

## Influence of Substrate Composition and Suspended Sediment on Insect Predation by the Torrent Sculpin, *Cottus rhotheus*<sup>1</sup>

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BRUSVEN, M. A., AND S. T. ROSE. 1981. Influence of substrate composition and suspended sediment on insect predation by the torrent sculpin, *Cottus rhotheus*. Can. J. Fish. Aquat. Sci. 38: 1444–1448.

Studies conducted in laboratory streams showed that torrent sculpins (*Cottus rhotheus*) congregated in regions of limited cover when exposed to a sand substrate. When cobbles were added, their distribution was more uniform. Various combinations of sand, pebbles, and cobbles significantly influenced sculpin predation on the stonefly *Hesperoperla pacifica*, the mayfly *Ephemerella grandis*, and the caddisfly *Rhyacophila vacca*. During 24-h tests, each species experienced 95–100% predation when tested on sand substrates. When different combinations of cobbles and pebbles were added, predation was appreciably reduced. Sculpin predation on *H. pacifica*, *Hydropsyche* sp., and *Heptagenia solitaria* was influenced more by substrate than suspended sediments when substrate and suspended sediment (0–1250 mg · L<sup>-1</sup>) were tested interactively. Predator avoidance tactics differed among prey species as changes were made in the physical characteristics of the environment.

*Key words:* predator–prey, sculpin, insects, suspended sediment, substrate, turbidity, behavior

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Des études en eau courante menées en laboratoire démontrent que les chabots de torrent (*Cottus rhotheus*) se rassemblent dans des régions avec abri limité lorsque exposés à un substrat de sable. Quand des moellons sont ajoutés au substrat, leur distribution est plus uniforme. Diverses combinaisons de sable, cailloux et moellons influencent de façon significative la prédation des chabots sur les perles *Hesperoperla pacifica*, les éphémères *Ephemerella grandis* et les phryganes *Rhyacophila vacca*. Chaque espèce, lorsque testée sur des substrats de sable, subit une prédation de 95 à 100%. Quand un substrat et des sédiments en suspension (0–1250 mg · L<sup>-1</sup>) sont testés interactivement, le substrat exerce une plus grande influence que les sédiments en suspension sur la prédation des chabots sur *H. pacifica*, *Hydropsyche* sp. et *Heptagenia solitaria*. Quand les caractéristiques physiques de l'environnement sont modifiées, les tactiques d'évitement du prédateur par les espèces proies diffèrent d'une espèce à l'autre.

Received February 18, 1980  
Accepted July 29, 1981

Reçu le 18 février 1980  
Accepté le 29 juillet 1981

THE behavior, distribution, and abundance of insects and fish are directly or indirectly influenced by the physical characteristics of a stream. Predator–prey relationships of these organisms contribute to an orderly transfer of energy, thus lead-

ing to community stability (Odum 1971). As watersheds are altered, streams and rivers undergo physical and chemical changes which alter biological processes and result in ecosystem instability. Suspended sediments and substrate characteristics are important factors associated with watershed alterations.

Cummins (1966) indicated that physical characteristics of the streambed are of great biological significance. Large deposits of sand and silt alter the characteristics of streams and cause changes in the benthic insect community (Cordone and

<sup>1</sup>Published with the approval of the Director of the Idaho Agricultural Experiment Station as Research Paper No. 8063.

Kelley 1961; Cummins and Lauff 1969; Brusven and Prather 1974; Rosenberg and Wiens 1975; Luedtke and Brusven 1976; McClelland and Brusven 1980). The effects of suspended sediments on benthic invertebrates has been measured primarily as a drift response, with increased suspended sediment concentration causing increased drift (Pearson and Franklin 1968; White and Gammon 1977).

Griffin (1938) noted that juvenile cutthroat trout (*Salmo clarki*) and chinook salmon (*Oncorhynchus tshawytscha*) continued to feed at suspended sediment concentrations  $>500 \text{ mg} \cdot \text{L}^{-1}$ . However, Olson et al. (1973) reported rainbow trout (*Salmo gairdneri*) feeding decreased sharply when turbidity exceeded 70 Jackson turbidity units (JTU), which for most sediment sources is considerably less than  $500 \text{ mg} \cdot \text{L}^{-1}$  by weight.

Because sculpins, common nongame fish in many streams and rivers in North America, are potential competitors in the food chain of game species, we conducted a series of laboratory experiments to study the poorly known predator-prey relationships of sculpins and insects under different substrate and suspended sediment conditions. The effects of these factors would help explain the feeding behavior of sculpins and provide a basis for making inferences about other vertebrate predators.

