vessels into an upper and lower chamber. The upper chamber was used to hold subject insects during the feeding trials, thus minimizing injury to the test insects by the stirring rods. Dark-light cycles were maintained by timers attached to four, 1.2-m fluorescent-light tubes suspended 0.6 m above the vessels. For all but one experiment (trial), the dark-light conditions were set at 12-12 h. A 6-18 h dark-light cycle was used during the trial conducted in December, 1983, in order to stimulate feeding of the winter-collected experimental animals.

The stream insects tested were the caddisfly Hesperophylax occidentalis (Banks) and the stonefly Pteronarcys californica Newport. These insects are leaf-shredders (Merritt and Cummins, 1978). Hesperophylax occidentalis is found in small mountain streams of the western United States (Martinson and Ward, 1982), while P. californica is common in the intermediate to larger streams of this region (Elder and Gaufin, 1964). Early and late instar larvae of H. occidentalis and first and second year P. californica naiads were used for assessing age-specific responses to suspended sediments. Field collected specimens were acclimated under experimental temperature and light conditions for a minimum of four days prior to testing in oval laboratory streams similar to those described by Brusven (1973).

All organisms were starved for two days prior to testing.

Wet weights of the insects were determined at the initiation of each trial; both wet and ash-free dry weights (AFDW) were assessed at the conclusion of each trial. The end-of-trial ratio of wet weight to AFDW was used to estimate the initial AFDW from the initial wet weights in order to calculate growth on a AFDW basis. During each trial, one insect was placed in each of the control and test chambers.

Alder (*Alnus rubra*) leaves were used as the food material in all trials. The leaves were conditioned in unchlorinated tap water kept at 40°C for one month prior to a trial, except for those trials conducted during the winter, in which the leaves were held in a conditioned state for two to four months.

Two pairs of 18-mm leaf disks were cut from each leaf with a cork borer. One disk from the first pair of disks was placed in the test vessel, while that pair's other disk was placed in an insect-free vessel. The second pair of disks was similarly placed in a control vessel and an insect-free vessel. This procedure was repeated for all chambers and assured presentation of similar leaf material to test and control insects. Daily leaf consumption was estimated as the difference in AFDW between the member of each pair of disks kept in an insect-free vessel and the corresponding member kept in a vessel with insects. This procedure allowed direct measurement of leaf loss due to insect feeding and is similar to that described by Grafius and Anderson (1979).

The test material was commercially graded fine sand sieved through a 75 µm mesh screen and added to the test chambers as a slurry. Suspension was maintained by magnetic stirrers positioned beneath each

test vessel. Two levels of suspended sediment concentrations (1500 mg/l and 3000 mg/l) were tested on each of the two size classes of each species for a total of eight trials. Suspended sediment treatments were randomly allocated to five of the chambers, with the remaining five chambers used as the control replicates.

Each trial was conducted for 14 days. At two- to seven-day intervals, depending on leaf utilization, the residual coarse leaf material was replaced by new leaf disks. The water from the chambers was also removed at these times and filtered through a 0.45- μ m filter to determine egestion rates. Egestion is defined here as the intestinal elimination of undigested residue involved in the feeding and digestion process. The filtered material was microscopically examined to estimate the proportion of undigested and digested organic materials.

RESULTS

Ingestion and Growth Rate Responses

Statistical significance ($P < 0.05$) for ingestion rates was not shown for any of the trials involving two shredder insect species representing two age classes subjected to two suspended sediment concentrations (Tables 1 and 2). While statistical significance was not achieved, mean daily ingestion rates were less among our test insects than control specimens for seven of the eight trials. For five of the eight trials, mean ingestion rates were suppressed by $\geq 41\%$ when compared to the insects held in 0.0 g/l suspended sediment environments. For a given age class, ingestion rates were less at 3.0 g/l vs. 1.5 g/l suspended sediments in half of the trials. Greater daily mean ingestion rates at the higher suspended sediment level was evident for early-instar tests for Hesperophylax occidentalis and second-year naiads of Pteronarcys californica.

