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INFLUENCE OF STREAM SEDIMENTS ON DISTRIBUTION OF MACROBENTHOS[1]

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ABSTRACT

Studies were conducted in the laboratory and field to determine the substrate relationships of five species of stream insects representing the orders Ephemeroptera, Plecoptera, Trichoptera and Diptera. Various combinations of pebble and sand were tested in the presence or absence of cobbles. Substrates with cobble were generally preferred over substrates without cobble. The preference for cobble generally increased as the sediments around the cobble decreased in size. Substrates with unembedded cobble were slightly preferred over half-embedded cobble; completely embedded cobble in fine sand proved unacceptable to most species. Three types of substrate-distribution patterns are recognized; stream insects which inhabit substrate surfaces; interstices; and both substrate surfaces and interstices.

Introduction

Sediment pollution is of increasing concern to stream ecologists. Excessive accumulations of sediment in mountain streams as a result of agricultural practices, logging, road construction, dredge mining, etc. can have serious detrimental effects on the stream biota. The role of sediments in the distribution and abundance of stream benthos has been reported by Pervical and Whitehead (1929), Cummins (1964, 1966), Scott (1966) and others. This paper is concerned with substrate relationships of insects, but we recognize that other trophic levels are also affected by sediments. Influence upon any one trophic level may cause profound side effects on other components in the ecosystem.

This paper attempts to clarify the substrate relationships and ecology of five stream insects studied in the laboratory and field and suggests reasons for specific affinities for certain substrate conditions.

Materials and Methods

Insect-substrate relationships were studied in the laboratory in artificial streams similar to one described by Brusven (1973). Temperature was

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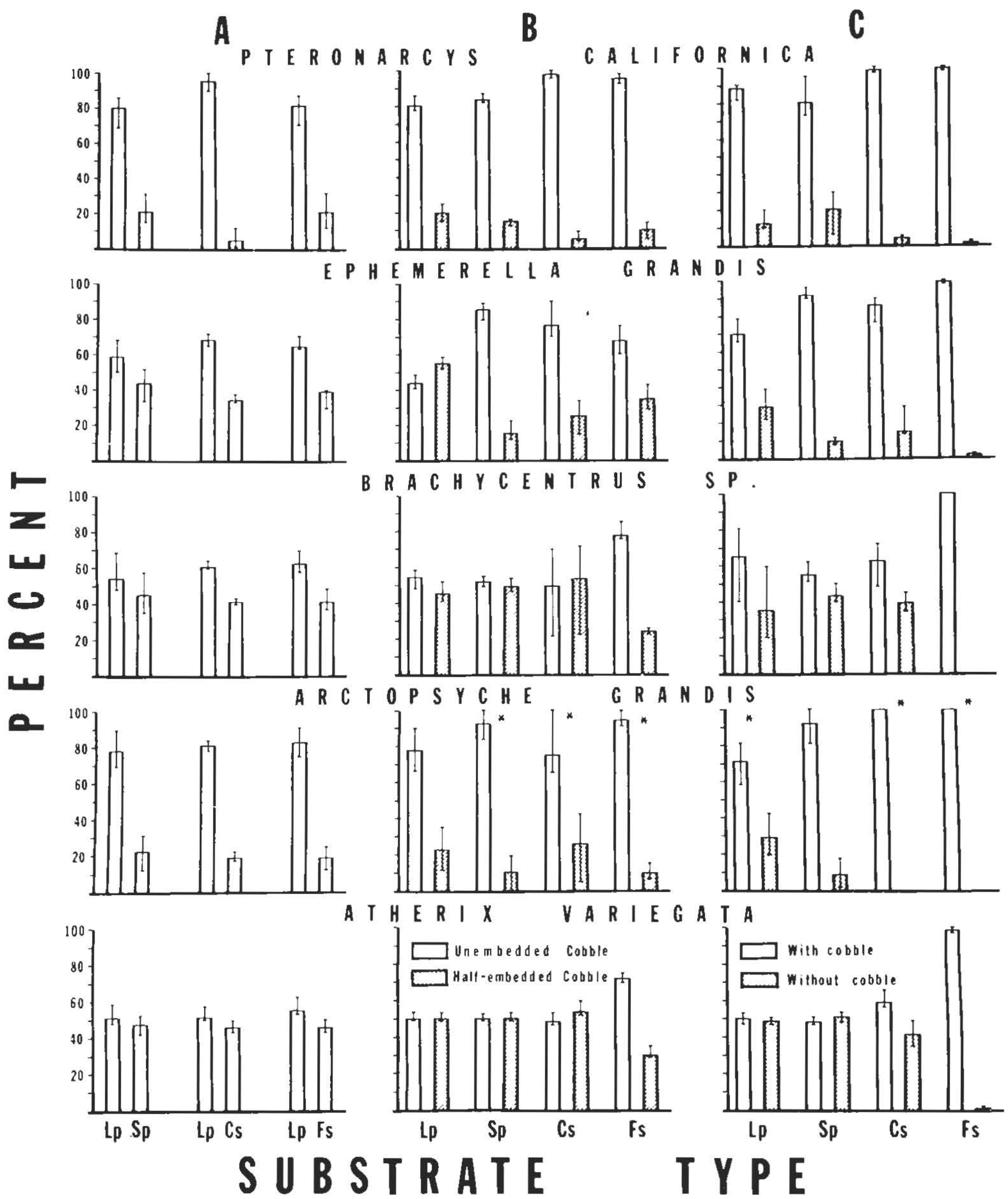

