THE CHOICE OF A SUITABLE SAMPLER FOR BENTHIC MACROINVERTEBRATES IN DEEP RIVERS

by

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INTRODUCTION

Both chemical and biological methods are used to assess the water quality of rivers. Many standard physical and chemical methods are now established, but biological procedures of comparable accuracy and versatility are still lacking. This is unfortunate because the biological assessment of water quality has several advantages over physical and chemical analyses. The latter analyses are valuable and give some indication of the quality of the water for living organisms, but it is obviously preferable to study the living organisms themselves. Physical and chemical conditions in rivers may fluctuate and single samples may be misleading, especially if they are taken at regular but large intervals of time. Continuous recorders will overcome this problem but their use will be probably restricted to a small number of variables. The most useful continuous recorders are the living organisms in the river and these may be used to detect environmental changes, including changes in water quality. The level of change that can be detected will depend upon many variables, including the type of organism, the sampling strategy, the data analysis, and ultimately the natural variation in the composition, numbers and biomass of the organisms used for water-quality monitoring.

Several groups of organisms have been used to assess water quality in rivers and these include Bacteria, Protozoa, Algae, macrophytes, macroinvertebrates and fish. Hellawell (1978) provides an excellent review of the advantages and disadvantages of these groups, and concludes that macroinvertebrates are the most useful for monitoring water quality. The advantages of macroinvertebrates are that many can be identified to species, at least in the British Isles; that they are useful for the integration of pollution effects, especially those species that have a life cycle of about one year or longer; and that they show a wide range of forms and habits so that the invertebrate community as a whole is likely to be a sensitive indicator. There are also some disadvantages! Macroinvertebrates can migrate upstream or drift downstream, and some adult insects can fly between sites and then return to the water or lay their eggs. Therefore some species may occasionally occur in places where they are only temporary residents because they are unable to maintain themselves permanently. Some species may be normally present at a site but may be absent from samples because they are in the egg stage, or are too small to be caught by the sampler, or are insects that have left the water as adults or pupae. Therefore the presence or absence of different species in samples must always be treated with caution and cannot be regarded as definitive for a particular set of conditions.

Although macroinvertebrates are relatively easy to sample in shallow water (depth < 1m), quantitative sampling poses more problems than qualitative sampling because a large number of replicate sampling units are usually required for accurate estimates of numbers or biomass per unit area. Both qualitative and quantitative sampling are difficult in deep water (depth > 1m). The present paper first considers different types of samplers with emphasis on immediate samplers, and then discusses some problems in choosing a suitable sampler for benthic macroinvertebrates in deep rivers.

SAMPLERS FOR MACROINVERTEBRATES

Macroinvertebrates are defined as invertebrates that are retained by a net or sieve with an aperture of 0.6 mm. A larger aperture of 0.95 mm is sometimes used in routine biological surveillance but this will not retain the early instars of some aquatic insects. A smaller aperture of about 0.25 mm may be necessary for special purposes, eg to ensure the capture of early instars. Several workers have reviewed their selections of samplers for macroinvertebrates in freshwater (APHA 1976; Brinkhurst 1967, 1974; Cummins 1962; Edmondson and Winberg 1971; Hellawell 1978; Lamotte and Bourliere 1971; Macan 1958; Mason 1977; Schwoerbel 1970; Slack et al. 1973; Sly 1969; Southwood 1966; Weber 1973; Welch 1948; Zhadin 1956, 1960). As some marine samplers can be also used in freshwater, reviews of marine samplers are also useful (eg Bouma 1969; Hedgpeth 1957; Holme 1964; Holme and McIntyre 1971; Hopkins 1964; Hough 1939). Samplers for macroinvertebrates can be divided into three broad categories: traps, colonisation samplers and immediate samplers (Figure 1). The first and second of these categories correspond to the 'passive' sampling methods in the scheme used by Hellawell (1978) whilst immediate samplers are the same as his 'active' sampling methods.