Exposure duration to suspended sediment influenced ingestion rates (Figs. 1-4). Feeding inhibition among test insects was typically more evident towards the end rather than the beginning of the trials (Figs. 1-4). The debilitating effect of extended exposure was particularly pronounced among the early-instar H. occidentalis larvae exposed to 3 g/l. For this species the mean ingestion rate of test insects remained similar to that of the control insects during the first 12 days of exposure, but fell to 12% of that of the control group during the final two days of the trial.

The growth of both control and test insects for all trials was negligible compared to their ingestion rates (Figs. 1-4). Mean daily

Table 1. Comparison of mean daily ingestion rates for Hesperophylax occidentalis larvae exposed to two suspended-sediment levels vs. those exposed to 0.0 g/l suspended sediment (control larvae). Trial duration: 14 days; individuals per treatment: 5; t and p values calculated using Student's t test levels.

Age Class	Sediment Concentration Level	Mean Daily Ingestion Rate (mg AFDW/day)			
		Control Insects	Test Insects	t	p
Early instar	1.5 g/l	0.42	0.21	2.06	0.11
Early instar	3.0 g/l	1.22	1.19	0.17	0.87
Late instar	1.5 g/l	1.47	0.86	1.38	0.24
Late instar	3.0 g/l	1.81	0.85	2.10	0.10

Table 2. Comparison of mean daily ingestion rates for Pteronarcys californica exposed to two suspended-sediment levels vs. those exposed to 0.0 g/l suspended sediment (control naiads). Trial duration: 14 days; individuals per treatment: 5; t and p values calculated using Student's t test.

Age Class	Sediment Concentration Level	Mean Daily Ingestion Rate (mg AFDW/day)			
		Control Insects	Test Insects	t	p
First-year	1.5 g/l	1.29	1.13	0.93	0.40
First-year	3.0 g/l	0.57	0.24	2.43	0.07
Second-year	1.5 g/l	1.70	0.76	2.09	0.10
Second-year	3.0 g/l	9.49	9.97	0.93	0.40

growth rates ranged from -1.2% to +1.6% of the mean daily ingestion rates. Differences in growth rates between control and test insects, although small, were apparently age-related. Early instar control insects in three of the four trials gained less weight or lost more weight compared to the test insects, while the opposite trend was true among later instars of the same species.

Effects of Suspended Sediments on Egestion Rates and Insect Energy Budgets

Low ingestion rates in seven of the eight trials and correspondingly minute amounts of egested organics precluded the determination of reliable egestion rates for these trials. The trial involving second-year P. californica naiads subjected to a high-sediment-concentration of 3.0 g/l, however, provided sufficient egestion residue for biomass determination (Table 3). For this trial, the mean assimilation efficiencies were 17.4% for the test animals and 21.3% for the control insects using the formula $(I-E)/I \times 100$, where I = ingestion rate and E = egestion rate.

The energy budget of an insect may be described as the amount of food ingested (I) and its allocation into growth (G), respiration (R) and egestion (E), or $I = G + R + E$ (Welch, 1968). This budget can be estimated for the second-year P. californica nymphs used in the high-sediment concentration trial, since ingestion, egestion, and growth rates were determined on the insects (respiration is calculated by subtraction). For both test and control insects, approximately 80% of the ingested material was egested with the remainder inferred to have been involved in growth and/or lost through respiration (Table 4). The

