Accuracy and precision in sampling hyporheic fauna

Brian G. Fraser and D. Dudley Williams

Abstract: A series of interstitial faunal samples was taken from a riffle in the Speed River, southern Ontario, Canada, to compare the field performance of four hyporheic samplers: the standpipe, colonization, and freeze corers and a pump sampler. Each of the samplers proved useful for collecting purely qualitative data, but statistical differences in some of the measured quantitative parameters were identified. The colonization corer significantly underestimated invertebrate density at each of the depths tested (20, 40, and 60 cm below the surface of the river bed). Taxonomic richness did not differ among the samplers. A sampling bias in the pump sampling method was identified in terms of both the proportion of insect larvae captured and the mean chironomid body size and is probably the result of a filtering effect of the interstices. Sampling precision estimates of density, richness, and organismal size ranged from 20 to 40%, but no pattern among the four samplers for any of the measures was observed. We conclude that, whereas the standpipe and freeze coring methods most effectively characterize the hyporheos, one of the other methods might prove acceptable under specific field circumstances or under certain practical constraints.

Introduction

Recognition of the hyporheic zone (the interstitial habitat bordered by the surface water of a stream or river above and true groundwater below) as an integral component of running waters has expanded the spatial extent of lotic ecosystems to include the vertical dimension (see Hynes 1980; Ward 1989). Yet, as hyporheic research progresses, it is prudent to acknowledge that a number of fundamental problems persist in obtaining accurate and precise quantitative and qualitative data on the hyporheos. Assessment of the relative collection efficiencies of different sampling devices, presently lacking, is essential if hyporheic research is to reach the experimental phase (Palmer 1993).

The numerous hyporheic sampling devices that have been used throughout the last few decades can be loosely assigned to four categories (Table 1). Although many of these designs have met with some success, no single sampler has been applied in all field situations, and there is disagreement as to which sampling techniques are most efficient (see reviews in Williams 1984 and Bretschko and Klemens 1986). In this study, we compared the field performance of hyporheic faunal samplers from each of the four categories. Specifically, for each sampler we assessed, at different sediment depths, accuracy and precision in terms of total invertebrate density, taxon richness, and invertebrate size distribution.

Study area

The Speed River, located in southern Ontario, flows through gently undulating hills, drumlin fields, glacial spillways, and swampy depressions (Chapman and Putnam 1966) with an average gradient of 2 m/km (Ontario Department of Planning and Development 1953). Approximately 80% of the watershed is used for mixed farming, although floodplains of the upper course are largely wooded, reforested, or maintained as rough pasture (Bishop and Hynes 1969). The main sampling area, the Rowan Farm study site (43°43′54″N, 80°16′24″W), ~5 km from the river’s spring source, consists of a 40 m long riffle.
River width varies from 4 to 6 m and water depth varies from 7 to 12 cm during baseflow conditions (mean weekly baseflow discharge approximately 3 m³/s) to 70 cm or more at the height of spring runoff. To a depth of 30 cm, the substrate is composed primarily of gravels (<10 cm diameter) intermixed with silts and sands together with a few larger dolomite slabs. Below 30 cm, substrate heterogeneity is low and substrate composition is dominated by medium and fine sand (Stocker and Williams 1972).

### Materials and methods

Between July 1 and July 21, 1994, six replicate samples from each of three depths (20, 40, and 60 cm below the surface of the river bed) were obtained at random locations along the length of the study riffle with each of four sampling devices: the standpipe corer (Williams and Hynes 1974); the freeze corer (after Stocker and Williams 1972); the colonization corer (Fraser et al. 1996); and a pump sampler (after Bou and Rouch 1967). All samples were preserved and stained in the field using a mixture of 10% formalin and Rose Bengal. In the laboratory, colonization corer (Fraser et al. 1996); and a pump sampler (after Bou and Rouch 1967); the freeze corer (after Stocker and Williams 1972). Following a colonization period of 7 to 12 cm during baseflow conditions (mean weekly baseflow discharge approximately 3 m³/s) to 70 cm or more at the height of spring runoff. To a depth of 30 cm, the substrate is composed primarily of gravels (<10 cm diameter) intermixed with silts and sands together with a few larger dolomite slabs. Below 30 cm, substrate heterogeneity is low and substrate composition is dominated by medium and fine sand (Stocker and Williams 1972).

