With best wishes,
Hugh

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Assessment of two mesh sizes for interpreting life cycles, standing crop, and percentage composition of stream insects

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Summary
Using Surber-type samplers and dip-net samplers, we assessed the efficiency of nets having pore sizes of 720 μm and 320 μm for determining standing crop and percentage composition of the stream fauna, and for collecting representative size-class specimens of Ephemeroptera and Plecoptera to be used in life-cycle studies. Except for one species, samples collected with either the 720-μm or 320-μm dip-net led to the same general inferences about the species' life cycle. Of fifty possible sample comparisons, there were twelve samples where the size-class frequencies of particular species collected in the 720-μm dip-net were significantly different from the size-class frequencies of the 320-μm dip-net; for five of these samples a deficit of large nymphs (>5·0 mm) in the 320-μm net mainly contributed to the significant χ^2 values. On one date, we used double-bag samplers with both the 720-μm and 320-μm nets attached to either the Surber or dip-net sampler. Approximately 50% of the insects by numbers passed through the 720 μm mesh of each sampler, but only 5% by volume-biomass. Shape of the insect as well as body length was important in assessing mesh-size efficiencies. The 720-μm mesh of the double-bag dip-net sampler retained most of the *Nemoura cinctipes* (having stout appendages) and *Epeorus longimanus* (flattened) nymphs 2·0 mm in body length and larger; whereas most *Baetis* (streamlined) nymphs smaller than 3·0 mm and all *Paraleuctra* (needle-like shape) nymphs passed through the 720-μm mesh.

Introduction

Inferences about stream faunas are often drawn with little or no regards to the reliability of the sampling device. Cummins (1962) divides stream samplers into two groups: devices that retain all the animals and the sediments, e.g., grabs, coring devices, and enclosed boxes; and devices that collect only the animals. Usually the latter employ some sort of net to collect the stream invertebrates. Both stationary nets, e.g., the Surber-type sampler, and mobile nets, e.g., dip-, or pond-, net samplers, are widely used in stream work. The Surber-type sampler is often used to estimate standing crop, and dip-nets are employed to determine the percentage composition of the various

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stream taxa and to collect quantitatively large numbers of specimens for life-cycle studies.

An important feature of any netting device is the mesh size, and except for the most general studies, its efficiency should be assessed. Recent studies (see discussion) have shown that numerically much of the stream fauna can pass through nets having pore sizes as small as 300 μm. However in the past most of the inferences about stream faunas have been based on samples collected with coarser-mesh nets. We assessed the efficiency of two relatively coarse-meshed nets for determining standing crop, percentage composition, and collecting representative size-class specimens to be used in life-cycle studies. Data were obtained as part of an ecological investigation of the mayfly (Ephemeroptera) and stonefly (Plecoptera) fauna of a Rocky Mountains foothills stream in Alberta, Canada (Zelt & Clifford, in prep.). Sampling started in May 1967 and continued through June 1968. During the ice-free season (May through October), samples were collected every 3 weeks; in the winter, samples were collected every other month.

Methods

The two nets were of silk bolting cloth. One had an average pore size of 720 μm; the other had a pore size of 320 μm. For comparative purposes the two nets are hereafter called the coarse net and fine net respectively. Four methods were used to assess the efficiency of the nets: (1) Samples were collected throughout the year with two long-handled dip-nets, one having coarse-mesh netting and the other having the fine-mesh netting. Each dip-net had a frame diameter of 32 cm. The coarse-meshed sampler was held on the stream bed of a large riffle and the substrate immediately upstream was vigorously stirred up by foot, the water sweeping the animals into the net. Working slowly upstream, this procedure was continued for 5 min, the sampler being emptied at irregular intervals. The procedure was then repeated further upstream using the fine-meshed net. (2) Samples were collected throughout the year with 0·1-m^2 Surber samples to which were attached either the coarse- or fine-meshed netting. For each date, five 0·1-m^2 samples were taken with each sampler across the width of a riffle area. (3) On one date, 6 June 1968, samples were taken with a double-bag dip-net sampler. The dip-net had a frame diameter of 32 cm and was composed of two nets, the inner net having coarse mesh and the outer net having fine mesh (Plate 1). The fine net was attached with a zipper to the outside of the coarse net, and hence could be removed before transferring the sample to a container. Organisms caught in the fine mesh had passed through the coarse mesh, and we assumed that organisms caught in the coarse mesh would have also been caught in the fine mesh net. (4) Also on 6 June 1968, samples were taken across a riffle area with a double-bag Surber sampler (Plate 1). Tanaka (1967) and Frost, Huni & Kershaw (1971) also used double-bag samplers to assess mesh-size efficiencies.

