Methods of Biological Sampling: Sampling of Benthic Macroinvertebrates in Deep Rivers 1983

Methods for the Examination of Waters and Associated Materials

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DEPARTMENT OF THE ENVIRONMENT

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Methods of the Examination of Waters and Associated Materials

Correction

Page 11. Table 2 Third Column
For 'm' read micrometres.

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Methods for the Examination of Waters and Associated Materials

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Warning to Users

The analytical procedures given in this booklet should only be carried out by competent trained persons, with adequate supervision when necessary. Local Safety Regulations must be observed. Laboratory procedures should be carried out only in properly equipped laboratories. Field operations should be conducted with due regard to possible local hazards, and portable safety equipment should be carried. Care should be taken against creating hazards. Lone working, whether in the laboratory or field, should be discouraged. Reagents of adequate purity must be used, along with properly maintained apparatus and equipment of correct specifications. Specifications for reagents, apparatus and equipment are given in manufacturer's catalogues and various published standards. If contamination is suspected, reagent purity should be checked before use.

There are numerous handbooks on first aid and laboratory safety. Among such publications are: 'Code of Practice for Chemical Laboratories' and 'Hazards in the Chemical Laboratory' issued by the Royal Society of Chemistry, London; 'Safety in Biological Laboratories' (Editors Hartree and Booth), Biochemical Society Special Publication No 5, The Biochemical Society, London, which includes biological hazards; and 'The Prevention of Laboratory Acquired Infection, 'Public Health Laboratory Service Monograph 6, HMSO, London.

Where the Committee have considered that a special unusual hazard exists, attention has been drawn to this in the text so that additional care might be taken beyond that which should be exercised at all times when carrying out analytical procedures. It cannot be too strongly emphasised that prompt first aid, decontamination, or administration of the correct antidote can save life; but that incorrect treatment can make matters worse. It is suggested that both supervisors and operators be familiar with emergency procedures before starting even a slightly hazardous operation, and that doctors consulted after any accident involving chemical contamination, ingestion, or inhalation, be made familiar with the chemical nature of the injury, as some chemical injuries require specialist treatment not normally encountered by most doctors. Similar warning should be given if a biological or radio-chemical injury is suspected. Some very unusual parasites, viruses and other micro-organisms are occasionally encountered in samples and when sampling in the field. In the latter case, all equipment including footwear should be disinfected by appropriate methods if contamination is suspected.

The best safeguard is a thorough consideration of hazards and the consequent safety precautions and remedies well in advance. Without intending to give a complete checklist, points that experience has shown are often forgotten include: laboratory tidiness, stray radiation leaks (including ultra violet), use of correct protective clothing and goggles, removal of toxic fumes and wastes, containment in the event of breakage, access to taps, escape routes, and the accessibility of the correct and properly maintained first-aid, fire-fighting, and rescue equipment. Hazardous reagents and solutions should always be stored in plain sight and below face level. Attention should also be given to potential vapour and fire risks. If in doubt, it is safer to assume that the hazard may exist and take reasonable precautions, rather than to assume that no hazard exists until proved otherwise.

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About this series

This booklet is part of a series intended to provide both recommended methods for the determination of water quality, and in addition, short reviews of the more important analytical techniques of interest to the water and sewage industries. In the past, the Department of the Environment and its predecessors, in collaboration with various learned societies, have issued volumes of methods for the analysis of water and sewage culminating in 'Analysis of Raw, Potable and Waste Waters'. These volumes inevitably took some years to prepare, so that they were often partially out of date before they appeared in print. The present series will be published as individual methods, thus allowing for the replacement or addition of methods as quickly as possible without need of waiting for the next edition. The rate of publication will also be related to the urgency of requirement for that particular method, tentative methods being issued when necessary. The aim is to provide as complete and up to date a collection of methods and reviews as is practicable, which will, as far as possible, take into account the analytical facilities available in different parts of the Kingdom, and the quality criteria of interest to those responsible for the various aspects of the water cycle. Because both needs and equipment vary widely, where necessary, a selection of methods may be recommended for a single determinand. It will be the responsibility of the users — the senior analytical chemist, biologist, bacteriologist etc. to decide which of these methods to use for the determination in hand. Whilst the attention of the user is drawn to any special known hazards which may occur with the use of any particular method, responsibility for proper supervision and the provision of safe working conditions must remain with the user.

The preparation of this series and its continuous revision is the responsibility of the Standing Committee of Analysts (to review Standard Methods for Quality Control of the Water Cycle). The Standing Committee of Analysts is a committee of the Department of the Environment set up in 1972. Currently it has seven Working Groups, each responsible for one section or aspect of water cycle quality analysis. They are as follows:

1.0 General principles of sampling and accuracy of results
3.0 Empirical and physical methods
4.0 Metals and metalloids
5.0 General nonmetallic substances
6.0 Organic impurities
7.0 Biological methods
9.0 Radiochemical methods.