#### Table 1. Summary of hyporheic sampler types.

<table>
<thead>
<tr>
<th>Sampler type</th>
<th>Method of collection</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Nonfrozen sediment cores</td>
<td>Simultaneous extraction of interstitial water, sediments, and fauna</td>
<td>Williams and Hynes 1974, Palmer 1993</td>
</tr>
<tr>
<td>(2) Artificial substrates</td>
<td>Retrieval of device filled with representative or standard artificial substrate after suitable period of exposure to colonization by hyporheos</td>
<td>Hynes 1974, Boulton et al. 1991, Panek 1991</td>
</tr>
<tr>
<td>(3) Frozen sediment cores</td>
<td>Extraction of sediment core frozen to the outside of a standpipe following delivery of a coolant (e.g., liquid N₂, liquid CO₂)</td>
<td>Stocker and Williams 1972, Pugsley and Hynes 1983, Bretschko and Klemens 1986, Panek 1991</td>
</tr>
<tr>
<td>(4) Pumps or bailers</td>
<td>Extraction of interstitial water and fauna from permanent or temporary standpipes or wells</td>
<td>Bou and Rouch 1967, Husmann 1971, Stanford and Ward 1988</td>
</tr>
</tbody>
</table>

#### Numerical analyses

Density and taxonomic richness data were compared using a one-way ANOVA (SPSS Inc. 1995, version 6.1.3) to detect among sampling technique differences. A post-hoc Tukey-HSD test (SPSS Inc. 1995, version 6.1.3) was used to identify differences among individual treatments. Log-transformed density data were homoscedastic (Fₚ,ₚₛₛ = P > 0.05) and normally distributed (Wilk–Shapiro).

A comparison of the mean size (body length) of chironomid larvae (the most common taxon encountered) was performed using a one-way ANOVA and a post-hoc Tukey-HSD test to evaluate potential size–capture bias of any of the sampling methods. To facilitate this comparison, all chironomids captured were grouped according to both sampling technique and depth (nine groups in total). Body length (distance between the anterior of the head and the posterior of the last abdominal segment; Meyer 1989) was measured from a random subsample (n = 25) from each group. Individuals were selected with the aid of a random numbers table (Morris and Rolph 1981).

The effectiveness of the samplers at describing the hyporheic community at the Speed River was assessed in two ways. First, we qualitatively compared all of the taxa (at the gross taxonomic level, e.g., order) captured with each of the sampling methods. Second, the proportions of insect larvae obtained with each of the four samplers at each depth sampled were compared with a one-way ANOVA followed by a Tukey-HSD test. Proportion data were arcsine transformed to fulfill the assumptions of ANOVA.
The coefficient of variation (CV; standard deviation expressed as the percentage of the mean; Sokal and Rohlf 1981) was used to measure precision among the four sampling devices for the density, taxon richness, and chironomid size data.

Separate studies using the standpipe corer (Williams 1981) and the freeze corer following in situ electropositioning (Bretschko 1985; Bretschko and Klemens 1986) concluded that each of the methods provided accurate quantitative estimates of hyporheic community structure (e.g., density). We therefore made the a priori assumption that the numbers derived from these methods (i.e., density, taxon richness, size, and community measures) would be the accuracy standard with which the colonization corer and pump sampler would be compared.