Traps can be used to catch invertebrates that are attracted to a light underwater (Espinosa and Clark 1972; Hungerford et al. 1955; Pieczynski 1962; Washino and Hokama 1968), or are drifting downstream with the current (see review by Elliott 1970), or are moving upstream against the current (Bishop and Hynes 1969; Elliott 1971; Hultin 1968; Lehmann 1967; Muller 1966; Waters 1965), or are adult insects and pupae that are emerging from the water (see reviews by Mundie 1956, and by Mundie and Morgan in Edmondson and Winberg 1971). As the activity patterns of most benthic invertebrates usually follow a diel rhythm, samples with traps have to be taken over at least one 24-hour period. The traps are usually highly selective; some invertebrates are not attracted to a light, some invertebrates drift downstream or move upstream more readily than others, and some emerging insects crawl up the banks and are not taken in emergence traps. In spite of these problems, Besch (1966) has suggested that drift samples may be useful for surveys, especially in deep rivers. Wilson and his co-workers (Wilson 1977; Wilson and Bright 1973; Wilson and McGill 1977) used drift samplers to catch the pupal exuviae of Chironomidae and have proposed that these may be used to determine the species present and hence the water quality at a particular site. Therefore traps may be used for special studies, but their selectivity will probably preclude their general use in biological surveillance.

Colonisation samplers are frequently called artificial-substrate samplers, but the latter name is slightly misleading because some of these samplers use natural substrata on a tray or in a perforated container. A wide range of samplers has been described and new designs or modifications frequently appear in the literature (see reviews of Beak et al. 1973; Hellawell 1978; Khalaf and Tachet 1978). The chief advantage of colonisation samplers is that they may provide fairly comparable samples from sites which may be difficult to sample by other means. Their chief disadvantage is that they frequently provide a habitat which is atypical of that occurring naturally. Therefore the sample will rarely provide a true picture of the macroinvertebrates occurring at a site. The magnitude of this discrepancy depends upon the type of sampler used. Most workers agree that colonisation samplers cannot be used to provide estimates of numbers or biomass per unit area of natural substratum. Several workers have found that some samplers provide a list of species present at a site and even some indication of relative abundance, but other workers do not agree with these conclusions. One additional problem with colonisation samplers is that they have to be left in position at a site for several days or even weeks, and this inevitably increases the risk of removal or damage by floods, drought or man. Therefore more comparative work is needed before the relative efficiencies of different colonisation samplers can be assessed. Some samplers, especially those embedded in the bottom of the river, will probably provide limited lists of species and perhaps an indication of relative abundance, but they will rarely provide estimates of population density or biomass.

Immediate samplers are used for the rapid removal of benthic macroinvertebrates from the natural substrata of rivers. The literature on these samplers has been listed in an annotated bibliography that includes not only freshwater samplers but also marine samplers that have been, or could be, used in freshwater (Elliott and Tullett 1978). References are divided into five major categories, according to the type of sampler, and are also classified according to the water depth in which the sampler can be operated, the type of substratum on which the sampler can be used, and whether the sampler was originally designed for marine or freshwater sampling (Table 1). This classification is based on the information given in the references and is assumed to be correct! Table 1 therefore provides a useful summary of the samplers available for different substrata in shallow streams and rivers (depth < 1m), and in deep rivers (depth > 1m). Samplers in the five major categories will now be briefly considered (as the original references are given in Elliott and Tullett 1978), they will not be repeated here).

Most of the nets and quadrat samplers in the first category are relatively simple devices that can be used in only shallow water. The three deep-water samplers that can be operated from above the water surface were all designed for sampling macrophytes or invertebrates on macrophytes, and are not suitable for more solid substrata. The diver-operated samplers in the first category are very simple square quadrat or cylindrical samplers that can be used in deep rivers if the diver can see underwater and maintain a fixed position on the bottom whilst the sampler is being used.

The second major group in Table 1 includes samplers that scoop sediment with a rotating container. Scoops have been used chiefly to sample a muddy substratum and the three scoops used to sample coarser marine sediments are all too heavy for use in deep rivers unless a large boat with a power winch is available, eg a Shipek scoop weighs about 70 kg, a Holme scoop is usually weighted to about 110 kg and a Holme double-scoop weighs about 115 kg. Shovels and dredges are also included in group 2. The nine shovel samplers are pushed through the substratum for a fixed distance, and were originally designed to sample a stony substratum in shallow water. These samplers are not therefore suitable for deep rivers. Dredges are dragged across the bottom and dig into the substratum. Some marine dredges are stated to be quantitative, but dredges are suitable only for qualitative sampling in streams and rivers, and will not provide estimates of population density or biomass. Some marine dredges are too heavy for use in freshwater unless a powerful boat is available to drag the dredge over the bottom. Three dredges that may be suitable for qualitative sampling in streams and rivers are illustrated in Figure 2 and will soon be tested by this laboratory. We have two sizes of the Naturalist's dredge (weight about 9 kg and 16 kg), a small Fast dredge (about 15 kg) and an Irish triangular dredge (about 2 kg).