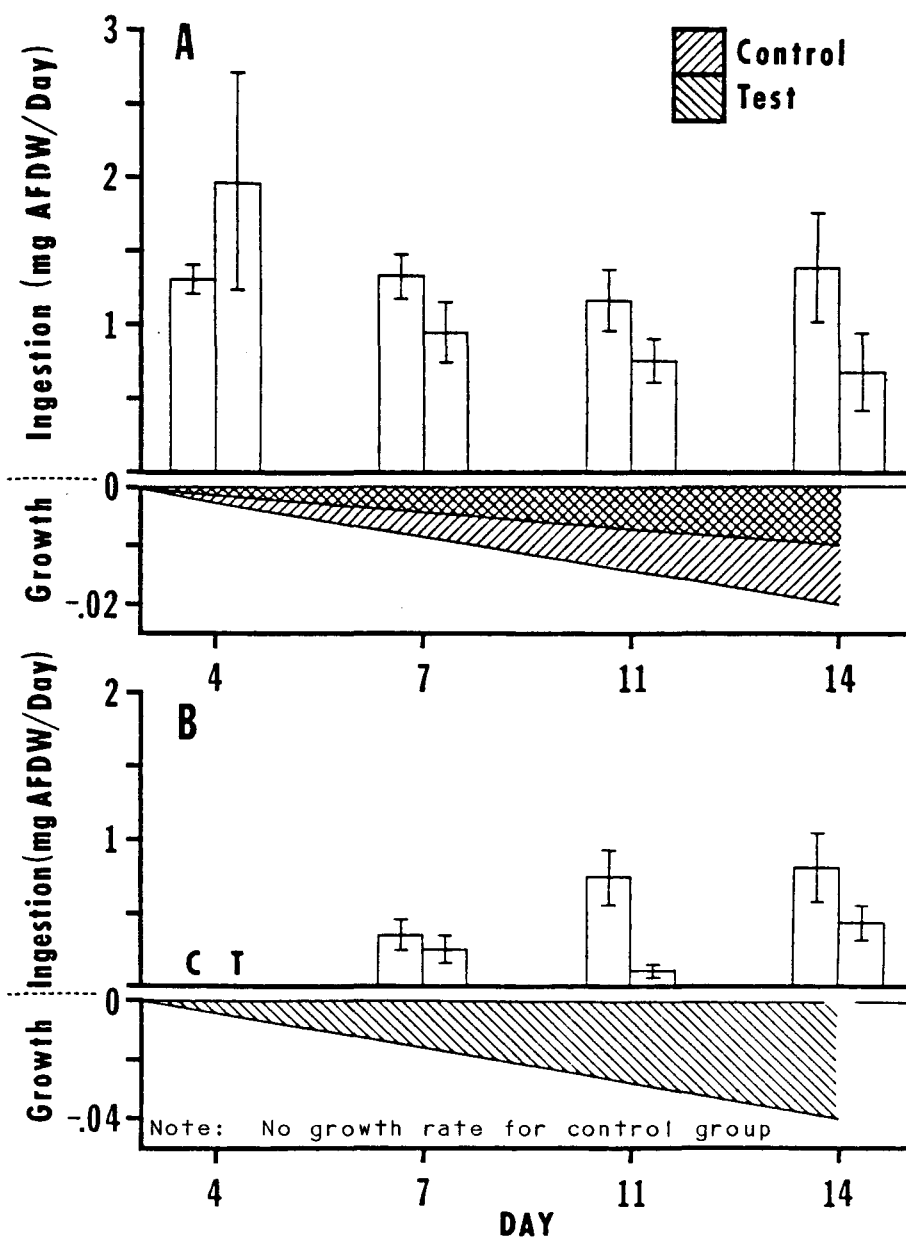


Figure 1. Mean daily ingestion and growth rates (mg AFDW/day) for first year naiads of *Pteronarcys californica* exposed to: A. 1.5 g/l and B. 3.0 g/l suspended sediment for 14 days. C = control insects, 0.0 g/l suspended sediment; T = test insects.

