High resolution of the photograph permits measurement of sand-size particles. Textural changes below the sediment–water interface are related to intensive deep reworking by *M. oolitica*. The depth of oxidation of the sediments can be estimated by observing the thickness of the light-colored surface sediment. The boundary between the oxidized and reduced (sulfide-rich) zone is somewhat obscured by the cutting edge of the guillotine but this transition zone can be estimated from the photograph to within a few millimeters. Deformation of sedimentary structures by penetration of the guillotine increases with decreasing content of sediment water. Sedimentary features within the upper 2 to 3 cm of the surface are least deformed as this interval contains >50% water (by wt) in highly burrowed muds (Rhoads and Young 1970). Some plastic deformation (streaking) takes place in sediment of lower water content.

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REFERENCES

EMERY, K. O., AND A. S. MERRILL. 1964. Combination camera and bottom grab. Oceanus **10**: 2–7.

RHOADS, D. C., AND D. K. YOUNG. 1970. The influence of deposit-feeding organisms on sediment stability and community trophic structure. J. Mar. Res. **28**: 150–178.

SUBSURFACE AND SURFACE SAMPLING OF BENTHIC INVERTEBRATES IN TWO STREAMS[1,2]

ABSTRACT

A new subsurface sampling technique for collecting macroinvertebrates in gravel-bottom streams is described. The cylinder sampler collects all species whose presence is indicated by a Surber sampler, but the percentage composition of the population sampled is different. With this method, a far larger number of benthic invertebrates is obtained, making it possible to reduce the number of samples to 10 or less and yet obtain estimates within 20% of the true mean of the benthic invertebrate population inhabiting the top 17.5 cm of substrate.

Much attention has been focused on artificial substrate sampling devices for providing comparative estimates of numbers of benthic invertebrates. A wide range of techniques has been used, such as the placing of blocks of concrete in lakes (Moon 1935), stone substrates in wire baskets in rivers (Mason et al. 1967; Bull 1968), and stone-filled trays or cylinders in streams (Wene and Wickliff 1940; Ulfstrand 1968; Hilsenhoff 1969; Coleman and Hynes 1970). Hilsenhoff (1969) pointed out that most of these studies are descriptive and do not include comparative quantitative data. None of the workers has determined the number of samples required to achieve a given degree of sampling accuracy.

However, all these devices, as well as the one here described, suffer from the shortcoming that they sample only a part of the zone occupied by the benthos. Hynes (1970) has pointed out that if samplers do not penetrate very deeply into the substratum they do not collect much of the hyporheal. Hynes and Coleman (1968) stated that sometimes 80% or more of the fauna is below 10-cm depth and penetrates at least 30 cm. It is apparent that stream sampling devices stand in need of modification and improvement; for this reason preliminary tests were undertaken with subsurface cylinder samplers, a procedure not dissimilar from that of Coleman and Hynes (1970). The results have been tabulated with regard to the number of sam-

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[2] Based on a thesis submitted by D.S.R. in partial fulfillment of the requirements for the degree of M.S. from the University of Calgary, Calgary, Alberta.

TABLE 1. *Average number of organisms for 10 cylinder samples per month taken at 2 stations on the Kananaskis River. Dry weights calculated assuming 80% loss in weight on drying*

Species / Station	2, 3 13 May	2, 3 15 Jun	2, 3* 15 Jul	1, 2 9 Aug	2, 3* 11 Sep
Alloperla spp.	13.6	7.4	3.45	9.7	8.45
Rhithrogena doddsi	1.45	0.85	0.50	1.00	1.80
Paraleuctra spp.	0.80	0.80	0.35	0.35	2.30
Isoperla spp.	0.35	0.05		0.15	1.95
Cinygmula spp.	0.05	0.25		0.25	1.10
Ephemerella doddsi	0.05	0.05	0.10	0.45	0.80
Baetis spp.			0.10	0.55	0.70
Brachyptera nigripennis	0.30				0.40
Ephemerella coloradensis	0.25		0.20	0.20	
Nemoura cinctipes				0.05	0.50
Ephemerella (*Simplex* gp.) sp.		0.05	0.15	0.20	
Acroneuria sp.		0.05		0.05	0.15
Nemoura oregonensis				0.05	0.20
Nemoura columbiana					0.15
Arcynopteryx spp.					0.10
Epeorus spp.				0.10	
Ephemerella spinifera				0.10	
Ameletus sp.				0.10	
Kathroperla perdita		0.05	0.05		
Trichoptera	0.15	0.05			0.25
Miscellaneous	0.6	1.8	2.25	1.35	0.55
Total No.	17.6	11.35	6.35	16.8	18.7
Total dry wt (mg)	4.3	6.0	4.1	8.0	5.0