Corers are tubes that are driven vertically into the sediment. More corers have been designed than any other type of sampler (see group 3 in Table 1), but most corers are suitable only for a muddy substratum. The six small-diameter corers than can be used on stony bottoms are all narrow tubes (diameter < 3 cm) that are driven into the substratum to sample the interstitial and hyporheal fauna of shallow streams. Many of the other small-diameter corers can be used in deep rivers if there is a thick layer of mud on the bottom. Such a substratum is usually restricted to the lower reaches of rivers. In other sections of the river, the bottom may appear to be muddy, but the mud may be only a thin layer over stones and therefore a corer cannot be used. As small-diameter corers have a small sampling area, a large number of replicate sampling units have to be taken for both qualitative and quantitative sampling of macroinvertebrates. It is therefore preferable to use a large-diameter (> 10 cm) corer or a multiple corer. Most of the marine large-diameter corers are too heavy to be used in freshwater unless a large boat with a power winch is available. Multiple-tube versions appear to be the most suitable corers for sampling macroinvertebrates in mud, but it must be remembered that the replicate sampling units are not strictly independent. This may affect the statistical analysis of the results unless some preliminary sampling has been performed to determine the possible bias of the sampler. Four diver-operated corers have been described; three are manual corers and one is a pneumatic corer. They can be used to sample the muddy substratum of deep rivers if the diver can maintain a fixed position on the bottom whilst the corer is being used.

Grabs are samplers with jaws that are forced shut by weights, lever arms, springs or cords. Many grabs are simply modifications of five basic types, Ekman (or Birge—Ekman), orange-peel, Petersen, Smith—McIntyre, Van-Veen (see group 4 in Table 1). Marine grabs are often too heavy for use in freshwater unless a large boat and power winch are available, eg a 'Campbell' version of a Petersen grab weighs 410 kg, an 'Okean' version of a Petersen grab weighs about 150 kg, a Smith—McIntyre grab weighs about 45 kg, a 'clamshell' bucket grab weighs about 135 kg. We have found that the weight of an empty grab must be less than 25 kg if the grab is operated manually from a small boat. Therefore the larger Petersen grab (Figure 3) with a weight well above 25 kg was too heavy, but the Friedinger version is lighter (weight about 11 kg) and may be suitable for sampling in streams and rivers. The Friedinger grab and the other grabs illustrated in Figure 3 are now being tested by this laboratory. The Petersen grab has weighted jaws but in the Friedinger version these jaws are also closed by wires that cross from one jaw to the other. Larger and smaller versions of the Friedinger grab have sampling areas of 0.083 m^2 and 0.030 m^2 respectively and weigh 11 kg and 8 kg respectively. A Birge—Ekman grab was included in the selection because it has been used frequently in freshwater. As this grab is quite light (weight 7 kg, sampling area 0.023 m^2), a pole-operated version was chosen and can be used in water up to 3 m deep. A second pole-operated grab, the Allan grab (weight 8 kg, sampling area 0.035 m^2), was also chosen and can be used to a depth of 3.3 m. Whilst the jaws of an Ekman grab are closed by strong springs, those of an Allan grab are closed by a manually operated rod and levers. The Dietz—La Fond grab was chosen from the range of 'mud—snappers' that are foot-triggered grabs with the jaws closed by a powerful spring. Although this grab is one of the largest and heaviest of the 'mud-snappers', it still samples from a very small area of bottom (weight 21.5 kg, sampling area 0.016 m^2). A Van-Veen grab was chosen because it is a popular marine sampler. The jaws are closed by the pincer-like action of two long arms (weight 21 kg up to 38 kg with additional weights, sampling area 0.1 m^2). Finally, a Ponar grab was chosen because it has proved to be an efficient sampler for lake benthos. The jaws are closed by the scissor-like action of two pivoted arms (weight 13.6 kg up to 22.6 kg with additional weights, sampling area 0.055 m^2). These six samplers are thought to be representative of the wide range of grabs that have been described, but their relative performance cannot be assessed until they have been tested in a series of trials on different substrata.

