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*Pteronarcys californica* (Plecoptera: Pteronarcidae)**

C. Evan Hornig  
*University of Idaho, Moscow*

Merlyn A. Brusven  
*University of Idaho, Moscow*

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# EFFECTS OF SUSPENDED SEDIMENT ON LEAF PROCESSING BY *HESPEROPHYLAX OCCIDENTALIS* (TRICHOPTERA: LIMNEPHILIDAE) AND *PTERONARCYS CALIFORNICA* (PLECOPTERA: PTERONARCIDAE)<sup>1</sup>

C. Evan Hornig<sup>2</sup> and Merlyn A. Brusven<sup>2</sup>

**ABSTRACT.**—The effects of suspended sediments on stream invertebrate detrital processing were investigated under replicated conditions in light and temperature-controlled chambers in the laboratory. The leaf-shredding insects *Pteronarcys californica* and *Hesperophylax occidentalis* were studied. Mean daily ingestion rates were lower among insects subjected to suspended sediments (1.5 and 3.0 g/l) than insects held in suspended sediment-free environments 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 suspended sediment-free environments. Feeding inhibition was typically greater at the end of the feeding trials (14 days) than at the beginning (0-4 days). The effects of suspended sediments on ingestion were apparently related to the feeding status of the insects at the time of a trial. Insects in an active feeding mode were less influenced by suspended sediment than those in an inactive feeding mode. We conclude that, depending on the season and the duration of impact, suspended sediment can suppress processing of coarse particulate organic matter and thus adversely influence important nutrient and energy pathways in low-order streams.

Inorganic sediment introduction is a common and ubiquitous cause of water quality deterioration. Certain practices used in agriculture, forestry, road construction, mining, and urban development may contribute to increased sediment loads of streams. The effects of bottom sedimentation on macroinvertebrate distribution and community structure have been well documented (Brusven and Prather 1974, Cordone and Kelley 1961, Cummins and Lauff 1969, Lemly 1982). Bjornn et al. (1977) found that different quantities of sediment and the degree to which cobbles were imbedded by fine sediments differentially affected species within the macroinvertebrate community.

Sedimentation can also affect the size of insect populations through degradation of food resources. Reice (1980) reported that leaf litter decomposition was less in silt than on coarse-particle sediments; Herbst (1980) reported decreased insect consumption of previously buried leaves.

The effects of suspended sediments on stream insects are poorly understood. Field investigations have shown that high suspended sediment loads cause increased insect drift (Rosenberg and Wiens 1975, White and Gammon 1977, O'Hop and Wallace 1983).

Although most suspended sediments are apparently not acutely toxic to aquatic life (Brusven and Hornig 1984, Oxberry et al. 1979), stressful responses, such as catastrophic drift, have been documented and prompted us to study other sublethal effects. Our study was designed to investigate the effects of suspended inorganic sediment on the degradation of leaf litter by stream insects.

## MATERIALS AND METHODS

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  $5\text{C} \pm 1$  to minimize algal growth. A magnetic stirrer was positioned in the bottom of each vessel to maintain water circulation and oxygen saturation. A 1.2-mm mesh screen was placed 3 cm above the magnetic stirrer in each beaker to protect the insects from injury. Photoperiod was controlled 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 to induce feeding by the experimental animals in December.

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<sup>2</sup>Department of Plant, Soil, and Entomological Sciences, University of Idaho, Moscow, Idaho 83843.

TABLE 1. Mean daily ingestion rates for *Hesperophylax occidentalis* larvae exposed to two levels of suspended sediment (1.5 and 3.0 g/l) and those for control larvae. (Trial duration: 14 days; individuals per treatment: 5; t and p values calculated using Student's paired t test.)

Age class	Sediment concentration level	Mean daily ingestion rate (mg/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. Mean daily ingestion rates for *Pteronarcys californica* naiads exposed to two levels of suspended sediment (1.5 and 3.0 g/l) and those for control naiads (Trial duration: 14 days; individuals per treatment: 5; t and p values calculated using Student's paired t test).

