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GRABS FOR SHELF BENTHIC SAMPLING

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Introduction

The sedimentary environment is theoretically one of the easiest to sample quantitatively and one of the most convenient ways to secure such samples is by means of grabs. Grab samplers are used for both faunal samples, when the grab contents are retained in their entirety and then sieved to remove the biota from the sediment, and for chemical/physical samples when a subsample is usually taken from the surface of the sediment obtained. In both cases the sampling program is reliant on the grab sampler taking consistent and relatively undisturbed sediment samples.

Conventional Grab Samplers

The forerunner of the grab samplers used today is the Petersen grab, designed by C.G.J. Petersen to conduct benthic faunal investigations in Danish fiords in the early part of the twentieth century. It consisted of two quadrant buckets that were held in an open position and lowered to the seabed (**Figure 1**). On the bottom, the relaxing of the tension on the lowering warp released the buckets and subsequent hauling caused them to close before they left the bottom. The instrument is still used today but is seriously limited in its range of usefulness, working efficiently only in very soft mud.

Petersen's grab formed the basis for the design of many that came after. One enduring example is the van Veen grab, a sampler that is in common use today (**Figure 2**). The main improvement over Petersen's design is the provision of long arms attached to the buckets to provide additional leverage to the closing action. The arms also provided a means by

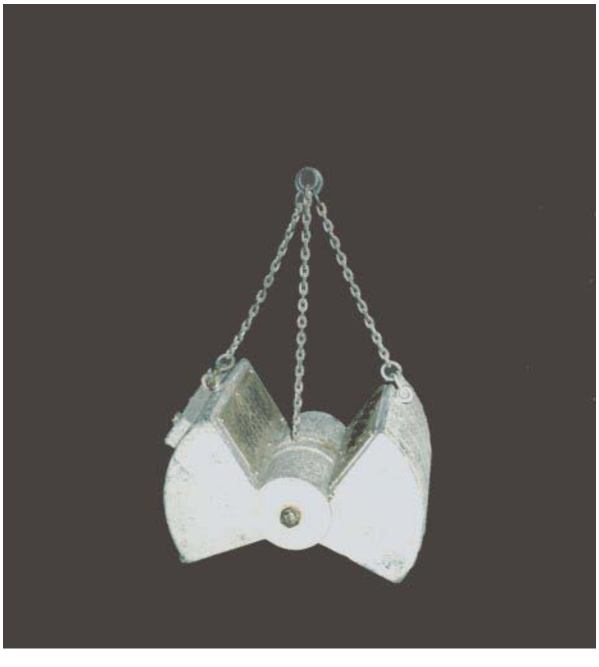

Figure 1 Petersen grab.

Figure 2 van Veen grab.

which the complex closing mechanism of the Petersen grab could be simplified with the hauling warp being attached to chains on the ends of the arms. The mechanical advantage of the long arms can be improved further by using an endless warp rig; this has the added advantage of helping to prevent the grab being jerked off the bottom if the ship rolls as the grab is closing. The van Veen grab was designed in 1933 and is still widely used in benthic infaunal studies owing to its simple design, robustness and digging efficiency. The van Veen grab typically covers a surface area of $0.1\,m^2$, although instruments of twice this size are sometimes used.

A more recent design of frameless grab is the Hunter grab (**Figure 3**). This is of a more compact design than the van Veen. The jaws are closed by levers attached to the buckets in a parallelogram configuration giving the mechanism a good overall mechanical advantage. The closing action requires no chains or pulleys and the instrument can be operated by one person. Its disadvantage is that the bucket design does not encourage good initial penetration of the sediment, which is important in hard-packed sediments.

