Method was extracted from full ASTM Standard Methods protocol

10500 B. Sample Collection

1. General Considerations

Before conducting a benthic survey, determine specific data quality objectives and clearly define the information sought. *Data quality objectives* are qualitative and quantitative statements developed to specify the quality of data needed to support specific decisions and conclusions about the information sought. Discussion with water chemists, hydrologists, limnologists, and individuals from other disciplines will be helpful. Ultimately, the choice of methodology will depend on whether the habitat to be studied is a stream, lake, reservoir, or marine area. For example, investigators only need a few sampling stations upstream and downstream of a discharge to determine whether the macroinvertebrate community downstream is damaged. However, if the objective is to delimit the extent of damage from a discharge or series of discharges, they will need reference stations upstream of, downstream of, and bracketing all discharges. In marine waters, they may need to sample a nearby estuary. In open ocean waters, they may need to sample some distance from the discharge point.

Characterize the physicochemical properties of faunal sampling-station substrate and overlying water. Measure such properties as sediment size class distribution (sand, silt, and clay); organic content and toxic pollutant concentrations; temperature, salinity, hardness, alkalinity, DO, total organic carbon (TOC), ammonia, sulfides, and nutrient (total and dissolved) concentrations; biochemical oxygen demand; water depth; and velocity of flowing streams.

After gaining a thorough understanding of the water body's characteristics, select specific areas to be sampled. There is no predetermined number of sampling stations that will be appropriate for all situations. No water quality survey is routine, nor can one be conducted totally on a "cookbook" basis. However, if investigators adhere to the following basic rules, they can design a sound survey.

a. Always establish a reference station(s) outside the influence of all wastewater discharges of concern (but in the same water body). Because most surveys are made to determine the damage that pollution causes aquatic life, this will be the basis for comparing biota in polluted and unpolluted areas. Preferably establish at least two reference stations: one far from the effluent discharge and the other near the discharge, but not subject to its influence. (For example, if the discharge were in a river, one station would be far upstream of the discharge and the other would be immediately downstream.) Whenever feasible, use reference stations with physicochemical characteristics similar to the receiving area's substrate and overlying water.

b. Locate a station immediately downstream of each discharge or in the affected area in its immediate vicinity, as appropriate.

c. If the discharge does not mix completely on entering the body of water, but instead channels along one side or disperses in a specific direction, then locate stations in the left-bank (looking upstream), midchannel, and right-bank sections of the stream; in concentric arcs in lakes and oceanic waters; or in any other configuration that will meet study objectives.

d. Establish stations at various distances downstream from the last discharge of concern to determine the linear extent of damage. In a marine environment, a nearby estuary may be sampled; in open ocean waters, samples may be taken in a nearby area with comparable currents, depth, sediment characteristics, and salinity.

e. To permit comparison of macroinvertebrate communities, be sure that all sampling stations are ecologically similar. For example, select stations with similar bottom substrate (e.g., sand, gravel, rock, mud, organic content), depth, presence of riffles and

pools, stream width, gradient, flow velocity, bank or shore cover, salinity, hardness, TOC, nutrient and DO concentrations, and wave exposure.

f. Collect samples for physical, toxicological (if applicable), and chemical analyses as close to biological sampling stations as possible to ensure correlation of findings; take such samples at the same time and from the same grab when possible. Collect substrate samples for physicochemical analyses from the upper few centimeters, where most organisms live.

g. Locate macroinvertebrate sampling stations in the best physical habitat [areas not influenced by atypical conditions (bridges, dams, etc.)].

h. Discharges in coastal areas may be subject to various degrees of salt water intrusion (salt water wedge). Macroinvertebrate populations may change drastically in such areas; document and/or allow for this effect.

i. When sampling in small, wadeable, first- to third-order streams, begin at the station farthest downstream and proceed upstream to minimize disruptions induced by the sampling itself. This is unnecessary for non-wadeable streams and rivers.

For a long-term biological monitoring program, consider collecting macroinvertebrates at each station at least once during each of the annual seasons, though this may not always be necessary and would depend on the study design.[1] More frequent sampling may be necessary if effluents' characteristics change or spills occur. Make allowance for collections at night where "drift" or night feeding organisms are of special concern. In general, the most critical period for macroinvertebrates in streams is during periods of high temperature and low flow, whereas in estuarine and marine environments it is the period of maximum stratification and poor vertical mixing. If available time and funds limit sampling frequency, make at least one survey during the critical time.

2. Sampling Design

Some terms have multiple meanings. In biology, for example, a *population* is a group of individuals that are all members of the same species or taxonomic group. In statistics, a *population* is the entire set of values for the characteristic of interest in a whole sampling universe. For example, researchers interested in determining the mean density of worms on a lake bottom might take ten grabs from lake sediments. The number of worms in each grab would be an *observation*, the density of worms would be the *characteristic of interest*, and the contents of each grab would be an *experimental unit* or *sampling unit*. The entire lake bottom would be the *sampling universe* and enough grabs to equate with the area of the entire lake bottom would be the *population* (of units).

Similarly, the term *sample* has two often contradictory uses. In typical studies, observations usually are not made of all possible sampling units; instead, observations are only made of a small fraction of the total. Statistically, this set of observations is called a *sample*. In the example given above, the ten grabs collectively would be a sample. However, in everyday language (and as used in this book and most scientific publications), a *sample* is a portion of the real world that has been selected for measurement (e.g., a water sample, plankton haul, or bottom grab). Therefore, in the example above, each individual grab would be a sample (i.e., "ten samples were taken").

Collecting a representative statistical sample is difficult because of variation in successive scientific samples. Without knowing the sampling variability, investigators cannot know the degree to which the data truly represent the population. Make replicate observations of a population if definitive statistical inferences about the population will be made.[2–11]

Standardize sampling design to consider the following requirements:

a. Approximate the set of all samples that can be selected (i.e., separate the sampling universe into all possible samples). For example, if the location (site) containing the population has an area of 1000 m^2 and the sampling device samples an area of 1 m^2, then 1000 samples could be collected in the sampling universe.

b. Assign each sample an equal probability of being selected. Using the situation above, divide the area to be sampled into 1000 discrete units.

c. Use a table of random numbers to select sites for sampling (i.e., sample randomly, not haphazardly).

d. The sampling design outlined above is known as *simple random sampling*. When using this design, it is often advantageous to determine the number of samples necessary for a certain level of precision:

$$N = \left(\frac{t \times s}{D \times \bar{x}}\right)^2$$

where:

- N = number of samples,
- t = tabulated t value at 0.05 level with the degrees of freedom of preliminary survey (generally $t \approx 2.0$ at larger sampling sizes),
- s = sampling standard deviation of samples, known from a preliminary survey,
- D = required level of precision expressed as a decimal (0.30 to 0.35 usually yields a statistically reliable estimate), and
- $\bar{x}$ = sample mean density of preliminary survey.