Samples were sorted in the laboratory. Aquatic insects were identified, counted, and total length measurements, when required, were made to the nearest 0·5 mm, cerci and antennae not included. Biomass was determined volumetrically, following the method of Welch (1948), but using a microburet.

Life cycles and mesh size

General interpretations

To examine the importance of mesh size for collecting aquatic insects to be used for

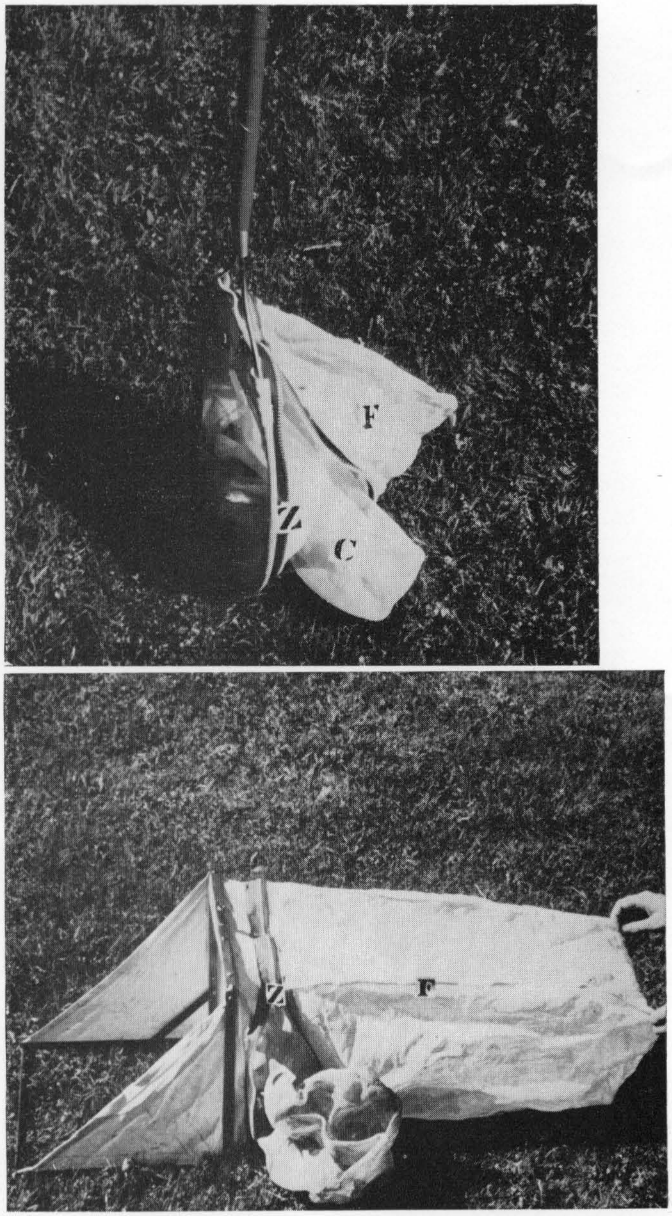

Plate 1. Upper: double-bag dip-net sampler; lower: double-bag Surber sampler. C, coarse mesh; F, fine mesh; Z, zipper.

life-cycle analysis, samples obtained with the coarse- and fine-meshed dip-nets were used. We chose species with fairly straightforward life cycles, i.e., species with one generation a year, without extensive delayed hatching, and with no overlapping generations. These criteria were necessary for a subsequent χ^2 analysis. The mayflies