The actual methods and reviews are produced by smaller panels of experts in the appropriate field, under the overall supervision of the appropriate working group and the main committee. The names of those associated with this method are listed inside the back cover. Publication of new or revised methods will be notified to the technical press, whilst a list of Methods in Print is given in the current HMSO Sectional Publication List No 5.

Whilst an effort is made to prevent errors from occurring in the published text, a few errors have been found in booklets in this series. Correction notes and minor additions to published booklets not warranting a new booklet in this series will be issued periodically as the need arises. Should an error be found affecting the operation of a method, the true sense not being obvious, or an error in the printed text be discovered prior to sale, a separate correction note will be issued for inclusion in that booklet.

L R PITTWELL
Secretary

31 October 1983

Methods of biological sampling: Sampling of benthic macroinvertebrates in deep rivers

1 Performance characteristics of the method and suppliers

1.1	Biota sampled	Benthic macroinvertebrates
1.2	Habitats sampled	Bottoms of rivers > 1 m deep
1.3	Types of samplers	Dredge, grabs, air-lift sampler
1.4	Basis of operation	Manually hauled dredge, mechanically operated grabs, vibrating air-lift pump
1.5	Form of data	Qualitative and/or quantitative
1.6	Limitations of method	(i) not on macrophytes (ii) not on stones > about 13 cm (iii) operator safety, e.g. in very fast rivers
1.7	Efficiency of method	Dependent upon type of sampler and substratum. Accuracy usually > 75%, sometimes close to 100%; precision (coefficient of variation) 44–91%
1.8	Logistics of sampling	Samplers of moderate weight (< 25 kg) requiring two people for safe operation from a boat.
1.9	Known UK suppliers	
	Naturalist's dredges	— Fabricate locally See Fig 1a and Table 2 or Holme and McIntyre 1971 for dimensions
	Birge-Ekman and Ponar grabs	— Offshore Environmental Systems Ltd 17 West Street Farnham Surrey GU9 7DR
	FBA air-lift sampler	— Engineering drawings and details of construction from: Freshwater Biological Association The Ferry House Ambleside Cumbria LA22 0LP and see Drake and Elliott (1982); and Drake, Winstanley, Ohnstad and Elliott (1984)

2 Introduction

Two previous publications in this series (HMSO 1979, 1982) describe the use of qualitative and quantitative samplers for benthic macroinvertebrates in shallow water. The present publication describes and evaluates apparatus for use in deep rivers (i.e. deeper than 1 m) on substrata ranging from mud to stones.

The choice of a sampler for sampling macroinvertebrates depends on the purpose of the exercise. The major objectives of sampling may be divided into the following three broad categories. They become progressively more difficult to fulfil because they demand a successive increase in the effort required both for sampling and the identification of the catch (Elliott, Drake & Tullett 1980).

2.1 The simplest objective is a list of taxa or species with no measure of abundance. Some biotic indices may be derived from such data and the complexity of the index depends upon the taxonomic level to which the invertebrates are identified. The minimum requirement is a sampler that adequately collects material from different types of microhabitat on the river bottom. A dredge would suffice.

2.2 A second objective may be to measure the relative abundance of species. This is useful because it can be used to calculate some community or biotic indices based on rank order or diversity. For this purpose, the sampler must operate in a standard manner on all the types of substrata that are to be investigated. Although a qualitative sampler, e.g. a dredge, is adequate, quantitative samplers are preferable because their performance is less biased by the operator.

2.3 The third objective may be to estimate the number or biomass of invertebrates per unit area, and these estimates can be used to compare spatial or temporal differences in populations using parametric tests, e.g. to detect small changes in water quality and rates of growth, reproduction and mortality. Only quantitative samplers — grabs, corers, air-lift samplers — may be used for this purpose and many replicate sampling units need to be taken on each type of habitat. The effort required is considerably greater than for objectives 2.1 and 2.2.

3 Problems in sampling deep rivers

Deep rivers are defined as those deeper than 1 m, i.e. those in which a pond net or shallow-water quantitative samplers cannot be used. The following problems occur, and are not encountered in shallow water.

(a) A boat is needed and therefore access to the sampling site is restricted.

(b) The boat must be kept on station using anchors and warps. This is especially important when using an air-lift sampler which must be kept upright for at least 30 s.

(c) The samplers must operate automatically and the operator has little control over the performance of the device.

(d) Samplers may not hit the bottom squarely in fast currents and therefore may not function properly.

(e) Some rivers have a substratum of large stones which prevent nearly all samplers from working.

The use of divers circumvents these problems because they can use 'shallow' water samplers. However, such operations are expensive on manpower and are potentially hazardous.

4 Equipment

4.1 After considering several hundred samplers which remove part of the substratum (Elliott and Tullett 1978 and 1983), seven grabs, four dredges and three air-lift samplers were chosen for comparative studies of their performance. A summary of the results for the fourteen samplers and a new Freshwater Biological Association (FBA) air-lift sampler is given (Table 1), (see also Elliott and Drake 1981 a, b; Drake and Elliott 1982; Drake, Winstanley, Ohnstad and Elliott 1984).

