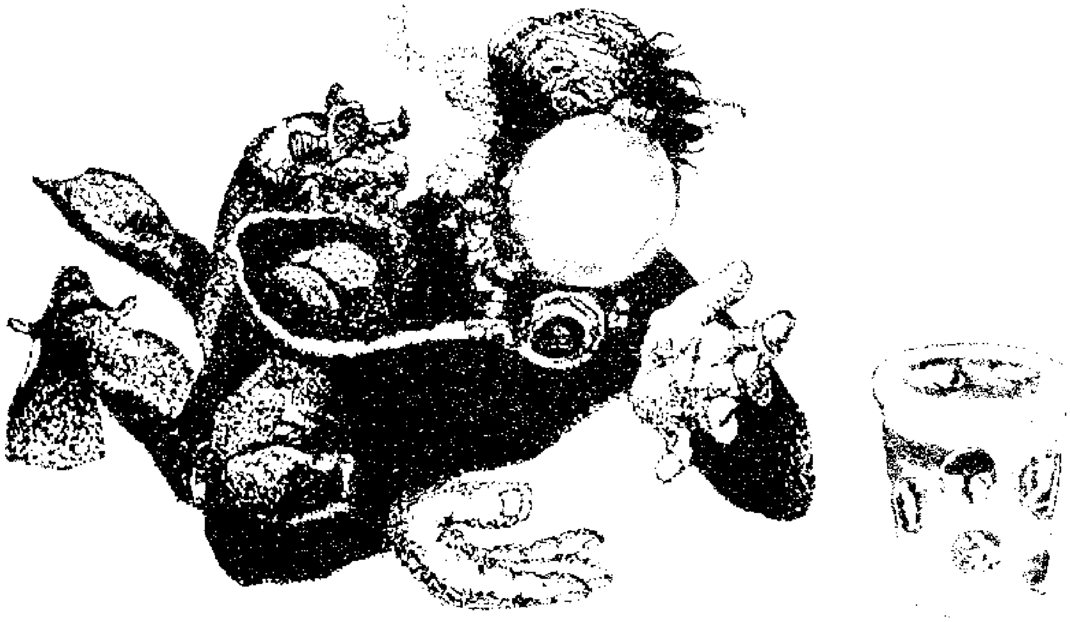
The Use of Underwater Equipment in Freshwater Research



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ADDENDUM

It should be noted that OSHA recently adopted the final standard regarding requirements for commercial diving operations (Federal Register, July 22, 1977). The standard also includes diving for scientific/educational purposes and means that research divers come under these recently proposed standards. The standard becomes effective on October 20, 1977. The general operations procedures are quite lengthy and currently existing research dive teams, or individuals considering the establishment of such teams, should review the general operations procedures for compliance with the standard.

Office of the Federal Register
1977. Commercial Diving Operations.
Federal Register
42(141): 37650-37673.

RESEARCH DIVING: AN OVERVIEW

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ABSTRACT

The use of self contained underwater breathing apparatus in aquatic environments for scientific purposes is a recent development. While its use for such purposes in marine enviornments has been well received and documented, corresponding useage in freshwater environments has languished. Reasons for this are attributed to: 1) misconceptions regarding safety, necessary levels of training, cost, and versatility; 2) the lack of adequate training programs; and 3) a generation of "decision makers" who themselves have not used such equipment and fail to recognize its potential. Available data on human fatalities indicate that the use of underwater breathing apparatus by well trained, qualified divers is less hazardous than most other activities in which a person normally engages. The evolution of adequate training courses or programs will depend upon the needs of the scientific community. Versatility and usefullness of the equipment depend upon the innovative ability of the researcher.

RESEARCH DIVING: AN OVERVIEW

The development of underwater breathing equipment is older than the recorded history of Man. No doubt pre-historic peoples used fore runners of today's snorkels, goggles and fins in their search for food and jewels (pearls). In many civilizations military uses provided the foundation for much of diving's support and development. It is reported that the Greek navies maintained a group of skin divers whose sole purpose was to sink enemy ships by a variety of sabotage techniques. Alexander the Great reportedly made a descent in a diving bell. Diving bells were used very frequently through the ages and were the basic diver support system until the 1800's when several new types of support systems emerged. W. H. James (ca. 1825) was the first to use compressed air which was contained in an iron doughnut worn around the waist. This apparatus, as well as similar pieces of equipment, were free-flowing and none utilized a demand regulator. In 1866, a Frenchman named Rouguaroyal, developed the first satisfactory demand regulator for open-circuit scuba. But since there were no containers which would hold high pressure air, or compressors to produce such high pressures, his invention went unnoticed. It was not until the development of steel tanks and high pressure compressors that the use of underwater equipment really became feasible. Haldane and his associates (ca. 1907) were the first to mathematically model the decompression problem and to relate decompression sickness to sound mathematical and physiological bases. Cousteau and Gagnan (ca. 1940) improved the demand regulator and combined it with high pressure air tanks to provide the first safe scuba system as we know it today. Due to the value of scuba for military purposes, considerable advancement was made during World War II and most nations developed underwater swimmer schools to train men to use underwater breathing apparatus. Details of the history of diving are provided by Dugan (1956), U.S. Department of the Navy (1973), Somers (1972), and others.