Age class	Sediment concentration level	Mean daily ingestion rate (mg/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

The stream insects tested were the caddisfly *Hesperophylax occidentalis* (Banks) and the stonefly *Pteronarcys californica* Newport. These insects are primarily leaf-shredders (Merritt and Cummins 1978). *Hesperophylax occidentalis* is found in small mountain streams of the western United States (Martinson and Ward 1982), whereas *P. californica* is common in larger streams of the region (Elder and Gaufin 1964). Early- and late-instar larvae of *H. occidentalis* and first- and second-year naiads of *P. californica* were used to assess age-specific responses to suspended sediments. Insects were collected in the field and acclimated to laboratory conditions for a minimum of four days prior to testing. All organisms were starved for two days prior to testing.

Alder (*Alnus rubra*) leaves were used as the food in all trials. The leaves were conditioned for one month in unchlorinated tap water held at 4 C; in winter feeding trials the leaves were held for two to four months. The suspended sediment material was commercially graded white sand sieved through a 75- $\mu$ m mesh screen and added to the test chambers as a slurry. Sediments were maintained in suspension by water circulation from the magnetic stirrers.

Two suspended sediment concentrations (1.5 g/l and 3.0 g/l) were tested against a con-

trol concentration of 0.0 g/l on each of the two nymphal or larval age classes and two insect species for a total of eight trials. For each trial, 12 vessels were arranged in pairs in a continuously circulating, temperature-controlled bath. Five pairs of vessels were used to determine insect feeding rates in suspended sediment and sediment-free environments; the sixth pair of vessels was used to hold and condition leaf disks in suspended and nonsuspended sediment conditions similar to the other five pairs, but in the absence of insects. Disks placed in the sixth pair of vessels were used as "blanks" and provided a correction factor caused by leaf leaching or decomposition during a trial. One vessel (test vessel) from each pair was randomly selected for sediment introduction, but the other vessel (control vessel) remained free of sediment. This design avoided the segregation of test and control replicates that may occur with a completely randomized design (Hurlbert 1984). Each trial was conducted for 14 days, with one insect placed in each of the 10 experimental vessels for the duration of a trial.

Five leaves were used to initially supply leaf disks to the five pairs of test and control vessels, with one leaf per vessel pair distributed as follows. Two pairs of leaf disks (each disk 18 mm in diameter) were cut from the leaf with a cork borer. One disk from the

first pair was placed in the test vessel and the pair's other disk in an insect-free container. The second pair of disks was similarly distributed to the matching control vessel and an insect-free container. Leaf consumption was estimated as the difference in ash-free dry weight (AFDW) between the disk of each pair placed in the insect-free container and the corresponding disk placed in a test or control vessel. This procedure allowed direct measurement of leaf loss due to insect feeding and is similar to that described by Grafius and Anderson (1979). Depending on leaf utilization, the residual coarse leaf material was replaced with new leaf disks at two- to seven-day intervals.

### RESULTS

Mean daily ingestion rates were less among test than control insects for seven of the eight trials, but were not significantly different at  $p=0.05$  (Tables 1 and 2). In five of the eight trials, mean ingestion rates were substantially suppressed (41% to 58%) when compared to the corresponding controls. When averaged over the trial duration, the mean ingestion rate appeared to be unrelated to species, age class, or the two suspended sediment concentrations tested (1.5 and 3.0 g/l). However, the length of time insects were exposed to suspended sediment apparently influenced their feeding rates.

Feeding inhibition among test insects was more evident at the end rather than the beginning of each trial (Figs. 1-4). The debilitating effect of prolonged exposure to suspended sediment was particularly pronounced among the early-instar *H. occidentalis* larvae exposed to 3 g/l suspended sediment. Whereas the mean ingestion rate of test and control insects was similar during the first 12 days of exposure to suspended sediment, the leaf consumption rate of test insects was only 12% of the control insect consumption rate during the final 2 days of the trial.