Suction and air-lift samplers form the final group of samplers in Table 1. The seven mud suckers take a very small sample, and are suitable only for microinvertebrates. Hydraulic suction samplers use pumped water, often through a venturi tube, to suck the sample up a large tube. Air-lift samplers use air under pressure to lift a sample from the substratum up a large tube and into a collecting net. The diver-operated samplers include portable hydraulic suction samplers, portable air-lift samplers, and hand suckers that are used to remove animals from a defined area of bottom which must be disturbed by hand. A diver must be able to maintain a fixed position on the bottom and to see underwater, especially when using a hand sucker. Apart from these diver-operated samplers, the air-lifts appear to be potentially the most useful for sampling in deep rivers. Two air-lift samplers, originally designed by Mackey and Pearson, Litterick and Jones, are now being tested by this laboratory. Mackey's sampler is basically a tube (diameter 8 cm, sampling area 0.005 m^2) that is pushed into the substratum. The action of the air-lift removes the lighter material, including macroinvertebrates, from the substratum inside the tube and this material is deposited in a bag above the water (Figure 4). In the sampler designed by Pearson et al., a series of air jets open into a square box (sampling area 0.04 m^2) that is connected to a tube (diameter 5 cm) leading to a collecting bag above the water (Figure 4). We are not only testing these two samplers, but are also examining the variables in the basic design of an air-lift sampler and how these variables affect the efficiency of the sampler.

THE CHOICE OF A SAMPLER

Before choosing a sampler for macroinvertebrates, it is important to clearly define the objectives of the investigation because these will partially determine the type of sampler and the sampling strategy. The immediate objective of the sampling is usually one of the following:

1. to obtain a list of taxa for a site with few taxa identified to species (eg some Plecoptera and Ephemeroptera), and most taxa identified to only genus (eg **Nemoura, Baetis, Gammarus, Asellus**), or family (eg families of Trichoptera, Coleoptera and Diptera), or class (eg Oligochaeta, Hirudinea). The advantages of such a simple objective are that the sampling does not need to be very extensive and that relatively simple qualitative samplers can be used, eg pond nets in shallow water and dredges in deep water. The major disadvantage is that only a small proportion of the potential information in a sample is being used because major groups with a large number of species are not being identified to species. For example, there are about 200 species of Trichoptera and 450 species of Chironomidae, whilst there are only 34 species of Plecoptera and 47 species of Ephemeroptera in Britain. The Trichoptera and Chironomidae are usually identified to families, and even the Plecoptera and Ephemeroptera are frequently identified only to genera. Although the maximum information content of a sample is thus restricted to about 100 taxa, this approach is usually all that is required for the calculation of simple biotic indices.

2. to obtain a list of taxa with most taxa identified to species. This objective greatly increases the amount of potential information in a sample and therefore more complex biotic indices can be calculated. One disadvantage is that extensive qualitative sampling is required at each site to ensure that representatives of each species are caught. However, relatively simple qualitative samplers can still be used because no information on numbers is required. The major disadvantage of this objective is that it requires keys for the identification of macroinvertebrates, and these keys are not available for some of the most useful groups, eg Chironomidae and some families of Trichoptera. Therefore this objective remains unfulfilled at present chiefly because of a lack of keys rather than a lack of suitable qualitative samplers.

3. to obtain a list of taxa, preferably with most taxa identified to species, and some measure of their relative abundance. Qualitative samplers can still be used but it is often preferable to use quantitative methods because the sampling effort must be similar at each site. The extensiveness of the sampling is determined chiefly by the need to capture the rarer species at a

site rather than the estimates of relative abundance. When information on the relative abundance of different species is available, it is possible to calculate some community indices and biotic indices based on rank order or diversity (see Hellawell 1978). Therefore both qualitative and quantitative samplers may be used to fulfill this objective but a large number of replicate sampling units need not be taken at each site.

4. to obtain estimates of numbers or biomass per unit area for each species and all species combined. Only quantitative samplers can be used to fulfill this objective and a large number of replicate sampling units are usually required at each site. If the overall purpose of the investigation is to detect small changes in water quality, then quantitative sampling is essential. Regular quantitative sampling will also provide information on rates of growth, mortality and production. These rates may be useful in specialised studies on particular aspects of water quality, eg changes due to the eutrophication of rivers.

Objectives one to four are progressively more difficult to fulfil, because they demand a gradual but marked increase in both the taxonomic and sampling effort. The first and second objectives do not require quantitative samplers and therefore virtually any kind of sampling device can be used, provided that it will catch most of the taxa (objective 1) or species (objective 2) present at a site. Quantitative samplers may be often required for the third objective and are essential for the fourth objective. In shallow water, there is no major problem in choosing a sampler for any of the four major objectives and several suitable samplers are listed in Table 2. Qualitative sampling in deep water should not be a problem and a dredge is the obvious first choice. However, we still do not know how dredges perform on different substrata in rivers, and it is possible that samplers such as air-lifts may be more suitable for qualitative sampling on some substrata. Quantitative sampling in deep water poses major problems. Various samplers are listed in Table 2 with notes on their limitations. A muddy substratum is probably the easiest to sample and there is a choice of corers, grabs and air-lift samplers. Other substrata are more difficult to sample and the problems increase as the bottom becomes more stony. Diver-operated samplers may be a solution, but the problems of visibility underwater and station maintenance in fast-flowing rivers are not always easy to overcome. The safety aspects of diving require diving teams and therefore the cost of sampling will be high.