With the cessation of military activities in the mid-1940's, the frogmen returned home and began practicing their scuba activities as a hobby. People, such as Cousteau, helped to popularize the activity, and by the late 50's and early 60's a bourgeoning sport was in operation. Early divers were generally likened to motorcycle enthusiasts, stunt pilots, and parachutists. This concept is still reflected today in insurance premiums and unacceptability of underwater equipment in research activities.

Training and Certification

In the early 1960's, various groups of divers, mostly military-trained personnel, banded together and established standards of instruction and safety for new divers. These efforts led to the formation of training and certifying agencies such as the National Association of Underwater Instructors (NAUI), the Professional Association of Diving Instructors (PADI), and a diving branch within the Young Men's Christian Association (YMCA).

Currently, there is a self-policing action within the diving industry. Generally, for an individual to buy or rent diving equipment, he must show proof of having completed a course sanctioned by a national/international diving association such as NAUI, PADI, or the YMCA. Each association trains its own instructors and much emphasis is placed on teaching technique and safety. Most beginning courses are ∿50 hours in length with ∿25 hours spent in classroom instruction, ∿20 hours in pool training and ∿5 hours in open water training exercises. The successful completion of a course reflects the instructor's confidence in the student and the instructor's willingness to recommend the student as a "safe diving partner."

Most beginning courses include an introduction to the concepts listed in Table 1, but due to the diversity of organizations offering such training (universities, dive shops, government, etc.), the content and level of training varies somewhat. At best, newly trained students are equivalent to youngsters with a learner's permit for driving. Most instructors realize, and should emphasize, that it will take many dives before the student develops the maturity to be a competent diver. In contrast to some opinions, the "seasoning" appears to be related not only to the frequency of dives but also to the variability of diving experiences. Therefore, if one dived only a few times each year and always in the same situation, he would never be a competent diver. Even "old water dogs" who dive regularly feel a certain degree of apprehension upon entering an underwater environment for the first time. Egstrom (Tzimoulis, 1976) believes that after a person finishes a basic diving course, he should make his next 10-12 open water dives under the close supervision of a certified instructor or a seasoned diver. The entire learning experience may span two years or more, and encompass some 40-50 open water dives.

The Metamorphosis of a Research Diver

Most divers who eventually participate in projects as bonafide research divers have come from the ranks of sport divers. The former group usually represent the few individuals who are organized in their efforts, self-disciplined and highly motivated, and are versed in some professional field other than diving. For example, it is much easier to teach an ecologist to dive than to teach a diver ecology. Most research divers have also acquired their status through "on the job training" since there are very few courses available which provide the opportunity for divers to develop the necessary skills for using specialized equipment in actual sampling processes. While there are many sport divers who "have tanks and will travel", there are relatively few individuals who are willing to discipline themselves and endure the long hours and often hard work under the most arduous conditions to ensure that a particular task is performed satisfactorily. In some cases the advanced diving courses taught through the various certifying agencies provide some of the training that is required in underwater research projects.

Since there is currently little or no opportunity for research diver training, such teams are usually the result of one individual (usually a research project leader) selecting the best of available sport divers and training them individually to perform the necessary skills or techniques which will help make the project a success. It appears that the lag in the use of underwater equipment in freshwater research stems from 1) research investigators who fail to appreciate the versatility and potential of such techniques because they, themselves, have not used underwater equipment for research purposes, 2) the lack of available courses to train research divers, and 3) the reluctance to implement existing research dive teams by administrators due to misconceptions regarding safety, cost and, benefits.

Safety Aspects

One of the main reasons that many project managers are hesitant to implement a research dive team into a project is because of the safety aspects. Table 2 compares the latest official data of scuba fatalities with other fatalities. Most fatality statistics, other than scuba, are based upon the number of deaths per 100,000 persons in the general population (National Safety Council, 1972). If one uses the same comparison for scuba fatalities (incurred with compressed air only), the probability of a diver becoming a fatality (scuba a.) is approximately 100 times less than for a person using an automobile for transportation, approximately 10 times less than for drowning, and 100 times less than fatalities due to home and firearm accidents. If one compares the scuba fatalities (scuba b.) with the estimated number of certified divers (Schenck and McAniff, 1975), the probability is still slightly less than our most common means of transportation. If one considers the fatality statistics for working divers only (scuba c.) with the estimated number of certified divers, the probability of a working (research) diver becoming a fatality statistic is still 10 times less than our most common means of transportation. Certainly the use of scuba by trained personnel is no more dangerous than most other daily activities in which we normally engage and much less dangerous than our most common means of transportation.