The following samplers are recommended: Naturalist's dredge (medium or large size), pole-operated Birge-Ekman grab, weighted Ponar grab and the new FBA air-lift sampler. The limitations of each sampler are given in section 5.

4.2 The Naturalist's dredge (Fig 1(a), see also Holme and McIntyre 1971, Elliott and Drake 1981 b) has a study rectangular frame (medium version, 46 × 19 cm; large version 61 × 20 cm; weighting 9.3 g and 15.25 kg, respectively) supporting a collecting net about 35 cm long. The mesh size of the net may be altered to suit the purpose of the study (see 5.5).

4.3 The pole-operated Birge-Ekman grab (Fig 1(b), see also Birge 1921, Elliott and Drake 1981 1a) is an open-ended box (15 × 15 × 15 cml sampling area 225 cm^2) with two spring-loaded jaws that are activated by a manually-operated release mechanism. Two hinged plates at the top of the box reduce the shock wave as the sampler approaches the bottom by allowing a free flow of water through the box and also reduce the loss of material as the sampler is raised. The pole-operated version allows greater control and penetration than one suspended from a rope but is limited to use in water depths 3 m. The weight of the sampler on a 2 m-pole is 7.75 kg. The bite profile of the grab is approximately square in mud and saucer-shaped in gravel and therefore the sample is biased towards surface-dwelling animals in gravel.

4.4 The weighted Ponar grab (sampling area 560 cm^2, weighting 22.6 kg) has two large jaws which are closed by a scissor action of a series of lever arms (Fig 1(c), see also Powers and Robertson 1967, Elliott and Drake 1981a). A crossbar holds the arms and jaws apart and is automatically released when the grab settles on the bottom. As the grab is raised, the jaws close. The bite profile of the grab is approximately semi-circular in mud and saucer-shaped in gravel; thus the sample is biased towards surface-dwelling animals.

4.5 The FBA air-lift sampler (sampling area 415 cm^2, weight *c.* 14 kg) has a 10 cm diameter riser whose length can be altered from 0.8 – 4.0 m by inserting lengths of pipe (Fig 1(d)). Air from compressed air bottles is fed through 12 mm hosing to the base of the riser. An inclined pipe at the top of the riser directs the water and sample into a net whilst air is vented at its other end. The sampling area is enclosed by an open-ended stainless steel cylinder (23 cm diameter) which allows continuous replacement of water during pumping. The cylinder and riser are connected by runners on which the riser can be raised 10 cm above the base of the cylinder, where it is held by catches which are released by a handle near the top of the sampler. An air-driven vibrator (rotating ball type, weight 1.1 kg) is attached to the cylinder and is operated at a pressure of 280,000 Pa (producing *c.* 9000 rpm) and air is supplied through 3-mm internal diameter pressure hosing. This helps to dislodge material within the cylinder, increases the uptake of material for a given air-flow, and can also increase the penetration of the cylinder into the substratum (see 5.4.2). Exhaust air from the vibrator is returned to the surface to supplement the supply to the riser. An air-flow gauge is inserted in the final section of air-line to the riser so that it measures the total flow to the riser. The gauge is essential for making the most efficient use of air under different conditions of water-depth and type of substratum.

5 Operation of the samplers

5.1 The Naturalist's dredge is suitable for obtaining qualitative samples from gravel and stones (particles > 2 mm) but not from mud. The large dredge collects about 1.4–2 times as much material as the medium size dredge (Elliott & Drake 1981b). Which version is chosen may depend on the objective (see section 6.1). The dredge is best operated from a boat but it may be thrown from the bank. From a boat, it is lowered to the bed and hauled after moving the boat upstream and anchoring it securely. This procedure is easier than towing the dredge directly because of the resistance of the dredge on the bottom. Note that the dredge, when full of stones, is a far more effective brake than most anchors sold for small boats. The distance of the hand may be standardized by letting out a known length of rope. The distance of each haul will depend on the nature of the bottom, e.g. on fine gravel, the net may fill after 1 m whereas on large stones, over which the dredge tends to bounce, it has to be hauled over a distance > 5 m before a representative sample is obtained. To prevent the dredge lifting off the bottom as it is hauled along, the angle of the rope to the river bed is best kept below 25° (Holme & McIntyre 1971). The sample is emptied into a suitable large container, taking care to remove animals retained in the net, then decanted before preserving and storing. A weak link is recommended when hauling from a power boat in case the dredge catches on obstructions. Details are given in Holme & McIntyre (1971).

5.2 The pole-operated Birge-Ekman grab is suitable for obtaining qualitative and quantitative samples on muddy and fine gravelly bottoms (Elliott & Drake 1981a). The grab is cocked by drawing back the jaws and fixing them to the release mechanism. The sampler is first lowered slowly to the bottom to prevent a shock wave from disturbing the substratum, and then pushed firmly against the substratum. The release mechanism is triggered by pressing the end of a rod that passes through the pole. The jaws close automatically and the sampler is withdrawn. The sample is treated in the same way as that for the dredge. Part of the sample is sometimes lost when small stones are caught between the jaws or fine particles (2–3 mm) lodge between the side of the box and the jaws and jam the jaws. When this happens the whole sample must be discarded. If the bottom is too stony (stones >16 mm) another sampler must be used.

