William L. Peters
with the author's
good wishes

INTERNATIONALE VEREINIGUNG
FÜR THEORETISCHE UND ANGEWANDTE LIMNOLOGIE

INTERNATIONAL ASSOCIATION
OF THEORETICAL AND APPLIED LIMNOLOGY

ASSOCIATION INTERNATIONALE
DE LIMNOLOGIE THÉORIQUE ET APPLIQUÉE

MITTEILUNGEN · COMMUNICATIONS
No. 8

T. T. MACAN

METHODS OF SAMPLING THE BOTTOM FAUNA IN STONY STREAMS

With 4 figures and 4 tables in the text

World List Abbreviation: *Mitt. int. Ver. Limnol.*
DIN Norm Abkürzung: *Mitt. internat. Verein. Limnol.*

STUTTGART 1958
E. SCHWEIZERBART'SCHE VERLAGSBUCHHANDLUNG
(NÄGELE u. OBERMILLER)

INTERNATIONALE VEREINIGUNG
FÜR THEORETISCHE UND ANGEWANDTE LIMNOLOGIE
Mitteilung No. 8
KOMITEE FÜR LIMNOLOGISCHE METHODEN, Veröffentlichung No. 8, 1958

Methods of sampling the bottom fauna in stony streams

T. T. MACAN
Freshwater Biological Association, Ferry House, Far Sawrey, Ambleside, Westmorland

With 4 figures and 4 tables in the text

The problem to which this publication is devoted is how to sample quantitatively the bottom fauna in a stream whose current is of such speed that the substratum consists of loose stones of varying size. First, samplers that other workers have used in running water are described briefly and their suitability or otherwise for substrata of this kind discussed; detailed accounts are not given, nor is any attempt made to list all the papers in which there is reference to them. Then there is a description of the apparatus that the writer has used, an instrument that has been invented before by several workers whose various designs are compared. Finally some results obtained with it are presented and discussed.

Description of samplers

General works on sampling methods have been written by STEINER (1919), WUNDSCH (1936) and WELCH (1948), and ways of sampling the substratum in running water can be divided into five categories:

1. Lifting by hand of individual stones.
2. Provision of a known area of removable substratum for colonization.
3. Boxes and cylinders. A given area is enclosed and the animals within it removed.
4. Fixed nets. A known area upstream is disturbed and the animals dislodged from it are washed into the net.
5. Nets that are pushed forward through the substratum. The selection of a briefer designation for instruments of this type is discussed later on.

Lifting by hand of individual stones

This method was first used by ALM but, as he described it in Swedish, I have taken his account of it from SCHRÄDER (1932), who evolved the method independently, and describes both his own and ALM's procedure. A stone is taken in the hand, lifted very gently off the substratum, and then enclosed in a net before being taken out of the water. Animals that have not dropped off into the net are scraped off into a dish. The area of the stone is then measured, though this has been done only quite roughly by the various users of the method. MÜLLER (1953), for example, merely finds the two longest dimensions measured in a straight line and multiplies them together.

This method is limited to substrata consisting of large stones with nothing between but, on such a bottom, it is probably the only one that can be used. SCHRÄDER (1932) notes that there is a big loss of animals when a net or dredge is employed to pick up the stones.

This is, perhaps, the appropriate point at which to interpolate some remarks about a method that the writer has used extensively in stream-fauna work, for it also involves picking up stones by hand, though, owing to the number of stones examined and the great range of their size, results were calculated on a time not a surface-area basis. It is scarcely a quantitative technique but does yield useful comparable figures. The work was done with an ordinary pond-net consisting of a bag attached to a wire ring which was wired onto a bigger ring, the main frame of the net. This had an internal diameter of 28.5 cm and could be secured to a pole by means of a winged nut. Two bolting-silk nets were used, a coarse one with a mesh of twenty threads to the inch, which means that each hole is about 1 mm square, and a fine one with 180 threads to the inch. This is the material used for phytoplankton nets by the Freshwater Biological Association, and nothing that was subsequently to be searched for with the naked eye could have passed through it. Even when the stream was in full flood, there was a rapid passage of water through the coarse net but after only moderately heavy rain the flow was so fast that the fine net filled, and water eddied out round the sides. Presumably, by increasing the area of bolting-silk or decreasing the area of the mouth, or both, it should be possible to make a net that could be used in torrential conditions, but this has not been tried.

Collecting was carried out for exactly 5 minutes or exactly 10 minutes during which the collector worked slowly upstream lifting stones and holding the net in such a way that anything beneath each stone was swept into it. Animals clinging to a stone were dislodged by vigorous swilling in the mouth of the net, and then the stone was thrown aside and another taken.

The net is more versatile than the quantitative sampler, for it can be used among stones too large to be sampled by any device worked by the human arm, and, further, whereas most other methods require a visible bottom, a net collection can be made by touch in turbid water. WUNDSCH (1924) remarks that one of the advantages of the pfahlkratzer, a similar instrument, is its versatility.

I learn from a personal communication that Dr H. B. N. HYNES prefers to hold his net against the bottom and then disturb the area just upstream of it with his feet. He believes that, with a little practice, it is possible to obtain reasonably comparable collections in this way, and there is the advantage that deeper water can be sampled with the legs than with the arms.

Provision of a known area of removable substratum for colonization

The tray method is described by MOON (1935), who used it extensively in his survey of Windermere. He reconstructed an area of bottom as faithfully as possible on a frame of known area, lowered it into the water, left it until it had been colonized by the animals from the substratum round it, and then hauled it up for removal and counting of these animals. The method seems to have been admirable for a lake but, in swift streams, proper bedding-down appears to be an insuperable difficulty because, as soon as an excavation is started, stones are washed into it from above; if the tray is not sunk deep enough, some animals, notably *Gammarus*, congregate under it not on it.

BRITT (1955) lowered for colonization a concrete block, which had been scored and grooved before it set to give it a surface like that of the stones among which it was placed. ALBRECHT (1953) used tiles in the same way, but informs me in a personal communication that she has now abandoned the method, because the surface may not be colonized by the same plants and animals that colonize the surface of the stones and rocks occurring naturally in the stream. This technique, however, can only catch the animals that occur on the bigger stones and must miss those on the smaller ones and gravel beneath.

Boxes and cylinders

From a box, the larger stones are picked by hand, smaller material is dug out with a shovel and sieved, and any animal that may leave the substratum and swim is caught by baling out the water into a sieve (BERG 1938, p. 7). JÓNASSON (1948) used this apparatus successfully for the survey of the Danish River Susaa. He describes it as: "a tin box without a bottom which covered an area of 450 sq. cm", and remarks that: "the chief consideration when taking samples with this box is that it should fit closely to the substratum, but this may be difficult on a rough bottom". It is impossible on the type of bottom under consideration. Moreover, any solid object, such as a box, immersed in the stream deflects the current downwards before it reaches the bottom and scours the very area that it is desired to sample.