Human Performance

In the majority of sport diving courses, much emphasis is placed on the buddy system and buddy breathing. Research divers in freshwater usually must work in very dark, cold environments where a buddy may be more of a liability than an asset. Under these conditions, there is usually enough work to keep one diver warm, but the second diver, being inactive, may begin to exhibit symptoms of hypothermia. Moreover, in dark water it is probably much better for a diver to be responsible only for himself, rather than attempt to try and find his buddy in an emergency. Dark water would also preclude the rescuing diver from seeing or recognizing the problem and providing the necessary assistance.

Self-reliance in an emergency is often a new concept for freshwater research divers. Such a diver must be acutely aware of his homeostatic condition, have the necessary equipment to apprise him of depth and remaining air pressure, a sharp knife which is readily accessible in case of entanglement, and a dependable bouyancy compensator. While working in dark water, it is absolutely essential for the diver to be mentally aware of his own position, the position of the equipment being used, and the position of anchor and communication lines. At the slightest indication that something is wrong (cramps, hypothermia, nausea, dizziness, etc.) he should be prepared and able to leave his position and float at the surface until picked up.

Given the necessary training, equipment, and precautions, some divers still become fatality statistics. Schenck and McAniff (1975) indicate that most of the fatalities attributed to medical and injury related causes were due to drowning as a result of possible exhaustion, embolism, or panic. My observations indicate that most divers who get into trouble do so because of panic. A supervisor rightly needs to know the probability that his divers can extricate themselves from a problem in an emergency situation. More importantly, a research dive team leader should know the relationship between stress levels and the reliability of human performance. These concepts deal with studies of human-reliability analyses and very little information of this type exists for any field of endeavour. However, two studies of interest are reported by the U.S. Nuclear Regulatory Commission (1975). In one study, Strategic Air Command crews were evaluated after they survived in-flight emergencies. In 16% of the cases, such highly trained crews either made emergency situations worse or did not provide the proper reaction to solve or eliminate the problem. In a seoond study, infantry recruits were subjected to a simulated mortar attack. As many as 33% failed to perform the necessary task that would have stopped the simulated attack. Other reported data on stress and human behavior (Appley and Turnbull, 1967) indicate that the relationship between stress and human performance is curvilinear (Fig. 1). At very low stress levels, the task is so dull that workers perform below maximum levels and accidents due to carelessness are quite likely. When stress levels become very high, performance begins to decline due to the psychological stress of a panic situation. Human performance is lowest at the highest stress levels. When the stress level of a task is intermediate between these extremes, optimum performance is reached.

The task of a research dive team leader is to keep his men at the optimal level of performance without introducing the psychological stress of fear which ultimately may lead to panic. In most cases, working in cold, dark water will prevent the job from being mundane or dull. The real problem is preventing high stress situations. Assuming proper training, reliable equipment, and good physical condition, the prevention of such situations can be accomplished by:

1. familiarizing the members with the project or details of the tasks that will be required of them before diving on the project,
2. leaving "time frames" for later dives,
3. beginning slowly and allowing sufficient underwater time for familiarization with the details of what is to be accomplished, and

4. having the diver repeat the process under close supervision a number of times until he becomes confident of his surroundings and the task that is required of him.

Even "seasoned" sport divers require a period of acclimation before they can satisfactorily perform the necessary tasks required in underwater research projects.

All of this points to the fact that a company or agency desiring underwater researchers should provide for the support of an experienced team of divers rather than rely upon "recent graduates" of a basic scuba course. It takes a considerable amount of training, hard work, and much "bottom time" to become a dependable research diver. Competent managers or adminstrators realize that there is no short-cut or inexpensive route to dependable workers, in general, and enthusiasm is no substitute for training and experience.

Underwater Research - Pros and Cons

No one wishes to fall into the trap of building research projects around new equipment. Underwater research equipment and techniques are not the answer to all freshwater research problems because these techniques definitely have their limitations. As in all research, there is a cost/benefit consideration. The projects should be of sufficient duration and frequency of recurrence to justify the use of underwater research equipment. The depth required for sampling or the altitude of the lake may pose decompression problems, although the use of surface supplied techniques as discussed by Somers (pp.54-55) may alleviate this problem. In most cases, the use of underwater equipment allows the researchers to perform existing tasks better, provides additional versatility, and allows the investigators to make valuable direct visual observations. In some cases, the cost of establishing a research dive team may pay for itself in the recovery of lost equipment.