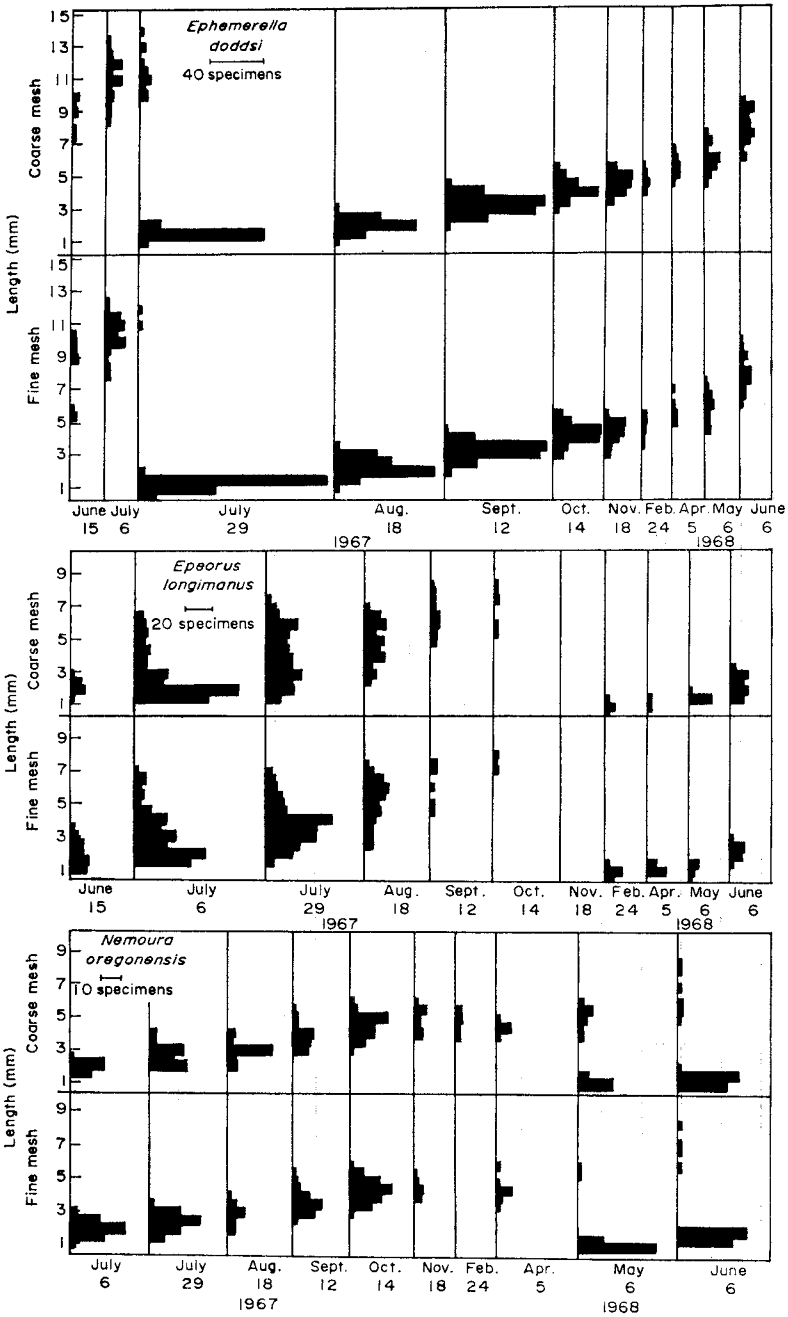

Fig. 1. Life-cycle histograms of *Ephemerella doddsi*, *Epeorus longimanus* and *Nemoura oregonensis* as constructed from specimens collected in the coarse- and fine-meshed dip-nets.

Ephemerella doddsi Needham and *Epeorus longimanus* (Eaton) and the stoneflies *Nemoura cinctipes* Banks, *N. oregonensis* (Claassen), *N. decepta* Frison, and *Brachyptera nigripennis* (Banks) satisfied these criteria.