5.3 The weighted Ponar grab is suitable for qualitative and quantitative use on mud and fine gravel with small stones not exceeding 16 mm long (Elliott & Drake 1981a). It may perform better than the Birge-Ekman grab on stones but the sample size is considerably larger (3–10 times) and therefore sorting time is greatly increased. The jaws are opened and kept apart by a cross-bar while the grab is suspended from its rope. The grab is lowered slowly to the bottom and the tension released in the rope. This allows the cross-bar to fall and the jaws close when the grab is hauled up. As the digging action of the grab depends upon its own weight, the grab must be hauled up slowly whilst the jaws are closing. The sample is treated as before, taking care to inspect the inside of the jaws when the grab is emptied. Samples must be discarded when the jaws are jammed open by stones or twigs. The unweighted Ponar grab (13.5 kg) is suitable for mud and is easier to handle, but the weighted version is superior on other substrata.

5.4 The FBA air-lift sampler may be used to obtain quantitative samples on substrata ranging from fine gravel to stones up to about 13 cm long, but is not recommended on mud (Drake & Elliott 1983. Drake, Winstanley, Ohnstad and Elliott 1984). Although the sampler will operate on a substratum that contains very large stones (see Table 1), it will not lift such stones nor remove the animals firmly attached to them.

The sampler is lowered to the bottom with the length of the riser adjusted so that the head above water is no higher than 30 cm. The riser is held by the catches in the raised position whilst it is being lowered. The cylinder is pushed into the bottom until the stop flange is reached (10 cm) by pressing down on the top of the sampler and rotating it back and forth by a few centimetres. The catches are then released, allowing the riser to slide freely, although it will not drop because it is now level with the substratum. A net is placed over the outlet of the riser and the air turned. on. The duration and amount of air used will depend upon the depth of water and the type of substratum; recommended values can be estimated from Fig 2. The sampler must be kept vertical during operation. The sample is treated as described previously. The sampler digs a vertically-sided hole with a saucer-shaped base and therefore the sample is biased only against animals living deeper than 8–10 cm.

If it is impractical to push the sampler into the substratum from the boat, it may be used quantitatively in the following less accurate but nevertheless adequate mode on stones up to 2 cm long. A 10–cm extension is fitted to the lower end of the riser. The sampler is lowered to the bottom and the catches are released without pushing the sampler into the substratum. The net is positioned and the air turned on as before. The cylinder will slowly vibrate itself into the bottom but because the sample is not totally enclosed, material is drawn into the sampling area under the descending cylinder. The profile of the hole is more conical than that produced using the method described in the previous paragraph, and the inaccuracy increases with increasing stone size.

Whichever mode is used, on fine sandy gravels, the riser sinks to its full depth (10 cm) very rapidly (within 5 s), and the vibrator must not be used because it compacts the sediment which restricts the flow of water to the riser. Under these conditions, the sampling area is excavated more rapidly if the operator takes the weight of the riser to prevent it sinking into the fine substratum and becoming blocked.

5.5 Collecting nets for all samplers

The purpose of sampling will determine the mesh size of the collecting nets of the dredge and air-lift sampler and of the sieve used when decanting all samples. Fine nets clog quickly and this can be reduced by increasing the size of the net. A large net is especially necessary for the air-lift sampler which pumps large volumes of water. Recommended sizes of meshes are given in Table 2.

6 Some aspects of sampling strategies

6.1 Qualitative sampling

The number of species or taxa taken in the samples usually increases as the size of the catch increases and the relationship often follows a power law (Fig 3). As the number of species is therefore related to the size of the sample, a representative species list may be obtained by taking many small sampling units or a few large units, assuming that all samplers catch all taxa with equal efficiency. Thus, many samples taken with the Birge-Ekman grab will give a similar result as a few hauls with the large Naturalist's dredge. The smaller sampler may be preferable in a heterogenous habitat because more widely spaced points may be sampled for the same total sample size. It is also difficult to compare the species richness or diversity of samples unless similar numbers of animals are taken in each sample. For example, a single Birge-Ekman sample may contain 100 animals in 13 species and a single sample taken with a dredge may contain 1000 animals in 22 species, both samples being taken from the same habitat.

6.2 Quantitative sampling

Three factors influence the number of sampling units required for quantitative sampling: the desired precision, the mean catch, and the amount of clumping of the invertebrates. The number of sampling units required for different combinations of these variables is given in Table 3 (from Elliott and Drake 1981a). The values of the constants a and b are obtained from Taylor's power law (Taylor 1961, Elliott 1977) using the means and variances of several samples. This requires that several samples are obtained from the site before the table can be used. The values in Table 3 are for the constant a = 1; if a = 1m then these values are multiplied by a to obtain the correct value. Exact values may be obtained using the equation

$$n = t^2\ a\ \bar{x}^{(b-2)}\ D^{-2} \qquad (1)$$

$$\text{or, } \log n = 2 \log t + \log a + (b-2)\ .\ \log \bar{x} + \frac{1}{2 \log D} \qquad (2)$$

where a and b are constants, n = number of sampling units, t = student's t, $\bar{x}$ = mean catch, and D = index of precision, ie 95% confidence limits expressed as a fraction of the mean.