**Materials** — Plexiglas oval streams ( $1.6 \text{ m} \times 0.51 \text{ m} \times 0.23 \text{ m}$ ), similar to those described by Brusven (1973), were used to investigate predator-prey interactions. Each stream had three habitat types: (1) end zone, (2) turbulent zone, and (3) non-turbulent zone (Fig. 1). Black Visqueen plastic was placed around the sides of the streams to minimize visual disturbance to the fish. A self-contained recirculation system was used. Stream discharge was maintained at  $30.8 \text{ L/min}$  at  $10 \text{ cm}$  in depth with a continuously run centrifugal pump. Temperature was held at a relatively constant level ( $11 \pm 1^\circ\text{C}$ ) with a thermostatically controlled compressor unit attached to a stainless steel cooling coil. Four-tube, 1.2-m-fluorescent-light fixtures were suspended  $0.6 \text{ m}$  above the streams and set for a 12-h dark-12-h light cycle with electronic timers.

A commercially screened clay-sand mixture (particle size  $<0.15 \text{ mm}$ ) was used to give desired suspended sediment levels in the stream. The material was introduced in the form of a slurry. Suspended sediment concentrations ( $\text{mg} \cdot \text{L}^{-1}$ ) were determined by filtration, drying, and weighing of sediment. The  $\text{mg} \cdot \text{L}^{-1}$  concentrations were scaled to JTUs as measured with a Hach surface scatter turbidimeter and continuously recorded with an Esterline Angus minigraph strip-chart recorder. A solenoid was electronically interfaced with the circuitry of the Hach turbidimeter so that a small amount of the slurry was automatically added when the low-sensitivity circuit was activated. Most of the coarser particles settled out within 6 h, but these did not appreciably alter the character of the substrate during a 24-h test.

Torrent sculpins (*Cottus rhotheus*) were obtained in the field by electrofishing. They were acclimated in holding streams similar to test streams for a minimum of 78 h prior to testing. Sculpins ranging from 6.6 to 9.0 cm long were used. Three groups of eight were segregated in the holding stream. Test groups were starved for 48 h prior to testing. Patten (1971) reported that a 48-h starvation period for the torrent sculpin increased the rate of predation by seven times over a

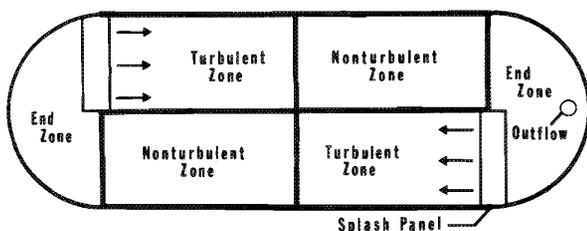


FIG. 1. Configuration of an artificial stream with habitat zones indicated.

24-h period. Live insects (species similar to test prey) were fed to the sculpins when periods of longer than 48 h occurred between tests. During the study, several groups of sculpins were obtained from the field because of occasional fish mortality in holding streams and unavailability of desired prey species during all times of the year. We observed no evidence of acute toxicity from suspended sediments to either sculpins or insects during the 24-h tests.

Insects used as prey were collected in the field by a kick screen. The mayflies *Ephemerella grandis* and *Heptagenia solitaria*, the stonefly *Hesperoperla pacifica*, and the caddisflies *Rhyacophila vaccua* and *Hydropsyche* sp. were used.

**Methods** — *Predation vs. substrate cover* — Insect predation by *C. rhotheus* was tested in laboratory streams on different substrate types. Rates of predation were determined for five substrate conditions: (1) sand (0.5–1.5 mm), (2) sand with cobbles (10.0–11.5 cm) unembedded in sand, (3) sand with cobbles half-embedded, (4) sand with pebbles (1.2–2.5 cm), and (5) pebble-covered sand with embedded cobbles. When cobbles were used, six having similar color, surface texture, and size were evenly spaced in each of the four rectangular quadrants of the stream.

Eight sculpins were placed in the test stream and allowed to acclimate for 15 min. Thirty insects of a given species (*E. grandis*, *H. pacifica*, and *R. vaccua*) were evenly introduced among the test sections of the stream. Each test was run for 24 h and replicated three times using different fish and insects. At the end of a 24-h test, divider screens were inserted between the test quadrants and between the test quadrants and end zones; the density and distribution of predators and prey were recorded.