The fauna is generally removed from cylinders in a more elaborate way. WELCH (1948) describes two samplers of this kind. WILDING's consists of a brass cylinder enclosing an area of 1 square foot. The cylinder is pushed against the bottom and rotated until it has sunk in a short distance, teeth attached to the lower margin aiding the penetration. Then larger stones are removed by hand and the remaining material is stirred well, the assumption being that this will dislodge all animals and leave them swimming or floating in the water where they can be caught in a

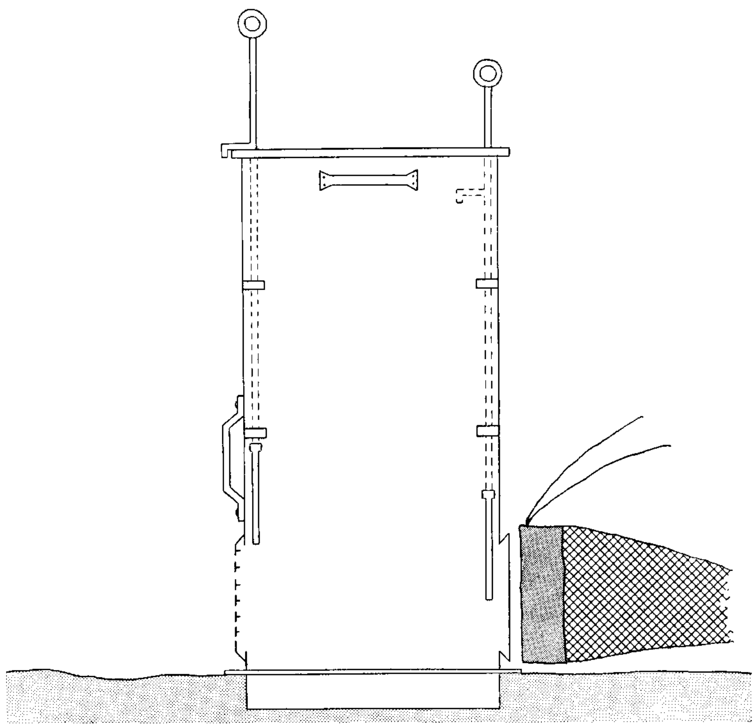

Fig. 1. Neill's cylinder.

second cylinder fitting exactly into the first. This inner cylinder, which is perforated and fitted with a valve at the end, is pushed down as far as it will go and then withdrawn after the valve has been closed.

Incidentally, 1 square foot is nearly $^1/_{10}$ square metre; to be exact 1 sq. ft = $30 \cdot 5$ cm^2 and $31 \cdot 7$ cm^2 = $^1/_{10}$ sq. m.

Neill (1938) used a similar cylinder 82 cm in height and 1000 sq. cm in cross-section (fig. 1). It had a flange that prevented it going more than 5 cm into the substratum and was without teeth. On the side that faced upstream was an opening covered by wire and, opposite, a similar one to which a net was attached. Sliding doors covered both openings. When the cylinder had been driven into the substratum, the larger stones within it were lifted, stripped of attached vegetation and clinging animals, brought out of the cylinder and thrown away. The rest of the bottom was then stirred up with a stick, also provided with a flange to prevent penetration deeper than 5 cm. Half a minute was allowed for the coarse particles to settle after stirring, both doors were then opened, and a current allowed to flow through the cylinder, whereby fine particles and animals were carried into the net. The stirring of the bottom and the admission of the current, which ran through for three minutes, was done three times.

Geijskes (1935), using a method described by Redeke in Dutch, drove a simple cylinder of about the same size as Neill's 5 cm into the substratum and then endeavoured, not always successfully, to close the end of the cylinder with a plate and bring out the sample entire.

Hess's sampler, also described by Welch, is difficult to categorize, but is most conveniently included here even though it fails to conform with the original definition in that it does not isolate the area of bottom that it surrounds. A cylinder of wire-netting in front and canvas behind is attached to two rings joined by two bars. A net is sewn into a hole in the canvas near the bottom. The lower ring is rotated into the substratum, the wire half of the cylinder being kept facing upstream, large stones are removed, and then the bottom is disturbed so that animals and light material are dislodged and washed into the net.

Neill writes of his sampler: "It's use is limited to those (streams) with a fair current, with a substratum into which it can cut, and of a depth not exceeding the arm length of the operator." The second of these conditions is not fulfilled in a stony stream. A solid cylinder will also deflect the current downwards and cause scouring of the bottom before it reaches it.

Fixed nets

A popular sampler in America, described by Moffett (1936) and by Surber (1937) and referred to by Welch and several other writers as the Surber sampler, consists of two square frames which fold together for carrying and open out at right angles for use. Each is 1 sq. ft in area. In operation, one lies flat on the bottom and serves to mark out the area to be sampled while the other stands vertically and supports a net into which the current washes specimens dislodged in the marked area. Welch's instructions are: "Turn over and stir stones, gravel and other coarser materials enclosed by horizontal frame, allowing dislodged materials to float into net; make certain that all materials within frame are stirred thoroughly to a depth of at least one inch."

The same principle was employed by Badcock (1949) and Illies (1952).

Leonard (1939) writes of the method: "It is very difficult to seat the net in rough gravel or rubble in such a way as to enclose accurately one square foot without possible loss of material under the net frame." This difficulty is not insuperable and Dr. Dittmar has sent me a description not yet published of an invention of his designed to overcome it. It is like a pond-net or pfahlkratzer with a robust frame to the bottom of which is attached a plate which projects forward a few inches to form a shovel-like blade. This can be driven into the substratum and held between the legs while the stones within a wire ring are lifted and brushed clean of animals.

The method, however, cannot be used where the flow exceeds a certain speed, because the current fills with material washed down from higher up any hole made by the removal of stones from the sampling area. Often too, if the bottom is not very stable, the displacement of one stone causes an extensive area of substratum to shift.

Nets that are pushed forward through the substratum

Steiner (1919) and Wundsch (1936) describe the "Pfahlkratzer", a name which it is proposed to retain since the instrument appears to be unknown in English-speaking countries and a literal translation into "pile-scratcher" would not convey any meaning except to readers who could translate it back into German. It is like a pond-net but more stoutly built and with at least one side of the frame sharpened to give a cutting edge. Steiner remarks that there are many versions, and figures one with a D-shaped and one with a triangular frame. Wundsch (1924) states that quantitative results can be obtained with it, but does not give details.

More elaborate instruments based on the same idea have been evolved independently several times in Britain. First there is the question of a name, deferred from an earlier section. Percival and Whitehead (1926) introduce their contrivance as "a kind of shovel" but afterwards refer to it both as a "shovel" and a "scoop". Allen (1940) applies the latter word consistently to his apparatus. Etymologically there seems little to choose between the two, but, in the writer's mind, "scoop" is associated less with hard work than "shovel" and seems more applicable to the soup ladles, or light dishes attached to sticks, that are used to collect mosquito larvae and other small creatures at the surface. This bias in favour of "shovel" is reinforced by Dittmar's (1955) use of the name "Bachgrundschaufel" for a similar type of sampler because a word that is the same or nearly the same in two languages is preferable to one that is not. The upshot, therefore, is a decision in favour of "shovel" as a name for the sampler.