The constant b also serves as an index of clumping. For most populations, b lies between 1 and 2, and for these populations, more sampling units are needed if the mean catch is low or the desired precision is high. For example, to estimate a population density with 95% confidence limits within 40% of the mean (D = 0.4), and preliminary samples gave mean catches ($\bar{x}$) of about 5 individuals per sampling unit and an index of clumping (b) of 1.5, then 13 sampling units would be required in future samples (Table 3). For populations with b = 2, only the precision influences the number of sampling units, and for b >2, the effect of increasing density is opposite to that for lower b–values and high precision is practically impossible for dense populations.

These methods are applicable not only to single species populations, but also to total populations of all species combined.

6.3 Accuracy and precision

Accuracy refers to the difference between the mean density of invertebrates calculated from samples and the actual density on the river bed. Precision refers to the reproducibility of the result for the same population and is often quoted as the coefficient of variation (CV) which is the standard deviation(s) expressed as a percentage of the sample mean (CV = 100 s / x). As this coefficient frequently increases with increasing mean density (Elliott and Drake 1981 a), it cannot be used as a basis for comparing the performance of samplers. Table 4 shows the accuracies of the two grabs and air-lift sampler on different sizes of substrata on which the actual density was known, using a laboratory experiment (Elliott and Drake 1981a, Drake and Elliott 1983).

7 Methods of analysis

Planning of sampling strategies and the statistical analysis of the results are covered in detail in several books. Elliott (1977) gives useful methods for the analysis of samples from non-normally distributed populations and Hellawell (1978) summarizes many biotic indices. Both books deal with sampling strategies (see also Southwood 1978, Green 1979).

8 Safety

When carrying out sampling procedures described in this publication, precautions laid down or recommended in 'Working on or near water', Water Authority Association, Safety Advisory Broadsheet, must be followed; furthermore, a general note on safety is given at the beginning of this booklet but as sampling from a small boat is potentially hazardous, the following additional precautions are recommended.

8.1 Inform someone of the time and locality visited and report when home.

8.2 Life jackets of the right size must be worn.

8.3 Carry oars if the boat is powered.

8.4 Carry a bailer.

8.5 Have anchors ready for use.

8.6 Know the navigation rules of waterways.

8.7 Rivers may be polluted with chemicals, pathogens etc. An anti-tetanus injection is recommended and injuries should be treated as soon as possible.

8.8 The usual precautions must be taken when using compressed air (see, eg "Safety Precautions in Laboratories" Medical Research Council, London 1973; Braker W and Mossman A L 1980 "Matheson Gas Data Book", Lyndhurst USA 6th ed.; "Safe Handling and Storage of Compressed Gases" BOC data sheet). A pressure regulator must be used on the compressed air cylinder for the air-lift sampler. In an unregulated system, blockages in the air-line (eg produced by kinking) may cause the pipe to burst and injure the operator. Pressure pipe must be used for the air-supply to the vibrator (see section 4.5) and nylon-reinforced hose for the low pressure supply to the riser. Although the latter will withstand pressures in excess of that recommended for the vibrator, it will experience such pressures only if blocked, and normally it operates at 35000 Pa.

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Table 1. Summary of qualitative and quantitative samplers that are suitable for different types of substrata in deep rivers.

The + indicates that a sampler can be used on a particular substratum, and F indicates that samplers sometimes fail for various reasons, e.g. grabs not closing properly, dredges being inefficient The air-lift samplers are used at an air-flow >200 l. min-¹.

Substratum	Mud	Fine gravel	Fine gravel+ small stones	Small stones	Large stones	Very large stones
Modal particle size (mm)	0.1	0.5–4	0.5–4 + 16–32	16–23	64–128	128–256+
Qualitative samplers						
Van Veen grab	+	+	+F			
Ponar grab	+	+	+F			
Weighted Ponar grab	+	+	+			
Birge-Ekman grab (pole-operated)	+	+F				
Allan grab (pole-operated)	+					
Dietz la Fond grab	Not recommended					
Friedinger grab	Not recommended					
Large Naturalist's dredge		+	+	+	+	+F
Medium Naturalist's dredge		+	+	+	+	+
Irish dredge (very large no. of samples)		+	+	+	+	+F
Fast dredge (large no. of samples)				+	+	+F
Mackey air-lift	+	+	+	+		
Pearson *et al.* air-lift	+	+	+	+		
Verollet & Tachet air-lift	Not recommended					
FBA air-lift		+	+	+	+	+?
Quantitative samplers						
Ponar grab	+	+				
Weighted Ponar grab	+	+	+			
Birge-Ekman grab (pole-operated)	+	+F				
Allan grab (pole-operated)	+					
Pearson *et al.* air-lift	+	+	+	+		
FBA air-lift		+	+	+	+	+?
Other samplers not quantitative						

Table 2. Recommended net mesh sizes

Survey Objective	Mesh Threads per cm	Maximum Aperture Size	Comments
General Biological Surveillance: Data from Surveys using Biotic Indicies	8	950 m	May not capture first instars of some insects
Surveillance with more complete records	12	610 m	More likely to capture first instars
Special Surveys requiring data in complete detail	24	265 m	Ensures capture of first instars and other very small organisms which may prove of value in water quality determination.