The cost would vary depending upon the objectives of the porject, the number of team members to be utilized, and the availability of rental equipment through professional dive shops in the area. As little as $500.00 might equip two divers for spring-fall work. However, as much as $15,000-20,000 or more could be spent to equip four men to operate 12 months a year in temperate latitudes. The equipment in this case could include a compressor with storage tanks, multiple sets of diving tanks and regulators, cold water suits, and supporting equipment.

Whatever the initial cost, the investment will more than pay for itself by:

1. allowing researchers to consider problems which had been previously inaccessible,
2. improving sampling techniques on existing projects, and

3. allowing the researchers to make direct observations of the underwater environment.

Summary

The use of underwater equipment for research purposes in any aquatic habitat is a relatively recent development. Training techniques, life support systems and sampling techniques are still in their early stages of evolution. While the use of underwater equipment for research purposes is readily accepted in marine fields (U.S. Department of Commerce, 1975), there has been a reluctance to utilize such techniques in similar freshwater environments. Much of the reluctance has stemmed from misconceptions regarding training requirements, safety, cost, and versatility of equipment and personnel. In fact, adequate sampling of specific habitats, such as the benthos of large rivers, may have to rely exclusively on research dive teams and the techniques designed for sampling such habitats. The purpose of the papers in this symposium is to demonstrate that:

1. the use of underwater research equipment by qualified divers is not as unsafe as one would be led to believe,
2. the use of underwater research equipment provides a dimension in sampling which, where feasible, vastly supercedes conventional hand-operated methods,
3. for a minimal investiment and the use of slightly modified conventional equipment, the use of underwater diving equipment allows greater sampling versatility and reliability, and
4. the use of divers for research purposes necessitates a level of training, discipline, and support beyond that of "recent graduates" from a basic, general course.

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Table 1. Topics covered in a general scuba course.

GENERAL COURSE CONTENT

A. Classroom
Introduction
Equipment
Diving Physics
Diving Physiology
Medical Aspects
Planning and Procedures
Underwater Environment

B. Pool
Qualification Tests
Use of Basic Skin Diving Equipment
Entries and Exits
Buddy Breathing
Towing
Hand Communication
Doff and Don
Artificial Respiration