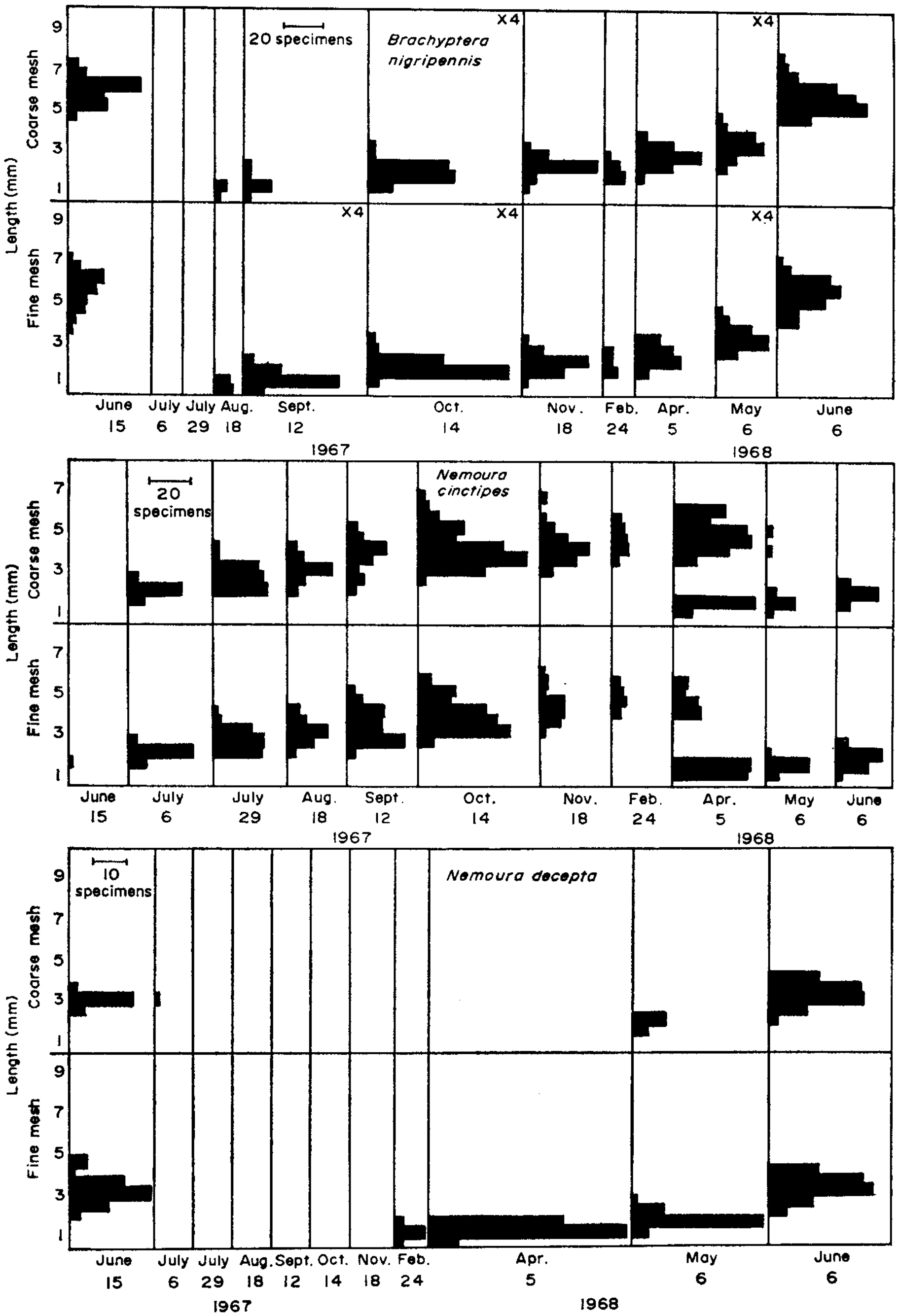

Fig. 2. Life-cycle histograms of *Brachyptera nigripennis, Nemoura cinctipes* and *N. decepta* as constructed from specimens collected in the coarse- and fine-meshed dip-nets.

For *E. doddsi*, *E. longimanus*, *N. oregonensis* and *B. nigripennis*, the minor differences between the coarse- and fine-meshed dip-net samples would not alter the general interpretations of the life cycles (Figs 1, 2). For *N. cinctipes*, no small nymphs were collected with the coarse net on 15 June 1967, when the nymphs were apparently hatching (Fig. 2). However the fine net collected only two specimens on 15 June, indicating that very few newly hatched nymphs were present at this time. The life-cycle histograms of *N. decepta* reveal major differences between the coarse- and fine-net samples (Fig. 2). *N. decepta* nymphs were not collected with the coarse dip-net on 24 February and 5 April 1968; whereas a large number of nymphs were collected with the fine net on these dates. Using only the coarse-net samples, one would conclude that *N. decepta* is a summer species, with the eggs remaining dormant throughout the winter. This is not correct, the fine-net samples indicating the eggs have hatched by 24 February.

Statistical interpretations

With the exception of *N. decepta*, both the fine- and coarse-net samples would lead to the same general inferences about the life cycles of the individual species. However the fine net tended to collect more of the smaller nymphs, and there were indications for certain species that the coarse net collected more of the larger nymphs. To determine if the frequencies of the various size classes (e.g., 1·0, 1·5, 2·0 . . . mm) of nymphs (species of Figs 1 and 2) collected with the coarse and fine nets were significantly different ($P = 0{\cdot}05$), the χ^2 test for independence was used. The assumption was that both dip-net samplers were sampling the same aquatic insect populations. The null hypothesis was that the nymphs of each species collected with the coarse-meshed dip-net had the same relative frequencies in respect to size as the nymphs collected with the fine-meshed dip-net. In short, the size-class distribution is independent of mesh size.