Percival and Whitehead (1926) describe their sampler as: "a kind of shovel open at the back and carrying a bag into which sediment can be scooped". The bottom measured 20 × 20 cm and the sides were 10 cm high. It differed from an ordinary shovel in that the posterior half of the top was closed by a metal plate, which held a fitting to receive a handle 18 cm long. Into the rectangle at the back fitted a bag, which hooked onto a band of wire-netting running round the inside of the shovel. The escape of organisms at the junction was prevented by a strip of leather which was attached to the inside of the shovel and which projected well into the net. The sampler was operated by digging it into the bottom and then pushing it forward for a determined distance.

A real shovel provides a large area on which a pile of something solid can be supported, but, if the material is to pass through the shovel into a net, all that is required is a frame with a cutting edge in front. This was the principle of ALLEN's (1940) sampler (fig. 2). The sides of his frame were in line with the handle which was 1·2 m long. Runners were attached below each side in such a way that, if they were flat on the bottom, the frame made an angle of about 30° with it. The sampler could be pulled as well as pushed. Two bags, the inner of wide-meshed netting to prevent the passage of large stones, were secured to a fine wire frame which was wired onto the main frame. Both nets were open at the back and for use were tied up like the cod end of a trawl. The sampler was 30·5 cm wide but only about half as high and, to prevent animals being carried over the top by the current, a metal hood was fitted.

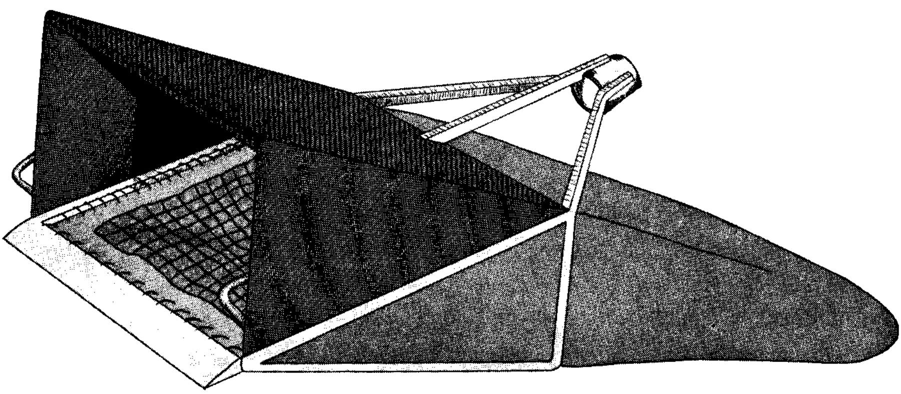

Fig. 2. ALLEN's sampler.

The writer's first sampler resembled that of PERCIVAL and WHITEHEAD, except that it was as tall as broad and the net was attached in a different way. In use a fault became manifest very soon. In order to drive the leading edge into the substratum before pushing it forward, the operator had to tilt the shovel slightly or even to an angle of as much as 45° with the stream bed. During the insertion, the bottom was disturbed, and this caused some animals to let go. These were generally lost because they were washed against the solid bottom of the shovel and then away round the sides. It was evidently preferable to have a narrow cutting edge and, behind it, something flexible that would be pressed down by the current so that any animal dislodged would be washed through, not round, the net and caught.

The second design, like ALLEN's, had a narrow cutting edge in front and a frame and a handle all in one line. The handle had once been part of a garden fork; the frame was of metal strips, flat one side and convex the other, 25 mm broad and 10 mm thick; the cutting edge was 35 mm broad and 7 mm thick at the back. The contrivance (fig. 3) differs from ALLEN's (fig. 2) in that the mouth of the net is as high as broad so that the likelihood of anything being washed over the top is less;

it is desirable to deflect a swift current as little as possible and therefore the hood of ALLEN's grab seems a feature with which it is better to dispense. The net differs, too, in being closed at the end, and in the method of attachment. A second frame of steel bar, 9 mm square in cross section, is welded to the sides of the main frame where they join the cutting edge in such a way that, when the shovel is being pushed forward with the main frame at an angle to the bottom, it stands upright. About two thirds of the way up, a flat plate of metal is attached to each

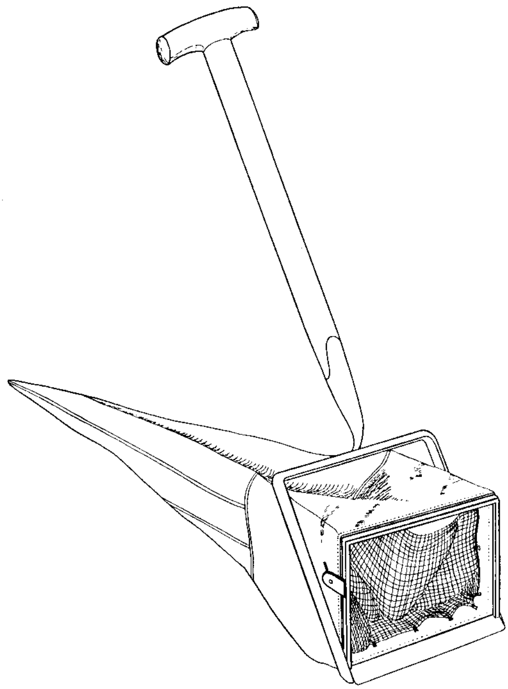

Fig. 3. The writer's sampler.

side of this frame, and to the inside of this plate is fixed a round disc of metal pierced eccentrically and provided with a small handle. The net, 55 cm long, is made of phytoplankton netting (180 threads to 1 inch) (1 inch equals approximately 25 mm) sewn onto a 25-cm-long canvas collar which is sewn onto a wire frame. A coarse net to stop stones hooks onto the inside of the canvas. The wire frame fits exactly behind the upright frame of the shovel and is gripped in position by a turn of the eccentrics. It is easily taken off and is turned inside out and swilled in a bowl of water to remove the catch. The sampler, as were the other two, is driven into the substratum and then pushed a known distance forward. In fact the opening is 22.5 cm across and therefore, if the shovel is pushed forward 22.2 cm, 500 sq. m or 1/20 sq. m have been sampled.

The larger the shovel, the smaller the sampling error, but also unfortunately the greater the difficulty of pushing it through a bed of stones. The writer's shovel, 22.5 cm wide, could have been a little bigger, but probably not much, for ALLEN found that two people were required to work his sampler, 30.5 cm wide. It seems preferable not to need two people, because a second person pulling and trampling the stream bed above the sampler must dislodge animals which may end up in the net; also, there is not always an assistant available. Mr. J. D. BRAYSHAW, who has used the apparatus, writes in an unpublished report: "I feel that the sample taken is a little small but that any increase in size in the shovel would make it quite unwieldy for one person."