* Data based on 5 samples.

ples necessary to achieve certain levels of accuracy in sampling a part of the zone occupied by the benthos.

METHODS

In essence, our sampling method provides a known volume of removable substratum for colonization. Empty 48-oz (1.4 liter) juice cans (17.5 cm high × 10.5-cm diam), open at the top and perforated with 30 to 40 small (0.6 cm) holes on the sides and bottom, were buried up to their tops in holes randomly excavated in the streambed. Iron stakes marked their location. The cylinders were filled with the displaced substrate and removed after colonization was assumed to have occurred.

Ulfstrand (1968) found that the number of individuals in his colonization trays stabilized after about 2 weeks. Others have found this period to be about 4 weeks, and our samples were taken at this interval. The substratum was washed through three screens (with 12.5, 25, and 40 meshes/cm) to separate the stream insects.

Flow changes ruined the experiment several times, so it was impossible to sample regularly in either of the study streams. Except for two instances when only 5 samples could be obtained, 10 samples per station were taken per month (Tables 1 and 2).

Three Surber samples (with 9 meshes/cm), taken to a depth of 2–4 cm, were obtained for comparative purposes whenever cylinder samples were removed. These were preserved in 10% formalin in the field and hand-sorted in the lab, with transfer to 70% ethanol.

RESULTS

Comparison with Surber sampler data

Figure 1 shows the average number and weight of organisms obtained from cylinder and Surber samples. Qualitatively, the sampler collects all species whose presence is indicated by the Surber sampler. However, there are several quantitative differences. The average number and weight present at any time is much greater

TABLE 2. *Average number of organisms for 10 cylinder samples per month for Lusk Creek*

Species	28 Feb	13 Mar	26 Apr	14 May	14 Jun	13 Aug	12 Sep
Alloperla spp.	9.3	11.2	12.1	22.6	21.9	10.9	11.2
Cinygmula sp.		8.0	3.2	4.9	3.3	2.9	3.3
Nemoura columbiana	1.6	2.7	0.6	2.2		1.0	1.3
Baetis spp.	4.1	5.5	9.1	0.5	1.7	0.6	0.5
Paraleuctra spp.				1.4	1.7		
Rhithrogena doddsi	1.4	0.9	0.8	0.6	1.4	0.3	0.5
Nemoura oregonensis	0.6	0.2	0.1	0.2	0.6	0.3	0.5
Ephemerella coloradensis	3.3		3.4	0.2	0.2	0.2	0.1
Nemoura cinctipes	0.1	0.7	0.5	0.2		0.2	0.2
Ameletus sp.						0.5	
Arcynopteryx aurea			0.1		0.1	0.4	
Isoperla spp.							0.3
Nemoura besametsa	8.9	15.4	20.8				
Trichoptera	0.1	0.6	1.2	0.8	0.6	0.1	0.1
Miscellaneous	3.1	4.4	5.3	2.1	2.3	1.1	0.5
Total No.	32.6	49.6	57.2	35.6	33.8	17.8	19.1
Total dry wt (mg)	13.4	16.9	18.4	9.3	6.3	6.4	6.9

for the cylinder sampler than the Surber sampler, if the devices are equated in terms of area; generally, the Surber sampler collects about 10% of the total numbers and 53% of the total weight indicated by cylinder samples. However, this is not strictly comparable since the cylinder takes a greater volume per unit area.

In terms of the seasonal species composition, the two sampling procedures also yield different results. For instance, the collections made by Surber samples suggest that *Alloperla* spp. constitute 3.1 and 6.0% of the total insect population by number in Lusk Creek and the Kananaskis River. The comparable figures for the cylinder sampler data are 67.4% in both cases (Fig. 2). Similar differences are evident for other species and cannot be attributed to substrates since similar types were sampled with both devices.