A disadvantage of the grab samplers discussed so far is that there is little latitude for horizontal movement of the ship while the sample is being secured. The smallest amount of drift and the sampler is

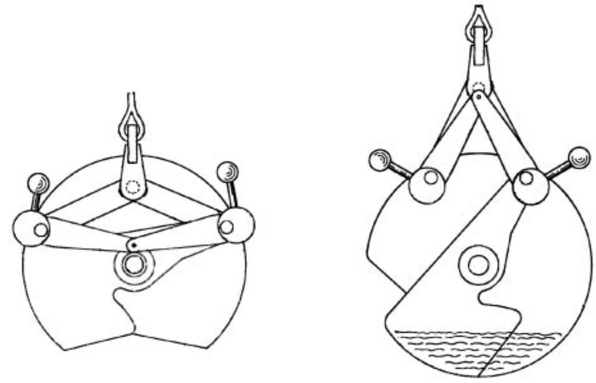

Figure 3 Diagram of a Hunter grab. Reproduced with permission from Hunter and Simpson (1976). A benthic grab designed for easy operation and durability. *Journal of the Marine Biological Association* 56: 951–957.

likely to be pulled over. The Smith–McIntyre grab was designed to reduce this problem by mounting the grab buckets in a stabilizing frame (**Figure 4**). Initial penetration of the leading edge of the buckets is assisted by the use of powerful springs and the buckets are closed by cables pulling on attached short arms in a similar way to that on the van Veen grab. The driving springs are released by two trigger plates one on either side of the supporting frame to ensure the sampler is resting flat on the sea bed before the sample is taken. In firm sand the Smith–McIntyre grab penetrates to about the same depth of sediment as the van Veen. Its main disad-

Figure 4 Smith–McIntyre grab.

Figure 5 Day grab.

vantage is the need to cock the spring mechanism on deck before deploying the sampler, a process that can be quite hazardous in rough weather.

The Day grab is a simplified form of the Smith–McIntyre instrument in which the trigger and closing mechanism remains the same, but without spring assistance for initial penetration of the buckets (**Figure 5**). The Day grab is widely used, particularly for monitoring work, despite its poor performance in hard-packed sandy sediments.

Most of the grabs thus far discussed have been designed to take samples with a surface area of $0.1\,m^2$ or $0.2\,m^2$. The Baird grab, however, takes samples of $0.5\,m^2$ by means of two inclined digging plates that are pulled together by tension on the warp (**Figure 6**). The grab is useful where a relatively large surface area needs to be covered, but has the disadvantage of taking a shallow bite and having the surface of the sample exposed while it is being hauled in.

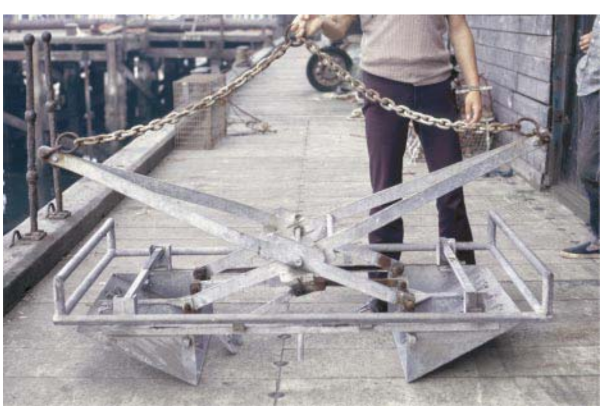

Figure 6 Baird grab.

Warp Activation

All the grabs described above use the warp acting against the weight of the sampler to close the jaws. However, direct contact with the vessel on the surface during the closure of the grab mechanism poses several problems.

Warp Heave

As tension is taken up by the warp to close the jaws, there is a tendency for the grab to be pulled up off the bottom resulting in a shallower bite than might be expected from the geometry of the sampler. This tendency is related to the total weight of the sampler and the speed of hauling and is exacerbated by firm sediments. For example, the theoretical maximum depth of bite of a 120 kg Day grab is 13 cm (based on direct measurements of the sampler), however, in medium sand, the digging performance is reduced to a maximum depth of only 8 cm (**Figure 7E**). The influence of warp action on the digging efficiency of a grab sampler can also depend on the way in which the sampler is rigged. This is particularly true of the van Veen grab. **Figure 7(B)** shows the bite profile of the chain-rigged sampler in which the end of each arm is directly connected to the warp by a chain. The vertical sides of the profile represent the initial penetration of the grab and the central rise the upward movement of the grab as the jaws close. **Figure 7(C)** shows the bite profile of a van Veen of similar size and weight (30 kg) rigged with an endless warp in which the arms are closed by a loop of wire passing through a block on the end of each arm (as in **Figure 2**). The vertical profile of the initial penetration is again apparent, however, in this case the overall depth of the sampler in the sediment is maintained as the jaws close. The endless warp rig increases the mechanical advantage of the pull of the warp while decreasing the speed at which the jaws are closed. The result is that the sampler is 'insulated' from surface conditions to a greater extent than when chain rigged giving a better digging efficiency.