**Results**

A significant difference was detected among density estimates derived with the four samplers at each of the three depths tested (Fig. 2A, Table 2). In each case, the Tukey-HSD test identified only the colonization corer estimates as different ($P < 0.05$) from those obtained with the other methods. In general, greater than 40–50% of all animals captured were found at a depth of 20 cm. This pattern was evident for each of the samplers and has been noted both at this site (e.g., Williams and Hynes 1974; Godbout and Hynes 1982) and others (e.g., Williams 1989; Bretschko 1992). Total density estimates for the standpipe and...
freeze corers and the pump sampler were similar to those reported previously at this site during the same time of year (Williams and Hynes 1974; Fraser 1995).

The potential capture bias of any of the hyporheic samplers for a particular taxon or group of taxa was determined by comparing mean richness among the samplers at the three test depths (Fig. 2C). No differences in taxonomic richness among the samplers were detected (Table 2). Richness was greatest at 20 cm and decreased with increasing depth; the same pattern was evident with each of the samplers tested.

Taxonomic capture bias was assessed also by comparing qualitative and quantitative aspects of hyporheic community structure. Qualitatively, all of the samplers captured individuals from greater than 90% of the same taxa. All samplers captured
individuals from the Nematoda, Mollusca, Ostracoda, Copepoda, Acari, Ephemeroptera, Plecoptera, Trichoptera, Coleoptera, and Diptera. However, Tardigrada were captured only with the freeze and pump samplers; Cladocera with the standpipe, colonization, and pump samplers; and Amphipoda with the standpipe, colonization, and freeze samplers. For a quantitative analysis, the proportion of larvae of all insect taxa present in samples obtained with each of the samplers for the three depths was compared (Fig. 2E). Only at a depth of 20 cm was a difference among samplers detected ($P < 0.05$). The proportion of insect larvae obtained with the pump sampler was different from the other three methods (Tukey-HSD test, $P < 0.05$). Although no significant differences were detected at depths of 40 or 60 cm, the proportion of insect larvae obtained with the pump sampler was generally less than that obtained with either the standpipe, colonization, or freeze corers.

Chironomid body size decreased with increasing depth for all of the samplers, although to a lesser extent for the pump sampler (Fig. 2F). A significant difference in size was detected among the samplers at a depth of 20 cm (Table 2) with the pump sampler collecting smaller larvae than the other three methods (Tukey-HSD test).

For all of the samplers tested and all of the measures compared (density, richness and size), the CV was generally between 20 and 40% and increased with depth (Figs. 2B, 2D, and 2G). No pattern was obvious among samplers, and none had consistently high CV values across all of the measures evaluated nor for any of the measures individually.

**Discussion**

**Accuracy and precision**

In a strict sense, only with sampling devices that remove an exact, representative portion of habitat is it possible to obtain absolute measures. Of the four samplers tested, only the freeze corer meets this criterion. Previous field and laboratory tests of the accuracy of the freeze coring technique, following in situ positioning, have concluded that the device provides accurate quantitative measures (Pugsley and Hynes 1983; Bretschko 1985; Bretschko and Klemens 1986). To our knowledge of the four sampler types tested in this study, only the standpipe corer has been previously evaluated quantitatively. Williams (1981) compared density estimates and the range of taxa captured with the standpipe corer to similar measures from buckets of substrate from which the cores were taken. The corer produced a mean error estimate of total numbers of only 19%, and virtually all of the most common taxa in the substrates sampled were captured. Both Elliott (1977) and Cummins (1975) suggest that this level of accuracy is acceptable in estimating benthic densities, and perhaps the same is applicable to the hyporheos.

Given the conclusions of these previous tests, we initially assumed that both the freeze and standpipe corers would provide accurate estimates for the variety of parameters we measured. No statistical differences were detected between the freeze and standpipe corers for any of the measured variables at any of the three test depths. As it is unlikely that both devices would exhibit the same capture bias in each case we believe that our a priori assumption was a reasonable one.