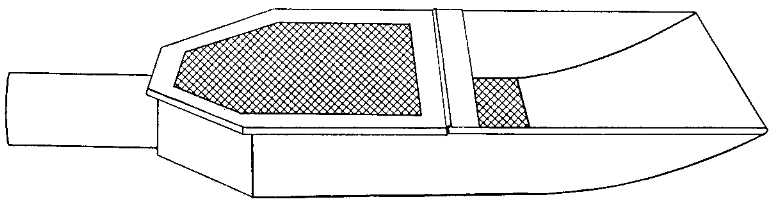

Fig. 4. DITTMAR's Bachgrundschaufel.

DITTMAR (1955) describes a "Bachgrundschaufel" which is similar in principle though different in many points of detail, but he has recently told me in a personal communication that, since he wrote his paper, he has devised a new and more robust version. Here I shall avail myself of the account of his latest model with which Dr. DITTMAR has very kindly furnished me (fig. 4). It is a flat box 35 cm long and 23 cm across with the front curving up to meet the top like that of a toboggan. The sides, the back and the upcurving part of the bottom are made of galvanized iron 4 mm thick, but the rest of the bottom is of wire gauze. A strip of galvanized iron runs across the top 25 cm from the back; in front of this the shovel is open, behind there is a detachable gauze plate. A hole in the back is barred to prevent large stones passing through it, and on the outside a detachable cylinder can be fitted. The cylinder of the original apparatus was made entirely of gauze but that of the later one has only a gauze bottom, the rest being of galvanized iron.

The apparatus is pushed through the substratum with the hands. Then it is taken to a quiet part of the stream and the top plate removed. The larger stones are brushed free of animals and thrown away and then all the animals, smaller stones, and debris are washed through into the gauze cylinder. The apparatus is shovel-sampler and sieve in one.

Dredges

All the methods mentioned have been suitable for shallow water only. The sampling of a stony bottom in a deep river presents a more difficult problem and probably the only apparatus that can be used is a dredge of some sort. Various kinds are described by STEINER (1919) and the two most suitable for a stony substratum are: FOREL's, whose frame was a strip of metal which, having been bent twice to give two sides and a top, was joined to a garden rake which formed the bottom; and STEINMANN's which had a three-cornered frame with teeth projecting outwards from each side. A modern dredge is described by USINGER & NEEDHAM (1956). The iron frame is 18 inches (45 cm) long, 5 inches (12·5 cm) high and 3 inches (7·5 cm) from back to front. The net is clamped by means of butterfly nuts between the frame and strips of metal. The net can be opened by means of a zip-fastener, though the smooth operation of this is often interfered with by grains of sand. The opening is crossed by 17 bars which project as points, and serve to dig into the substratum and disturb the fauna. They extend in both directions and therefore the operator does not have to worry about which way up the dredge is. There is no information about how many animals cling to the stones and rubbish which accumulate on the bars without passing into the net.

SCHRÄDER (1932) maintains that, in practised hands, the dredge may be made to yield samples that are comparable, and describes how he manoeuvres his boat and his dredge to achieve this end.

Ancillary operations

PERCIVAL and WHITEHEAD and ALLEN sieved their samples and took home only what was left in the finer sieves. ALLEN's residue was carried in a bag. The writer tipped the stones in the coarse net into a bucket containing a solution of calcium chloride of specific gravity 1·1 and stirred. In this solution the animals floated to the top and could be concentrated by pouring the liquid through the net, which, as described above, was easily detached from the main frame. The stones were immersed in the calcium chloride solution and stirred three times. The writer was interested primarily in Ephemeroptera; the disadvantage of this technique is that Trichoptera larvae in stone cases and *Ancylus* remain at the bottom in the stones.

DITTMAR's gauze cylinder was detached from the shovel after a sample had been taken and put in a special container of the same shape, about one third of it containing water. The advantage of this method is that the gauze provides anything that requires it with something to cling to, and the water can be changed easily; if necessary the gauze cylinder and its prisoners can be immersed in a cool stream for a while. This would seem to be an excellent idea if the journey home is long and specimens in good condition are required.

BRITT (1955) dips stones in a 0·03—0·06% solution of HCl in 2—5% alcohol and finds that clinging animals immediately let go in it. The solution is then poured through a sieve and, if the residue of animals is washed thoroughly in water, it is found that few of them have been harmed.

If it is desired to pick out every organism in a sample, some fairly tedious sorting is inevitable. MOON (1935) found that the labour was eased if the material from his finer sieves was graded by an elutriation technique in a trough 1·3 m long, 20 cm wide and 6·4 cm deep. There were two baffles running nearly across the trough and causing eddies when water flowed. The current was not strong enough to wash the coarse sand and larger particles out of the trough, but it shifted and at the same time graded them behind the baffles. Debris and animals were swept right through and caught in sieves beneath the outflow. MOON reckoned that the resulting piles of sand and small stones could be sorted more easily than if they had been mixed up with each other and with the animals and debris.

ALLEN used a similar trough without partitions, and, for sorting, a pipette with a trap and continuous suction from a filter pump. He counted his catch in an apparatus originally designed for plankton work (ULLYOTT 1937). It consists of a long trough, a little narrower than the field of the microscope to be used, which can be pulled along a rail beneath the microscope with halts whenever the contents are so dense that the operator cannot count them as they pass across the field. The original traction force was gravity and the trough was halted by means of a brake connected to a foot pedal. Innumerable modifications to all parts of the apparatus have been made by various members of the staff of the Freshwater Biological Association. The trough has been pulled along by direct pressure of a pedal which turned a drum and wound up a weight whereby the drum was revolved to its original position when the pressure was released; being connected to it by a pawl and ratchet, the drum turned the axle only on the downstroke. Later, traction was provided by a gramophone motor and by an electric motor. The counter was also electrified.

Results

Under this heading are compared:

1. catches made at the same time at the same place by the same method;
2. what remains in the stones and what passes through to the net when the writer's shovel sampler was used;
3. catches with the shovel sampler and catches with a hand-net;
4. catches made with a fine net and a coarse net.

First, a brief description of the three lowermost stations in the stream where most of the comparative tests were done must be given. Ford Wood Beck and its tributaries traverse or rise on a plateau, over parts of which they flow sluggishly. They then descend steeply over flat sheets of rock separated by pools filled with boulders and large stones and unite in a valley in which the rate of flow is not so fast. The rock is of Silurian age and tends to break into rather flat angular stones. The valley itself is a rock basin now filled with material which was probably washed in at the end of the Ice Age and which consists of clay with stones of all sizes and boulders embedded in it. At the head of the valley, just below the rock outcrop, the stream bed is floored with relatively large stones, many the size of a man's outstretched hand though thicker and some twice or more as big. Most of the stones have probably been plucked off the rocks, but the current has never been strong enough to carry the largest very far. Consequently there is a tendency for the size of the biggest stones to decrease down the valley but an even grading it not very obvious, partly because wall-builders have thrown their rejects into the stream at various places. These big stones lie over and protect from the current smaller stones beneath which there is gravel, sand and clay. The shovel sampler can penetrate 5—8 cm into the bottom, but sometimes it encounters a stone bedded immovably in the fine material lower down, and then the only course is to start again in another place.