Figure 1. Substrate preference of five species of aquatic insects. A. Preference for two sizes of pebble and sand; B. Preference for unembedded and half-embedded cobble when in presence of pebble and sand; and C. Preference for substrates with and without cobble. Vertical lines indicate extremes of three replications. Lp=large pebble; Sp=small pebble; Cs=coarse sand; Fs-fine sand. *-fewer than 25 insects recovered from test quadrants during one replication.

maintained at approximately 5°C and water velocity at 15 cm/sec with substrates of coarse sand or larger sediments and 8 cm/sec with fine sand. As a bed material fine sand became unstable at velocities greater than 8 cm/sec. Alternating 12-hour dark-light cycles were maintained with artificial lighting and automatic timers. Each test lasted 48 hours.

Five species of stream insects, *Pteronarcys californica* Newport, *Ephemerella grandis* Eaton, *Arctopsyche grandis* (Banks), *Brachycentrus* sp. and *Atherix variegata* Walker, representing the orders Plecoptera, Ephemoptera, Trichoptera and Diptera were studied. The insects were collected in the field and acclimated in a laboratory stream similar to the test stream. Middle and late instar larvae and nymphs were used because they proved less subject to injury when handled than early instars.

Substrate preference experiments were conducted to determine the preference of the insects: among four substrate particle sizes, for totally, partially or unembedded cobble substrates, and substrates with vs. without cobble. Cobble used in this context refers to rocks having diameters of 64-256 mm. Rocks averaging 115 mm in diameter were used during cobble preference tests; six of these were uniformly spaced in each of the four test quadrants of the stream. Sediments of less than cobble size were screened into four size classes: large pebble (12.0-25.0 mm), small pebble (6.0-12.0 mm), coarse sand (2.5-6.0 mm) and fine sand (1.0-1.5 mm).

The insects were uniformly distributed in the test quadrants of the stream at the beginning of each test. A minimum of 35 specimens of a species was introduced into the stream; recovery of 25 live specimens from test quadrants was considered necessary to validate a test. Each test was replicated three times.

In addition to recording the number of insects recovered from each stream section and respective substrate types, the number of insects on or under cobble was recorded and expressed as a percentage of the total number of insects in each quadrant. This was done to determine the role played by cobble in microhabitat distribution as the sediment surrounding cobble increased or decreased in size.

In addition to laboratory studies, numerous field investigations were conducted and provided a basis for an autecological analysis of the species in question in their natural environs.

RESULTS

Comparative Insect-Substrate Performance

Five species of aquatic insects in the laboratory demonstrated differential preferences when tested on various combinations of substrate particle sizes (Fig. 1A). The stonefly, *Pteronarcys californica* Newport, and the caddisfly, *Arctopsyche grandis* Banks, preferred a substrate of large pebble over small pebble and coarse and fine sand. The mayfly, *Ephemerella grandis* Eaton, and the caddisfly, *Brachycentrus* sp., displayed a moderate preference for large pebble over coarse and fine sand, but little distinction between large and small pebble. The dipteran, *Atherix variegata* Walker, showed little preference for one sediment over another.