To estimate the number of samples needed, analysts first need specific information (the mean and standard deviation) about the population to be sampled. Because this information is unknown (because sampling has yet to occur), estimate the population's mean and standard deviation by one of three ways: conduct a pilot study, use results from an earlier or similar study, or make educated estimates.[3,12] For example, if investigators want to determine the mean chironomid density in relatively homogeneous lake sediments during summer, and they know that six grabs taken the previous summer produced a mean density of 4230 chironomids/m^2 and a standard deviation of 1628 chironomids/m^2, then they can use these data to estimate their study's mean chironomid density [$\pm$30%, with a 5% probability of error ($\alpha = 0.05$)]. Using the formula given above,

$$N = \left(\frac{2.5706 \times 1628}{0.30 \times 4230}\right)^2$$

($t = 2.5706$ at a 5% probability of error and 5 degrees of freedom)

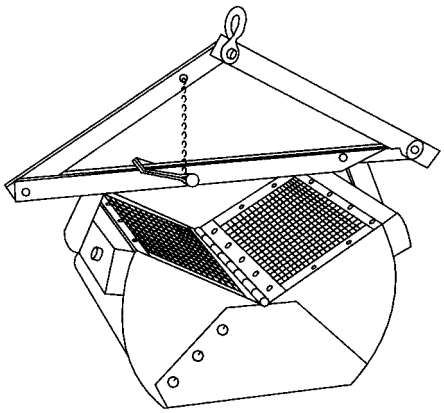

Figure 10500:1. Petersen grab.

$$N = 10.88 \approx 11$$

Thus, it is estimated that 11 grabs will be necessary.

e. A simple random sampling design is useful when sampling relatively homogeneous areas. However, most taxa are not distributed uniformly over water bottoms. Different habitats (sand, mud, gravel, or organic material) support different densities and species of organisms. In which case, a stratified random design is more useful.

In a stratified random sampling design, a heterogeneous universe (different bottom substrates, current velocities, depths, temperatures, etc.) is divided into more homogeneous strata. Once the strata are defined, use simple random sampling within each stratum. Stratified random sampling has two important advantages: it provides data on various subsets of a population (e.g., density of benthic invertebrates in each sediment type), and it reduces variability because it deals with more homogeneous subpopulations, allowing for more accurate and precise population estimates.

The data needed to divide the population into various strata usually is acquired via pre-study reconnaissance (a pilot study). A systematic sampling design often is used in such pilot studies. In a systematic-transect design, investigators conduct sampling at equal intervals along a number of transects in a habitat to identify and locate existent strata.[3,12]

f. In descriptive studies, investigators should take at least three replicate sampling units per station.[3,13] If statistical testing is planned, more replicates probably will be needed.

g. Standardize data acquisition and recording when practical. Use metric units.

3. Sampling Devices, Quantitative

Quantitative and qualitative samplers have been designed to collect organisms from the bottom of different water bodies. The most common quantitative sampling devices are the Petersen, Ponar®,* and Ekman grabs and the Surber or square-foot stream bottom sampler, all described below.

a. Grab samplers:

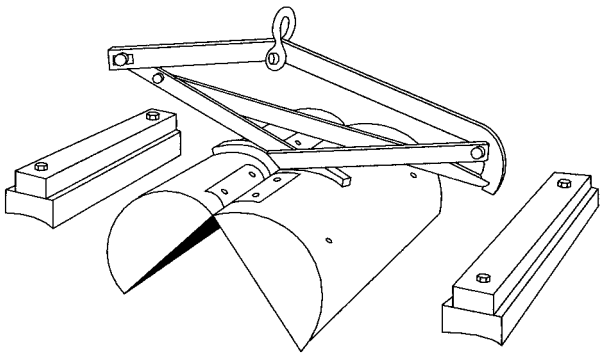

Figure 10500:2. Ponar® grab.

Before using each grab sampler, calibrate it for actual surface area sampled.

1) *The Petersen grab* (Figure 10500:1) is used for sampling hard bottoms (e.g., sand, gravel, marl, and clay) in swift currents and deep water.[3] It is an iron, clam-type grab manufactured in various sizes that will sample an area between 0.06 and 0.09 m^2. It weighs approximately 13.7 kg, but may weigh as much as 31.8 kg when auxiliary weights are bolted to its sides. The extra weights make the grab stable in swift currents and provide more cutting force in fibrous or firm bottom materials. Modify the sampler by adding end plates, by cutting large strips out of the top of each side, and by adding a hinged 30-mesh screen (as in the Ponar grab).[14]

To use the Petersen grab, set the hinged jaws and lower to the bottom slowly to avoid disturbing lighter bottom materials. Ease rope tension to release the catch. As the grab is raised, the lever system closes the jaws.

2) *The Ponar grab* (Figure 10500:2) is used increasingly in medium to deep rivers, lakes, reservoirs, and estuaries.[15] It is similar to the Petersen grab in size, weight, lever system, and sample compartment, but has side plates and a screen on top of the sample compartment to prevent sample loss during closure. With one set of weights, the standard 23- × 23-cm sampler weighs 20 kg. A 15- × 15-cm petite Ponar may be used. The large surface disturbance associated with a Ponar grab can be reduced by installing hinged (rather than fixed) screen tops, thereby reducing the pressure wave associated with the sampler's descent. This sampler is best used for mud, sand, gravel, or small rocks with mud, but it can be used in all substrates except bedrock.

3) *The Van Veen grab* (Figure 10500:3) is used to sample in open marine waters and in large lakes. The sampler's long arms tend to act as stabilizers without disturbing water at the water–substrate interface. It is basically an improved version of the Petersen grab for mud, gravel, pebble, and sand substrates. The sampler is heavy; lower it from a boat or ship platform via mechanical or hydraulic lifts.

4) *The Smith-McIntyre grab* (Figure 10500:4) has the heavy steel construction of the Petersen, but its jaws are closed by strong coil springs.[16] Its chief advantages are stability and easier control in rough water. Its bulk and heavy weight require operation from a large boat equipped with a winch. The 45.4-kg grab can sample an area of 0.2 m^2,[17–19] but smaller models (0.1 m^2 or 0.05 to 0.06 m^2) are available.

* Registered trademark of Morris & Lee, Inc. d/b/a Wildlife Supply Co., Buffalo, NY.

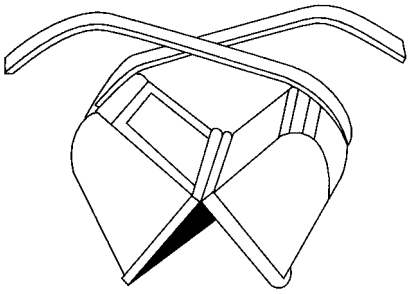

Figure 10500:3. Van Veen grab.

5) *The Shipek®† grab* (Figure 10500:5) is designed to take a sample from virtually any substrate; samples have a surface area of 0.04 m^2 and are approximately 10 cm deep at the center.[3] The sample compartment is composed of two concentric half cylinders. When the grab touches bottom, inertia from a self-contained weight releases a catch and helical springs rotate the inner half cylinder by 180°. The sample bucket may be disengaged from the upper semi-cylinder by releasing two retaining latches. This grab is for special use in marine waters and large inland bodies of water (e.g., in compact substrates).