There were fifty possible sampling dates, e.g., nine for *E. doddsi*, ten for *E. longimanus*, etc., for which a significant difference of size classes might occur (Table 1, Column I). Also there were five dates when a particular species was collected with

Table 1. Summary of χ^2 analysis. Column I. Number of sampling dates in which nymphs appeared in both fine- and coarse-meshed nets. II. Sampling dates in which frequencies of the size classes of the two nets were significantly different ($P = 0{\cdot}05$). III. Number of dates in which nymphs appeared in either the fine-(F) or coarse-(C) meshed net, but not both nets

			III	
	I	II	F	C
Ephemerella doddsi	9	29 July 1967	0	0
Epeorus longimanus	10	29 July 1967 6 May 1968	0	0
Nemoura cinctipes	10	14 Oct. 1967 5 April 1968	1	0
Nemoura decepta	3	6 May 1968	2	1
Nemoura oregonensis	9	6 June 1968	1	0
Brachyptera nigripennis	9	0	0	0
Totals	50	7	4	1

either the coarse or fine net, but not by both nets. For these samples the χ^2 test could not be made, and we assumed a significant χ^2 value for the species on these five dates. Hence of a total of fifty possible samples, there were twelve samples where the size-class frequencies of the various species were significantly different in the two nets. An examination of the observed and expected frequency columns (or the life-cycle histogram in cases where the nymphs were collected in only one net) for these twelve dates indicated that for six dates a deficit of small nymphs (<2·5 mm) in the coarse net mainly contributed to the significant χ^2 value. For five dates a deficit of large nymphs (>5·0 mm) in the fine net mainly contributed to the χ^2 value; and for one date, differences in the intermediate size classes were most important.

The possibility of missing large numbers of small organisms when collecting with a coarse net is self-evident, and there have been several studies that have critically

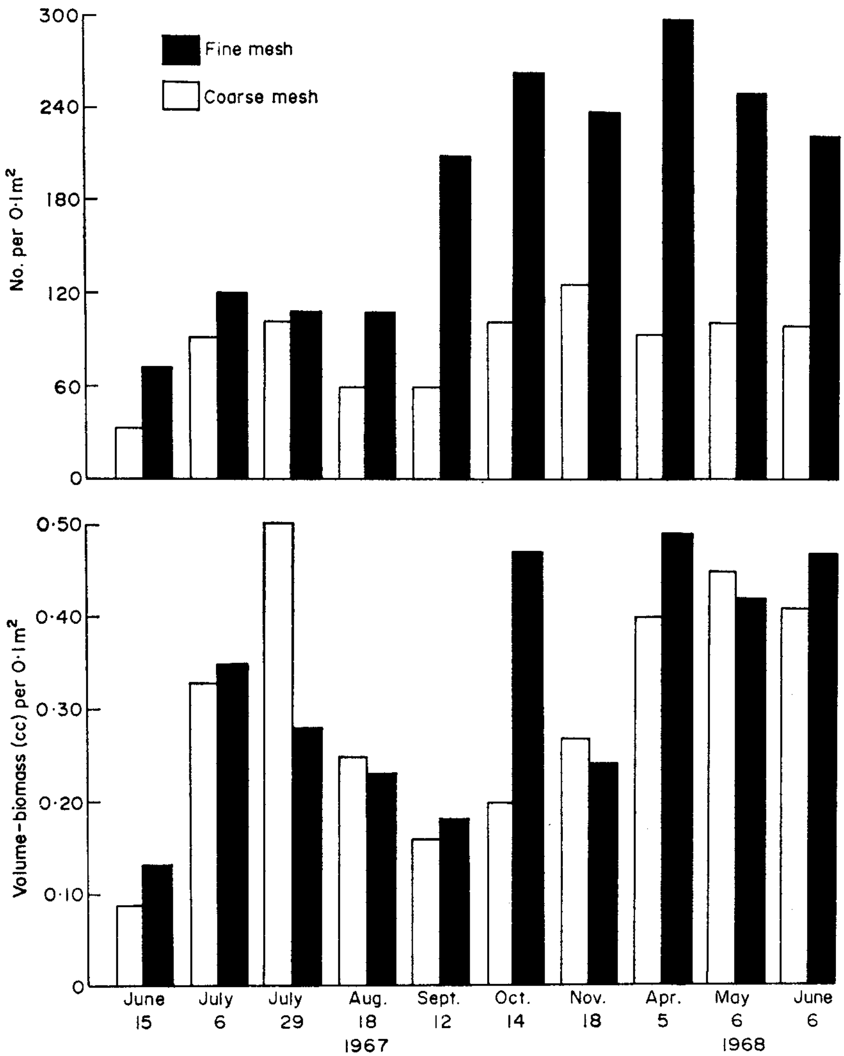

Fig. 3. Combined total numbers and volume-biomass of Ephemeroptera, Plecoptera, Trichoptera, Coleoptera and Diptera as collected with the coarse- or fine-meshed Surber samplers.

assessed the errors involved. A few workers, e.g., Mackereth (1957) and Macan (1958) have also reported that a fine net sometimes fails to collect as many large aquatic insects as a coarse net. As suggested by Macan (1958), this is probably because water does not pass so rapidly through the fine net, and hence large nymphs might escape before the net is emptied. Our results indicate that finer-meshed nets can be considerably less efficient than coarser nets for collecting large, motile specimens. Factors other than mesh size *per se* are important here, e.g., how frequently the net is emptied, shapes of the nymphs, clogging of pores with detritus, etc. Some of these are discussed in later sections.