When embeddedness of cobble was added as a variable, *P. californica* and *A. grandis* preferred fully exposed over half-embedded cobble when in association with all four surrounding sediment sizes (Fig. 1B). *E. grandis* preferred exposed cobble with surrounding sediments of small pebble and coarse and fine sand. *Brachycentrus* sp. and *A. variegata* preferred exposed to half-embedded cobble with surrounding sediment of fine sand; however, no preference was indicated for the two embeddedness values when cobble was associated with large and small pebble and coarse sand.

P. californica, E. grandis and *A. grandis* preferred cobble over substrates without cobble (Fig. 1C), while *Brachycentrus* sp. and *A. variegata* showed a high preference for cobble only when cobble was in the presence of fine sand. A small to moderate preference was indicated by *Brachycentrus* sp. for cobble over substrates without cobble when the latter had large and small pebble and coarse sand associated with it. *A. variegata*, on the other hand, showed no preference for substrates with cobbles underlain with pebbles.

Cobbles were differentially selected as places of inhabitation when placed in various combinations with pebble and sand (Fig. 2A). The results from this test differed from the previous test in that specific associations with cobble as a microenvironment were determined as opposed to general distribution in test quadrants having or not having cobble. The data indicate that the affinity of *P. californica, E. grandis* and *A. grandis* for cobble generally increased as the sediments surrounding cobble decreasd in size. A similar relationship for the case-bearing caddisfly, *Brachycentrus* sp. was not noted. The dipteran, *A. variegata,* had affinities to cobble only when cobble was in the presence of fine sand.

Adding the embeddedness of cobble as a factor influencing microdistribution, the data (Fig. 2B) indicate a weak to moderate preference for unembedded over half-embedded cobble. Like the previous test (Fig. 2A), *Brachycentrus* sp. had higher affinities to both unembedded and half-embedded cobbles than all other species when these cobbles were tested with various combinations of smaller surrounding sediments. *A. variegata* reflected low affinity to cobbles except when the latter were in the presence of fine sand. In this respect, the results were similar to the previous test when cobble was unembedded.

Autecology

Laboratory studies provided control over such substrate variables as sediment size and type, presence or absence of cobble and embeddedness of cobble but arrangement and segregation of sediments in the laboratory was artificial. The substrate characteristics of natural streams are heterogeneous, often precluding microenvironmental interpretation of insect-substrate relationships. Therefore, in order to integrate the two aspects of laboratory results and field observations, the following is an autecological analysis of the five species studied with respect to their substrate affinities and microenvironment:

Ephemerella grandis Eaton. This mayfly occurs in moderately fast, clean to lightly sanded, cobble streams. Nymphs occur in the interstices of pebble and gravel or on the surface of cobble. In the laboratory they often sought refuge in depressions of rocks. In heavily sanded streambeds, nymphs demonstrated increased affinities for cobble. Unembedded cobbles were much preferred to partially embedded cobbles when in the presence of sands. Large numbers of nymphs were often encountered in filamentous tails of moss (*Fontinalis* sp.) attached to the downstream sides of rocks. Being