6) *The Ekman grab* (Figure 10500:6) is only useful for sampling mud, silt, muck, and sludge in water with little current.[3] It is difficult to use in areas with rocky or sandy bottoms or moderate macrophyte growth because small pebbles or grit or macrophyte stems prevent proper jaw closure. The grab weighs approximately 3.2 kg. The box-like part holding the sample has spring-operated jaws on the bottom, which must be cocked manually (exercise caution when cocking and handling the grab because of possible injuries if jaws are tripped accidentally). At the top of the grab are two hinged overlapping lids that are partially held open during descent by water passing through the sample compartment. These lids are held shut by water pressure when the sampler is being retrieved. The grab is made in three sizes—15 × 15 cm, 23 × 23 cm, and 30 × 30 cm—but the smallest size is usually adequate. A taller model of this sampler

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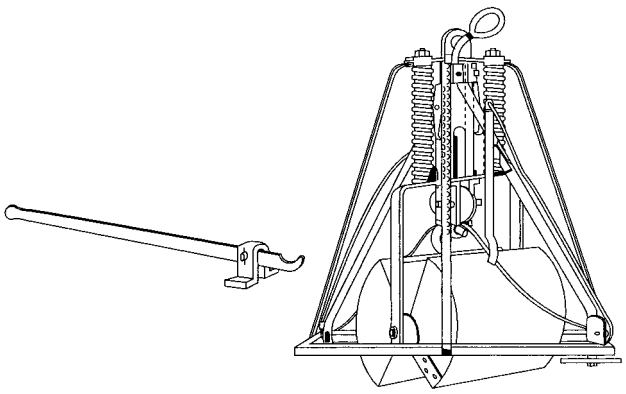

Figure 10500:4. Smith-McIntyre grab.

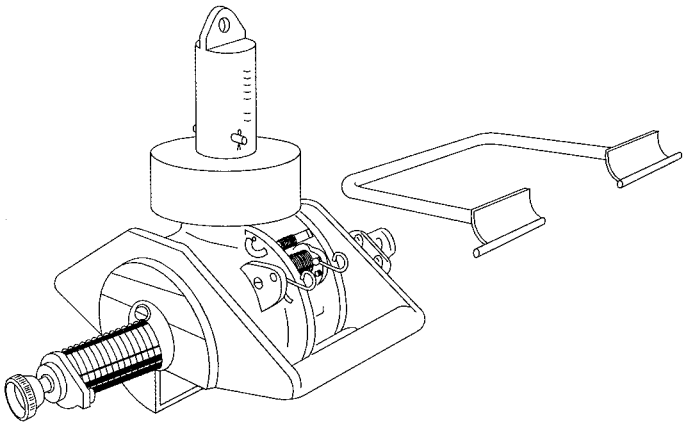

Figure 10500:5. Shipek grab.

(23 cm or 30.5 cm tall) is available. To prevent sample overflow and loss, place a Standard U.S. No. 30 sieve insert in the top of any Ekman grab sampler for deep sediments.

b. Riffle/run samplers:

1) *Surber-type samplers* (Figure 10500:7)[20] consist of two brass frames—each 30.5 cm (1 ft) square—hinged together along one edge. When in use, the two frames are locked at right angles, one frame marking off the area of substrate to be sampled, and the other supporting a net to collect organisms washed into it from the sample area.

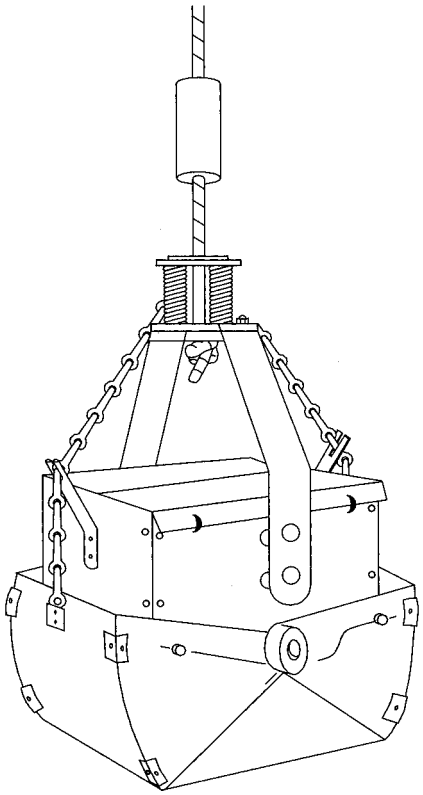

Figure 10500:6. Ekman grab.

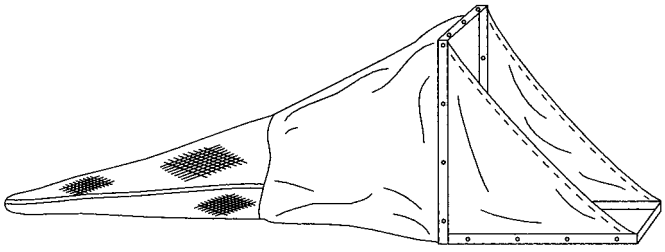

Figure 10500:7. Surber or square-foot sampler.

The net usually is 69 cm long, and its first few centimeters and its wings are constructed of heavier material (canvas, taffeta) to increase durability. The rest of the net is a standard 30 mesh size (595 to 600 μm). While a finer mesh might collect more of the smaller invertebrates and young instars, it also will clog more easily and resist the current more, possibly resulting in a loss of organisms due to backwashing. This sampler is specific for macrobenthos; many microcomponents of the benthos are not collected.

Use this sampler in shallow, flowing water (no more than 30 cm deep). In deeper water, some organisms may flow over the top of the sampler. Position sampler securely on the stream bottom parallel to water flow, with the net portion downstream. Take care not to disturb the substrate upstream of sampler. Leave no gaps under the edges of the frame that would allow water to wash under the net. Fill any gaps along the back edge of the sampler by carefully shifting rocks and gravel along the outside edge. When sampler is in place (it may be necessary to hold it in place with one hand in a strong current), carefully turn over and lightly hand-rub all rocks and large stones inside the frame to dislodge organisms clinging to them. Examine each stone for organisms, larval or pupal cases, etc., that may be clinging to it before discarding. Scrape attached algae, insect cases, etc., from the stones into the sampler net. Stir remaining gravel and sand with hands or a stick to a depth of 5 to 10 cm (depending on substrate) to dislodge bottom-dwelling organisms. It may be necessary to hand-pick some mussels and snails that the current does not carry into the net.

Remove sample by inverting net into sample container. Carefully examine net for small organisms clinging to it. Remove these—preferably with forceps to avoid damage—and include in sample. Rinse sampler net after each use.

A common problem when using the Surber sampler is that organisms wash under the bottom edge of the sampler. The following modifications have been suggested for different substrates:

• For loose gravel—Extend bottom edge of Surber frame to 5 or more cm so frame can be inserted deeper into substrate. This method works well in soft substrates (e.g., sand and gravel), where the current causes substrate shifting.

• For coarse gravel and rock—Add serrated extension to the back edge of frame to secure it and reduce washing from under this edge. This method is helpful in hard gravel and rock substrates, where sinking the entire frame is impossible.

• For gravel and bedrock—Add a 5-cm band of flexible material to the bottom edge of sampler to create a seal in rocky, uneven substrates. Make band of foam rubber or fine-textured synthetic sponge. Remove organisms that stick to foam and include in sample.

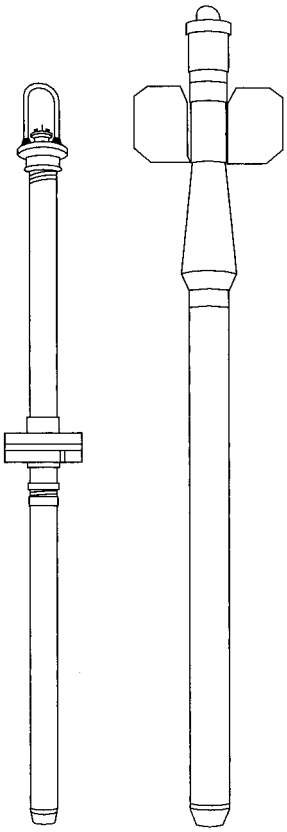

Figure 10500:8. Phleger core sampler.