Station 1 of Ford Wood Beck was near the mouth below an outcrop of rock, station 2 some 500 m upstream, and station 3, another 200 m or so upstream, was at the foot of the steep part of the stream.

Table 1. Collections made with shovel sampler on 9 and 10 October 1952.

Rhithrogena semicolorata	*Ecdyonurus torrentis* and sp.	*Baetis rhodani*	*Baetis pumilus*	*Hydropsyche*	other Trichoptera	Plecoptera	Coleoptera	Diptera	*Gammarus pulex*	Oligochaetes	Hydracarina	Total
99	13	87	41	6	0	63	4	13	17	19	0	362
106	16	21	30	1	9	52	19	13	37	4	1	309
80	6	70	20	8	0	34	5	8	11	2	1	245
130	2	119	36	5	6	72	10	10	6	7	0	403

Variation between two catches

Two catches with a shovel sampler are unlikely to be identical for three reasons:

1. There is a sampling error at the edge of the sampler. It is hoped that, for every stone which the side of the grab pushes outwards, a similar one is pushed inwards and caught together with its fauna, but obviously gains and losses from this cause will never balance exactly. The larger the individual stones, the greater the discrepancy may be. Mottley, Rayner and Rainwater (1939) believe that with a Surber sampler an error of up to 30% may spring from this source.
2. It is not known exactly what factor affects the abundance of the fauna. The sample is in terms of overall surface area but what is probably important to an animal is free surface area of stone, or perhaps the length of crevice where it may lie touching stone with back and belly or sides. Both these could vary greatly within one square metre of superficial area. Both will increase as stones get smaller, but below a certain size the interstices will be too small for the larger animals.
3. Even if there was no variation from the above two causes, the fauna is not randomly distributed (Harker 1953).

As there is no means of assessing the amount of variation due to each of these three causes, it is not possible to calculate the "error" of the sampler, that is variation due wholly to shortcomings in the method of sampling. All that can be done is to present some results and examine them.

Generally two samples were taken from each place, but on one occasion four were taken and obviously this will yield the most satisfactory data for an examination of variation (table 1). *Rhithrogena semicolorata* is the most abundant species in all the collections, with a mean of 104. The standard deviation is 21 and, if this be doubled and added to and subtracted from the mean in accordance with standard practice, the answer is 62 and 146; this means that, at that time of year in that part of the stream the number of *Rhithrogena* in $^1/_{20}$ sq. m lies somewhere between those two figures. Between 1240 and 2920 per sq. m is rather a large range in, for example, a calculation of the productivity of the stream, and evidently a distinctly greater number of samples would be desirable for such a purpose. It is not profitable to take this examination further, because no generalization is possible and the amount of variation will be peculiar to each stream, if not to different parts of each stream. A recent contribution to the statistical study of samples from streams has been made by USINGER & NEEDHAM (1956), but I understand from various personal communications that this is not to be taken as the last word on the subject.

Comparison of catches among the stones and in the net of the shovel sampler

As expected, the flattened clinging ecdyonurids tend to stay in the stones, whereas *Baetis* and *Gammarus* are washed through into the net. Percentages in the net were:

Rhithrogena semicolorata	61%	*Baetis rhodani*	89%
		B. pumilus	95%
		Gammarus pulex	87%

Comparison of catches made with hand-net and with shovel sampler

This not only yields further information about behaviour but also makes it possible to relate numbers taken with the net to area. The comparison must, however, be made cautiously, for it is certain that neither instrument is a perfect sampler. Only the commonest species have been selected for comparison and their numbers are broken up into size groups (table 2). The number of shovel samples and five-minute collections with the fine net was:

	Aug.	Sept.	Oct.		Nov.	Dec.	Total
station	2	3	1	2	2	2	
number of net collections	1	1	1	1	1	1	6
number of shovel samples	1	1	2	4	2	2	12

In order to obtain a ratio of two shovel samples to one net collection each time, the totals caught in the net in August and September and in the four shovel samples in October have been halved. The figures in table 2 are, therefore, based on ten shovel samples und five net collections except those for *Rhithrogena* which was not present in August.

Table 2. Comparison of the proportions of the various size groups of various species caught by shovel sampler and fine net.

mm long:	0—1	1—2	2—3	3—4	4—5	5—6	6—7	7—8	8—9	Total
Rhithrogena semicolorata										
$4^1/_2$ net	—	16	84	102	58	24	—	—	—	284
9 shovel	1	165	232	123	40	7	—	—	—	568
Ecdyonurus torrentis										
5 net	—	3	21	29	20	20	12	3	1	109
10 shovel	1	8	18	24	13	13	4	5	—	86
Baetis rhodani										
5 net	1441	5098	1156	274	88	81	45	10	2	8195
10 shovel	55	240	201	100	34	16	13	—	—	659
Baetis pumilus										
5 net	12	110	136	103	10	3	—	—	—	374
10 shovel	3	160	78	14	6	1	—	—	—	262
Gammarus pulex										
5 net	—	—	—	—	—	—	—	—	—	232
10 shovel	—	—	—	—	—	—	—	—	—	173

The shovel sampler caught exactly twice as many specimens of *Rhithrogena* as the net, but this was because it caught large numbers of specimens 1—2 mm long, whereas the net caught few (table 2). Of the larger specimens, more were taken by net than by shovel. *Ecdyonurus torrentis,* though similar in structure to *Rhithrogena,* affords a contrast; the numbers taken by the two methods are close with a small advantage to the net except in the smallest size groups. The deduction from these figures is that the two species have different habits when very small; *Rhithrogena,* it is postulated, inhabits the small stones and gravel where the shovel catches it but the net, which samples mainly the superficial stones, does not, whereas *Ecdyonurus* spends all its life on the larger stones.

Baetis rhodani is quite different from these two, for the net catches a great many more specimens of all sizes of it. The most likely explanation is that the larger specimens at least can escape more easily from the shovel than from the net. It has been shown that baetids let go more readily than ecdyonurids and it seems likely that, as soon as nymphs feel the substratum shifting as the shovel blade passes under it, they swim away, some heading upstream and out of the sampler. It seems improbable, however, that great numbers of small nymphs escape this way and their abundance in the net may be due to the fact that they congregate and the net, covering a bigger area, is more likely to hit a swarm than the shovel. Possibly they congregate under big stones which would also tend to make them more numerous in the net. Many egg-batches are usually laid close together, because the females tend to choose a stone which is projecting obliquely from the stream, and walk down the shaded side into the water to lay their eggs. Whatever the explanation, it is clear that here is a serious source of error in the shovel sampler, though a limited one because *Baetis* is the only inhabitant of running water, other than fish, which can swim fast. No way of obviating it is apparent; a technique whereby an area was suddenly and swiftly surrounded is theoretically the right one for quick swimmers, but it is not practicable because of the difficulty of obtaining a good seal on stones.