*Predation vs. substrate cover and suspended sediment concentration* — The interactive effects of substrate and suspended sediments on sculpin predation on *Hydropsyche* sp., *H. solitaria*, and *R. pacifica* were studied at three levels of turbidity (clear: 4–6 JTU; moderate: 100–150 JTU  $\approx 310 \text{ mg} \cdot \text{L}^{-1}$ ; and high: 300–350 JTU  $\approx 1250 \text{ mg} \cdot \text{L}^{-1}$ ) and two substrate conditions (sand, sand with embedded cobbles). Eight sculpins and 30 insects of a given species were introduced into the stream. Tests were run for 24 h and replicated three times. Each test used a different group of sculpins and insects. At the end of a test, screened dividers were placed between the quadrants of the stream and between the end zones of the quadrants; the water level was lowered, and location and numbers of insects and fish were recorded.

We tested the interactive effects of substrate and suspended sediment on predation using a Kruskal-Wallis test at the 5%

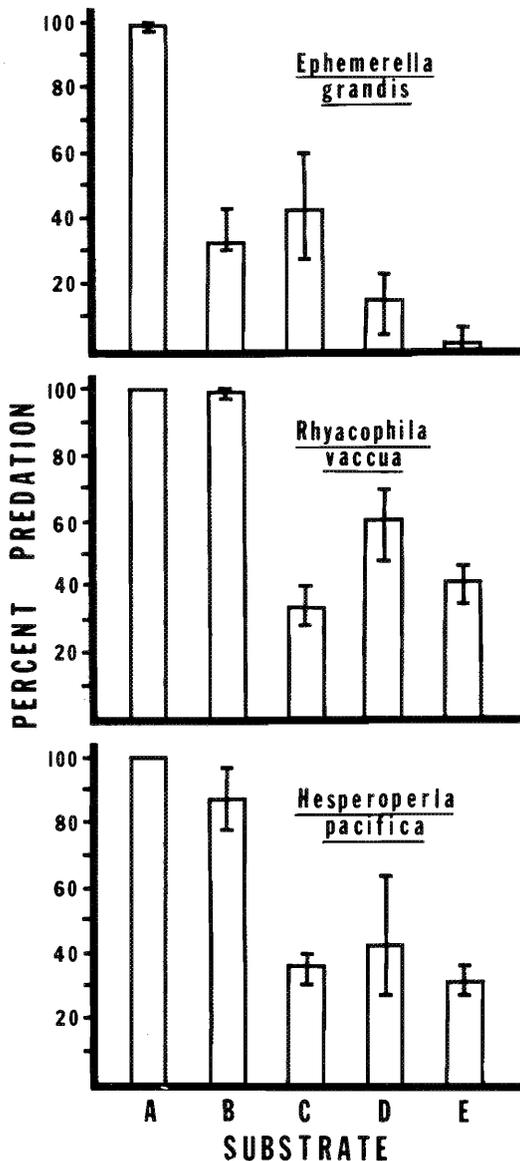


FIG. 2. Percent predation by *Cottus rhotheus* on three species of insects subjected to five substrate conditions. A = sand, B = sand with half-embedded cobbles, C = sand with unembedded cobbles, D = sand with pebbles, and E = pebble-covered sand with unembedded cobbles. Vertical lines represent range of three replications.

level. To elucidate the individual significance of suspended sediment and substrate on insect predation, we used a Mann-Whitney test which provided a nonparametric protected least significance comparison; because of the low number of replications involved in pairwise comparisons, we used a 10% level for significance. We tested the distribution of fish among stream regions at the 5% level with a chi-square contingency test.

**Results** — Five substrate conditions caused different levels of predation by *C. rhotheus* on three species of insects