It is more probable that the mesh size of the Surber sampler was too large to retain small specimens while much of the fauna was missed by not sampling the subsurface zones. The results indicate that the Surber sampler took only a very small percentage of the standing crop; the values are almost certainly far too low.

The proportion of the standing crop taken by the cylinder sampler is not known, since the maximum depth sampled was only 17.5 cm; it is clear, however, that the proportion is substantially greater than that obtained by the Surber sampler.

The proportion of *Alloperla* spp. passing through 9 meshes/cm was unfortunately not established. This amount is likely substantial, therefore our data may be misleading with regard to the hyporheal distribution of this genus. The numbers present in the topmost 4 cm of substrate may be considerably greater than indicated by the Surber sampler and it remains to be determined what amount actually inhabits this zone.

Determination of number of samples required to achieve adequate accuracy

In estimating populations it is reasonable to accept an error within 10% of the mean (Southwood 1966). The number of samples required to achieve this degree of precision from an ecologically homogeneous habitat can be calculated from the formula given by Southwood. The number of samples required (N) is given by:

$$N = \left(\frac{ts}{D\bar{x}}\right)^2,$$

where $\bar{x}$ = mean, s = standard deviation, D = the required level of accuracy expressed as a decimal (0.1 or 0.2), and t is a quantity dependent on the number of samples