### DISCUSSION

Our results indicate that inert suspended solids, although not acutely toxic at high levels, may cause sublethal effects on aquatic invertebrates by reducing feeding activity.

Impacts on the biological functioning of large-particle detritivores (shredders) such as the species tested in this study may have serious ramifications on other biotic components of the ecosystem. In small, first-to-third order streams riparian vegetation often shades the stream, suppresses algal growth, and supplies the stream with coarse particulate organic matter. These ecosystems are highly dependent on allochthonous material as a primary source of energy (Anderson and Sedell 1979). Processing of large-particle detritus by shredder invertebrates provides fine-particle detritivores energy and nutrients from fecal production. For example, Short and Maslin (1977) found that in laboratory streams supplied with alder leaves, *Pteronarcys californica* increased the food availability to *Hydropsyche* by 35%–100% and to *Simulium* 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 supported 20%–50% of the more abundant simuliid population found in the creek. This is not surprising, because the fecal production rate of *Lepidostoma* has been calculated to be 50 times its growth rate (Grafius and Anderson 1980).

We believe the differences we observed in the feeding rates of our control insects may be related to a physio-ecological response keyed to the season when the specimens were collected in the field. We were unable to induce noticeable feeding activity in the December-collected, first-year *P. californica* naiads until the dark-light cycle was altered to 6-18 h. Feeding rates for these insects were still much lower than first-year *P. californica* naiads collected in November. Among the second-year *P. californica* naiads tested, those collected in October had higher feeding rates than those collected during August. Water temperature and food availability should theoretically make autumn the most opportune time for feeding by leaf-shredding insects.

The early-instar *H. occidentalis* larvae collected in mid-February had higher ingestion rates than those collected during early January. Field observations at the collection site suggest that greatest larval growth occurs during early spring. Rapid growth is likely induced by seasonal cues such as photoperiod

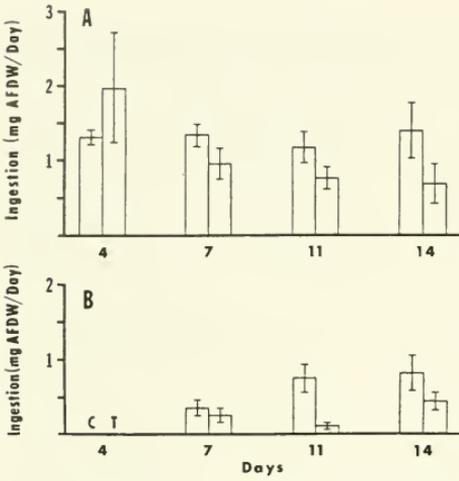


Fig. 1. Mean daily ingestion rates (mg AFDW/day) for first-year naiads of *Pteronarcys californica* exposed to: A, 1.5 g/l. B, 3.0 g/l suspended sediment for 14 days. C = control insects, 0.0 g/l suspended sediment; T = test insects. Vertical lines = 95% confidence interval for mean ingestion rate.

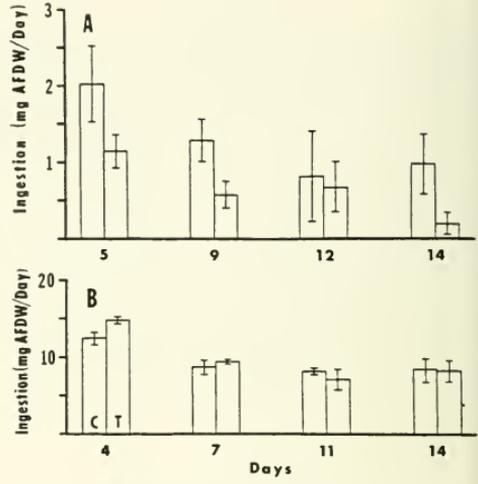


Fig. 2. Mean daily ingestion rates (mg AFDW/day) for second-year naiads of *Pteronarcys californica* exposed to: A, 1.5 g/l. B, 3.0 g/l suspended sediment for 14 days. C = control insects, 0.0 g/l suspended sediment; T = test insects. Vertical lines = 95% confidence interval for mean ingestion rate.