2) *Hess-type samplers* are cylindrical with enclosed sides and an open top. They function much like Surber-type samplers.[3]

c. Core or cylindrical samplers: Use core or cylindrical samplers to sample sediments in depth. Efficient use as surface samplers requires dense animal populations. Core samplers vary from hand-pushed tubes to explosive-driven and automatic-surfacing models.[3,21]

1) *The Phleger corer* (Figure 10500:8) is widely used and operates via gravity.[3] Styles and weights vary among manufacturers; some use interchangeable weights that allow variations between 7.7 and 35.0 kg, while others use fixed weights weighing 41.0 kg or more. Core length will vary with substrate texture.

2) *The KB®‡ core sampler* (Figure 10500:9), or a modification known as the Kajak–Brinkhurst corer, may be useful in obtaining estimates of the standing stock of benthic macroinvertebrates inhabiting soft sediments.[22]

3) *Box core samplers*[23–27] are used to sample soft substrate in large rivers, lakes, and estuaries. They are available in several sizes, can sample a variety of sediments, and are used in marine waters and in the Great Lakes[3,28] to collect benthic macrofauna. The sampler may be deployed from ships or platforms, but diver-collected cores are preferred.

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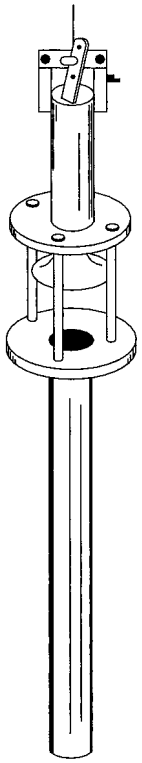

Figure 10500:9. KB corer.

The KC Box Corer frame is made of 60 × 60 × 6 mm, sandblasted, hot galvanized stainless steel square tubes.[27] The 30 × 20 cm or 32 × 32 cm sampler tube is made of 3-mm electropolished stainless steel. The sampling surface area is either 600 or 100 cm^2, and it samples a depth of 20 to 40 cm.

Preferably use a box coring device with a rectangular corer whose cutting arm can seal the sample before retracting from the bottom. To sample enough individuals and taxa, and integrate the patchy distribution of benthic fauna, use a sampler with a surface area of at least 100 cm^2 and a sediment depth of at least 20 cm. A box corer that can sample deeper sediment may be needed to collect deep-burrowing infauna. For sandy sediments, it may be necessary to substitute a grab sampler to adequately penetrate sediment and collect samples. Visually inspect each sample to ensure that an undisturbed, adequate amount of sample is collected.

4) *The Wilding or stovepipe sampler* (Figure 10500:10)[29–30] is made in various sizes and with many modifications.[3] The Wilding sampler is made from any tubular material (e.g., 60- to 75-cm sections of 30-cm-diam stovepipe[30] or 75-cm sections of 30-cm-diam aluminum irrigation pipe fitted with handles). The Maine Department of Environmental Pollution uses a 5-gal bucket with the bottom removed.

The sampler is pressed into the substrate and its contents are agitated. It is especially useful for quantitatively sampling a bottom with dense, vascular plant growth. It may be used to sample vegetation, mud–water interface sediment, or most shallow stream substrates. However, large volumes of vegetation, when sampled in this way, may require a great deal of time for laboratory processing.

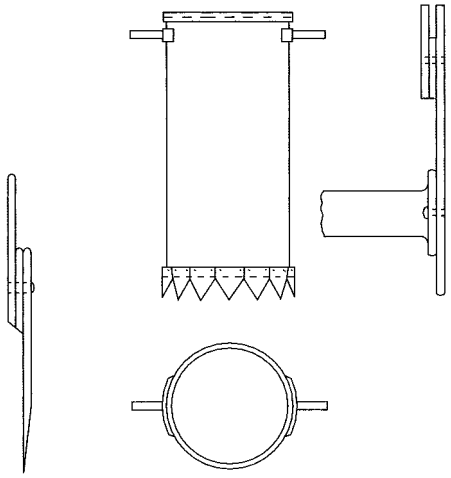

Figure 10500:10. Wilding or stovepipe sampler.

d. Drift samplers: Drift samplers, usually in the form of nets (Figure 10500:11), are anchored in flowing water to capture macroinvertebrates that have migrated or been dislodged from the bottom substrates into the current. Drift organisms are important to the stream ecosystem because they are prey for fish and should be considered in the study of fish populations. Drift organisms respond to pollutional stresses (e.g., spills) by increased drift from an affected area so drift is important in water-quality investigations, especially of spills of toxic materials. Drift also is a factor in recolonizing denuded areas and contributes to recovery of disturbed streams.

Use nets with a 929-cm^2 upstream opening and mesh equivalent to U.S. Standard No. 30 screen (595-μm pore size). After placing the net in the water, frequently remove organisms and debris to prevent clogging and subsequent diversion of water at the net opening. Use replicate samples, as appropriate, to meet study objectives. Set drift-net samples for any specified time (usually 1 to 3 h) but use the same time for each station. Sampling between dusk and 1 a.m. is optimal.

The total quantity (numbers or biomass) of organisms drifting past a given station is the best measure of drift intensity. Report data in terms of numbers or biomass/m^3.[31–33]

4. Sampling Devices, Qualitative

When sampling qualitatively, search for organisms in as many habitats as possible.[34] Collect samples by any method that will capture representative species.

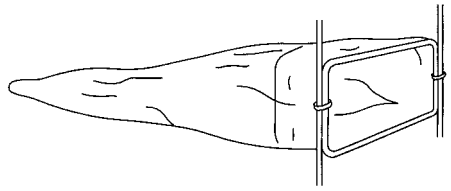

Figure 10500:11. Drift net sampler.

a. Dip, kick nets are the most versatile collection devices for shallow, flowing water and for lake shorelines. When combined with a standardized kicking technique,[35] these nets are appropriate for quantitatively sampling macroinvertebrates.[36]

b. Tow nets, dredges, or trawls range from simple sled-mounted nets to complicated devices with teeth that dig into the bottom. Some models feature special apparatus to hold the net open during towing and to close it during descent and retrieval. Available styles have been discussed elsewhere.[21,37,38]

5. Sampling Devices, Artificial Substrate Samplers

Artificial substrate samplers are devices of standard composition and configuration placed in water for a predetermined exposure period to be colonized by macroinvertebrate communities. Because many of the physical variables encountered in bottom sampling are minimized (e.g., depth, light penetration, temperature differences, and species substrate preferences), artificial substrate sampling complements other types of sampling. Like natural submerged substrates (e.g., logs and pilings), artificial substrates are colonized primarily by immature aquatic insects, crustaceans, coelenterates, bryozoans, and to some extent worms, gastropods, and mollusks. In lotic systems, the organisms that colonize artificial substrates are primarily drift organisms (e.g., immature insects and eggs) carried by water currents. Placement conditions should be similar so the numbers and kinds of organisms reflect the capacity to support aquatic life.

Position artificial substrates in the euphotic zone (0.3 m) for maximum abundance and diversity of macroinvertebrates.[13] Optimum time for substrate colonization is 6 weeks in most waters. For uniformity of depth, suspend sampler from floats on a 3.2-mm steel cable. If vandalism is a problem, use subsurface floats or place sampler near the bottom. Regardless of installation technique, use uniform procedures.