When *B. pumilus* is compared with *B. rhodani*, the most striking point is that only a comparatively small number of little specimens was taken in the net. A possible explanation is that, whereas tiny *B. rhodani* remain near the surface, which seems likely because they are positively phototactic in the sorting-dish, tiny *B. pumilus* occur among the smaller stones and gravel. PLESKOT (1954) writes of the nymphs of this species: ... "fissikol. Sie halten sich in den Lückenräumen zwischen den Steinen des Bachgrundes ..." Larger nymphs are less numerous in the shovel than in the net and probably escape just as those of *B. rhodani* do.

Thus, from comparison of catches in net and shovel, deductions about the behaviour of some of the animals has been possible. Next comes the problem of estimating the area that a 5-minute net collection covered. *Baetis* is no use for this purpose because, being a swift swimmer, it can avoid the shovel more easily than the net; small *Rhithrogena* must also be discarded because they congregate in a place not sampled equally by the two methods. There is, however, no evidence that large *Rhithrogena* or *Ecdyonurus* nymphs congregated anywhere where one method would catch more of them than the other, and they are not good swimmers. The same is true of *Gammarus*. It seems, therefore, that the numbers of these caught by the two methods may be compared directly. Such a comparison shows that in 5 minutes the fine net caught a little more than twice as much as the shovel, which sampled $^1/_{20}$ sq. metre. Therefore it covered a little more than $^1/_{10}$ sq. m, which is an unexpectedly small area for a collection that went on for 5 minutes.

The number of collections was rather small and conclusions must be tentative, but the explanation of difference in numbers caught by the two methods in terms of the habits of the species is plausible. The important converse is that anyone employing only one method must know the habits of at least the important species. The present comparison is a crude one because it was not the chief aim of the original collection. An investigation in which, during 5-minute periods, only stones approximating to a certain size were collected would probably be profitable.

Relative numbers to be expected in net and shovel having thus been established, information about some of the less numerous animals may be gained from a study of the quantities caught by the two methods. Table 3 shows the numbers of Coleoptera of the families Helmidae, Helodidae, Dryopidae and Hydrophilidae, a group selected because first impressions were that it was not taken equally by the two instruments. Since no seasonal change is apparent, the corrections applied to the figures in table 2 have not been considered necessary and the total of 12 shovel samples includes 4 at st. 2 in October but only 1 in each of the previous two months. The figures demonstrate that all three kinds of larvae are predominantly dwellers in the small stones and gravel.

Table 3. Numbers of Coleoptera taken in the net and in the shovel sampler.

	6 net samples		12 shovel samples	
	times taken	number taken	times taken	number taken
Helmis maugei	2	2	1	1
Helmid larvae	3	3	8	24
Helodid larvae	2	4	9	40
Dryopid larvae	3	3	8	24
Hydraena gracilis	3	12	5	11

PLESKOT (1953) has applied the name "Schlängler" to species which are neither true burrowers nor true stone clingers but which can glide snakelike (whence the name) through the interstices between small stones.

Comparison between catches made with the coarse and fine hand-nets

The coarse-net collection of specimens of *Rhithrogena* 1—2 mm long is but 20% of that of the fine net, in the next size group about 40% (table 4). Doubtless these small nymphs pass through the coarse net. The catches of specimens 3—4 mm long by the two nets are similar and evidently 3 mm is about the maximum length of a specimen that can pass through the mesh. The coarse net caught more specimens in the 4—5 mm group and the difference is significant according to the formula of BUCHANAN-WOLLASTON (1945, p. 36), though of what is not clear. Thereafter catches are very similar and the totals in the two nets of specimens over 5 mm long were 673 and 663. *Ecdyonurus torrentis* is similar except that the preponderance of specimens 4—5 mm long in the coarse net is smaller and not significant. *Heptagenia lateralis* is similar too.

Table 4. Numbers of Ephemeroptera of various sizes taken in 65 parallel collections with a coarse net and a with fine net.

	Rhithrogena		*Ecdyonurus*		*Heptagenia*		*Baetis rhodani*		*B. pumilus*	
size mm	fine	coarse	fine	coarse	fine	coarse	fine	coarse	fine	coarse
0—1	—	—	1	0	—	—	19,986	25	92	0
1—2	104	20	124	13	8	1	21,872	226	727	6
2—3	303	131	153	108	73	40	7,730	252	930	21
3—4	397	373	165	156	126	113	2,657	424	657	44
4—5	354	448	112	133	74	46	1,244	724	331	93
5—6	290	252	110	136	27	18	787	761	206	169
6—7	126	157	69	96	7	5	320	409	41	69
7—8	123	136	45	78	1	3	174	311	8	6
8—9	84	80	51	49	3	3	107	152	—	2
9—10	34	35	39	23	1	1	10	76	—	—
over 10	16	3	51	55	—	—	17	46	—	—

In the genus *Baetis*, as might be expected, the picture is totally different. Nearly every specimen under 1 mm long and most of those under 2 mm long go through the coarse net. As they are long and slim, it is to be expected that many should do so, but the proportion gives perhaps cause for surprise. The net often collects a fair amount of debris but it would seem that the instinct of the nymphs is not to seek shelter in this but to pass downstream with the current. With increasing size the proportion of nymphs that go through the nets decreases but, up to 5 mm, there is a significant difference between the catches in the two. They capture roughly the same number of specimens in the 5—6 mm size group, but thereafter the coarse net catches more than the fine one, significantly more too. The explanation proffered is that the fine net is easier for a big nymph to escape from because the water does not pass through it so rapidly.

The most striking thing about the figures in table 4 is the colossal catches of the tiny nymphs of *Baetis rhodani*, more than forty thousand under 2 mm, compared with the modest three-figure totals of the other species. This great abundance is not reflected in larger size-groups. Numbers recorded in monthly samples depend on actual numbers and on time spent in that particular stage, but it cannot be postulated that *B. rhodani* grows slowly when tiny and the other species fast, because, were this the case, the others would show comparable numbers in some larger size-group, which they do not. Nor is there any reason to believe that *B. rhodani* lays many more eggs than other species. Behaviour may be partly responsible, for, as was shown above, there is evidence that the smallest nymphs of *Rhithrogena* and *Baetis pumilus* seek shelter among the smallest stones and gravel; *B. rhodani* does not and, therefore, the nymphs are in a place where the net will catch them. Another factor is that the nymphs are attracted to light in the sorting dish and are therefore easy to catch. Numbers of other species were so small that it was not possible to be certain whether they went towards light or not; if not, a certain number would be missed during sorting. It does not seem likely, however, that either observation provides a full explanation, and the origin of the vast numbers of tiny *B. rhodani* remains a mystery; so does their fate.