C. Open Water Training Exercies
Introduction to Open Water
Pool Skills
Specific Tasks

Table 2

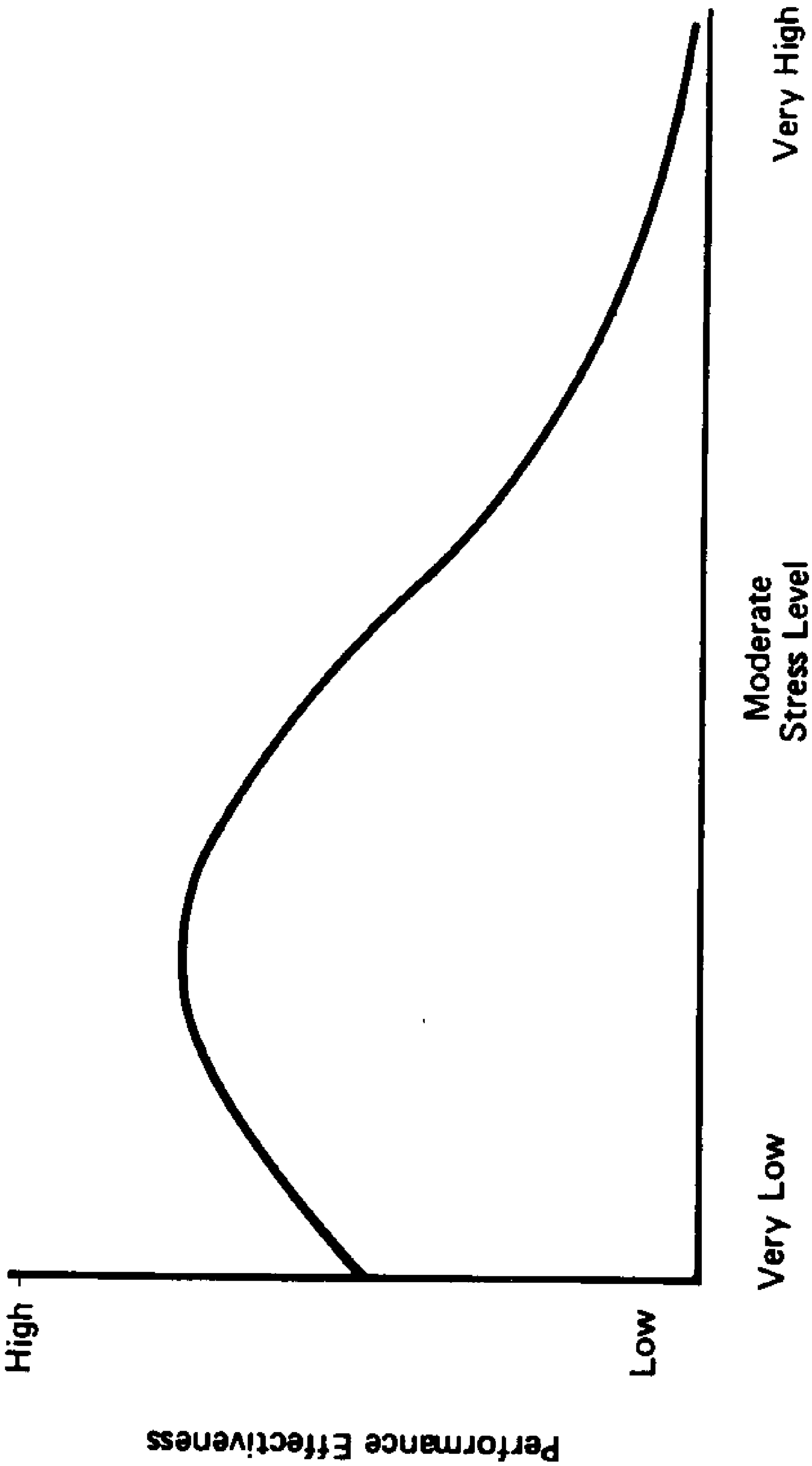
FATALITY PROBABILITIES

Cause		Probability
Transportation		
Airplane		7/10,000 (1)
Train		4/1,000,000 (1)
Automobile		4/10,000 (1)
Daily Activities		
Home		1/10,000 (1)
Firearm		1/10,000 (1)
Drowning		4/100,000 (1)
Boating		1/10,000 (1)
Underwater Breathing Apparatus		
Scuba	a.	6/1,000,000 (2)
	b.	2/10,000 (2)
	c.	1/100,000 (2)

(1) National Safety Council Facts (1972)

(2) Schenck and McAniff (1975)

Figure 1. Relationship between human performance effectiveness and stress levels.



SCUBA, THE PROBLEM SOLVER IN SAMPLING RIVER BENTHOS

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ABSTRACT

When sampling river benthos it is often impossible to: 1) visually delineate bottom habitats in turbid water; 2) penetrate rocky substrates with conventional grabs and corers; 3) position the sampler accurately; and 4) obtain samples large enough to formulate population estimates of scarce organisms. These problems can be surmounted by using the innovative sampling gear, diving accessories, and scuba techniques reviewed here. Ancillary uses of scuba in studies of water chemistry, periphytic algae, fish reproduction, and other similar areas are discussed.

SCUBA, THE PROBLEM SOLVER IN SAMPLING RIVER BENTHOS

The objectives of this presentation are to review problems encountered when sampling large rivers with conventional sampling gear and to suggest solutions to these problems using scuba. Problems of surveying the benthos on rocky substrates are stressed. Examples provided are based upon studies that I have participated in, and were selected because of my familiarity with them. There were, however, few other choices, since scuba has received shamefully little use in river studies. In such studies the importance of observation, the basic element in the scientific method, seems to have been ignored.

SOME PROBLEMS IN SAMPLING THE BENTHOS

Inability to Delineate Bottom Habitats

The inability to delineate bottom habitats because of deep, turbid water is one of the main problems in sampling rivers. This problem can be serious and may result in the adoption of an undesirable type of sampling program. For example, if all substrates are to be sampled in waters where the bottom cannot be seen, a "simple random sampling" program may have to be selected.

Simple random sampling should usually be avoided, however, for it can be grossly inefficient. This is especially true in lotic waters where substrate types change abruptly. Too many samples may have to be taken from common substrates to obtain enough from uncommon ones. Because the overall cost of the study is directly related to the number of samples taken, selective processes will favor the efficient biologist (or group of biological consultants) who can provide a unit of information based upon the fewest samples. As the acquisition of ecological data becomes an increasingly large business enterprise, competition for contracts will become more intense. To survive, the biologist of the future may have to forsake simple random sampling programs and favor some form of "stratified sampling" instead. The latter is more efficient (Cummins 1962) and therefore less costly.

A stratified sampling program is not difficult to implement if the bottom is visible, at least during initial phases when sampling sites are established. Can there be a more direct, simpler method of viewing the river bottom in deep, turbid water than with scuba?