Grab 'Bounce'

In calm sea conditions it is relatively easy to control the rate of warp heave and obtain at least some consistency in the volume of sediment secured. However, such conditions are seldom experienced in the open sea where it is more usual to encounter wave action. Few ships used in offshore benthic studies are fitted with winches with heave compensators so that the effect of ship's roll is to introduce an erratic motion to the warp. This may result in the grab 'bouncing' off the bottom where the ship

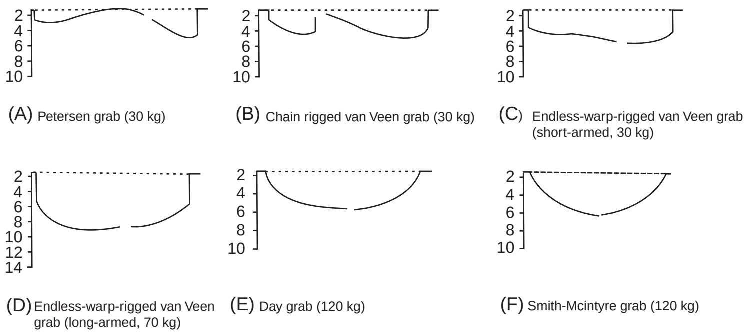

Figure 7 Digging profiles of a range of commonly used benthic grab samplers obtained in a test tank using a fine sand substratum. (A) Peterson grab (30 kg); (B) chain-rigged van Veen grab (30 kg); (C) endless-warp-rigged van Veen grab (short-armed, 30 kg); (D) endless-warp-rigged van Veen grab (long-armed, 70 kg); (E) Day grab (120 kg); (F) Smith–McIntyre grab (120 kg).

rises just as bottom contact is made, or in the grab being snatched off the bottom where the ship rises just as hauling commences. In the former instance it is unlikely that any sediment is secured, in the latter the amount of material and its integrity as a sample will vary considerably depending on the exact circumstances of its retrieval.

The intensity of this effect will depend on the severity of the weather conditions. **Figure 8** shows the relationship between wind speed and grab failure rate, which is over 60% of hauls at wind force 8. What is of more concern to the scientist attempting to obtain quantitative samples is the dramatic increase in variability with increase in wind speed with a coefficient of variation between 20 and 30 at force 7. The high cost of ship-time places considerable pressure on operators to work in as severe weather conditions as possible and it is not unusual for sampling to continue in wind force 7 conditions with all its disadvantages.

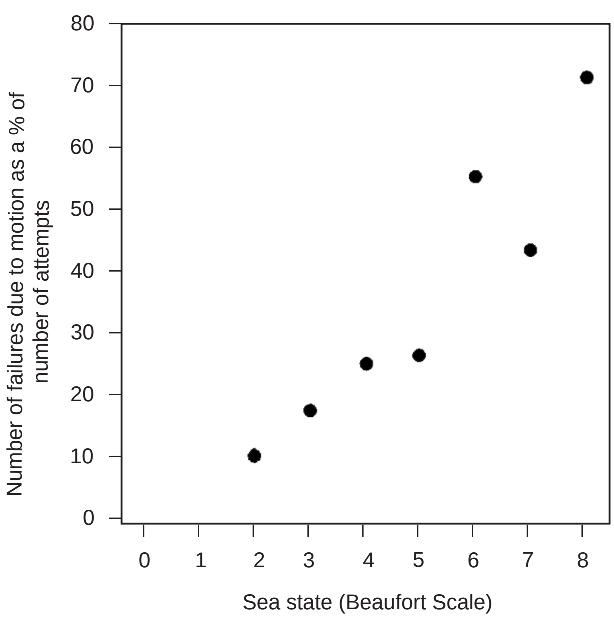

Figure 8 Relationship between wind speed and grab failure rate.