At shallow water stations (less than 1.2 m deep), install samplers so they are midway in the water column at low flow. For samplers installed in July, when water depth is about 1.2 m and the August average low flow is 0.6 m, install 0.3 m above the bottom. Take care not to let samplers touch the bottom or they may become covered with silt, thereby increasing the sampling error. In shallow streams with sheet rock bottoms, secure artificial substrates to 0.95-cm steel rods driven into the substrate or secure to rods mounted on low, flat, rectangular blocks.

Before removing samples from water, it may be necessary to enclose them in an oversized plastic bag (double wrapping) that is tightly sealed to prevent possible organism loss or else remove them via a large dip net (mesh equivalent to a U.S. Standard No. 30 sieve). Disassemble sampler and brush it in a pan of water in the field or add preservative to the bag containing the intact sampler, and disassemble and brush it later in the laboratory.

Although many styles of artificial substrate samplers have been tested,[39] the basket sampler[13] and the Fullner[40] modification of the Hester–Dendy[41] multiplate sampler are widely used.

a. Multiple-plate (modified Hester–Dendy) sampler (Figure 10500:12) is constructed of 0.3-cm-thick tempered hardboard with 7.5-cm round plates and 2.5-cm round spacers with center-drilled holes. The plates are separated by spacers on a 0.63-cm-diam eyebolt, held in place by a nut at the top and bottom. In each sampler, 14 large plates and 24 spacers are used. Separate the top 9 plates by one spacer. Separate Plate 10 by two spacers, Plates 11 and 12 by three spacers, and Plates 13 and 14 by four spacers. The sampler is approximately 14 cm long and 7.5 cm in diameter, has an exposed surface area of approximately 1300 cm^2, and weighs about 0.45 kg. Do not reuse samplers exposed to oils and chemicals that may inhibit colonization. Because it is cylindrical, the sampler fits inside a wide-mouth container for shipping and storage. The sampler is inexpensive, compact, and lightweight.[13,40,41]

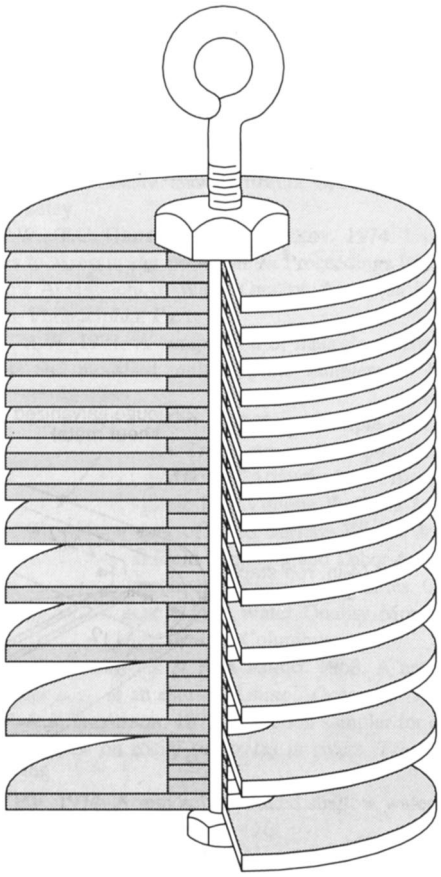

Figure 10500:12. Hester–Dendy artificial substrate unit.

Another type of modified Hester–Dendy, multiple-plate artificial substrate sampler is constructed of 0.3-cm tempered hardboard cut into 7.6-cm square plates and 2.5-cm square spacers.[34] Eight plates and twelve spacers are used for each sampler. The plates and spacers are placed on a 1/4-in. (0.64-cm) eyebolt so there are three single spaces, three double spaces, and one triple space between plates. The sampler's total surface area, excluding the eyebolt, is 939 cm^2 (0.9 m^2). Generally, five samplers are used and placed in streams tied to a concrete construction block as anchor. This prevents samplers from coming into contact with natural substrates.

b. The basket sampler[13] (Figure 10500:13) is a cylindrical "barbecue" basket 28 cm long and 17.8 cm in diameter, filled with approximately thirty 5.1-cm-diam rocks or rocklike material weighing 7.7 kg. A hinged side door allows access to the contents. The sampler provides an estimated 0.24 m^2 of surface area for colonization. The factors governing proper installation

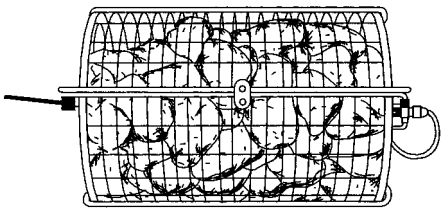

Figure 10500:13. Basket sampler.

and collection are the same as those described for the multiplate sampler. Some investigators prefer using the basket because natural substrate materials are used for colonization.

c. Marsh net sampler (Figure 10500:14) is used for sampling macroinvertebrates in estuarine and marine environments.[42] It can be used in different habitats (e.g., marsh, beach, tidal creek, and tidal flat) of estuarine and marine intertidal zones to depths of 3 m. The metal frame is constructed of No. 22 galvanized sheet metal and 1/4-in. (6-mm) welding rods. A 0.5-m plankton net of nylon monofilament screen is laced to the posterior end of the frame. The net has a bayonet-type cod end for easy removal. The mesh size of the plankton net and cod end is about 1 mm (bar measure). The frame and net weigh 5 kg. The collecting procedures are the same in all intertidal zone habitats. The net is placed at one end of the sampling area, and 30 m of rope is paid out in an arc to prevent the operator from disturbing the sampling site. The net is then retrieved by hand at a rate of about 0.3 m/s. Advantages are that the sampling distance does not have to be measured before taking the sample, the net can be towed at a constant speed, and samples also can be taken over soft mud bottoms.[42]

6. Suction Samplers

Suction samplers are widely used to collect benthic macroinvertebrate samples.[43,44] These samplers can be placed directly on specific sampling sites, but a SCUBA diver is required to collect samples.[45] More accurately located sampling sites and the ability to collect a large number of replicate samples may outweigh the disadvantage of using a diver. Suction samplers have been used widely in sampling marine environments, but they have obvious depth limitations.

7. References

1. Alden, R.W., III, S.B. Weisberg, J.A. Ranasinghe & D.M. Dauer. 1997. Optimizing temporal sampling strategies for benthic environmental monitoring programs. *Mar. Pollut. Bull.* 34:913.
2. Snedecor, G.W. & W.G. Cochran. 1967. Statistical Methods. Iowa State Univ. Press, Ames.
3. Klemm, D.J., P.A. Lewis, F. Fulk & J.M. Lazorchak. 1990. Macroinvertebrate Field and Laboratory Methods for Evaluating the Biological Integrity of Surface Waters, EPA-600/4-90-030. Environmental Monitoring Systems Laboratory, U.S. Environmental Protection Agency, Cincinnati, Ohio.
4. Green, R.H. 1979. Sampling Design and Statistical Methods for Environmental Biologists. John Wiley & Sons, New York, N.Y.
5. Zar, J.H. 1984. Biostatistical Analysis, 2nd ed. Prentice-Hall, Englewood Cliffs, N.J.
6. Underwood, A.J. & C.H. Peterson. 1988. Towards an ecological framework for investigating pollution. *Mar. Ecol. Progr. Ser.* 46:227.
7. Mantel, N. 1987. The detection of disease clustering and a generalized regression approach. *Cancer Res.* 27:200.
8. Legendre, P. & M.J. Fortin. 1989. Spatial patterns and ecological analysis. *Vegetation* 80:107.
9. Green, R.H., J.M. Boyd & J.S. MacDonald. 1993. Relating sets of variables in environmental studies: the sediment quality triad as a paradigm. *Environmetrics* 4:439.
10. Underwood, A.J. 1994. On beyond BACI: sampling designs that might reliably detect environmental disturbances. *Ecol. Appl.* 4:3.
11. Landis, W.G., G.B. Matthews, R.A. Matthews & A. Sargent. 1994. Application of multivariate techniques to endpoint determination, selection and evaluation in ecological risk assessment. *Environ. Toxicol. Chem.* 13:1917.