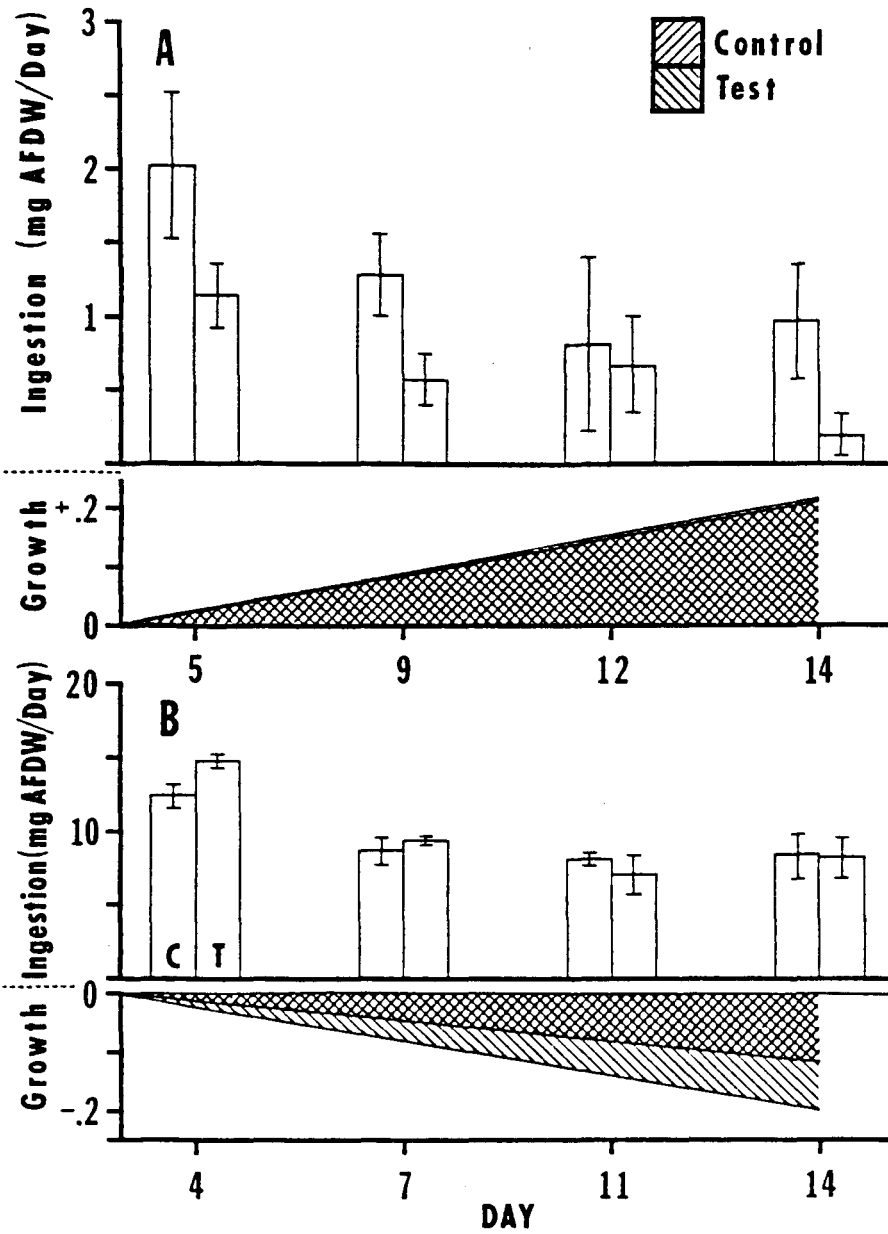


Figure 2. Mean daily ingestion and growth rates (mg AFDW/day) for second year naiads of *Pteronarcys californica* exposed to: A. 1.5 g/l and B. 3.0 g/l suspended sediment for 14 days. C = control insects, 0.0 g/l suspended sediment; T = test insects.