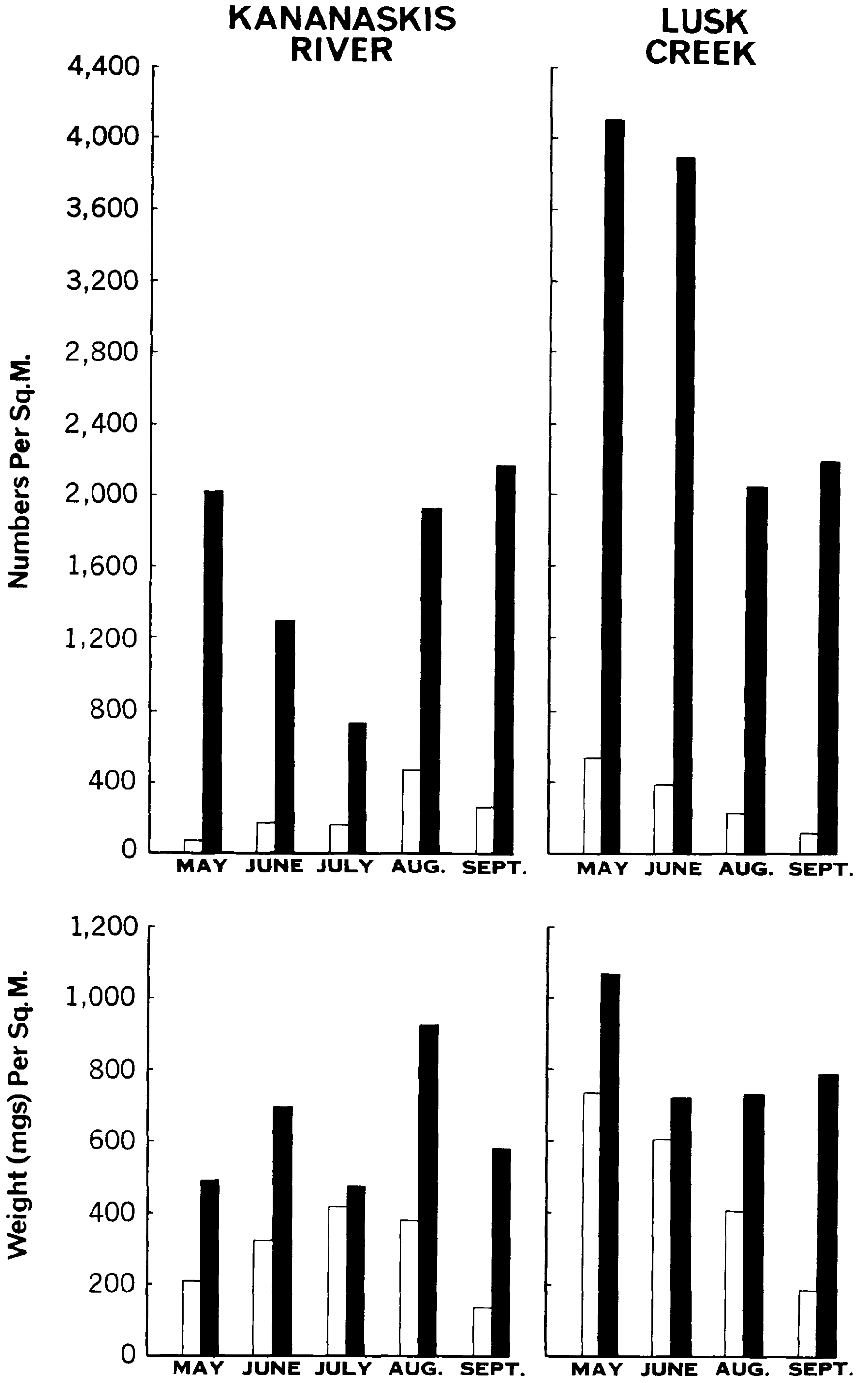

FIG. 1. The average number and dry weight (mg) of organisms obtained from cylinder (shaded) and Surber (unshaded) samples taken in the Kananaskis River and Lusk Creek.

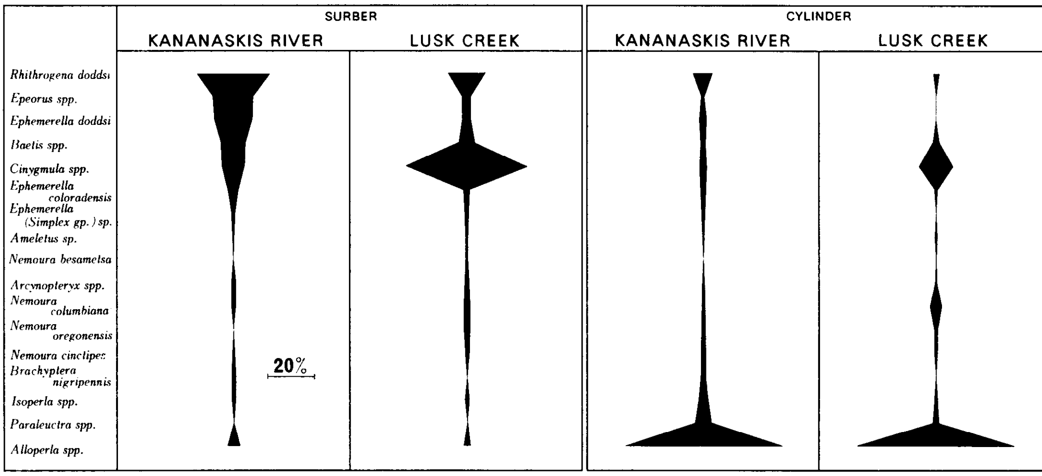

FIG. 2. The percentage composition (May–September) of organisms (Ephemeroptera and Plecoptera) obtained by two bottom fauna sampling procedures in Lusk Creek and the Kananaskis River.

and is obtained from tables (for example, the *t* distribution). Table 3 presents the mean number (and range) of samples that were necessary, using both uncorrected (unaltered) and corrected (minus rare species with unusual attributes) data for both total numbers and weights, to obtain an estimate within 10 or 20% of the true amount of macroinvertebrates present in the zone sampled.