Inability to Penetrate the Substrate

Another common problem, one fairly well confined to rocky-bottomed rivers and lakes, is an inability to penetrate the substrate with conventional grabs and corers. Obviously, the Surber square foot sampler (Surber 1937), which was designed for a rocky substrate in shallow water streams, is unsuitable for moderately deep water or strong currents. Drag nets and various other samplers, designed for shallow streams, are equally useless in a large river. This inability to obtain quantitative samples with conventional gear has caused many researchers to use artificial substrates.

Several kinds of artificial substrates have resulted, but all share inherent problems; of these, the need to wait for macroinvertebrate colonization is paramount. Many undesirable events may occur during this delay. For example, the sampler may collect larger amounts of detritus and create a unique habitat unrepresentative of the river bottom. If the sampler is marked by a surface buoy, it may be destroyed by vandals or swept away by floating debris or ice. If the sampler is unmarked, the biologist may be unable to relocate it; if he can, he may be unable to retrieve it from a boat. Even if the sampler survives to yield a sample that can be retrieved in a way preventing the loss of macroinvertebrates, one still questions how well the sample reflects the size and composition of the benthic community on the natural substrate.

Inability to Situate the Sampler

The need to collect samples from a specific location (such as behind a boulder or next to a log) presents a third sampling problem. The biologist, in a boat pivoting on the anchor rope, is in a poor position to control a sampler lowered by a line into strong currents. It is practically impossible to sample precipitous bottoms and steeply sloping river banks from a boat. There is also a need for sampling accuracy in studies where samples are selected to obtain specific organisms visible on the substrate.

Inability to Obtain a Large Sample

Estimating the population size of scarce organisms, such as freshwater mussels, poses a substantial problem in both lotic and lentic waters. Formulating such an estimate requires a tremendous number of grab or core samples. Drag or push devices which sample a large area are unsuitable for irregular substrates and a small mesh would probably clog quickly in fine substrates. Accurate determination of the size of area sampled is impossible. Consequently, few investigators bother to estimate the population size of scarce organisms even though they may compose a large percentage of the benthic biomass.

THE ALTERNATIVE, SAMPLING BY SCUBA -- A CASE HISTORY

A review of specific problems and the solutions provided by scuba in a six year study of the rocky-bottomed Susquehanna River will be used as a case history. The Susquehanna in Pennsylvania is a large, turbid river with moderate to strong currents. Near our Berwick laboratory the river is over 300 m wide with depths up to 10 m. Secchi disc values in 1973-74 ranged from 2 to 179 cm and often there was no visible light near the river bottom; currents sometimes reached 3 m/sec. In 1970, before establishing scuba competency, we tested a variety of samplers in the river and found that none were suitable for the coarse substrate. Even the use of Bar-B-Q baskets filled with stones (Mason et al. 1967) presented problems by collecting large amounts of detritus. We decided that a new approach to sampling was needed and that a biologist should receive scuba training. After designing new diving accessories and refining scuba techniques, we were able to function in the Susquehanna with relative ease. We were then ready to attack the problem of the rocky substrate with new types of sampling gear.

Diving Accessories

When we began to sample with scuba, a series of small but urgent problems arose; most of these were associated with current. Strong currents pose the largest, most nearly universal obstacle to sampling with scuba in rivers. Because sampling success is directly related to the diver's ability to cope with the current, he must learn not only to minimize its effects upon him, but alos, to use the current to his advantage. The diver can perform surprising feats through the judicious use of compressed air, gravity, and current.

The first problem was anchoring in strong currents. We needed an anchor light enough to be lifted from the water, yet strong enough to hold against the great drag created by the diver clinging to the boat. Most anchors are designed for sand or silt, and are unsuitable for cobbles and boulders like those in the Susquehanna. We ended the problem by building and using two compact, "lead-filled" anchors, each weighing about 27 kg (Fig. 1). The anchors' large "wrap-around" handles made them easy to manipulate and carry. The anchors were placed in "series" with sufficient rope between them to allow each to be lifted separately from the water. Anchors in series held better than those on separate lines.

The second problem was to reach the river bottom without being swept downstream. Initially, the diver descended to the river bottom by climbing hand-over-hand along the anchor rope. But, in strong currents, this method was too exhausting. We found that he could easily reach the bottom and ascend from it by utilizing the current and a separate rope (ascent/descent line) attached to a weight. To descend, the diver held to the rope, lowered his head into the water, and allowed the current to force him to the bottom. To ascend, he held to the rope, raised his head into the current and allowed the water to lift him to the surface. The diver would need to inflate his vest to ascend if he wore two weight belts.