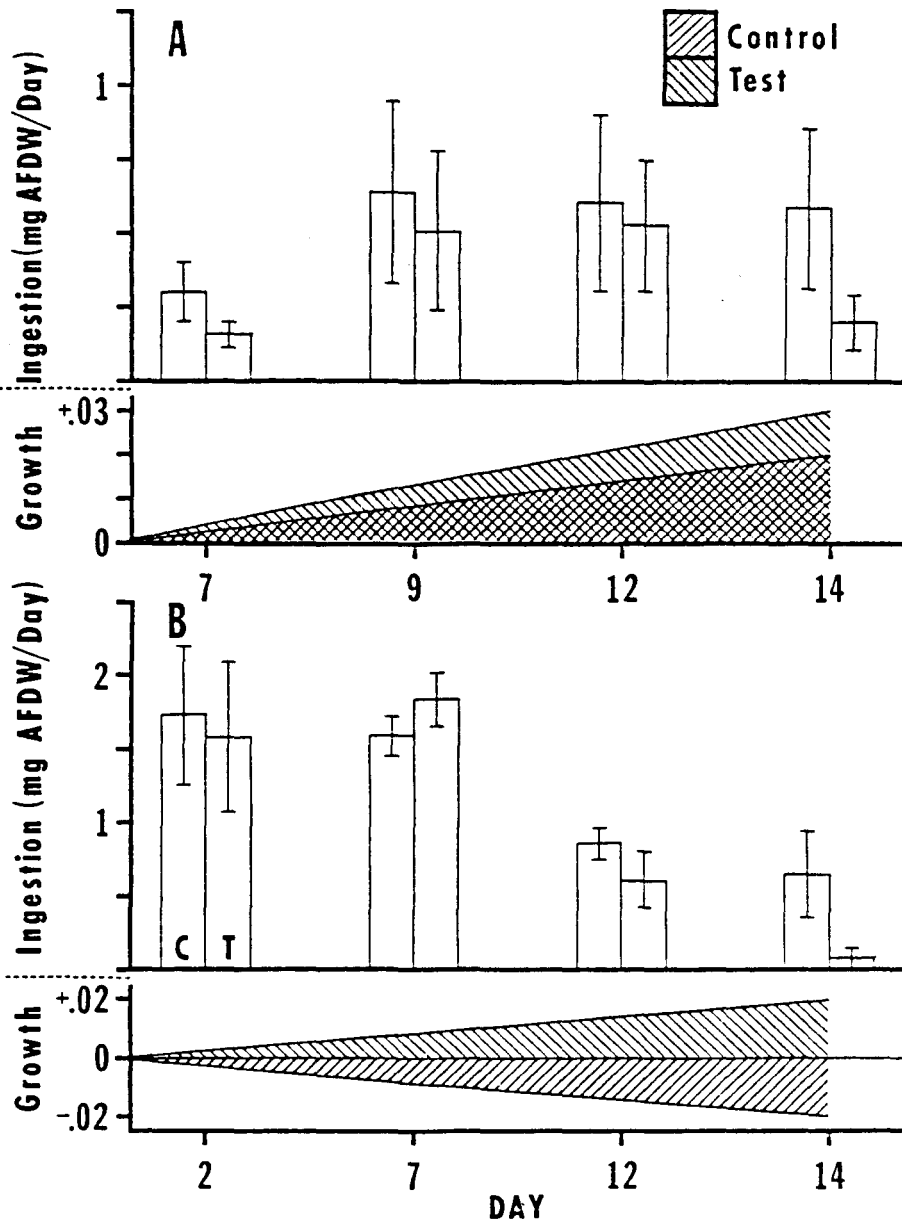


Figure 3. Mean daily ingestion and growth rates (mg AFDW/day) for early instar larvae of *Hesperophylax occidentalis* exposed to: A. 1.5 g/l and B. 3.0 g/l suspended sediment for 14 days. C = control insects, 0.0 g/l suspended sediment; T = test insects.