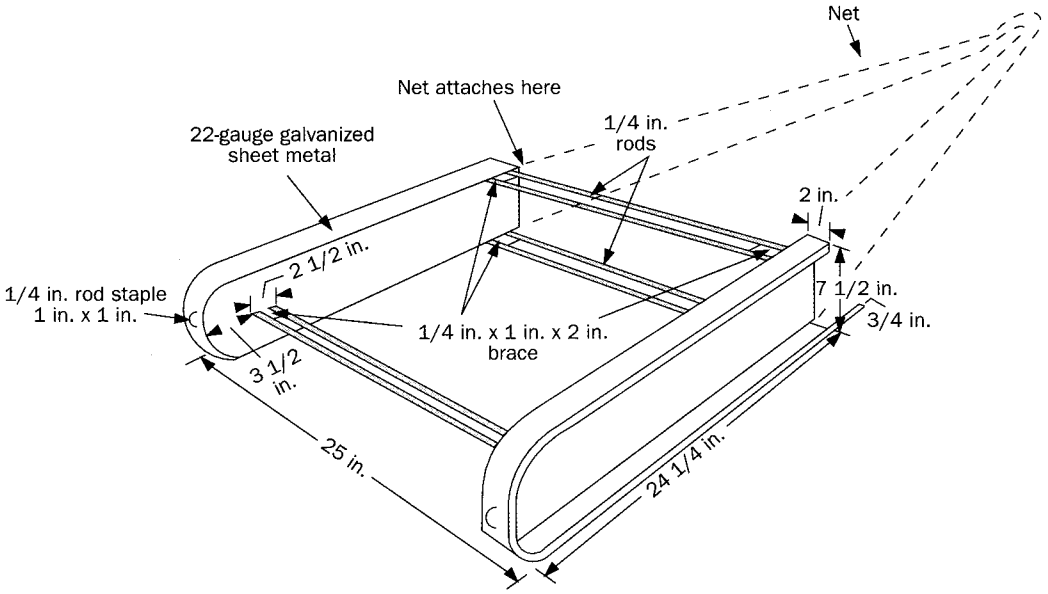

Figure 10500:14. Marsh net sampler.

12. GAUGUSH, R.F. 1987. Sampling Design for Reservoir Water Quality Investigations, Instruction Rep. E-87-1. Waterways Experiment Station, Vicksburg, Miss.
13. MASON, W.T., JR., C.I. WEBER, P.A. LEWIS & E.C. JULIAN. 1973. Factors affecting the performance of basket and multiplate macroinvertebrate samplers. *Freshwater Biol.* 3:409.
14. WEBER, C.I., ed. 1973. Biological Field and Laboratory Methods for Measuring the Quality of Surface Waters and Effluents, EPA-670/4-73-001. U.S. Environmental Protection Agency, Cincinnati, Ohio.
15. POWERS, C.F. & A. ROBERTSON. 1967. Design and Evaluation of an All-Purpose Benthos Sampler, Spec. Rep. No. 30. Great Lakes Research Div., Univ. Michigan, Ann Arbor.
16. SMITH, W. & A.D. MCINTYRE. 1954. A spring-loaded bottom sampler. *Mar. Biol. Assoc. U.K.* 33:257.
17. ELLIOTT, J.M. 1971. Some Methods for the Statistical Analysis of Samples of Benthic Invertebrates, Sci. Publ. No. 25. Freshwater Biological Assoc., Ambleside, U.K.
18. MCINTYRE, A.D. 1971. Efficiency of Marine Bottom Samplers. *In* N.A. Holme & A.D. McIntyre, eds. Methods for the Study of Marine Benthos, IBP Handbook No. 16, p. 140. Blackwell Scientific Publications, Oxford, England.
19. WIGLEY, R.L. 1967. Comparative efficiency of Van Veen and Smith-McIntyre grab samplers as recorded by motion pictures. *Ecology* 48:168.
20. SURBER, E. 1937. Rainbow trout and bottom fauna production in one mile of stream. *Trans. Amer. Fish. Soc.* 66:193.
21. BARNES, H. 1959. Oceanographic and Marine Biology. George Allen and Unwin, Ltd., London, England.
22. BRINKHURST, R.O., K.E. CHUA & E. BATOOSINGH. 1969. Modifications in sampling procedures as applied to studies on the bacteria and tubificid oligochaetes inhabiting aquatic sediments. *J. Fish Res. Board Can.* 26:2581.
23. HOLME, N.A. & A.D. MCINTYRE, eds. 1984. Methods for the Study of Marine Benthos, IBP Handbook 16. Blackwell Scientific Publ., Oxford, England.
24. HESSLER, R.R. & P.A. JUMARS. 1974. Abyssal community analysis from replicate box cores in the central north Pacific. *Deep-Sea Res.* 21:185.
25. PROBERT, P.K. 1984. A comparison of macrofaunal samples taken by box corer and anchor-box dredge. *New Zealand Oceanogr. Inst. Rec.* 4(13):149.
26. ELEFTERIOU, A. & N.A. HOLME. 1984. Macrofauna techniques. *In* N.A. Holme & A.D. McIntyre, eds. Methods for the Study of Marine Benthos, IBP Handbook 16, Chapter 6, p. 140. Blackwell Scientific Publ., Oxford, England.
27. GERDES, D., M. KLAGES, W.E. ARNTZ, R.L. HERMAN, J. GALERON & S. HAIN. 1992. Quantitative investigations on macrobenthic communities of the southeastern Weddell Sea shelf based on multibox cored samples. *Polar Biology* 12:291.
28. REYNOLDSON, T.B. & A.L. HAMILTON. 1993. Historic changes in populations of burrowing mayflies (*Hexagenia limbata*) from Lake Erie based on sediment tusk profiles. *J. Great Lakes Res.* 19:250.
29. WILDING, J.L. 1940. A new square-foot aquatic sampler, Special Pub. No. 4. Limnol. Soc. Amer., Ann Arbor, Mich.
30. KAJAK, Z. 1963. Analysis of quantitative benthic methods. *Ekol. Polska* (A) 11:1.
31. WATERS, T.F. 1961. Standing crop and drift of stream bottom organisms. *Ecology* 42:532.
32. DIMOND, J.B. 1967. Pesticides and Stream Insects, Bull. No. 2. Maine Forest Serv., Augusta & Conservation Foundation, Washington, D.C.
33. WATERS, T.F. 1972. The drift of stream insects. *Annu. Rev. Entomol.* 17:253.
34. OHIO ENVIRONMENTAL PROTECTION AGENCY. 1989. Biological Criteria for the Protection of Aquatic Life: Volume II, Users Manual for Biological Field Assessment of Ohio Surface Waters & Volume III, Standardized Biological Field Sampling and Laboratory Methods for Assessing Fish and Macroinvertebrates Communities. Ohio Environmental Protection Agency, Div. Water Quality Monitoring & Assessment, Surface Water Section, Columbus.
35. FROST, S., A. HUN & W. KERSHAW. 1971. Evaluation of a kicking technique for sampling stream bottom fauna. *Can. J. Zool.* 49:167.
36. CROSSMAN, J.S., J. CAIRNS, JR. & R.L. KAESLER. 1973. Aquatic Invertebrate Recovery in the Clinch River Following Hazardous Spills and Floods, Water Resour. Res. Center Bull. 63. Virginia Polytechnic Inst. & State Univ., Blacksburg.
37. WELCH, P.S. 1948. Limnological Methods. Blakiston Co., Philadelphia, Pa.
38. USINGER, R.L. 1956. Aquatic Insects of California, with Keys to North American Genera and California Species. Univ. California Press, Berkeley.
39. BEAK, T.W., T.C. GRIFFING & G. APPLEBY. 1974. Use of artificial substrates to assess water pollution. *In* Proc. Biological Methods for the Assessment of Water Quality. American Soc. Testing & Materials, Philadelphia, Pa.
40. FULLNER, R.W. 1971. A comparison of macroinvertebrates collected by basket and modified multiple-plate samplers. *J. Water Pollut. Control Fed.* 43:494.
41. HESTER, F.E. & J.B. DENDY. 1962. A multiple-plate sampler for aquatic macroinvertebrates. *Trans. Amer. Fish. Soc.* 91:420.
42. PULLEN, E.J., C.R. MOCK & R.D. RINGO. 1968. A net for sampling the intertidal zone of an estuary. *Limnol. Oceanogr.* 13:200.
43. GALE, W. & J. THOMPSON. 1975. A suction sampler for quantitatively sampling benthos on rocky substrates in rivers. *Trans. Amer. Fish. Soc.* 104:398.
44. LARSEN, P.F. 1974. A remotely operated shallow water benthic suction sampler. *Chesapeake Sci.* 15:176.
45. SIMMONS, G.M., JR. 1977. The Use of Underwater Equipment in Freshwater Research, VPI-SG-77-03. Virginia Polytechnic Inst. & State Univ., Blacksburg.