In strong currents, the diver found it impossible to move upstream along the bottom or to maintain a constant position for any extended period of time; these were essential for exploration, mapping, and sampling. These problems were eliminated by designing a "creeper" device (Fig. 1) that he used to move forward (Fig. 2), backward, and laterally across the rocky bottom (Gale and Thompson 1974a). The creeper was a convenient place to secure sampling gear in the current and it also served as a pivot for the diver's "search line" (Fig. 2). The creeper provided an underwater anchor where the diver could attach himself to work or rest with his hands free.

A pair of vise grip pliers can be modified (Fig. 3) to provide the diver with a reliable means of attaching himself to underwater objects (J. Douglas Thompson, Clearbrook, Minnesota, personal communication). The adjustable jaws of the pliers can be clamped to the creeper, to an underwater rope, or to other gear the diver may be using. A 70 cm cord joins the pliers to a large clip attached to a ring on the diver's weight belt. The diver can release himself easily by pressing the pliers' quick-release handle. If the diver uses a longer cord, for greater mobility, he cannot reach the pliers quickly to release himself. This problem can be solved by reversing the relative positions of the clip and pliers. That is, the clip is placed on the anchoring object and the pliers are clamped to the diver's belt. The pliers, with the cord wrapped around them lengthwise, can be snapped to the ring on his belt when not in use. Snapping the pliers to the ring, which may not be in view, may require a little practice.

Reentering a boat anchored in strong currents was an exhausting task for a diver burdened by air tanks and weight belt(s) and such gear may be lost if removed in the water. Yet, a diver cannot afford to waste energy if much work is to be done, especially where the continual struggle against the current brings quick fatigue. We mastered reentry with a detachable diver's ladder (Gale and Thompson 1975a) that mounted on the boat's transom out of the current. It fit at an angle, allowing the diver to lean forward while mounting (Fig. 4) which reduced strain on his shoulders. The ladder's "open steps" provided easy access for the diver's fins. The ladder also provided an "in-the-water" site where the diver could stand or kneel to "catch his breath". Sometimes it was more valuable as a resting site than as a means of reentering the boat.

A drifting boat is easier to reenter than an anchored one. If the boat must be anchored, it should be quickly releasable by the boat operator. This can be accomplished by passing the anchor rope twice around a metal snubbing post at the bow and fastening the loose end in a cam cleat near the back seat. To free the boat, the operator has only to lift the rope from the cleat. On the other hand, if the boat is unanchored, the operator can keep it "standing by" several meters downstream from the diver's bubbles; the diver can drift to it in a few seconds after surfacing. When he reaches the boat, the engine is stopped to nullify the effects of current upon him. For the diver's safety, the boat and motor should be in excellent condition and the boat operator should be thoroughly familiar with their use. The operator should also be familiar with the diver's routine and know exactly what to do in an emergency.

Occasionally, we needed to transport bulky, fragile loads to and from the river bottom. For this purpose we built a light-weight, submersible raft (Fig. 5) capable of lifting loads of up to 45 kg (Gale and Thompson 1974a). Although load balance was important, the raft was simple to use. To submerge, two ball valves on top were opened to let air out; water filled the pontoons through bottom holes, causing the raft to sink. The diver closed the ball valves after reaching the bottom; to ascend, he forced water from the pontoons by jetting air into them from his tank. While the raft was ascending and descending it was attached to a stationary object such as the boat transom or a heavy anchor.

Sampling the Benthos with Artificial Substrates

Relocating "unmarked" baskets in almost total darkness and retrieving them without losing macroinvertebrates required the development of special search techniques and the fabrication of basket-retrieval bags (Gale and Thompson 1974b). Relocation of the baskets was facilitated by attaching them at intervals to a long rope, fastened at the upstream end by an iron stake driven flush with the bottom (Fig. 6). The diver could relocate the rope, even in the dark, by touch. Using the creeper or an anchor as a pivot, the diver swung from a search line in widening arcs across the substrate (Figs. 2 and 6). One hand was dragged along the bottom to detect the basket rope. Ropes were used in a similar fashion as hidden, semipermanent, underwater markers. Such markers did not collect detritus, freeze into the ice, or present a hazard to boats.

Sampling the Benthos with a Suction Sampler

Unfortunately, Bar-B-Q baskets collected substantial amounts of detritus, even with deflector cones over upstream ends. Rather than expending more effort trying to improve a system that could only partially answer our benthological questions, we decided to build a self-contained suction sampler the diver could take underwater to collect quantitative samples in habitats ranging from sand to bedrock. Suction samplers of various types have been used in marine work for several years (Gale and Thompson 1975b); however, marine suction samplers and the one Zimmermann and Ambühl (1970) used in German rivers were not self-contained and had to be connected to a pump in a boat.