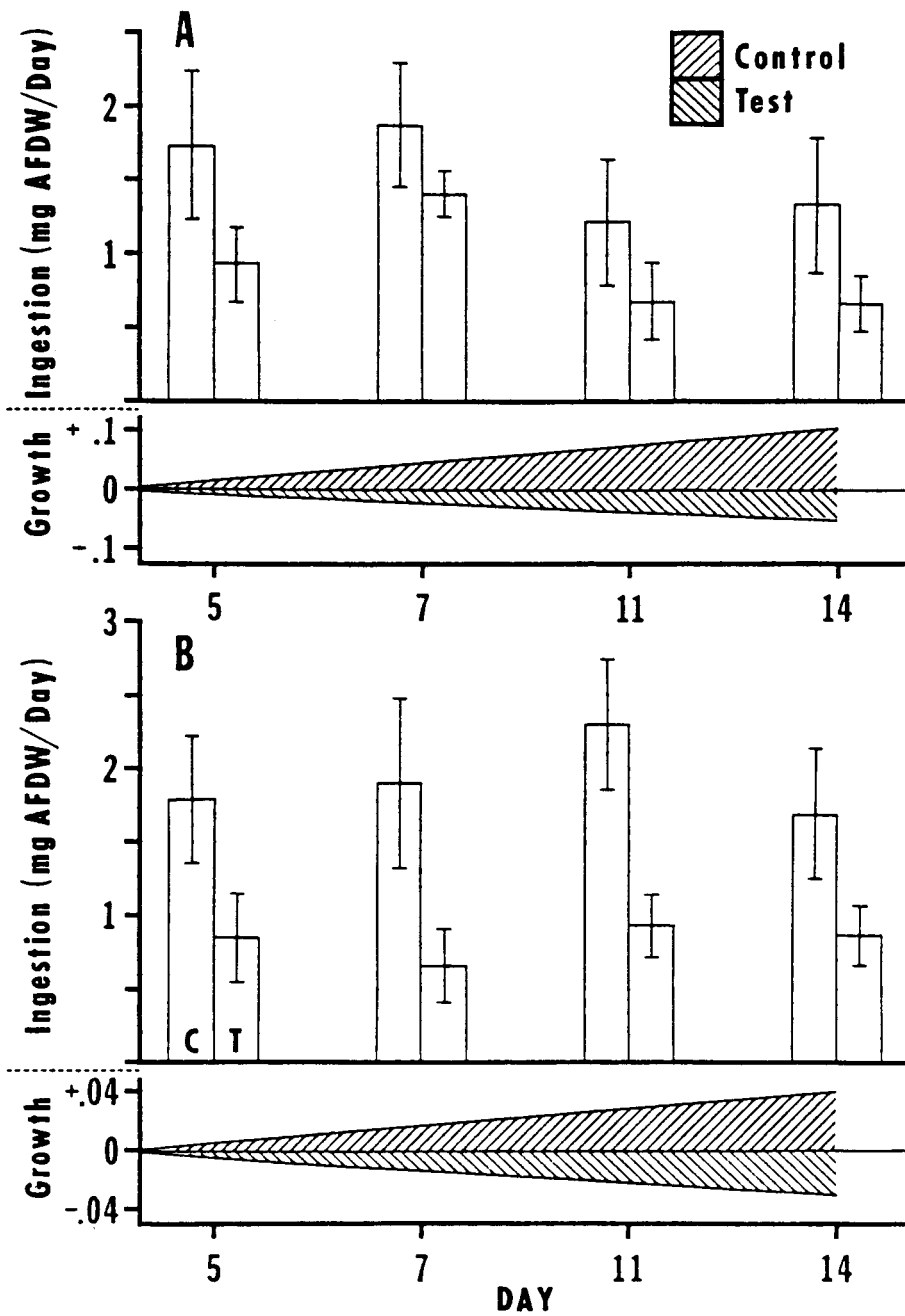


Figure 4. Mean daily ingestion and growth rates (mg AFDW/day) for late instar larvae of *Hesperophylax occidentalis* exposed to: A. 1.5 g/l and B. 3.0 g/l suspended sediment for 14 days. C = control insects, 0.0 g/l suspended sediment; T = test insects.

presence of suspended sediment, apparently had little effect on the proportion of ingested food being passed through the gut or the amount of energy required for maintenance.