Standing crop

The combined standing crop of immature Ephemeroptera, Plecoptera, Trichoptera, Coleoptera, and Diptera, as collected with the coarse- and fine-meshed Surber samplers is shown in Fig. 3. Even considering possible variation due to the diversity of habitats, there was for all sampling dates a larger average number of organisms per unit area in the fine-meshed samples than in the coarse-meshed samples. The discrepancies in numbers were large in all seasons except summer. In contrast to numbers, average total volume-biomass in each of the two Surber samplers was similar for most of the year. For 29 July and 14 October 1967, the differences in volume-biomass were mainly due to the presence or absence of large *Acroneuria pacifica* nymphs. In short, on a yearly basis the coarse-meshed Surber sampler would seriously underestimate standing crop in terms of numbers, but not in terms of volume-biomass.

Double-bag samplers

Comparisons so far presented have been from necessity based on the assumption that the coarse- and fine-meshed nets were sampling the same aquatic insect populations. But streams exhibit a diversity of microhabitats and the fauna usually has a clumped distribution. If large areas of the stream bed are not sampled, it is possible that two stream samplers might not be sampling the same insect population. The coarse- and fine-meshed dip-nets collected animals from very large areas and it is unlikely that

Table 2. Mesh-size efficiencies of the double-bag Surber and dip-net samplers, 6 June 1968

	Total no. or volume-biomass (cc) in both nets of the double-bag sampler		Numbers or volume-biomass passing through coarse-meshed net	
	Dip-net	Surber	Dip-net	Surber
Numbers				
Ephemeroptera	1398	694	629	359
Plectopera	580	358	168	197
Diptera	347	59	291	40
Trichoptera	46	35	1	14
Coleoptera	46	20	7	14
Volume-biomass				
Ephemeroptera	4·47	1·52	0·20	0·11
Plecoptera	2·20	0·63	0·02	0·01
Diptera	0·17	0·18	0·01	0·01

the dip-nets were collecting from different populations. However, the coarse- and fine-meshed Surber samples were collected from only a small area of the stream bed. On 6 June 1968, we collected samples with the double-bag dip-net sampler and the double-bag Surber sampler. Since the coarse and fine nets attached to each sampler would be collecting from the same area, we were certain that our coarse and fine net comparisons were based on the same populations being sampled.

Large numbers of specimens passed through the coarse nets of both double-bag samplers (Table 2). Considering the five orders collectively, in terms of numbers 45% of the insects passed through the coarse mesh of the dip-net and 54% of the insects passed through the coarse mesh of the Surber sampler. Since only small specimens passed through the coarse nets, the biomass loss from the coarse nets was considerably smaller, 3% for the dip-net and 6% for the Surber sampler.

The percentage composition of the five orders as compiled from numbers of specimens in the coarse mesh of the double-bag dip-net was Ephemeroptera (58%), Plecoptera (31%), Diptera (5%), Trichoptera (3%) and Coleoptera (3%); as compiled from specimens in both the fine and coarse nets of the dip-net samplers, the values for the above orders were 58, 24, 14, 2 and 2% respectively. These are similar compilations considering the large numbers passing through the coarse mesh. About the same proportion of each order (except for Diptera) passed through the coarse mesh. Just how much percentage-composition estimates will vary between nets of different sizes will depend ultimately on the taxonomic level being considered. Abundant dipterans of most streams are mainly small chironomid and simuliid larvae; even the mature larvae of many species, being very small and cylindrical, will not only pass through a coarse net but also a net with a pore size of 320 μm. Other taxa, e.g., Ephemeroptera, Plecoptera, and Trichoptera, have specimens with a larger size range and retention by a particular mesh size will depend on the life-cycle stage of the individual species.