8. Bibliography

MACAN, T.T. 1958. Methods of sampling bottom fauna in stony streams. *Mitt. Int. Ver. Limnol.* 8:1.

DICKSON, K.L., J. CAIRNS, JR. & J.C. ARNOLD. 1971. An evaluation of the use of a basket type artificial substrate for sampling macroinvertebrate organisms. *Trans. Amer. Fish. Soc.* 100:553.

WASHINGTON, H.G. 1984. Diversity, biotic and similarity indices. A review with special relevance to aquatic ecosystems. *Water Res.* 18:653.

WRONA, F.J., P. CALOW, T. FORD, D.J. BAIRD & L. MALTBY. 1986. Estimating the abundance of stone-dwelling organisms: a new method. *Can. J. Fish. Aquat. Sci.* 43:2025.

BRITTAIN, J.E. & T.J. EIKELAND. 1988. Invertebrate drift—A review. *Hydrobiologia* 166:77.

FERRARO, S.P., F.A. COLE, W.A. DEBEN & R.C. SWARTZ. 1989. Power-cost efficiency of eight macroinvertebrate sampling schemes in Puget Sound, Washington, U.S.A. *Can. J. Fish. Aquat. Sci.* 46:2157.

CUFFNEY, T.F., M.E. GURTZ & M.R. MEADOR. 1993. Methods for collecting benthic invertebrate samples as part of the National Water-Quality Assessment Program, Open-File Rep. 93-405. U.S. Geological Survey, Raleigh, N.C.

SCRIMGEOUR, G.J., J.M. CULP & N.E. GLOZIER. 1993. An improved technique for sampling lotic invertebrates. *Hydrobiologia* 254:65.

HUGHES, R.M. 1995. Defining acceptable biological status by comparing with reference conditions. *In* W.S. Davis and T. Simon, eds. Biological Assessment and Criteria, Tools for Water Resource Planning and Decision Making, Chapter 4, p. 31. Lewis Publishers, Boca Raton, Fla.

REYNOLDSON, T.B., R.H. NORRIS, V.H. RESH, K.E. DAY & D.M. ROSENBURG. 1997. The reference condition: a comparison of multimetric and multivariate approaches to assess water-quality impairment using benthic macroinvertebrates. *J. N. Amer. Benthol. Soc.*16:833.

BARBOUR, M.T., J. GERRITSEN, B.D. SNYDER & J.B. STRIBLING. 1999. Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish, 2nd ed., EPA 841-B-99-002. U.S. Environmental Protection Agency, Off. Water, Washington, D.C.

HEINO, J. 2000. Lentic macroinvertebrate assemblage structure along gradients in spatial heterogeneity, habitat size and water chemistry. *Hydrobiologia* 428:229.

FLOTEMERSCH, J.E., B.C. AUTREY & S.M. CORMIER. 2001. Comparison of Boating and Wading Methods Used to Assess the Status of Flowing Waters, EPA 600-R-00-108. U.S. Environmental Protection Agency, Cincinnati, Ohio.

FLOTEMESCH, J.E., J.B. STRIBLING & M.J. PAUL. 2006. Concepts and Approaches for the Bioassessment of Non-wadeable Streams and Rivers, EPA 600-R-06-127. U.S. Environmental Protection Agency, Cincinnati, Ohio.

AMERICAN SOCIETY for TESTING and MATERIALS. 2010. ASTM D 4342-84: Standard practice for collecting of benthic macroinvertebrates with Ponar grab sampler. *In* Standard Guide for Collection, Storage, Characterization, and Manipulation of Sediments for Toxicological Testing and Selection of Samplers Used to Collect Benthic Invertebrates, 2010 Annual Book of Standards, Vol. 11.06: Biological Effects and Environmental Fate; Biotechnology. [Annex A1 in ASTM E1391-03 (Reapproved 2008)]. American Soc. Testing & Materials, W. Conshohocken, Pa.

AMERICAN SOCIETY for TESTING and MATERIALS. 2010. ASTM D 4343-84: Standard practice for collecting benthic macroinvertebrates with Ekman grab sampler. *In* Standard Guide for Collection, Storage, Characterization, and Manipulation of Sediments for Toxicological Testing and Selection of Samplers Used to Collect Benthic Invertebrates, 2010 Annual Book of Standards, Vol. 11.06: Biological Effects and Environmental Fate; Biotechnology. [Annex A1 in ASTM E1391-03 (Reapproved 2008)]. American Soc. Testing & Materials, W. Conshohocken, Pa.

AMERICAN SOCIETY for TESTING and MATERIALS. 2010. ASTM D 4344-84: Standard practice for collecting benthic macroinvertebrates with Smith–McIntyre grab sampler. *In* Standard Guide for Collection, Storage, Characterization, and Manipulation of Sediments for Toxicological Testing and Selection of Samplers Used to Collect Benthic Invertebrates, 2010 Annual Book of Standards, Vol. 11.06: Biological Effects and Environmental Fate; Biotechnology. [Annex A1 in ASTM E1391-03 (Reapproved 2008)]. American Soc. Testing & Materials, W. Conshohocken, Pa.