Drift

For a warp-activated grab sampler to operate efficiently it should be hauled with the warp positioned vertically above. Where there is a strong wind or current these conditions may be difficult to achieve. The result is that the grab samplers are pulled on to their sides. This is a particular problem with samplers, such as the van Veen grab, that do not have stabilizing frames. Diver observations have shown, however, that at least in shallow water, where the drift effect is at its greatest on the bottom, even the framed heavily weighted Day and Smith–McIntyre grabs can be toppled.

Initial Penetration

It is clear that the weight of the sampler is an important element in determining the volume of the sample secured. Much of the improved digging efficiency of the van Veen grab shown in **Figure 7(D)** can be attributed to the addition of an extra 40 kg of weight which increased the initial penetration of the sampler on contact with the sediment surface.

Initial penetration is one of the most important factors in the sequence of events in grab operation determining the final volume of sediment secured. **Figure 9** shows the relationship between initial penetration and final sample volume obtained for a van Veen grab. Over 70% of the final volume is determined by the initial penetration. Subsequent digging of the sampler is hampered, as already shown, by the pull of the warp.

For most benthic faunal studies it is important for the sampler to penetrate at least 5 cm into the sedi-

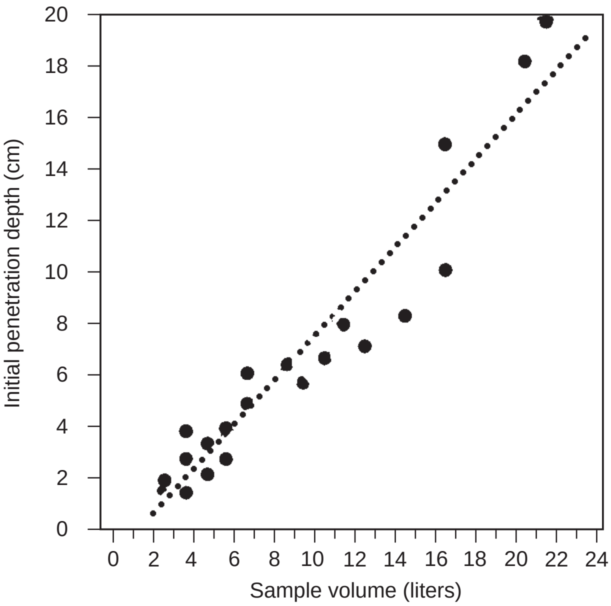

Figure 9 Relationship between initial penetration of a van Veen grab sampler and volume of sediment secured.

ment (for a 0.1 m^2 surface area sample this gives 5 liters of sample). In terms of number of species and individuals, over 90% of benthic macrofauna are found in the top 4–5 cm of sediment. **Figure 10** shows how the number of individuals relates to average sample volume for 18 stations in the southern North Sea (each liter recorded represents 1 cm of penetration). Although there is considerable variation in the numbers of individuals between stations, there is no significant trend linking increased abundance with increased sample volume penetration. No sample volumes of less than 4.5 l were taken indicating that at that level of penetration most of the fauna were being captured.

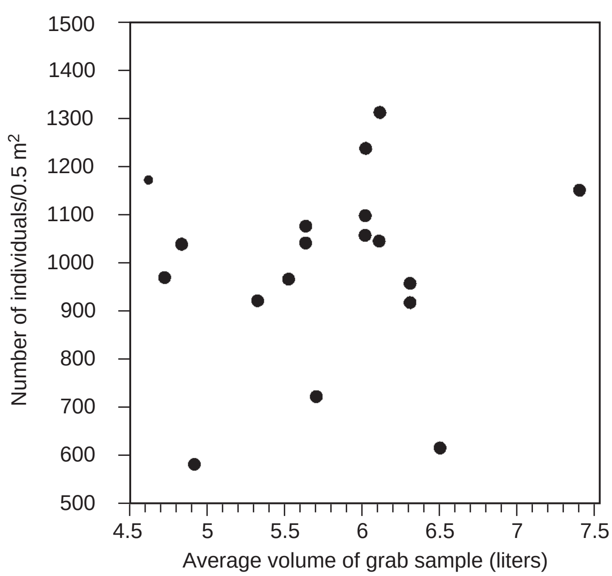

Figure 10 Relationship between number of benthic fauna individuals captured and sample volume for a boreal offshore sand substratum.