All four of the samplers tested would suffice for collecting purely qualitative (e.g., species list) data; however, this is not the case for quantitative measures. The colonization corer consistently underestimated total invertebrate density. We suggest that this could be a result of loss of animals upon retrieval of the inner, substrate-filled acrylic sleeves. Alternatively, it is possible that the introduced substrate lacked the particle packing, arrangement, and (or) organic matter content of the natural interstitial sediments and therefore was colonized by a novel invertebrate community. Whereas there has been extensive work done on the colonization of artificial benthic substrates (see review in Rosenberg and Resh 1982), to date little is known about the physical habitat requirements of the hyporheos. It may be that the information presently available regarding the colonization of sediments may be inaccurate for hyporheic substrate colonization samplers. More investigation of subsurface colonization dynamics therefore is clearly required.

The pump sampler we tested was capture selective in terms of both insect larvae and organism size. This bias was most conspicuous at a depth of 20 cm, coincidentally the depth at which the largest proportion of insect larvae and the biggest animals (i.e., near-emergence late-instar individuals) were found. We suggest that this bias is the result of a filtering effect of the interstices. Larger animals and animals with a body morphology that make it possible for them to grasp on to substrate particles are likely to resist the suction of the pump and are therefore likely to be underrepresented during sampling.

High levels of precision in the data would be desirable, for example, in manipulative studies where some control condition is compared with an experimental treatment. In this situation it would be advantageous to use a sampling device that had a reliably high level of precision for the measure of interest. None of our samplers outperformed the others for all measures or for any measure individually, with respect to precision. It would appear, therefore, that any one of the samplers would be equally appropriate to generate an acceptable level of precision.

**Comments on the performance and applicability of hyporheic fauna samplers**

Despite their similar qualitative performance, it is unlikely that any one device would be useful in all field situations or for all

<table>
<thead>
<tr>
<th>Measure</th>
<th>Depth</th>
<th>$F$</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>20</td>
<td>28.9044</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>12.2996</td>
<td>0.0001</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>10.1102</td>
<td>0.0003</td>
</tr>
<tr>
<td>Taxonomic richness</td>
<td>20</td>
<td>0.7685</td>
<td>0.5251</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>0.2373</td>
<td>0.8693</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>0.1255</td>
<td>0.9439</td>
</tr>
<tr>
<td>Chironomid size</td>
<td>20</td>
<td>5.2686</td>
<td>0.0021</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>1.6674</td>
<td>0.1792</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>0.7409</td>
<td>0.5303</td>
</tr>
<tr>
<td>Proportion of insect larvae captured</td>
<td>20</td>
<td>4.5807</td>
<td>0.0134</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>2.8676</td>
<td>0.0622</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>0.3740</td>
<td>0.7727</td>
</tr>
</tbody>
</table>
makes it possible to collect not only faunal samples, but also the water sampling tubes fixed to the outer standpipe permit continuous monitoring of the hydrogeological and chemical features of the system. The colonization corer, therefore, has the potential to be an effective hyporheic sampling device, especially for experimental manipulations in the field.

The standpipe corer was effective for characterizing all aspects of the hyporheic community: it is a versatile sampler that provides instantaneous samples with minimum disturbance and can be easily modified to collect interstitial water. The two most obvious disadvantages to the standpipe corer are both mechanical: (i) it is very labour intensive in that it may take up to several minutes of continuous sledge hammering to insert the standpipe into deeper parts of the bed; and (ii) any large substrate particles, and probably their associated fauna, will not be sampled.

Although pump samplers have been and are currently being used extensively in hyporheic studies, our data indicated that all types of insect larvae and particularly late-instar chironomids, were underrepresented in samples obtained with this technique. Pump samplers are not without some merit, for example, they can be permanently installed to facilitate continuous monitoring with minimal physical effort and long-term habitat disturbance. Permanently installed standpipes or wells can be used also as piezometers and, therefore, can facilitate collection of hydrogeologic and (or) water chemistry data.

We conclude that the ideal hyporheic sampler still eludes researchers and indeed may not be attainable. Nevertheless, within the range of samplers examined in this study, protocols exist that allow acceptable levels of sediment description, water sampling and faunal characterization to be made, although not through one apparatus alone.

Acknowledgements

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