Acknowledgements

Dr M.-L. Albrecht, Professor Kaj Berg Ph. D., Dr H. Dittmar, Dr J. Illies and Dr H. B. N. Hynes have read the typescript, have made criticisms, have drawn my attention to publications unknown to me or have contributed original observations which I have incorporated. I acknowledge with gratitude this kind assistance. I wish to thank also Dr G. Pleskot and Dr A. Wurtz for the German and French summaries respectively, and Mr T. Gledhill who drew figs. 1 and 2 and Mrs Jean C. Mackereth who drew fig. 3.

Zusammenfassung

Es wird das Problem behandelt, wie man in Fließgewässern, die infolge höherer Strömungsgeschwindigkeit einen Untergrund von losen Steinen verschiedener Größe haben, zu quantitativen Aufsammlungen gelangen kann. Es werden fünf Methoden, die in verschiedenartigen Fließgewässern verwendet worden sind, diskutiert und ihre Brauchbarkeit für schnellfließende Gewässer untersucht.

1. Man kann die Steine mit der Hand aufheben und abmessen, was offenbar nur dann durchführbar ist, wenn der Untergrund nur aus großen Steinen besteht und nicht außerdem auch noch kleine Steine vorhanden sind. Der Autor machte zahlreiche Aufsammlungen, wobei er eine bestimmte Zeit lang stromaufwärts arbeitete und dabei die beim Aufheben der Steine wegschwimmenden Tiere in einem Handnetz fing.

2. Einen künstlichen Untergrund zur Neubesiedlung in den Gewässerboden einzubringen, ist in schnell fließendem Wasser nicht durchführbar, da die Strömung das Ausgraben einer genügend tiefen Grube unmöglich macht.

3. Die Abgrenzung eines bestimmten Areals durch Kasten oder Zylinder (Abb. 1) kann selten verwendet werden, da es zwischen großen Steinen nicht möglich ist, eine Abdichtung am Untergrund herzustellen.

4. Eine Methode, die in langsam fließendem Wasser oft angewendet wird, ist das Aufwühlen eines abgesteckten Areals und Auffangen der aufgestörten Fauna in einem fixierten Netz. Dieses Verfahren wird dann unanwendbar, wenn die Strömung stark genug ist, daß die Bewegung eines einzelnen Steines eine Veränderung in einem ausgedehnteren Bereich nach sich zieht.

5. Am brauchbarsten scheint noch der „Schaufelsammler“ zu sein, wie er vom Autor (Abb. 3) und verschiedener Autoren (Abb. 2 und 4) unabhängig voneinander entwickelt worden ist. Der Apparat wird über eine bestimmte Strecke vorwärts bewegt, wodurch ein bestimmter Bereich des Untergrundes ausgegraben wird. Ein grobes Netz hält die großen Steine zurück, während kleinere Bodenteile und der Großteil der Fauna sich in einem feineren Netz sammeln.

Alle diese Methoden können nur in seichtem Wasser angewendet werden. In tieferem Wasser muß man sich mit einer Dredge irgendeiner Art behelfen.

Die Trennung der Fauna von den Untergrundteilen kann in einer Lösung von Kalziumchlorid mit dem spezifischen Gewicht 1,1 leicht vorgenommen werden; *Ancylus* und die Trichopteren in Steingehäusen gehen allerdings dabei verloren. Verschiedene Schlämmverfahren zur Erleichterung des Aussortierens sind versucht worden.

Zwei Fänge, die nahe beieinander in derselben Art und zur selben Zeit entnommen wurden, können eine sehr verschiedene Zahl von Tieren ergeben (Tab. 1), was nicht verwunderlich ist, weil zwei an der Oberfläche scheinbar gleiche Untergrundquadrate in der Größe und Art der freien Oberfläche sowie im Volumen der Lückenräume völlig verschieden sein können und weil man noch sehr wenig über die Abhängigkeit der Fauna von solchen Faktoren weiß.

Der Vergleich von Fängen, die mit verschiedenen Sammelmethoden durchgeführt wurden, bringt Aufschlüsse über das Verhalten einzelner Arten und über die Fehlerquellen jeder Methode (Tab. 2 und 3). Im Handnetz z. B. fehlen einige der Tiere, die an Steinen haften oder in den Lückenräumen des Kieses leben; im Schaufelsammler fehlen diese nicht. Dagegen entkommt *Baetis,* ein kräftiger Schwimmer, eher dem Schaufelsammler als dem Handnetz; allerdings entkommt sie auch dem Handnetz immer leichter, je größer sie wird: Die Zahl dieser Tiere scheint überhaupt in einem quantitativen Fang nie vollständig erfaßbar zu sein.

Mit einem feinen Netz wurden sehr große Mengen von sehr kleinen *Baetis rhodani*-Larven erbeutet, aber durch ein gröberes Netz entkamen nahezu alle diese Larven (Tab. 4).

Résumé

Le problème est d'obtenir des prélèvements quantitatifs dans des rivières et torrents où le courant est tellement rapide que le fond est composé de cailloux libres de taille variable. Cinq méthodes utilisées dans les eaux courantes sont décrites et leur emploi en fort courant est discuté.

1. Les cailloux sont soulevés à la main et mesurés, ce qui semble être la seule méthode pratique lorsque le fond est composé entièrement de gros cailloux, mais non lorsqu'il y en a également des petits. L'auteur a fait de nombreuses récoltes, travaillant pendant un temps donné en remontant le courant, en soulevant les cailloux et recueillant les animaux délogés dans un filet tenu à la main.

2. La création d'une surface artificielle pour la colonisation n'est pas possible dans les forts courants, car ceux-ci empêchent de creuser un trou assez profond pour enterrer le cadre de la surface de peuplement.

3. Des boîtes et des cylindres (fig. 1) délimitant une surface donnée d'où les animaux pourraient être enlevés, peuvent être rarement utilisés parce qu'il n'est pas possible de réaliser une bonne étanchéite par rapport au fond, parmi les gros cailloux.

4. Une méthode habituellement utilisée dans les eaux à courant moins fort, qui consiste à remuer vivement les cailloux d'une surface donnée et à recueillir la faune délogée dans un filet fixe, n'est pas utilisable si le courant est tellement fort que le fait de remuer un seul caillou entraîne des variations sur une plus grande étendue.

5. L'instrument qui a donné le plus de satisfaction est une «pelle à récoltes» mise au point par l'auteur (fig. 3) ainsi que par d'autres auteurs, independamment (figs. 2 et 4). La «pelle» est poussée en avant sur une distance connue, et une surface donnée du substratum est ainsi creusée. Les gros cailloux sont retenus dans un filet grossier, alors que les éléments plus petits et la plus grande partie des animaux sont recueillis dans un filet fin.