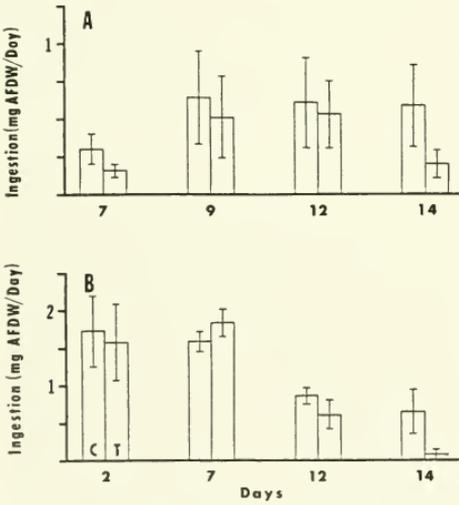


Fig. 3. Mean daily ingestion rates (mg AFDW/day) for early-instar larvae of *Hesperophylax occidentalis* exposed to: A, 1.5 g/l. B, 3.0 g/l suspended sediment for 14 days. C = control insects, 0.0 g/l suspended sediment; T = test insects. Vertical lines = 95% confidence interval for mean ingestion rate.

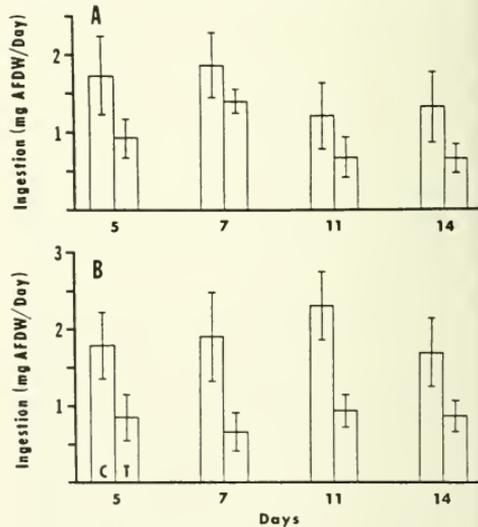


Fig. 4. Mean daily ingestion rates (mg AFDW/day) for late-instar larvae of *Hesperophylax occidentalis* exposed to: A, 1.5 g/l. B, 3.0 g/l suspended sediment for 14 days. C = control insects, 0.0 g/l suspended sediment; T = test insects. Vertical lines = 95% confidence interval for mean ingestion rate.

and temperature. Similar growth responses have been reported for other insects by Beck (1980), Hynes (1970), and Lutz (1974).

Another factor that may have affected feeding rates between trials was 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 between

leaves conditioned for one month vs. those conditioned for 2-4 months.

The effect of suspended sediment on invertebrate ingestion appears to be largely influenced by the season and feeding status of the insects. Feeding rates of insects in a relatively active feeding mode, as reflected by the control specimens, may not be as affected by suspended sediment as insects in a less active feeding mode. We speculate that the short-term effects of suspended sediments on feeding rates of insects vary seasonally. Our study provides evidence that prolonged exposure to suspended sediments can adversely affect both actively and nonactively feeding insects by reducing their mean daily ingestion rates.

Previous research on the sublethal effects of suspended sediments on leaf processing by aquatic invertebrates is minimal and largely limited to zooplankton studies (Arruda et al. 1983, McCabe and O'Brien 1983). These studies demonstrated that suspended sediments can decrease feeding rates of *Daphnia* spp. by at least 90%. These filter-feeders ingested large quantities of silt from the water column, which resulted in dense packing of the gut with inorganic particles. A decreased filtering rate is likely caused by excessive gut loading (McCabe and O'Brien 1983). Although the sediment ingestion rate would likely be lower among nonfilterers, it may have been a factor influencing the early-instar *H. occidentalis* larvae, which displayed a sudden decrease in feeding after 12 days' exposure to 3 g/l suspended sediment in our study.