Table 3. Mean daily ingestion and egestion rates (mg AFDW/day) and mean assimilation efficiencies for second-year *Pteronarcys californica* naiadsexposed to 3.0 g/l suspended sediment and for naiads exposed to 0.0 g/l suspended sediment (control).

	Days of Trial								
	1-4		5-7		8-11		12-14		
	Ingestion	Egestion	Ingestion	Egestion	Ingestion	Egestion	Ingestion	Egestion	
Control Replicate 1	15.4	14.9	8.3	6.0	5.0	5.0	9.4	6.1	
Control Replicate 2	15.2	12.6	9.8	6.3	4.9	2.4	3.6	3.2	
Control Replicate 3	13.0	13.0*	9.0	5.7	9.8	9.4	7.7	5.5	
Control Replicate 4	15.2	15.2*	10.3	6.6	10.6	10.6*	11.9	7.6	
Control Replicate 5	15.1	15.1*	9.0	8.5	5.0	4.0	8.3	8.3*	
\bar{X} Assimilation Efficiency = 21.3%									
Test Replicate 1	10.9	10.2	7.1	3.2	8.0	7.6	6.7	4.6	
Test Replicate 2	14.0	7.0	11.0	11.0*	9.6	7.6	11.5	9.4	
Test Replicate 3	13.0	6.1	6.1	5.2	7.5	6.2	5.3	5.2	
Test Replicate 4	10.1	8.5	8.7	8.0	7.4	7.4	12.2	8.9	
Test Replicate 5	14.0	7.9	10.6	7.2	8.1	6.8	5.9	5.0	
\bar{X} Assimilation Efficiency = 17.4%									

*Measured egestion values have been corrected (limited) to 100% of egestion.

Table 4. Mean egestion, growth and respiration expressed as percent of ingestion for second-year Pteronarcys californica naiads exposed to 3.0 g/l suspended sediment (test) and for naiads exposed to 0.0 g/l suspended sediment (control).

Experimental Group	Egestion	Growth	Respiration
Control	78.7	-0.1	21.4
Test	82.6	-0.1	17.5

DISCUSSION

Previous research on the sublethal effects of suspended sediments on aquatic invertebrates is minimal and largely limited to zooplankton studies (Arruda et al., 1983; McCabe and O'Brien, 1983). The latter studies determined that suspended sediments decrease feeding rates of Daphnia spp. by at least 90%. These filter-feeding invertebrates were found to ingest large quantities of silt from the water column, resulting in dense packing of the gut by inorganic particles. A decreased filtering rate is likely to be a physiological response to this excessive gut loading (McCabe and O'Brien, 1983). Ingestion by filter-feeding stream macroinvertebrates, such as Simuliidae, that directly feed from the water column may be similarly affected in turbid waters. Although the sediment ingestion rate would likely be lower among non-filterers, it may have been a factor for the early-instar H. occidentalis larvae, which displayed a sudden decrease in feeding after 12 days of exposure to a level of 3 g/l suspended sediment. The trend of increased feeding impairment of aquatic detritivores with longer exposures to suspended sediments, as evidenced in several of our trials, indicates that prolonged periods of turbidity may severely affect their growth and ability to process large amounts of leaf detritus.

The differences we observed in the feeding rates of our control insects may be related to physio-ecological changes keyed to the season the specimens were collected in the field. We were able to induce noticeable feeding activity in the December collected, first-year P. californica naiads only after altering the dark-light cycle to 6-18 h, thereby increasing the number of daylight hours. Feeding rates for

these insects were still much lower than for first-year, November-collected P. californica naiads. Among the second year P. californica naiads tested, those collected in October fed at much higher rates than those collected during August. Temperature and food availability should make autumn the most opportune time for this leaf-shredding insect to actively feed.