AMERICAN SOCIETY for TESTING and MATERIALS. 2010. ASTM D 4345-84: Standard practice for collecting benthic macroinvertebrates with Van Veen grab sampler. *In* Standard Guide for Collection, Storage, Characterization, and Manipulation of Sediments for Toxicological Testing and Selection of Samplers Used to Collect Benthic Invertebrates, 2010 Annual Book of Standards, Vol. 11.06: Biological Effects and Environmental Fate; Biotechnology. [Annex A1 in ASTM E1391-03 (Reapproved 2008)]. American Soc. Testing & Materials, W. Conshohocken, Pa.

AMERICAN SOCIETY for TESTING and MATERIALS. 2010. ASTM D 4346-84: Standard practice for collecting benthic macroinvertebrates with Okean 50 grab sampler. *In* Standard Guide for Collection, Storage, Characterization, and Manipulation of Sediments for Toxicological Testing and Selection of Samplers Used to Collect Benthic Invertebrates, 2010 Annual Book of Standards, Vol. 11.06: Biological Effects and Environmental Fate; Biotechnology. [Annex A1 in ASTM E1391-03 (Reapproved 2008)]. American Soc. Testing & Materials, W. Conshohocken, Pa.

AMERICAN SOCIETY for TESTING and MATERIALS. 2010. ASTM D 4347-84: Standard practice for collecting benthic macroinvertebrates with Shipek (scoop) grab sampler. *In* Standard Guide for Collection, Storage, Characterization, and Manipulation of Sediments for Toxicological Testing and Selection of Samplers Used to Collect Benthic Invertebrates, 2010 Annual Book of Standards, Vol. 11.06: Biological Effects and Environmental Fate; Biotechnology. [Annex A1 in ASTM E1391-03 (Reapproved 2008)]. American Soc. Testing & Materials, W. Conshohocken, Pa.

AMERICAN SOCIETY for TESTING and MATERIALS. 2010. ASTM D 4348-84: Standard practice for collecting benthic macroinvertebrates with Holme (scoop) grab sampler. *In* Standard Guide for Collection, Storage, Characterization, and Manipulation of Sediments for Toxicological Testing and Selection of Samplers Used to Collect Benthic Invertebrates, 2010 Annual Book of Standards, Vol. 11.06: Biological Effects and Environmental Fate; Biotechnology. [Annex A1 in ASTM E1391-03 (Reapproved 2008)]. American Soc. Testing & Materials, W. Conshohocken, Pa.

AMERICAN SOCIETY for TESTING and MATERIALS. 2010. ASTM D 4387-84: Standard guide for selecting grab sampling devices for collecting benthic macrovinvertebrates. *In* Standard Guide for Collection, Storage, Characterization, and Manipulation of Sediments for Toxicological Testing and Selection of Samplers Used to Collect Benthic Invertebrates, 2010 Annual Book of Standards, Vol. 11.06: Biological Effects and Environmental Fate; Biotechnology. [Annex A1 in ASTM E1391-03 (Reapproved 2008)]. American Soc. Testing & Materials, W. Conshohocken, Pa.

AMERICAN SOCIETY for TESTING and MATERIALS. 2010. ASTM D 4401-84: Standard practice for collecting benthic macroinvertebrates with Petersen grab sampler. *In* Standard Guide for Collection, Storage, Characterization, and Manipulation of Sediments for Toxicological Testing and Selection of Samplers Used to Collect Benthic Invertebrates, 2010 Annual Book of Standards, Vol. 11.06: Biological Effects and Environmental Fate; Biotechnology. [Annex A1 in ASTM E1391-03 (Reapproved 2008)]. American Soc. Testing & Materials, W. Conshohocken, Pa.

AMERICAN SOCIETY for TESTING and MATERIALS. 2010. ASTM D 4407-84: Standard practice for collecting benthic macroinvertebrates with orange peel grab sampler. *In* Standard Guide for Collection, Storage, Characterization, and Manipulation of Sediments for Toxicological Testing and Selection of Samplers Used to Collect Benthic Invertebrates, 2010 Annual Book of Standards, Vol. 11.06: Biological Effects and Environmental Fate; Biotechnology. [Annex A1 in ASTM E1391-03 (Reapproved 2008)]. American Soc. Testing & Materials, W. Conshohocken, Pa.

AMERICAN SOCIETY for TESTING and MATERIALS. 2010. ASTM D 4556-85: Standard guide for selecting stream-net sampling devices for collecting benthic macroinvertebrates. *In* Standard Guide for Collection, Storage, Characterization, and Manipulation of Sediments for Toxicological Testing and Selection of Samplers Used to Collect Benthic Invertebrates, 2010 Annual Book of Standards, Vol. 11.06: Biological Effects and Environmental Fate; Biotechnology. [Annex A1 in ASTM E1391-03 (Reapproved 2008)]. American Soc. Testing & Materials, W. Conshohocken, Pa.

AMERICAN SOCIETY for TESTING and MATERIALS. 2010. ASTM D 4557-85: Standard practice for collecting benthic macroinvertebrates with Surber and related type samplers. *In* Standard Guide for Collection, Storage, Characterization, and Manipulation of Sediments for Toxicological Testing and Selection of Samplers Used to Collect Benthic Invertebrates, 2010 Annual Book of Standards, Vol. 11.06: Biological Effects and Environmental Fate; Biotechnology. [Annex A1 in ASTM E1391-03 (Reapproved 2008)]. American Soc. Testing & Materials, W. Conshohocken, Pa.

AMERICAN SOCIETY for TESTING and MATERIALS. 2010. ASTM D 4558-85: Standard practice for collecting benthic macroinvertebrates with

drift nets. *In* Standard Guide for Collection, Storage, Characterization, and Manipulation of Sediments for Toxicological Testing and Selection of Samplers Used to Collect Benthic Invertebrates, 2010 Annual Book of Standards, Vol. 11.06: Biological Effects and Environmental Fate; Biotechnology. [Annex A1 in ASTM E1391-03 (Reapproved 2008)]. American Soc. Testing & Materials, W. Conshohocken, Pa.

AMERICAN SOCIETY for TESTING and MATERIALS. 2010. ASTM E 1468-92: Standard practice for collecting benthic macroinvertebrates with basket sampler. *In* Standard Guide for Collection, Storage, Characterization, and Manipulation of Sediments for Toxicological Testing and Selection of Samplers Used to Collect Benthic Invertebrates, 2010 Annual Book of Standards, Vol. 11.06: Biological Effects and Environmental Fate; Biotechnology. [Annex A1 in ASTM E1391-03 (Reapproved 2008)]. American Soc. Testing & Materials, W. Conshohocken, Pa.

AMERICAN SOCIETY for TESTING and MATERIALS. 2010. ASTM E 1469-92: Standard practice for collecting benthic macroinvertebrates with multiplate sampler. *In* Standard Guide for Collection, Storage, Characterization, and Manipulation of Sediments for Toxicological Testing and Selection of Samplers Used to Collect Benthic Invertebrates, 2010 Annual Book of Standards, Vol. 11.06: Biological Effects and Environmental Fate; Biotechnology. [Annex A1 in ASTM E1391-03 (Reapproved 2008)]. American Soc. Testing & Materials, W. Conshohocken, Pa.