Nontoxic materials, such as inorganic silt, or sublethal concentrations of toxicants may not cause spectacular and immediate impacts on aquatic macroinvertebrates, but they may cause a reduction in secondary production, energy-transfer efficiency, and nutrient cycling in stream ecosystems.

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## EFFECTS OF WATERSHED ALTERATION ON THE BROOK TROUT POPULATION OF A SMALL BLACK HILLS STREAM

Timothy Modde<sup>1</sup>, Henry G. Drewes<sup>1</sup>, and Mark A. Rumble<sup>2</sup>

**ABSTRACT.**—The impacts of adjacent landscaping activity and livestock presence on the brook trout (*Salvelinus fontinalis*) population of a small Black Hills stream were evaluated. Moderate changes in temperature, turbidity, and fecal coliform numbers did not influence brook trout densities. Stream morphometry, particularly factors affecting stream cover, appeared to have the greatest impact on numbers of trout. Brook trout were poor indicators of moderate changes in water quality, but they were adequate indicators of the physical perturbations within the stream.

The aquatic biota of streams within the forests of our nation are being increasingly stressed by logging, livestock grazing, mining, road construction, and residential development. Impacts of these activities on streams are often manifested by changes in water quality or through physical changes in the habitat, such as channel modification or reduction in stream flow. Such environmental changes can produce biological responses that alter composition and abundance of resident species. Organisms sensitive to environmental change function as indicators of environmental modification and may be useful in evaluating the magnitude of an impact.

Not all aquatic organisms exhibit equal sensitivity to the same stresses, however. Aquatic invertebrates are sensitive to water quality changes resulting from organic enrichment (Hilsenhoff 1977, Jones et al. 1981) and toxic pollutants (Hocutt 1975) but are not always effective in evaluating moderate physical modifications (Marsh and Waters 1980). Conversely, because of their mobility, Price (1979) suggested that fishes may not be reliable indicators of change in water quality, although fish frequencies do respond to changes in structure of the habitat (Platts 1974, Binns and Eiserman 1979).

The objective of this study was to evaluate the response of a resident brook trout (*Salvelinus fontinalis*) population to water quality and habitat changes in a small Black Hills stream subjected to landscaping activities (clearcutting an adjacent slope and pond dredging) and intermittent livestock grazing within the watershed.

### METHODS

The study area included five sampling stations within the upper Slate Creek watershed (Fig. 1) in Pennington County, South Dakota. Two stations were established above a development site within the watershed, one on South Slate Creek and the other on Slate Creek proper, both first order streams. A third sampling station was located 0.1 km downstream from the development site on Slate Creek; two additional stations were established downstream at approximately 1.0 km intervals. Stations above the construction site were not exposed to grazing except for a confined watering site above station 1, whereas stations below the construction site were exposed to grazing during the late fall and winter months.

Twelve water quality variables were measured at three-week intervals during the spring and summer of 1981 and 1982. During the period between August 1981 and April 1982, water samples were collected at intervals ranging between six and eight weeks. Total hardness, alkalinity, dissolved oxygen, pH, and conductivity were determined on-site with field analysis units. Turbidity, total phosphorus (ortho and total), nitrogen (Kjeldahl and ammonia), and fecal coliform bacteria were determined in the laboratory.

Fishes were collected from each station by electrofishing a 61 m section of stream blocked from both directions by 6.4 mm mesh seines. Population estimates were repre-

<sup>1</sup>Department of Wildlife and Fisheries Sciences, Box 2206, Brookings, South Dakota 57007.

<sup>2</sup>USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, South Dakota School of Mines Campus, Rapid City, South Dakota 57701.