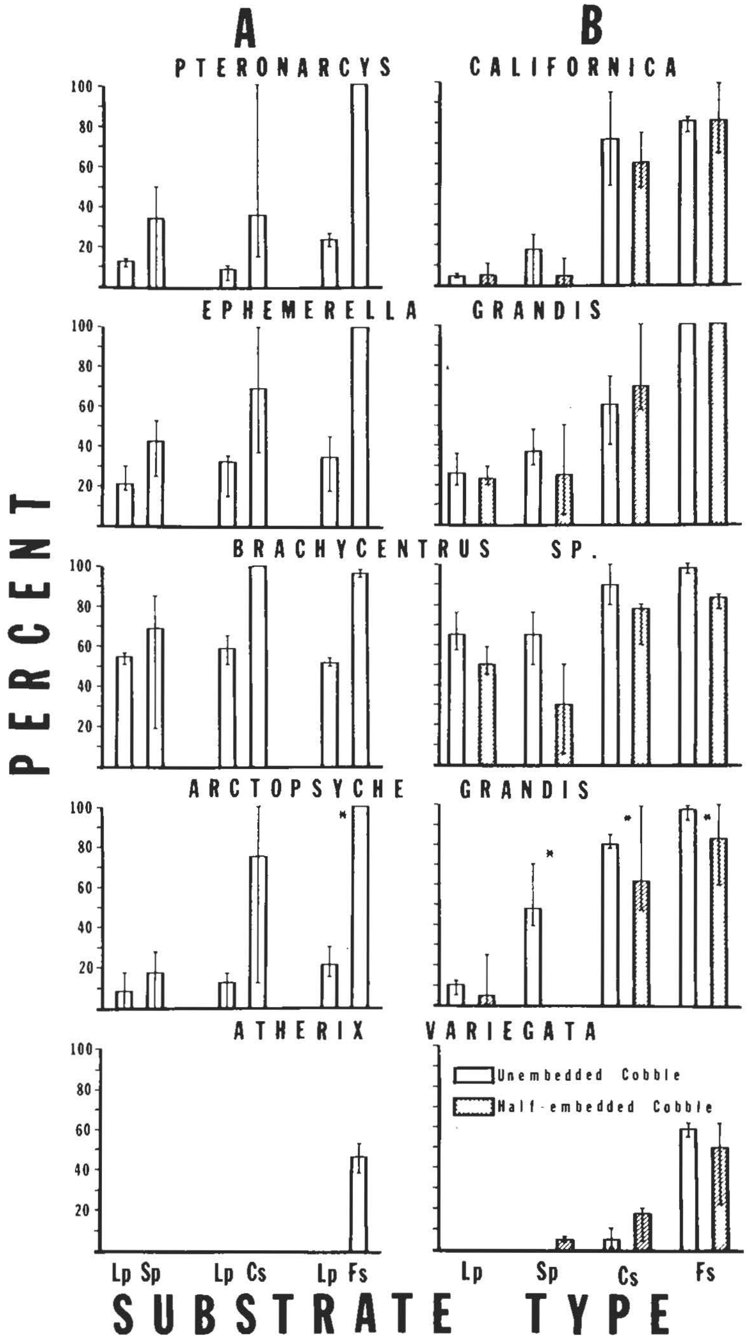

Figure 2. Substrate preference of five species of aquatic insects. A. Percentage of insects recovered on or under unembedded cobble-surrounding substrate test; B. Percentage of insects recovered on or under half- and unembedded cobble when cobble was tested in relation to four surrounding substrate sizes. Vertical lines indicate extremes in replications. Lp=large pebble, Sp-small pebble; Cs=coarse sand; Fs=fine sand. *=fewer than 25 insects recovered from test quadrants during one replication.

cryptically colored and lethargic, they often escape detection. The rough, spiny body surface of this mayfly undoubtedly restricts its distribution to accessible microhabitats.

Pteronarcys californica Newport. Mature nymphs of this stonefly are some of the larger in the Plecoptera. The species has a multiple-year life with overlapping generations. It occurs in moderately fast, rocky streams where the rocks are largely unembedded in fine sediments. Although sands are often present in small to moderate quantities, the species still abounds where the lower surface or sides of cobbles are available for retreat. In substrate preference tests in the laboratory, older age class nymphs of this species did not extensively utilize pebble substrates when cobble substrates were present; however, when cobble was unavailable, pebble substrates were highly selected over fine sediments (Fig. 1A). Affinities with the undersurface and sides of cobbles did not occur except where cobbles were in the presence of sand, particularly fine sand (Fig. 2A). The species is secretive during the day, residing commonly under rocks or shallow interstices.

Brachycentrus sp. This is a case-bearing caddisfly, the larvae of which are poorly known taxonomically. The cases are square in cross section and made of plant material. It occurs most commonly in slow to moderate streams. Preferred bottom types are usually gravel with cobble. Filamentous tails of moss and algae as well as wood pieces lodged in the stream often harbor large concentrations. Unlike many stream insects, this species lives largely on the surface of the substrate rather than in the interstices or under rocks. Unembedded cobble is only slightly preferred over half-embedded cobble (Fig. 1B). Owing to its nonsecretive behaviour and clumped distribution, it is vulnerable to vertebrate predation.

This caddisfly shows a positive correlation between body size and transverse channel distribution. Late instars frequent deeper, faster water than early instars, which tend to be close to shore.

Larvae are relatively sedentary, at least during the day. Their orientation is upstream. The mesothoracic and metathoracic legs are extended and elevated, presumably as a means of filtering particulate organic matter from the water for food. A conspicuous diel drift cycle has been reported for this species (Brusven, 1970), drift being the greatest during the night.

Arctopsyche grandis Banks. The larvae of this caddisfly are net spinners; the nets catch particulate organic matter upon which they feed. The larvae occur mostly on rocky, gravelly riffles were the nets are usually attached to the roughened edges of pebbles, between pebbles and coarse sand grains, under rocks, or in cracks and fissures in rocks. Unlike the brachycentrid previously discussed, this caddisfly occurs primarily in the interstices of the substrate. A relatively permeable substrate is prerequisite for successful functioning of the nets.