Therefore there is an urgent need for quantitative samplers that can be operated from above the water surface. A large number of problems in the scientific management of rivers require answers to quantitative questions, eg are there detectable changes in numbers, biomass, or rates of growth, mortality and production? These important questions cannot be answered by qualitative sampling and estimates of relative abundance (or "semi-quantitative" sampling as it is sometimes ambiguously called!). We are therefore testing selected dredges, grabs and air-lift samplers (Figures 2—4), on different substrata. When this work is completed, we should be able to describe the limitations and efficiencies of these samplers. This information should facilitate the choice of a sampler for different substrata, but may reveal that none of these samplers is suitable for some substrata in rivers. It would be wrong to claim that all the problems of sampling macroinvertebrates in rivers will be solved at the end of this three-year project. If the solutions were that simple, they would have been found several years ago! However, we hope to present objective criteria for the assessment and development of samplers, and to indicate where future work is required.

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Table 1. Summary of the literature on immediate samplers (references to the end of November 1977).

			Water depth		Substratum				Origin		Total
			< 1 m	> 1 m	Mud	Gravel	Stones	Plants	Marine	Freshwater	
1. Nets and quadrat samplers	1.1	Simple	32	3	3	21	21	15	2	33	35
	1.2	Diver operated		4	2	3	3	2	2	2	4
2. Scoops, shovels and dredges	2.1	Scoops	1	8	9	3			7	2	9
	2.2	Shovels	9			9	9			9	9
	2.3	Dredges	3	42	41	35	12	1	33	12	45
	2.4	Anchor dredges		6	6	6			6		6
3. Corers	3.1	Diameter < 10 cm	25	82	107	6	3		55	52	107
	3.2	Diameter ⩾ 10 cm	3	38	41	2			28	13	41
	3.3	Multiple		7	7				4	3	7
	3.4	Diver operated		4	4	1			1	3	4
4. Grabs	4.1	Ekman type		15	15	1			3	12	15
	4.2	Orange-peel type		5	5				4	1	5
	4.3	Petersen type		8	8				7	1	8
	4.4	Smith-McIntyre type		3	3	1			3		3
	4.5	Van-Veen type		5	5	2			5		5
	4.6	Other grabs	3	25	26	14		3	8	20	28
	4.7	Diver operated		1	1				1		1
5. Suction and air-lift samplers	5.1	Mud suckers		7	7				4	4	7
	5.2	Hydraulic suckers	1	7	8	6			7	1	8
	5.3	Air-lifts		4	4	4			2	2	4
	5.4	Diver operated		23	22	18	7	4	19	4	23

Table 2. Immediate samplers suitable for macroinvertebrates in streams and rivers.

1. **Shallow water** (depth <1 m)

1.1 **Qualitative**

Pond net

Dredge?

(+ samplers under 1.2)

1.2 **Quantitative**

Quadrat sampler (eg Surber, Hess-Waters, Neill cylinder)

Shovel sampler

Manual corer (chiefly suitable for mud, perhaps gravel and small stones).

2. **Deep water** (depth >1 m)

2.1 **Qualitative**

Dredge (limitations of substratum not known; further testing needed).

(+ samplers under 2.2)

2.2 **Quantitative**

Large diameter corer) (chiefly suitable
Multiple corer) for mud)

Grab (<25 kg unless large boat and power winch is available.

Smaller grabs chiefly suitable for mud, perhaps gravel and small stones; further testing needed).

Air-lift samplers (limitations of substratum unknown; further testing needed).

Diver operated:

a. quadrat and cylindrical samplers (if diver can see underwater and maintain position);

b. corers (suitable for mud only);

c. grab (modification of Birge-Ekman grab is only one available);

d. suction and air-lift samplers.