Samplers in which the jaws are held rigidly in a frame have no initial penetration if the edge of the jaw buckets, when held in the open position, are on a level with the base of the frame. The lack of any initial penetration in such instruments has the added disadvantage in benthic fauna work of under sampling at the edges of the bite profile (see **Figure 7E** and **F**) although the addition of weight will usually increase the sample volume obtained.

Pressure Wave Effect

The descent of the grab necessarily creates a bow wave. Under field conditions it is usually impracticable to lower the grab at a rate that will eliminate a preceding bow wave, even if the sea were flat calm. There have been several investigations of the effects of 'down wash' both theoretical, using artificially placed surface objects and *in situ*. The effects of down wash can be reduced by replacing the upper surface of the buckets with an open mesh. Although there is still a considerable effect on the surface flock layer (rendering the samples of dubious value for chemical contamination studies), the effect on the numbers of benthic fauna is generally very small.

Self-activated Bottom Samplers

There can be little doubt that one of the most important factors responsible for sampler failure or sample variability in heavy seas is the reliance of most presently used instruments on warp-activated closure. The most immediate and obvious answer to this problem is to make the closing action independent of the warp by incorporating a self-powering mechanism.

Spring-powered Samplers

One solution to the problem is to use a spring to actuate the sampler buckets. Such instruments are in existence, possibly the most widely used being the Shipek grab, a small sampler (0.04 m^2) consisting of a spring-loaded scoop (**Figure 11**). This instrument is widely used where small superficial sediment samples are required for physical or chemical analysis. The use of a pretensioned spring unfortunately sets practical limits on the size of the sampler, since to cock a spring to operate a sampler capable of taking a 0.1 m^2 sample would require a force that would be

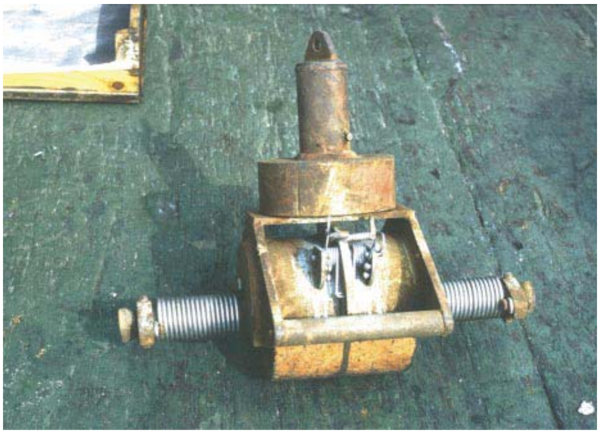

Figure 11 Shipek grab.

impracticable to apply routinely on deck. In addition, in rough weather conditions a loaded sampler of this size would be very hazardous to deploy.

Compressed-air-powered Samplers

Another approach has been to use compressed air power. In the 1960s Flury fitted a compressed air ram to a modified Petersen grab with success. However, the restricted depth range of the instrument and the inconvenience of having to recharge the air reservoir for each haul limited its potential for routine offshore work.

Hydraulically Powered Samplers

Hydraulically powered grabs are commonly used for large-scale sediment shifting operations such as seabed dredging. The Bedford Institute of Oceanography, Nova Scotia successfully scaled down this technology to that of a practical benthic sampler. Their instrument is relatively large, standing 2.5 m high and weighing some 1136 kg. It covers a surface area of 0.5 m^2 and samples to a maximum sediment depth of 25 cm. At full penetration the sediment volume taken is about 100 l. The buckets are driven closed by hydraulic rams powered from the surface. The grab is also fitted with an underwater television camera which allows the operator to visually select the precise sampling area on the seabed, close and open the bucket remotely, and verify that the bucket closed properly prior to recovery. The top of the buckets remain open during descent to minimize the effect of down-wash and close on retrieval to reduce washout of the sample on ascent. The current operating depth of the instrument is 500 m. The instrument has been successfully used on several major offshore studies, but does require the use of a substantial vessel for its deployment.