Body shape and mesh-size efficiency

To account for different mesh-size efficiencies, the obvious (and most readily quantifiable) dimensional feature of insects would be total body length. However the life-

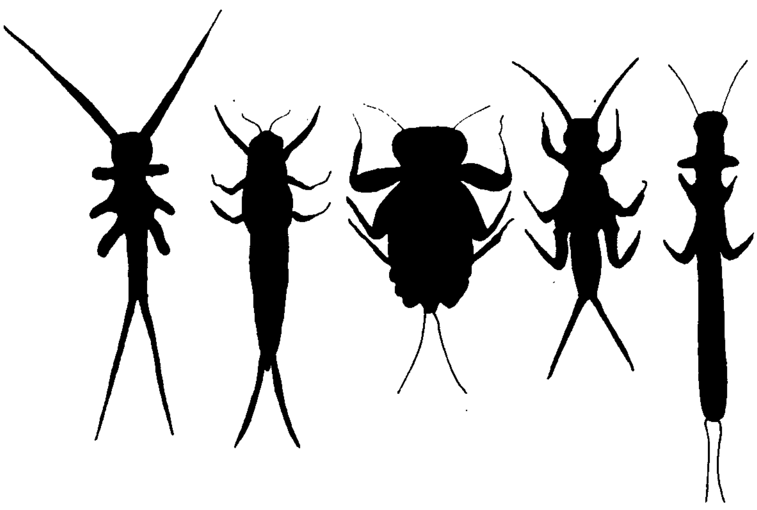

Fig. 4. Shape as related to length for three stonefly and two mayfly nymphs. From left to right: *Brachyptera nigripennis*, *Baetis* sp., *Epeorus longimanus*, *Nemoura cinctipes* and *Paraleuctra*.

cycle histogram of *B. nigripennis* indicated that the coarse-meshed dip-net collected specimens with a relative size-class distribution almost identical to that of the fine-meshed dip-net (Fig. 2). The shape of the nymphs could account for this. *B. nigripennis* has stout antennae that are disproportionately long in relation to body length (Fig. 4).