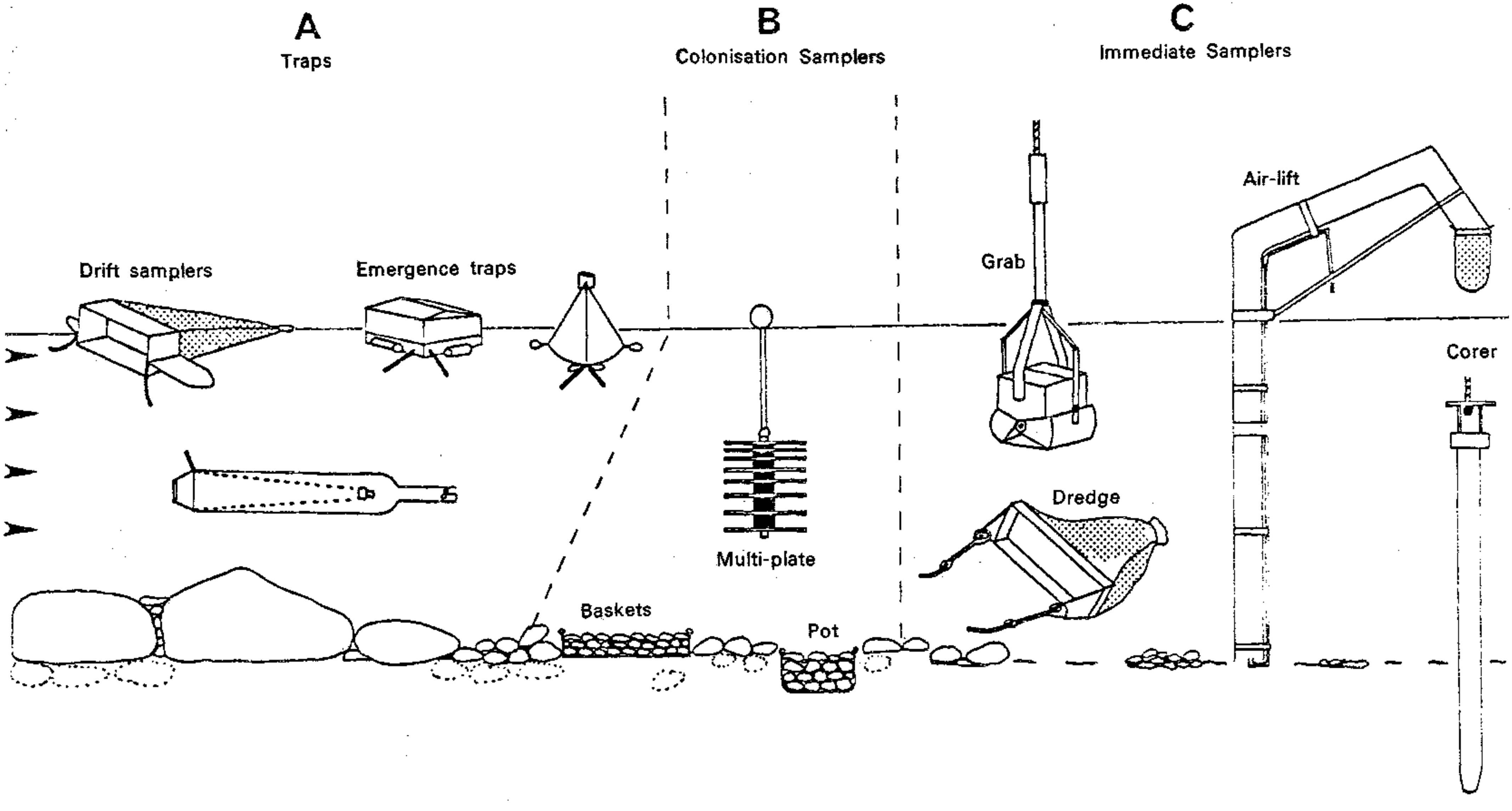
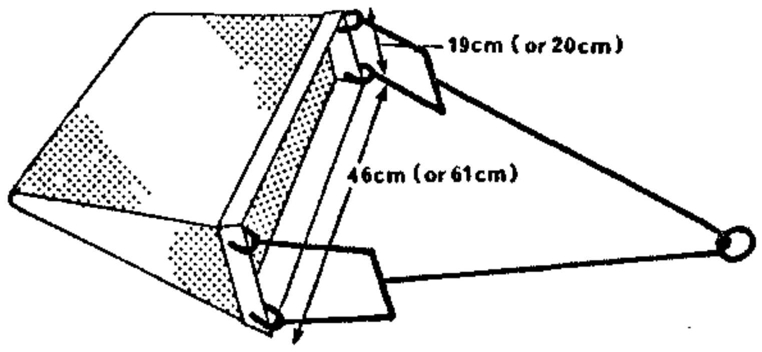
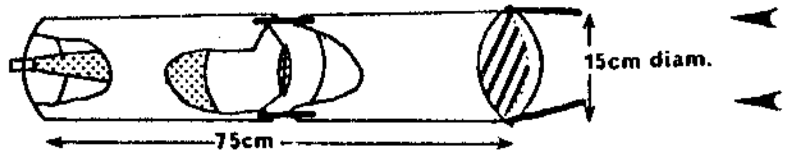