Hydrostatically Powered Samplers

Hydrostatically powered samplers use the potential energy of the difference in hydrostatic pressure at the sea surface and the seabed. The idea of using this power source is not new. In the early part of the twentieth century a ‘hydraulic engine’ was in use by marine geologists that harnessed hydrostatic pressure to drive a rock drill. Hydrostatic power has also been used to drive corers largely for geological studies. However, these instruments were principally concerned with deep sediment corers and were not designed to collect macrofauna or material at the sediment–water interface.

A more recent development has been that of a grab built by Heriot-Watt University, Edinburgh. The sampler uses water pressure difference to operate a hydraulic ram that is activated when the grab reaches the seabed. **Figure 12** shows the general layout of the instrument. Water enters the upper chamber of the cylinder when the sampler is on the seabed, forcing down a piston that is connected to a system of levers that close the jaws. The actuating valve is held shut by the weight of the sampler and there is a delay mechanism to prevent premature closure of the jaws resulting from ‘bounce’. Back on the ship, the jaws are held shut by an overcenter locking mechanism and, on release, are drawn open by reversal of the piston motion from air pressure built up on the underside of the piston during its initial power stroke. Since the powering of the grab jaws is independent of the warp the sampler may be

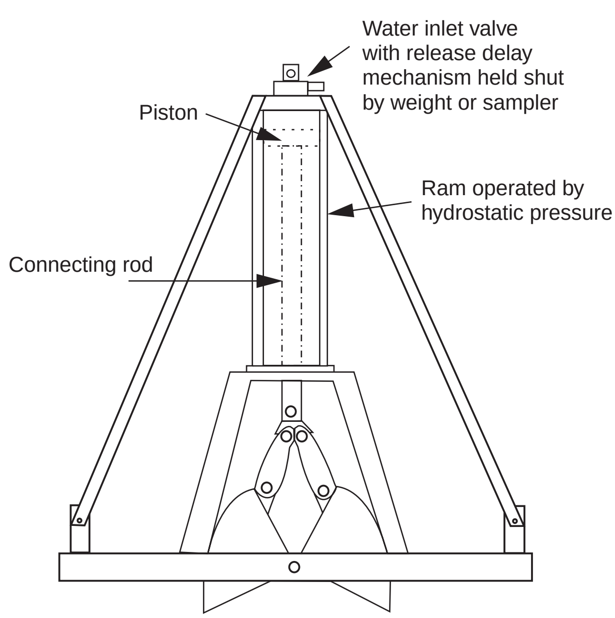

Figure 12 Diagram of a grab sampler using hydrostatic pressure to close the jaws.

used successfully in a much wider range of surface weather conditions than conventional grabs.

Alternatives to Grab Samplers

Ideally a benthic sediment sample for faunal studies should be straight-sided to the maximum depth of its excavation and should retain the original stratification of the sediment. Grab samplers by the very nature of their action will never achieve this end.

Suction Samplers

One answer to this problem is to employ some sort of corer designed to take samples of sufficient surface area to satisfy the present approaches to benthic studies. The Knudsen sampler is such a device and is theoretically capable of taking the perfect benthic sample. It uses a suction technique to drive a core tube of $0.1\,m^2$ cross-sectional area 30 cm into the sediment. Water is pumped out of the core tube on the seabed by a pump that is powered by unwinding a cable from a drum. The sample is retrieved by pulling the core out sideways using a wishbone arrangement and returning it to the surface bottom-side up (**Figures 13** and **14**). Under ideal conditions the device will take a straight-sided sample to a depth of 30 cm. However, conditions have to be flat calm in order to allow time for the pump to operate on the seabed and evacuate the water from the core. This limits the use of the Knudsen sampler and it is generally not suitable for sampling in unsheltered conditions offshore. Mounting the sampler in a stabilizing frame can improve its success rate and it is used regularly for inshore monitoring work where it is necessary to capture deep burrowing species.