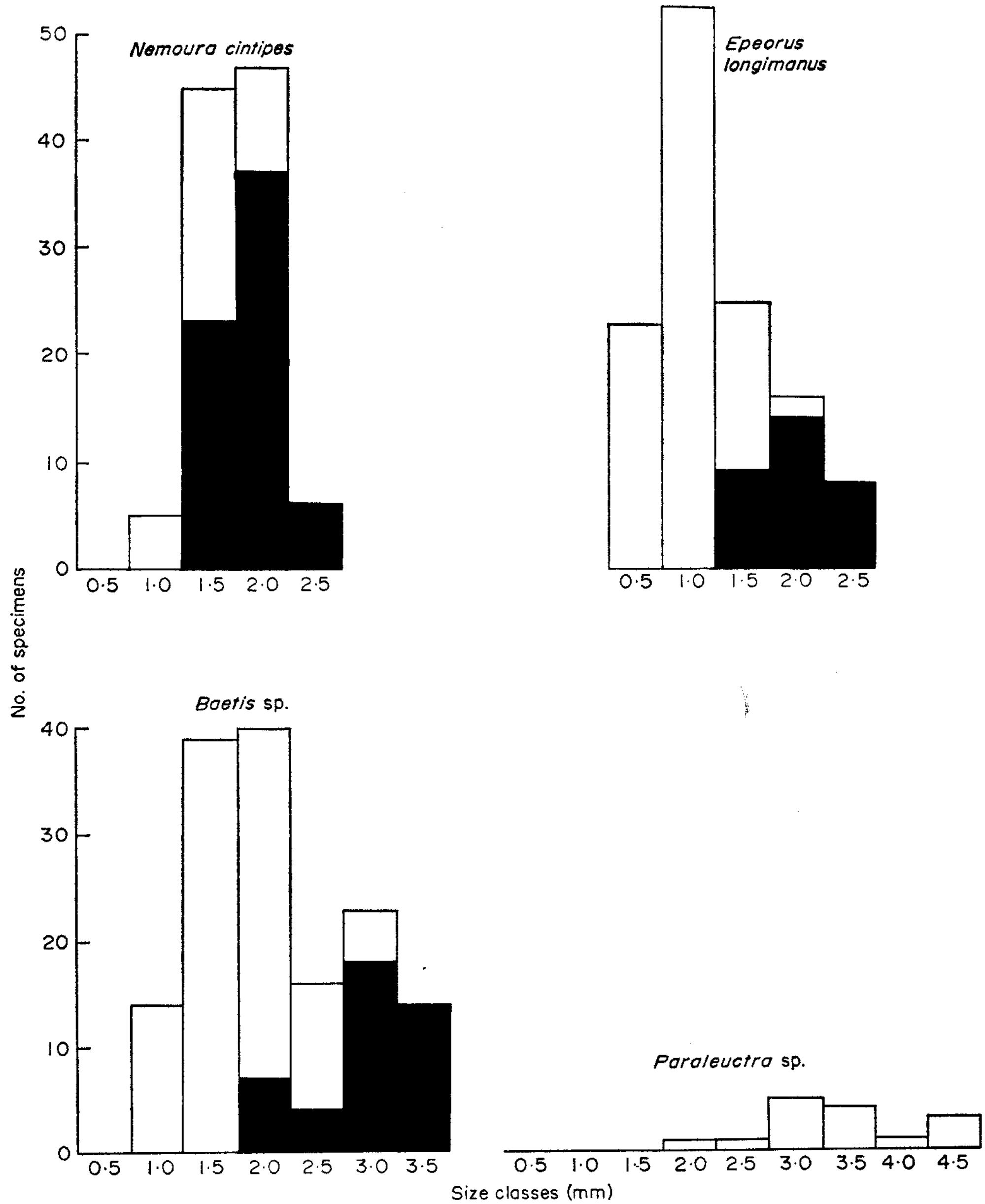

Fig. 5. Total number of *N. cinctipes*, *E. longimanus*, *Baetis* sp. and *Paraleuctra* sp. in each size class collected with the double-bag dip-net sampler, 6 June 1968. Shaded area represents number of nymphs caught in the coarse mesh; unshaded area represents number of nymphs caught in the fine mesh and hence passing through the coarse mesh.

Using the double-bag dip-net samples of 6 June 1968, we further examined the relationship between body shape and mesh-size efficiency. As indicated in Fig. 4, both *Baetis* and *Paraleuctra* are cylindrical and streamlined, *Paraleuctra* having a needle-like shape. In contrast *Epeorus* is flattened; and *N. cinctipes*, although cylindrical, has large laterally extended appendages. Both *N. cinctipes* and *Epeorus* have a relatively greater overall width than do *Baetis* and *Paraleuctra*. The coarse mesh of the double-bag dip-net sampler retained most of the *N. cinctipes* and *Epeorus* nymphs 2·0 mm in body length and larger (Fig. 5). In contrast most of the *Baetis* nymphs smaller than 3·0 mm and all the *Paraleuctra* nymphs passed through the coarse mesh. Obviously shape of individuals, as well as body length, can be an important attribute in assessing mesh-size efficiencies.

Discussion

We made comparisons between nets with pore sizes of 720 and 320 μm, calling these coarse and fine nets; but since there are no 'standard' net sizes* for stream samplers, these are simply descriptive terms. A 320-μm pore size net would be considered a fairly coarse net when compared to some nets that have been used in stream work, e.g., Mundie (1971) used a net with a pore size of 50 μm, and Maitland (1964) did extensive stream sampling with a mesh of 65 threads/cm (pore size of about 76 μm). Other works as well have used very fine-meshed nets for stream work or sieving lake samples. The consensus is that any net with a pore size of 300 μm or larger misses over half the fauna by numbers, especially if chironomids and simuliids are an important component of the fauna.

If large numbers of stream insects pass through a 300-μm net, shape of the small organisms must be of paramount importance, since most stream insects even in the first instar will have a body length greater than 0·3 mm. Jónasson (1955) found that chironomid larvae as large as 10 mm will pass through a 0·6 mm mesh gauge if the head capsule is able to pass through. Mundie (1971) reports that generally the head capsule width of a newly hatched chironomid will be about 60 μm. In our study we found that shape of immature hemimetabolous insects, e.g., Ephemeroptera and Plecoptera, is also important in assessing the efficiencies of the relatively coarse 720- and 320-μm nets. For mayflies and stoneflies, general body shape and length and stoutness of the appendages are very important. Although many small mayfly and stonefly nymphs passed through our 720-μm dip-net, our life-cycle studies (and subsequent χ^2 analysis) indicated that the 320-μm dip-net was often deficient in collecting the larger nymphs. One would suspect that the finer the mesh the more pronounced this phenomenon would be; how frequently the nets are emptied would be an important factor here.

Dip-net samplers, because they are mobile and can sample in a short period extensive areas and a variety of stream habitats, are probably one of the best devices for collecting mayfly and stonefly nymphs for general life-cycle studies. In light of our study, we suggest that more useful life-cycle data might be obtained by using in turn a 720-μm dip-net and then a net with a pore size of about 100 μm of even plankton net size (76 μm). The finer-meshed sampler could be used sparingly, emptying the net at very short intervals, and taking some of the samples from deep in the substrate. It is also

* The manufacturer's standard mesh size for Surber-type samplers purchased in North America is usually 9 threads/cm (pore size of about 1·02 mm). Recently Hynes (1971) suggested that stream samplers should have a mesh size of at least 30 threads/cm (pore size of about 240 μm).

suggested that, regardless of the mesh size, empirically determined pore sizes be reported instead of the manufacturer's stated pore size or instead of threads per unit area. Silk, perlon, and nylon threads do not necessarily have the same diameters and silk threads tend to swell once submerged in water (Schwoerbel, 1970).

Acknowledgments

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