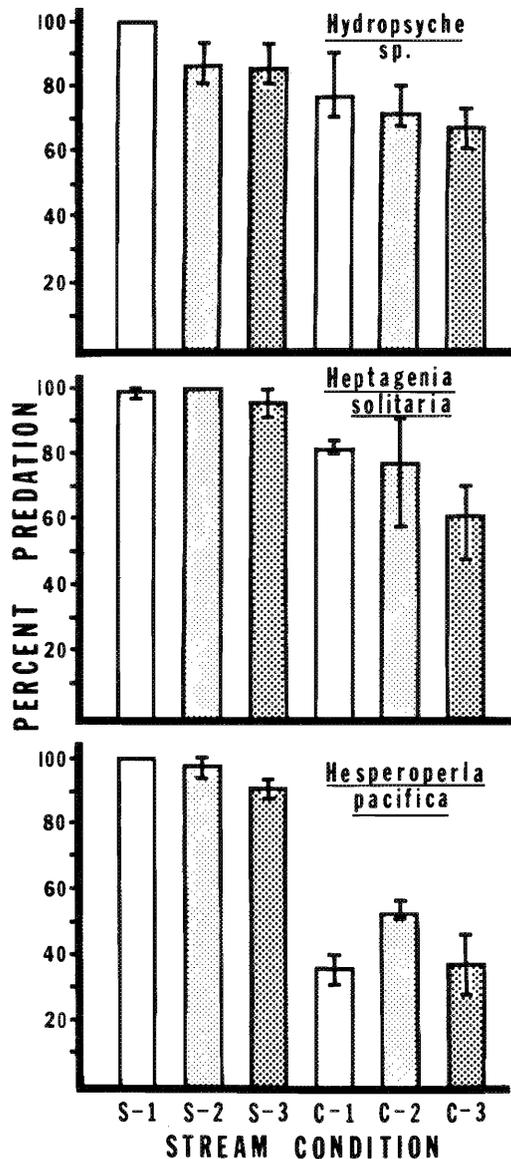


FIG. 3. Percent predation by *Cottus rhotheus* on three species of insects subjected to two substrate conditions (S = sand, C = unembedded cobbles on sand) and three suspended sediment concentrations (1 = clear,  $0 \text{ mg} \cdot \text{L}^{-1}$ ; 2 = moderate turbidity  $310 \text{ mg} \cdot \text{L}^{-1}$ ; 3 = high turbidity,  $1250 \text{ mg} \cdot \text{L}^{-1}$ ). Vertical lines represent range of three replications.

(Fig. 2). A Kruskal-Wallis nonparametric one-way ANOVA showed that, for each prey species, the substrate had a significant effect on percent predation. Not all substrate treatments for a species were different when compared pairwise, however. In most cases predation on sand clearly differed from most of the other treatments. Predation on sand and sand with half-embedded cobbles was nearly equal for *R. vaccua* and *H. pacifica* but not for *E. grandis*. Individuals of *E. grandis* most successfully escaped predation (90% escaped on a substrate of pebbles on sand with unembedded cobbles).

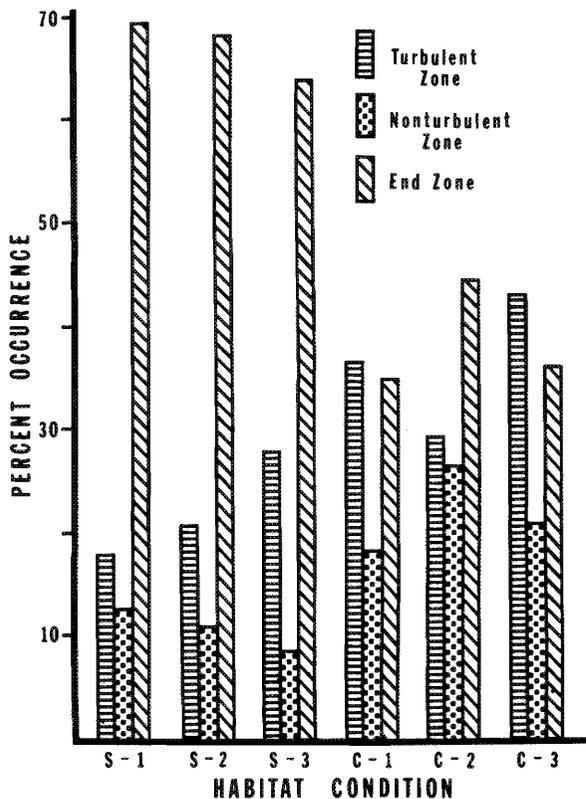


FIG. 4. Relative occurrence of *Cottus rhotheus* from three stream regions having three suspended sediment concentrations and two substrate conditions: S = sand, C = cobble on sand. 1 = clear,  $0 \text{ mg} \cdot \text{L}^{-1}$ ; 2 = moderate turbidity,  $310 \text{ mg} \cdot \text{L}^{-1}$ ; 3 = high turbidity,  $1250 \text{ mg} \cdot \text{L}^{-1}$ .

Three suspended sediment concentrations and two substrate conditions caused profoundly different sculpin predation on three species of insects (Fig. 3). The interactive effects of substrate and suspended sediment on predation were significant. When testing the influence of suspended sediment levels alone on predation on the three species of insects, we found significant differences in only one of nine comparisons (i.e. *Hydropsyche* sp. clear vs. high turbidity). However, when comparing the effects of substrate composition alone, significant differences were demonstrated for all three prey species. The least difference in predation between substrates was noted for *Hydropsyche* sp. For the conditions tested, substrate condition rather than suspended sediment had the greatest influence on depressing predation.