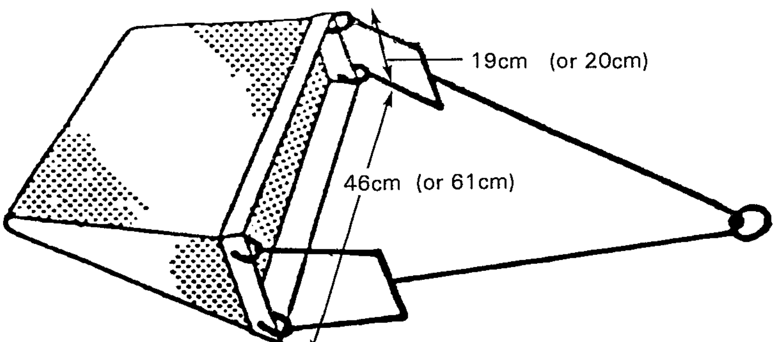
Table 3. The number (n) of sampling units per sample required for different levels of precision (95% confidence limits expressed as a percentage of the sample mean), for different values of the sample arithmetic mean ($\bar{x}$) (NB $\bar{x}$ is the mean number per sample, not mean number m^{-2}), and for diferent values of b in equation (1), the value of t was 2 for n >25 but more exact values were used for n < 25. The value of a in equation (1) is assumed to be one for this table but if a ≠ 1, then multiply the appropriate value of n by a to obtain the correct estimate of n.

Precision of sample (100 D)	0.5	1	5	10	20	50	100	1000	Index of clumping (b)
					Values of n				
10%	800	400	80	40	22	10	6	1	
20%	200	100	22	12	7	3	1	1	For radom
40%	50	26	7	4	1	1	1	1	distribution
60%	24	13	3	1	1	1	1	1	b = 1
80%	14	8	1	1	1	1	1	1	
100%	10	6	1	1	1	1	1	1	
10%	566	400	178	126	90	56	40	15	
20%	140	100	45	32	24	16	12	5	
40%	35	26	13	10	8	6	5	1	some clumping
60%	17	13	7	5	4	2	1	1	b = 1.5
80%	11	8	5	3	2	1	1	1	
100%	8	6	2	2	1	1	1	1	
10%	400	400	400	400	400	400	400	400	
20%	100	100	100	100	100	100	100	100	Clumped b = 2
40%	26	26	26	26	26	26	26	26	data follow
60%	13	13	13	13	13	13	13	13	log normal
80%	8	8	8	8	8	8	8	8	
100%	6	6	6	6	6	6	6	6	
10%	283	400	894	1265	1789	2828	4000	12649	
20%	70	100	224	316	447	707	1000	3162	
40%	19	26	56	79	112	177	250	791	Very clumped
60%	10	13	26	35	50	79	111	351	b = 2.5
80%	6	8	14	20	28	44	63	198	
100%	4	6	9	13	18	28	40	126	

Table 4. Accuracy (%) of capture of artificial invertebrates in a laboratory tank using three samplers on different sizes of substrata. Values are for the recommended operating levels for the air-lift sampler.

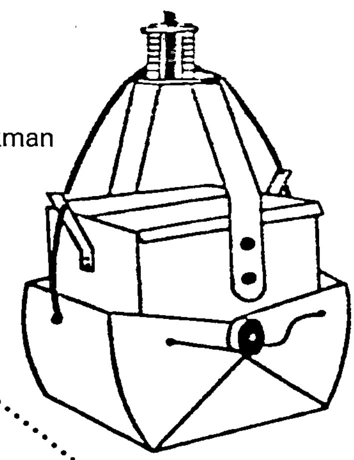
	Modal stone size (mm)				
	2–4	8–16	16–20	16–32	32–36
Birge-Ekman grab	54	19	–	11	–
Ponar grab (weighted)	94	75	–	11	–
Air-lift sampler	98	–	95	–	86