Spade Box Samplers

Another approach to the problem is to drive an open-ended box into the sediment, using the weight of the sampler, and arrange for a shutter to close off the bottom end. The most widespread design of such an instrument is that of the spade box sampler, first described by Reineck in the 1950s and later subjected to various modifications. The sampler consists of a removable steel box open at both ends and driven into the sediment by its own weight. The lower end of the box is closed by a shutter supported on an arm pivoted in such a way as to cause it to slide through the sediment and across the mouth of the box (**Figure 15**). As with the grab samplers previously described, the shutter is driven by the act of hauling on the warp with all the attendant disadvantages. Nevertheless, box corers are very successful and are used widely for obtaining relatively undisturbed samples of up to $0.25\,m^2$ surface area (**Figure 16**). One big advantage of the box sampler is that the box can usually be removed with the sample and its overlying water intact allowing detailed studies of the sediment surface. Furthermore, it is possible to subsample using

Figure 14 Knudsen sampler in ascent position.

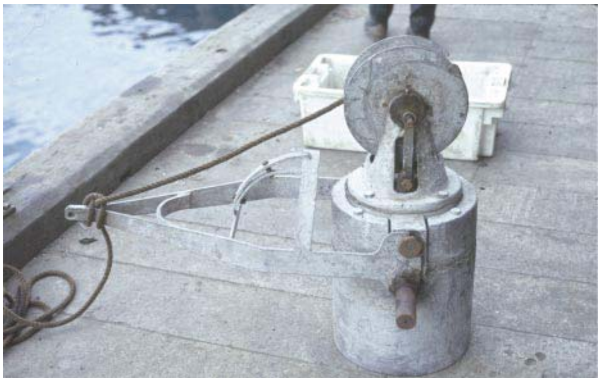

Figure 13 Knudsen sampler in descent position.

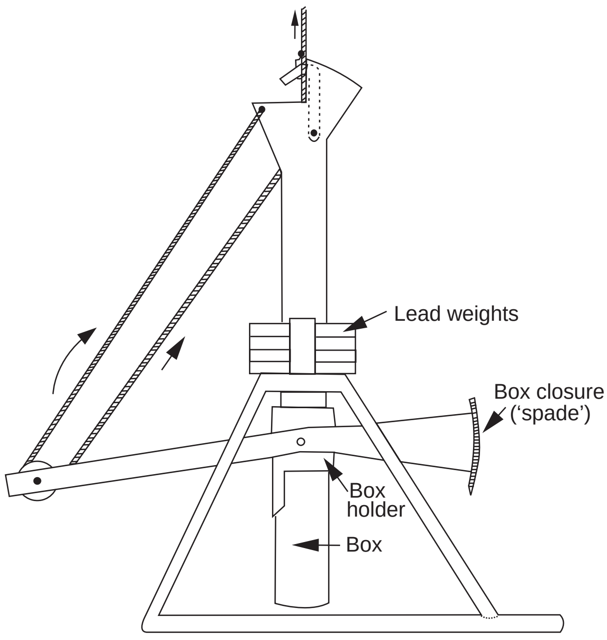

Figure 15 Diagram of a Reineck spade box sampler.

small-diameter corers for chemical and physical characteristic studies. Despite their potential of securing the 'ideal' sediment sample, box corers are rarely used for routine benthic monitoring work. This is largely because of their size (a box corer capable of taking a 0.1 m^2 sample weighs over 750 kg and stands 2 m high) and the difficulty in deployment and recovery in heavy seas.

Figure 16 A 0.25 m^2 spade box sampler.

Precision Corers

For chemical monitoring it is important that the sediment–water interface is maintained intact, for it is the surface flock layer that will contain the most recently deposited material. Unfortunately, such undisturbed samples are rarely obtained using grab samplers or box corers. Precision corers are capable of securing undisturbed surface sediment cores, however they are unsuitable for routine offshore work because of the time taken to secure a sample on the seabed and dependence on warp activated closure. Additionally, the cross-sectional area of the core (0.002–0.004 m^2) would necessitate the taking of large numbers of replicate samples in order to capture sufficient numbers of benthic macrofauna to be useful. This would be impracticable given the time taken to take a single sample. Large multiple precision corers have been constructed; these are usually too large and difficult to deploy for routine macrobenthos sampling. At present there is no instrument that fulfils the requirements for a quick turnaround precision multiple corer for offshore sampling.