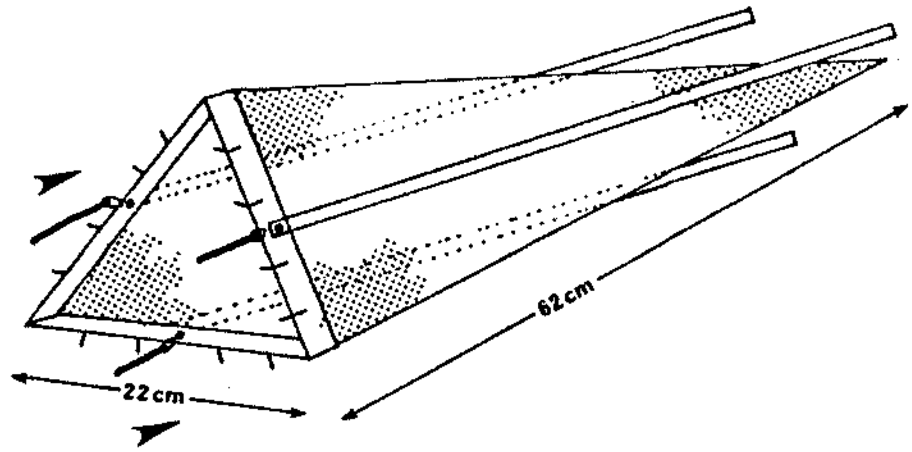
FIG.1 Samplers for macroinvertebrates



Naturalists Dredge



Fast Dredge



Irish Dredge

FIG.2 Dredges

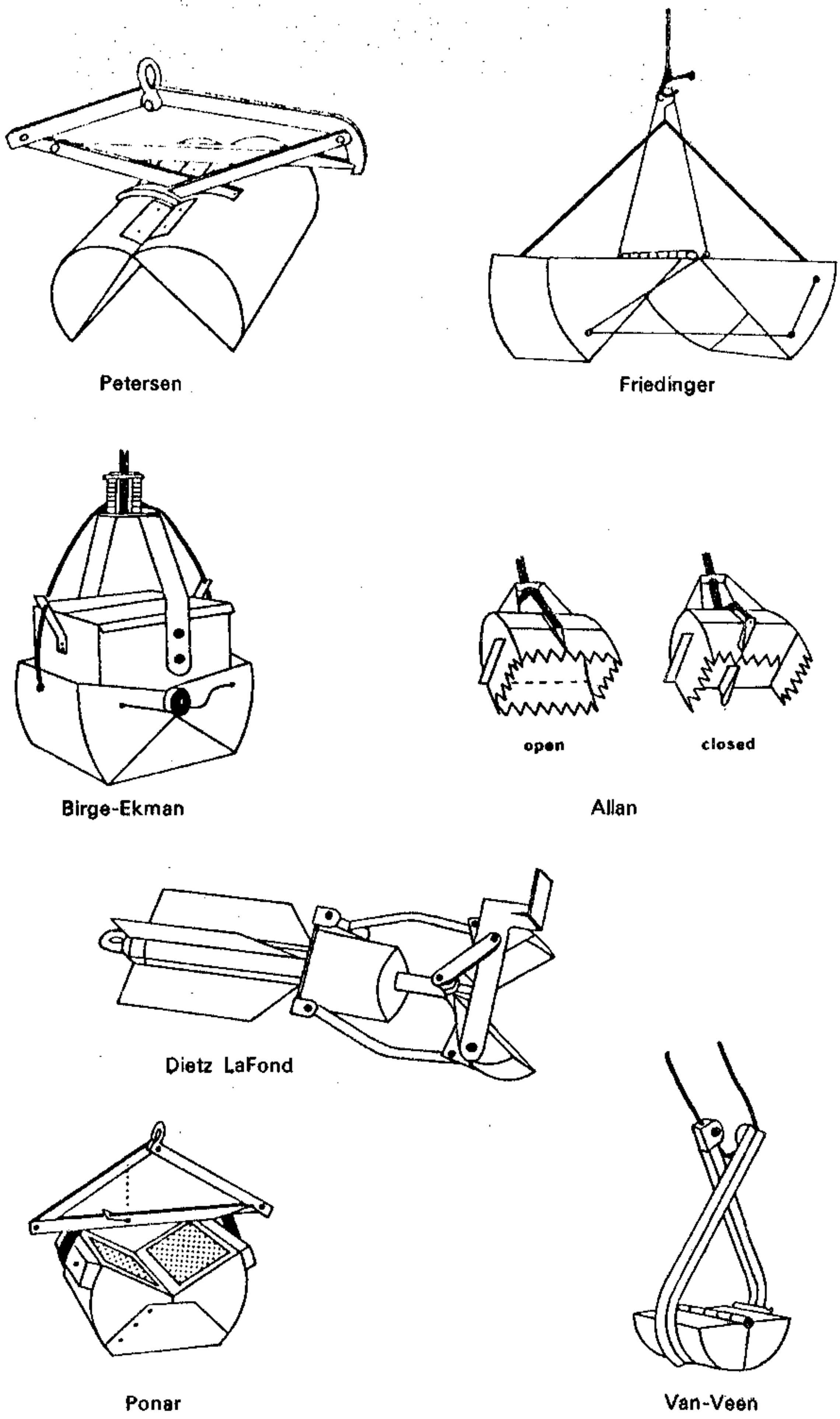