Ideally, one should strive for as small an error as possible in an estimate, but it is clear from Table 3 that accuracy within 10% of the true mean may often be impractical for stream studies because too many samples would be required. An average of 44 samples would be necessary in Lusk Creek and 91 in the Kananaskis River for such an estimate of total numbers. A similar pattern exists for mean

TABLE 3. *The range and mean ($\bar{N}$) of the number (N) of samples necessary to obtain an estimate within 10 or 20% of the true mean (of total numbers and weights) for uncorrected and corrected cylinder sampler data obtained from formula cited in text*

	Sampling accuracy	No. of samples required (*N*) Uncorrected	Corrected
		Lusk Creek	
Total No.	true mean ± 10%	30–125 ($\bar{N}$ = 71)	14–105 ($\bar{N}$ = 44)
Total No. (a)	true mean ± 20%	7–31 ($\bar{N}$ = 18)	3–26 ($\bar{N}$ = 11)
Total wt	true mean ± 10%	30–487 ($\bar{N}$ = 168)	30–127 ($\bar{N}$ = 112)
Total wt (b)	true mean ± 20%	7–122 ($\bar{N}$ = 42)	7–54 ($\bar{N}$ = 28)
		Kananaskis River	
Total No.	true mean ± 10%	61–1,413 ($\bar{N}$ = 268)	15–270 ($\bar{N}$ = 91)
Total No. (c)	true mean ± 20%	15–353 ($\bar{N}$ = 67)	4–67 ($\bar{N}$ = 23)
Total wt	true mean ± 10%	106–769 ($\bar{N}$ = 468)	53–539 ($\bar{N}$ = 220)
Total wt (d)	true mean ± 20%	27–192 ($\bar{N}$ = 117)	4–135 ($\bar{N}$ = 55)

Number of times that workable numbers of samples (10 or less) were obtained by accepting an error within 20%: (a) 4/7; (b) 1/7; (c) 6/10; (d) 0/10.

total weight per sample. These results are analogous to those of Needham and Usinger (1956). In a study of the variability in a single riffle they found that a prohibitively high number of Surber samples would be required to give significant data (73 on total numbers of organisms and 194 on total weights in their study) at a 95% level of confidence.

Nonetheless, it is possible to arrive at a workable sample number (10 or less) by accepting an error within 20% of the true mean and rejecting representatives of rare species with unusual attributes (extreme weight); this is practicable for total numbers in Lusk Creek. It is more difficult to accomplish the same for total weights. However, in streams of higher productivity than the Kananaskis River and Lusk Creek (and this would probably include the majority) such a sample may not be difficult to achieve.

CONCLUSIONS

In this study, we found that a coarse-meshed Surber sampler (9 meshes/cm) collected about 10% of the fauna obtained by the cylinder sampler for the same area. Recently, Zelt (1970) has shown that a fine-meshed Surber sampler collects about twice as much of the fauna as a coarse-meshed one. It may therefore be assumed that the cylinder method described here will obtain about 5 times as many benthic invertebrates (for the same area) as would a fine-meshed Surber sampler.

The differences in species composition exposed by sampling at and below the surface of the substrate (Fig. 2) are partially explicable by the behavior of some of the insects. The common ephemeropteran species belong to the families Heptageniidae and Ephemerellinae and these are algal grazers (Chapman and Demory 1963); thus they are confined to the surface. Plecopteran nymphs of the families Leuctridae, Capniidae, and Chloroperlidae burrow into the gravel (Hynes 1970) and are largely missed by surface samplers; this can result in erroneous ecological interpretations since our data illustrate that these groups are important components of the stream community.

Several problems occur with cylinder sampling. The samplers are stationary and require at least 1 month for colonization to occur, so fluctuating water levels can make sampling unreliable. The cylinders may be left exposed with constriction of stream channels and are often completely buried after a series of unusually high flows. Variations in current velocity are also troublesome. However, in small streams of relatively stable discharge these aspects could be unimportant, and, if insect populations were high, this procedure could prove valuable in studies of their population dynamics. The samplers are much simpler in design and operation than those of Coleman and Hynes (1970) but are less versatile; they are impractical for studying the depth distribution and horizontal movement of insects because of their size. A larger sampler would be more useful and might indicate patterns of distribution at the surface more precisely. A small amount of substrate (sand) is lost through the perforations on removal of the samplers and this is a disadvantage since some organisms may also be lost. Some species (*Arcynopteryx* spp. and *Parapsyche* spp.) are probably undersampled because of behavioral peculiarities. However, the procedure does offer a simple and inexpensive method of obtaining a reasonably accurate estimate of the populations of many benthic stream invertebrates inhabiting the top 17.5 cm of substrate in gravel-bottom streams.