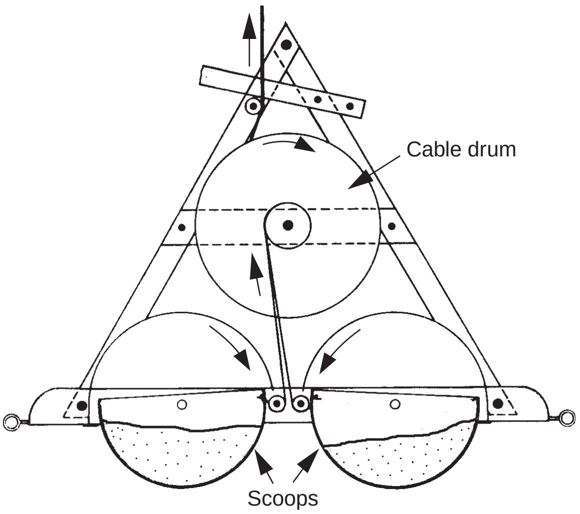

Figure 17 Diagram of a Holme scoop. Reproduced with permission from Holme NA (1953). The biomass of the bottom fauna in the English Channel off Plymouth. *Journal of the Marine Biological Association* 32: 1–49.

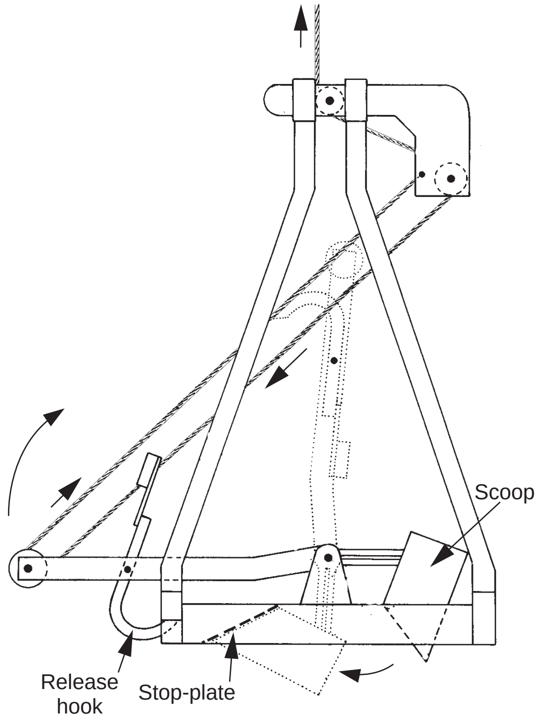

Figure 18 Diagram of a Hamon scoop.

Sampling Difficult Sediments

Most of the samplers so far discussed operate reasonably well in mud or sand substrata. Few operate satisfactorily in gravel or stony mixed ground either because the bottom is too hard for the sampler to penetrate the substratum or because of the increased likelihood of a stone holding the jaws open when they are drawn together. To get around this problem various types of scoops have been devised. The Holme grab has a double scoop action with two buckets rotating in opposite directions to minimize any lateral movement during digging. The scoops are closed by means of a cable and pulley arrangement (**Figure 17**) and simultaneously take two samples of 0.05 m^2 surface area.

The Hamon grab, which has proved to be very effective in coarse, loose sediments, takes a single rectangular scoop of the substratum covering a surface area of about 0.29 m^2. The scoop is forced into the sediment by a long lever driven by pulleys that are powered by the pull of the warp (**Figure 18**). Although the samples may not always be as consistent as those from a more conventional grab sampler, the Hamon grab has found widespread use where regular sampling on rough ground is impossible by any other means.

See also

Benthic Organisms Overview. Benthic Boundary Layer Effects.

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GRAVITY

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Introduction

The gravity field varies over the oceans on account of lateral variations in density beneath the ocean surface. The most prominent anomalies arise from undulations on density interfaces, such as occur at the water–rock interface at the seafloor or at the crust–mantle interface, also known as the Moho discontinuity. Because marine gravity is relatively easy to measure, it serves as a remote sensing tool for exploring the earth beneath the oceans. The interpretation of marine gravity anomalies in terms of the Earth's structure is highly nonunique, however, and thus requires simultaneous consideration of other geophysically observed quantities. The most