Toutes ces méthodes ne peuvent être utilisées qu'en eau peu profonde. En eau plus profonde, une drague d'un type quelquonque doit être employée.

Il est facile de séparer la faune de son substratum à l'aide d'une solution de chlorure de calcium de poids spécifique 1·1, mais les *Ancylus* et les Trichoptères dans des fourreaux en pierres sont perdus par cette méthode. Plusieurs techniques d'élution pour faciliter le tri à la main ont été essayées.

Il peut y avoir de grandes différences dans le nombre d'animaux de deux récoltes faites en même temps et de la même manière (tableau 1), ce qui n'est pas surprenant, car, sous deux surfaces identiques et apparement similaires, l'étendue et la nature de la surface exposée ainsi que le volume des interstices peuvent varier beaucoup, et l'on sait peu de choses quant aux réactions des animaux à ces facteurs.

Le comparaison de récoltes faites de différentes manières apporte des données sur le comportement d'espèces particulières, et sur les sources d'erreur de chacune des méthodes (tableaux 2 et 3). Le filet à main, par exemple, ne recueille pas certains animaux fixés sur les cailloux ou vivant dans les interstices du gravier, tandis qu'avec la pelle à récoltes on les attrape. Par contre, *Baetis*, bon nageur, arrive plus facilement à s'échapper de la pelle que du filet. Il semble s'échapper en plus grand nombre du filet, lorsqu'il devient plus gros; il apparaît d'ailleurs comme un animal dont il est impossible de recueillir en nombre des récoltes quantitatives.

De très grands quantités de très petits larves de *Baetis rhodani* ont été attrapées par un filet fin, mais presque toutes ces larves se sont échappées à travers un filet dont les mailles leur permettaient juste de passer (tableau 4).

References

ALBRECHT, M.-L. 1953. Die Plane und andere Flämingbäche. *Z. Fisch.* **1**, 389—476.

ALLEN, K. R. 1940. Studies on the biology of the early stages of the salmon *(Salmo salar)*. 1. Growth in the River Eden. *J. Anim. Ecol.* **9**, 1—23.

BADCOCK, R. M. 1949. Studies in stream life in tributaries of the Welsh Dee. *J. Anim. Ecol.* **18**, 193—208.

BERG, K. 1938. Studies on the bottom animals of Esrom Lake. *K. danske vidensk. Selsk. Skr.* **8**, 1—255.

BRITT, N. W. 1955. New methods of collecting bottom fauna from shoals or rubble bottoms of lakes and streams. *Ecology* **36**, 524—525.

BUCHANAN-WOLLASTON, H. J. 1945. On statistical treatment of the results of parallel trials with special reference to fishery research. *Sci. Publ. Freshwat. Biol. Ass. Brit. Emp.* no. **10**.

DITTMAR, H. 1955. Ein Sauerlandbach. *Arch. Hydrobiol.* **50**, 305—552.

GEIJSKES, D. C. 1935. Faunistisch-ökologische Untersuchungen am Röserenbach bei Leistal im Basler Tafeljura. *Tijdschr. Ent.* **78**, 249—382.

HARKER, J. E. 1953. An investigation of the distribution of the mayfly fauna of a Lancashire stream. *J. Anim. Ecol.* **22**, 1—13.

ILLIES, J. 1952. Die Mölle. Faunistisch-ökologische Untersuchungen an einem Forellenbach im Lipper Bergland. *Arch. Hydrobiol.* **46**, 424—612.

JÓNASSON, P. M. 1948. Quantitative studies of the bottom fauna in BERG, K. Biological studies on the River Susaa. *Folia. limnol. scand.* **4**, 204—284.

LEONARD, J. W. 1939. Comments on the adequacy of accepted stream bottom sampling technique. *Trans. N. Amer. Wildl. Conf.* 4, 288—295.

MOFFETT, J. W. 1936. A quantitative study of the bottom fauna in some Utah streams variously affected by erosion. *Bull. Univ. Utah.* **26**, 1—32.

MOON, H. P. 1935. Methods and apparatus suitable for an investigation of the littoral region of oligotrophic lakes. *Int. Rev. Hydrobiol.* **32**, 319—333.

MOTTLEY, C. M., RAYNER, H. J., and RAINWATER, J. H. 1939. The determination of the food grade of streams. *Trans. Amer. Fish Soc.* **68**, 336—343.

MÜLLER, K. 1953. Produktionsbiologische Untersuchungen in nordschwedischen Fließgewässern. Teil 1. Der Einfluß der Flößereiregulierungen auf dem quantitativen und qualitativen Bestand der Bodenfauna. *Rep. Inst. freshwat. Res. Drottningholm* **34**, 90—121.

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

NEILL, R. M. 1938. The food and feeding of the Brown Trout (*Salmo trutta* L.) in relation to the organic environment. *Trans. roy. Soc. Edinb.* **59**, 481—520.

PERCIVAL, E., and WHITEHEAD, H. 1926. Observations on the biology of the mayfly *Ephemera danica*, MÜLL. *Proc. Leeds phil. lit. Soc.* **1**, 136—148.

PLESKOT, G. 1953. Zur Ökologie der Leptophlebiiden (Ins., Ephemeroptera). *Österreich. zool. Z.* 4, 45—107.

PLESKOT, G. 1954. Ephemeroptera in: *Die Nordostalpen im Spiegel ihrer Landtierwelt.* Innsbruck: WAGNER.

SCHRÄDER, T. 1932. Über die Möglichkeit einer quantitativen Untersuchung der Boden- und Ufertierwelt fließender Gewässer. *Z. Fisch.* **30**, 105—125.

STEINER, G. 1919. Untersuchungsverfahren und Hilfsmittel zur Erforschung der Lebewelt der Gewässer. *Handbuch der mikroskop. Technik.* pt. 7 and 8, 1—148.

SURBER, E. W. 1937. Rainbow Trout and bottom fauna production in one mile of stream. *Trans. Amer. Fish. Soc.* **66**, 193—202.

ULLYOTT, P. 1937. An apparatus for plankton counting. *Int. Rev.* **34**, 15—23.

USINGER, R. L., and NEEDHAM, P. R. 1956. A drag-type riffle-bottom sampler. *Prog. Fish-Culturist* **18**, 42—44.

WELCH, P. S. 1948. *Limnological methods.* Philadelphia: BLAKISTON.

WUNDSCH, H. H. 1924. Die quantitative Untersuchung der Bodenfauna und -flora in ihrer Bedeutung für die theoretische und angewandte Limnologie. *Verh. int. Ver. Limnol.* **2**, 13—59.

WUNDSCH, H. H. 1936. Die Arbeitsmethoden der Fischereibiologie in ABDERHALDEN. *Handbuch der biologischen Arbeitsmethoden* **11** (2nd part, 2nd half), 853—1208.