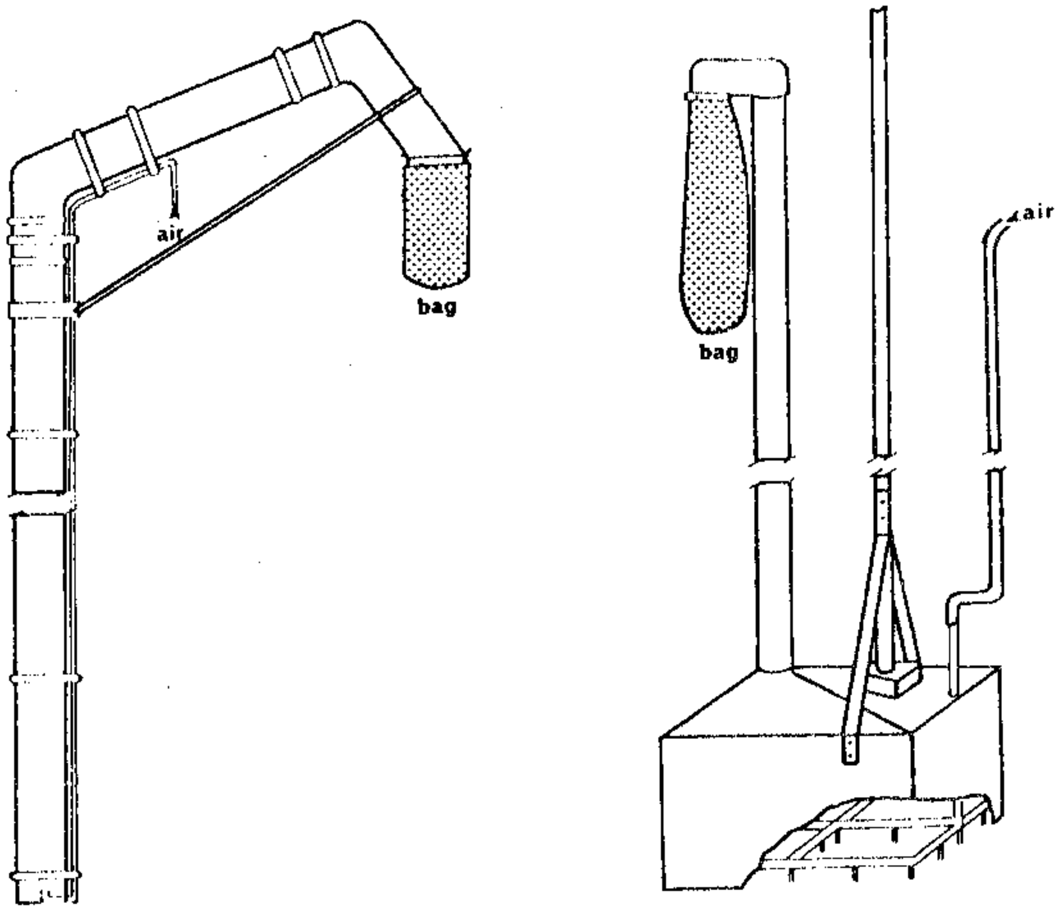

Petersen
Friedinger
Birge-Ekman
open
closed
Allan
Dietz LaFond
Ponar
Van-Veen

FIG.3 Grabs



Mackey

Pearson, Litterick & Jones

FIG.4 Air-lift samplers