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REFERENCES

BULL, C. J. 1968. A bottom fauna sampler for use in stony streams. Progr. Fish Cult. **30**: 119–120.

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Chapman, D. W., and R. L. Demory. 1963. Seasonal changes in the food ingested by aquatic insect larvae and nymphs in two Oregon streams. Ecology **44**: 140–145.

Coleman, M. J., and H. B. N. Hynes. 1970. The vertical distribution of the invertebrate fauna in the bed of a stream. Limnol. Oceanogr. **15**: 31–40.

Hilsenhoff, W. L. 1969. An artificial substrate device for sampling benthic stream invertebrates. Limnol. Oceanogr. **14**: 465–471.

Hynes, H. B. N. 1970. The ecology of stream insects. Annu. Rev. Entomol. **15**: 25–42.

———, and M. J. Coleman. 1968. A simple method of assessing the annual production of stream benthos. Limnol. Oceanogr. **13**: 569–573.

Mason, W. T., J. B. Anderson, and G. E. Morrison. 1967. A limestone filled artificial substrate sampler-float unit for collecting macroinvertebrates in large streams. Progr. Fish Cult. **29**: 74.

Moon, H. P. 1935. Methods and apparatus suitable for an investigation of the littoral region of oligotrophic lakes. Int. Rev. Gesamten Hydrobiol. Hydrogr. **32**: 319–333.

Needham, P. R., and R. L. Usinger. 1956. Variability in the macrofauna of a single riffle in Prosser Creek, California, as indicated by the Surber sampler. Hilgardia **24**: 383–409.

Southwood, T. R. E. 1966. Ecological methods with particular reference to the study of insect populations. Methuen.

Ulfstrand, S. 1968. Benthic animal communities in Lapland streams. Oikos Suppl. 10.

Wene, G., and E. L. Wickliff. 1940. Modification of a stream bottom and its effect on the insect fauna. Can. Entomol. **72**: 131–135.

Zelt, K. A. 1970. The mayfly (Ephemeroptera) and stonefly (Plecoptera) fauna of a foothills stream in Alberta with special reference to sampling procedures. Alberta Fish Wildl. Div., Res. Rep. 6.

A Device for Determining Velocity of Flow Near the Substrate

ABSTRACT

The design, construction, operation, and performance of a device for measuring flow in a 2-mm layer of water are described. Within the flowmeter, a ball in a variable-aperture microflowtube inserted between two openings of a differential-pressure sensing head indicates flow velocities of 2–30 cm/sec in freshwater and 5–35 cm/sec in seawater.

In lotic waters, the velocity of flow generally varies relatively little through most of the water column but decreases markedly in the boundary layer adjoining the substrate (Ambühl 1959; Rosenhead 1963). Thus the benthos is usually in a region where velocity of flow is considerably reduced from the mean velocity in the water column.

Studies of the effects of water currents on the benthos of freshwater and tidal streams have been hampered by the lack of a device capable of measuring flow velocity near these organisms. Such a device requires a sensing head no larger than the organisms studied and sensitive to low velocities. As Eriksen (1966) has remarked, the sensing heads of current meters commonly used in stream surveys are too large for this purpose. Miniaturized propeller-type meters with heads as small as 1-cm diam are possibly the smallest sensitive instruments commercially available. Even these are rather large, fragile, and expensive. Previously described versions of differential-pressure heads connected to the arms of a robust portable manometer (Cole 1935; Folsom 1956) or a flowtube (Eng. News Rec. 1934; Everest 1967) are insensitive to velocities <10 cm/sec, and amplifying differential-pressure heads such as the Pitot-Venturi (Freeman 1929; Stoll 1953) or Dall-Pitot (Dall 1959) are too large for the stated purpose. Timing the rate of movement of particles suspended in the water, though sometimes useful for determining velocities in tanks (Ambühl 1959), is generally impractical because it is difficult to measure the height of particles above the bottom, and in many instances turbulence causes this height to vary. I have constructed a flowmeter with a miniaturized sensing head and a considerable increase in sensitivity to low velocities.

This flowmeter was used during an investigation into the distribution of astacid crayfishes in streams (supported by Na-