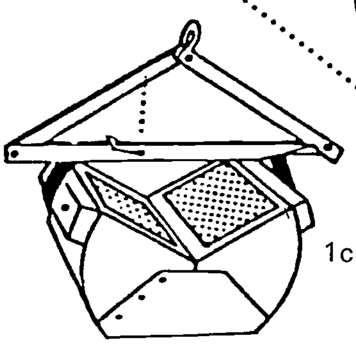
Figure 1 TYPICAL SAMPLING DEVICES



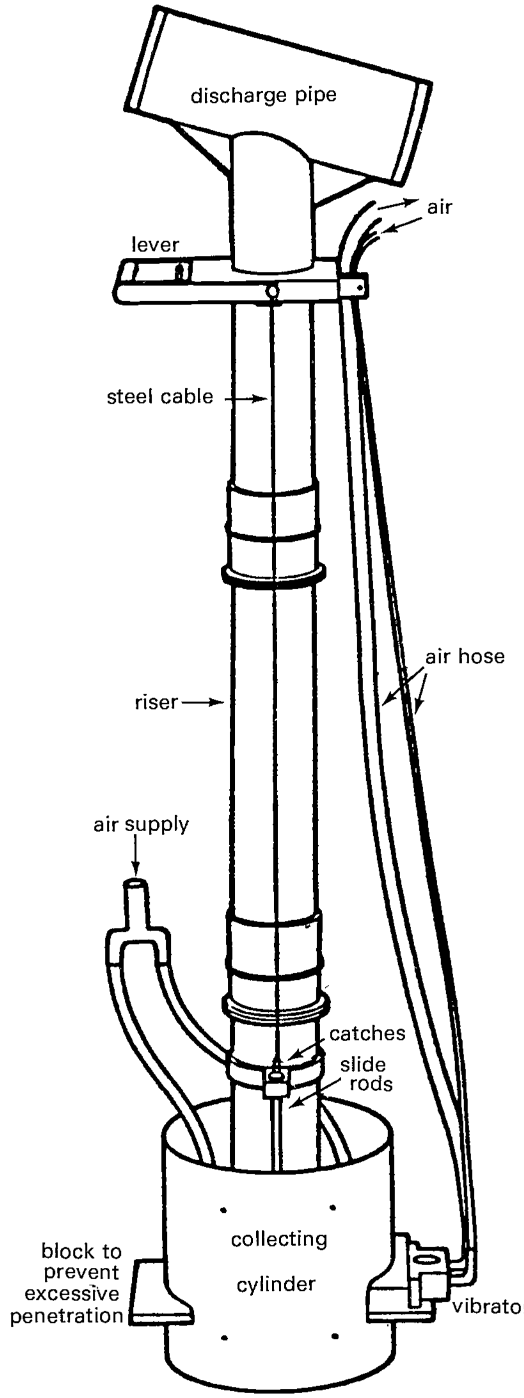
1a Naturalists Dredge

1b Birge-Ekman

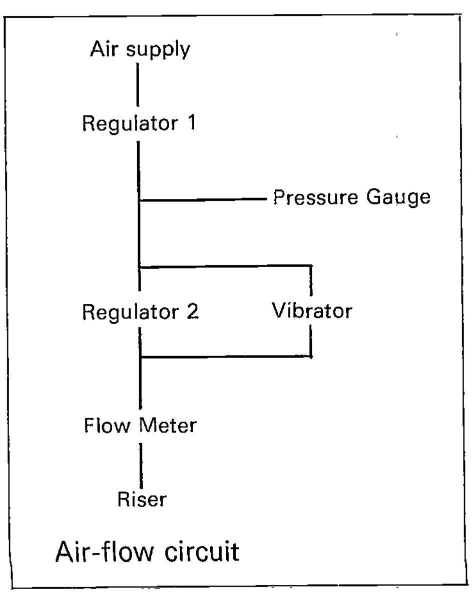




1c Ponar



1d FBA Air-lift sampler



Cut-away section

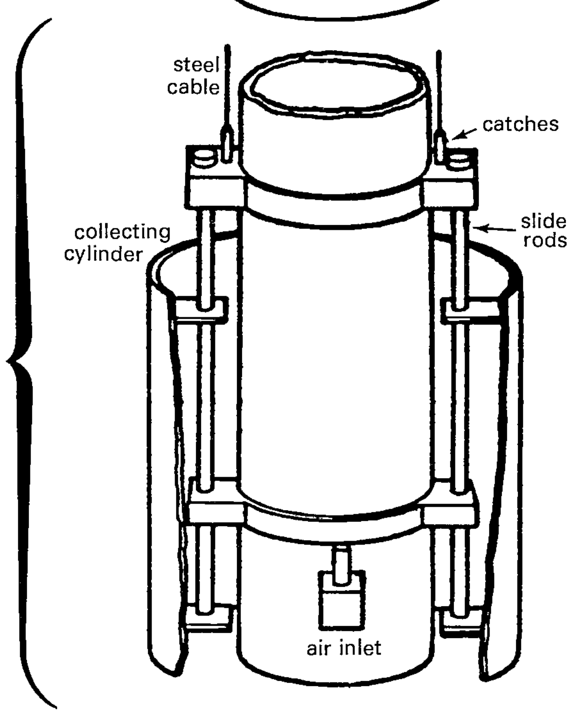