Laboratory studies revealed this species to be remarkably similar to the stonefly, *P. californica*, in substrate preference for all combinations of sediment and cobble tested (Figs. 1-2), i.e. coarse sediments of pebble were preferred over sand, cobble substrates without cobble and unembedded over half-embedded cobble.

Atherix variegata Walker. The larvae of this rhagionid dipteran are occasionally common in gravelly, moderately fast mountain streams of the western United States. The genus is represented by this single species in North America. Laboratory studies indicated that the larvae had little preference for pebble over fine and coarse sand (Fig. 1A) and that the presence or absence of cobble had little influence on sediment preference except when cobble was associated with fine sand. The larvae showed little affinity for cobble as a microhabitat except when the cobble was associated with fine sand (Fig. 2A). Equipped with ventral prolegs and a fusiform body, the larvae are effective burrowers, living and moving in the interstices of the streambed. It appears to have one of the widest ranges of substrate tolerance of species studied in the laboratory and field and its absence from some streams is likely due to factors other than substrate.

Discussion

The results from this study indicate that sediments influence in a major way benthic composition and micro-distribution in streams. Cummins (1964, 1966) suggested that sediment particle size is a primary factor influencing microdistribution of benthos and that current, water chemistry and food are other important factors.

Vertical distribution was not a principal point of investigation in this study; however, the results revealed obvious distributional differences among the species. Benthic insects can be classified generally into three categories with respect to vertical distribution: those that inhabit substrate surfaces, interstices, and substrate surfaces and interstices. Until recently most quantitative studies have been limited to shallow, surface sediments (5-7 cm). Recent studies by Coleman and Hynes (1970), Mundie (1971), and Bishop (1973), demonstrated that a large percentage of the benthic fauna lives at considerably greater depths. Although the sediment bed in the artificial streams used here was only 7 cm deep, it was apparent that the dipteran *A. variegata* was an interstitial inhabitor, apparently capable of burrowing deep within the streambed given proper sediment size and permeability; *A. grandis* was also an interstitial inhabitor, *Brachycentrus* sp. a substrate-surface inhabitor, and *P. californica* and *E. grandis* combination substrate surface-interstitial inhabitors. The latter classification would probably apply to most species in riffle communities.

We view unembedded or partially embedded cobble as an important substrate component in a viable, diversely-productive mountain stream. Unimpacted cobble permits maximum inhabitation around the cobbles, particularly to insects that cannot burrow, have exoskeletal armature or body size inhibiting interstitial burrowing, or have the habit of living under or on the surface of cobbles. Fine sediments around cobbles tend to produce a "gasket effect" by creating a seal, thereby restricting access to the undersurface of the cobbles or deep sediments except to specialized, burrowing forms such as midge (Diptera: Chironomidae) or tipulid (Diptera: Tiplidae) larvae. The diversity of species is almost always reduced in heavily silted, sanded streams, but these streams may still be productive as indicated by Hynes (1970).

Silt was not used as a test during this study because of the low velocities needed to avoid particle suspension. In an artificial channel, Cummins (1969) using velocities of 3 cm/sec, determined that eight of 10 species of insects tested experienced minor effects when exposed to a skim of silt over the streambed. In a natural stream, Nuttall and Bielby (1973) reported large adverse effects of clay on stream insects. Sands, particularly fine sands are a more serious pollutant than silt to riffle communities in many Idaho batholith streams because of the associated soils, the gradient, and discharge of the streams. Sands impact the streambed during low flows; silts tend to be displaced in suspension, settling out behind impoundments or in slow, low-gradient reaches.

The critical nature of sediments with respect to insect diversity and productivity in streams is sometimes lessened by development of a carpet of algae over the streambed (Brusven *et al.*, in press). Algal filaments serve as the effective microenvironment of many insects and in some cases replace sediments as places for inhabitation.

The impact of various kinds and amounts of sediments on all stages of insect development is still in a conjectural state. Whereas previous studies have dealt largely with the critical nature of sediments on nymphs and larvae, the egg stage may be the most sensitive stage with respect to sediment pollution. Determination of age-specific effects of sediments on insects is largely unresolved under field conditions. When these questions are answered we shall have a much clearer undrstanding of the role played by sediment pollution in benthic stream ecology.

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