Fish distribution within the stream was highly significant ( $P < 0.01$ ) for stream region (Fig. 4). On a sand substrate without cobbles, the end zones were preferred habitats over the linear turbulent and nonturbulent regions. When cobbles were placed in the latter two regions, sculpin distribution was more uniform among the three habitat types, with the nonturbulent zone being least utilized.

**Discussion** — Studies by Brusven and Prather (1974) showed that selected species of mayflies, stoneflies, and caddisflies preferred substrates having cobble-sized rocks rather

than sand and pebbles, and that cobbles were increasingly more preferred as the sediment particles under or around cobbles decreased in size. We believe the time spent by prey on or under rocks and pebbles of the streambed, cryptic coloration, and diel behavior strongly influence the vulnerability of insects to predation.

Our present study shows that the distribution of *C. rhotheus* is also greatly influenced by substrate composition. Fish congregated in the end zones, especially under the splash panels (the only available cover) when a uniform sand substrate was present. When cobbles were placed in the turbulent and nonturbulent quadrants, the fish were more uniformly distributed among the three habitats. The preference of sculpin for cobbles agrees with our observations in the field, and those of Bailey (1962) and Bond (1963). Bond (1963) and Patten (1971) reported *C. rhotheus* feeding in late afternoon, morning or night; we observed them feeding during daylight hours in laboratory streams. Most of the feeding occurred when insects passed within 15 cm of the sculpins. We observed little evidence of the fish moving from one region of the stream to another in quest of prey even though prey were actively moving. For the most part, the fish resided on the bottom of the streambed, often partially covered with fine sand.

Various combinations of sand, pebbles, and cobbles greatly influenced sculpin predation on *H. pacifica*, *E. grandis*, and *R. vacca*. During all tests involving sand substrate, 95–100% predation occurred on all three species. When cobbles and pebbles were added, considerable reduction in predation occurred.

The predation observed can be explained by differences in prey behavior. *Ephemera grandis* is an inactive, slow-moving insect that typically lives under, on the sides of, or in cracks and depressions of rocks and debris. This insect is cryptic and not easily detected by a sight-feeding predator when stationary or inactive. Further protection resulted when cobbles were present; predation with cobbles was less than half that on sand without cobbles.

*Hesperoperla pacifica* and *R. vacca* differed from *E. grandis* in their vulnerability to predation when subjected to unembedded and half-embedded cobbles. Both species are more active than *E. grandis* and prefer the undersurface of cobbles and pebbles. When cobbles were unembedded in sand, predation was ~35%, but when cobbles were half-embedded, predation was >90%. The undersurfaces of cobbles become less available to these insects as the cobbles become more embedded and the substrate particles around them become smaller. Differential palatability was not a factor among these three species because nearly 100% predation occurred when tested with sand. The same or similar insects have been reported fed upon by sculpin (Bailey 1952; Northcote 1954; Antonelli et al. 1972; Novak and Estes 1974).

Our studies showed that the substrate influenced predation by *C. rhotheus* on *Hydropsyche* sp., *H. solitaria*, and *H. pacifica* more than suspended sediments at a concentration of  $1250 \text{ mg} \cdot \text{L}^{-1}$ . Only the net-spinning caddisfly *Hydropsyche* sp. and the mayfly *H. solitaria* were preyed upon less in highly turbid water ( $1250 \text{ mg} \cdot \text{L}^{-1}$ ) than clear water when tested on a substrate of unembedded cobbles on sand. All three prey species were relatively active and potentially vulnerable to predation during the initial hours of a test. *Hydro-*

*psyche* sp. began net construction shortly after being introduced into the stream. The few individuals escaping predation during a 24-h test had partially constructed nets on the walls of the stream when cobbles were absent or on cobbles when they were present. We suspect that predation on this or similar species would be reduced once nets were fully constructed because the larvae would be less conspicuous to a sight-feeding predator. Highly secretive and negatively phototactic behavior of *H. pacifica* undoubtedly contributed to the lower overall predation when cobbles were present as cover. The results of our experiment show that predator avoidance tactics differ among species and that differences in behavior and the physical characteristics of environment contribute to this variation.

Peckarsky (1980) reported highly variable predator-prey interactions between stoneflies and mayflies. In addition to visual and tactile stimuli, she proposed that contact and non-contact chemoreception are possible mechanisms involved in predator avoidance. One can only speculate that if indeed chemoreception exists between predator and prey insects, then it may also be operative in fish-insect interactions.

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