The early-instar H. occidentalis larvae collected in mid-February manifested higher ingestion rates than those collected during early January. Field observations at the collection site suggest that greatest larvae growth occurs during early spring. Our hypothesis that feeding rates are influenced by seasonal cues and ambient conditions, particularly photoperiod, is supported by a number of studies of insect responses to such environmental cues (Hynes, 1970; Lutz, 1974; Beck, 1980).

Another factor which may affect feeding rates between trials is the conditioning time of the leaf material (Golladay et al., 1983). In our study, leaf disks used during our winter trials were conditioned for longer than one-month, however, there was little evidence to support differential feeding rates in relation to conditioning time.

The effect of suspended sediment on invertebrate ingestion appears to be influenced by the season and the feeding status of the insects. Feeding rates of insects in an active-feeding mode may not be as affected as insects in a less active-feeding mode. We speculate that the effects of short-term turbidity will, therefore, vary with the season. Our study did, however, provide evidence that longer exposure to turbidity will eventually adversely affect both the active and non-active feeding status of the insects tested.

Our results indicated that ingestion is a key energy-budget parameter of large-particle detritivores affected by suspended solids. The limited effect that high concentrations of suspended sediments had on the assimilation efficiency of second-year P. californica is supported by the work of Golladay et al. (1983). They found that, although environmental factors affected the ingestion rate of Pteronarcys proteus naiads, the assimilation efficiencies remained within a relatively narrow range of 13.4 to 21.9%. If this pattern is consistent in natural systems, the reduced feeding activity of Pteronarcys caused by suspended sediments or other inimical factors will likely translate into a proportionate reduction in the production of feces.

The egestion rates found in our study are probably overestimated due to the interference by autochthonous growths in some of the chambers. The preponderance of egestion measurements with values higher than 100% of ingestion (corrected to 100%) from the test chambers as compared to the control chambers (five versus one) strongly suggest that autochthonous-production interference was common in the test waters. This is not surprising as sediment particles can act as substrate for bacterial growth (Lemly, 1982). The difference between the mean assimilation efficiencies of the test and control replicates was probably less than the estimated 2.9%, and, for the purposes of our data, can be considered roughly equivalent. Another factor that can bias egestion estimates is the fine leaf material broken off during feeding, but not ingested. Microscopic examination of the filtered water, however, indicated that less than 10% of the fine-particle leaf material was undigested.

Impacts on the biological functioning of large-particle aquatic detritivores (shredders) such as the species tested in this study may have serious ramifications on other members of the stream biota. This is particularly true for small first-to-third order streams which are heavily influenced by a riparian canopy. The riparian vegetation shades the stream, suppresses algal production, while supplying the stream with large amounts of coarse particulate organic matter. The result, is an ecosystem chiefly dependent on allocthonous inputs as its primary source of energy (Anderson and Sedell, 1979). Processing of large-particle detritus by shredder invertebrates has been shown to provide fine-particle detritivores with the energy and nutrients they require. For example, Short and Maslin (1977) found that the addition of Pteronarcys californica to laboratory streams supplied with alder leaves increased the food availability to Hydropsyche, a filter-feeding caddis, by 35-100% and to Simulium, a filter-feeding dipteran, by 600-700%. Grafius and Anderson (1979) found that although the production of the leaf shredder Lepidostoma quercina was itself a minor component in a small Oregon stream, the feces produced by this insect was estimated to support 20-50% of the much more abundant simuliid population found in the creek. This is not surprising, as the fecal production rate of Lepidostoma has been calculated to be 50X its growth rate (Grafius and Anderson 1980).

The results of this study should encourage future research into the effects of water quality deterioration on the biological functioning of stream ecosystems. Nontoxic materials, such as inorganic silt, or sublethal concentrations of toxicants, although not manifesting spectacular and immediate impacts on aquatic populations, may

nevertheless result in lowered productivity of populations and decreased efficiency of energy transfer and nutrient cycling in stream ecosystems.

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