FIGURE 2 ESTIMATING THE MINIMUM AIR-FLOW REQUIRED TO LIFT STONES

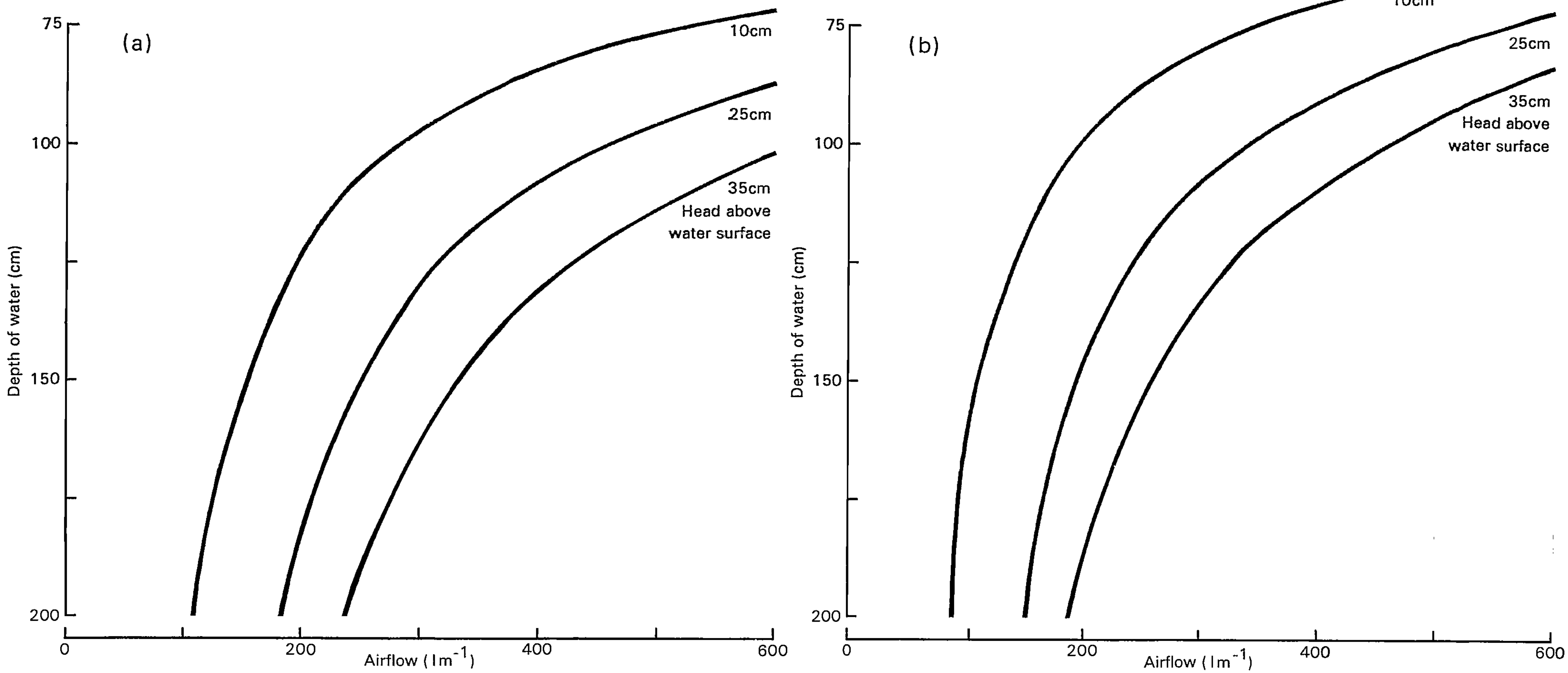
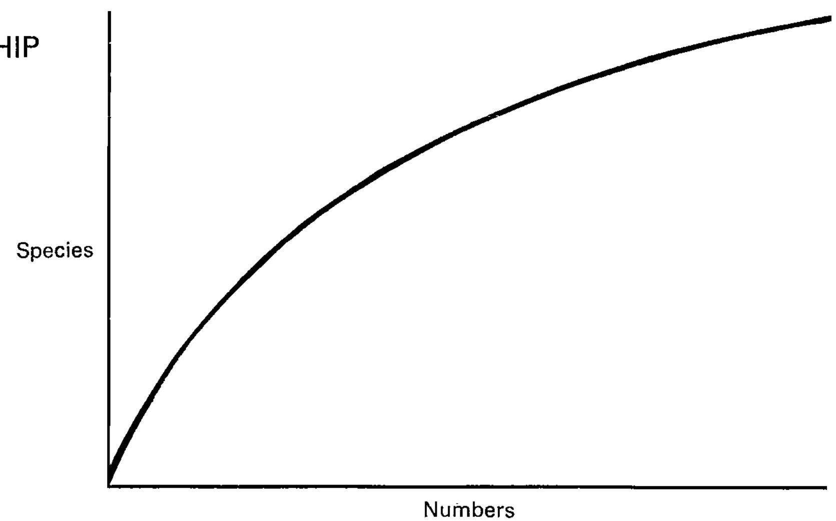


FIGURE 3 TYPICAL RELATIONSHIP BETWEEN NUMBER OF SPECIES FOUND AND CATCH SIZE



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