Dome suction samplers with two types of bands were built (Gale and Thompson 1975b). One had a serrated band for use on sand and gravel, with a few cobbles mixed in (Fig. 7), and the other had a self-adjusting foam cylinder band for use in cobbles and bedrock. We usually transported the sampler to the sampling site in a boat. It could be carried on a raft, floated under an inner tube (Fig. 7), or carried by a person wading from shore. The sampler could be precisely placed on specific sampling sites, thereby solving a basic sampling problem.

To collect a sample, the diver reached inside the sampler and vacuumed the substrate for a fixed period of time. The suction was created by a bilge pump powered by a 12-volt motorcycle battery. Macroinvertebrates, sand, organic detritus, and silt were pumped into a detachable collecting net. By using more than one collecting net, several samples were collected at a site without returning to the river surface; sometimes samples were sent to the surface on inflatable floats (or in other ways) for processing by the boat operator while more samples were taken. Most stones in the Susquehanna were rather smooth and coated with iron and some silt. Usually no macroinvertebrates were left on them after vacuuming. Vacuuming of macroinvertebrates from irregular, uncoated stones might be more difficult and require that a brush, scraper, or tine be added to the intake nozzle.

The dome suction sampler worked well in our study area, and it was used in frigid waters as well as in total darkness. The components slipped together simply, and the collecting net, pump, and battery were replaceable underwater without difficulty.

The sampler is being used by other research groups in North America and abroad. Some other investigators (personal communication) have indicated satisfaction with its performance. How well the sampler will work in a particular environment may depend upon the ability of the user to improvise. At least one individual (Mr. Jack DeWolf, Philadelphia Academy of Natural Sciences, personal communication) has neatly solved the problem of filling gaps that remain under the serrated band when it is used on very coarse substrates. He placed up to six bags, made from ladies support stockings partially filled with lead shot and coarse sand (Fig. 8), around the serrated band where it touched the substrate. The bags could be contoured to fit the substrate closely. He also modified the lower end of the collecting net to empty samples directly into a gallon jar, without spillage, for shipment back to the laboratory.

Collecting Large Samples With a Quadrat Frame

We did not need to collect samples larger than those taken with the dome suction sampler ($0.16m^2$) in our study. Scarce organisms, such as mussels, could have been sampled by hand-collection from areas marked by quadrant frames. Scruggs (1960) used a quadrat frame with scuba to sample mussels in impounded portions of the Tennessee River about 6 to 9 m deep. He collected more species of mussels with a greater range of sizes with scuba than with a crowfoot brail. Dennis (1974) used a quadrat frame to sample mussels in shallow rivers in Tennessee and Virginia. A screen on the downriver side of the frame caught small mussels that dropped as handfuls of substrate were lifted from the water for inspection.

Dennis (personal communication) indicated that small clams in the substrate could not be seen in water about a meter or more deep. This problem might be avoided if all large specimens were removed from inside the frame by hand and the remainder were pumped into an underwater screen with the substrate. Silt would sweep downstream and not obscure the diver's vision in all but very mild currents. A bilge pump like the one used on the dome suction sampler would be ideal for pumping sediments and small mussels into the screen.

Use of quadrat frames in rivers might be simplified to avoid using a boat and to reduce the number of persons necessary for sampling. In wadable waters, frames could be transported on submersible rafts (or made floatable and submersible themselves by adding pontoons to them). The raft could float the frame and other sampling gear to the sampling station and then submerge, carrying the load to the bottom.

In water too deep for wading, the raft can be used with a floatable anchor (Figs. 5 and 9). This type of anchor is connected to the raft fy a rubber air hose. The hose serves as an "anchor line" and the means of inflating and deflating the inner tube. The end of the hose near the stern of the raft contains a combination air-filler and air-bleeder valve (Fig. 9), constructed by drilling a hole in the side of a 1/4-inch gas-line shut-off valve. The air hose is wrapped around the inner tube (Fig. 9) to remove stress from the tube's filler stem. The diver fills the tube with an air chuck in an air line from the low pressure port on his first stage regulator. The floating anchor is more convenient to work with if a "quick-coupler" fitting is placed in the air hose just before it divides into a "Y"-shaped bridle that attaches to the raft.

To sample, the diver should enter the river with the floating anchor and raft upstream from the sampling sites. The air hose can be coiled and tied to avoid tangling. After reaching deep water, the diver can float in his partly-inflated vest beside the raft and slightly downstream from the anchor, until the current carries him near the sampling site. Then the air hose is untied (the cord is fastened to the hose to prevent its loss) and the air-release valve in the air hose is opened to deflate the tube and sink the anchor. If the anchor starts to sink too quickly, the diver can stop its descent by placing his finger over the hole in the side of the air-release valve. After the anchor reaches the bottom, the air-release valve is closed. As the raft stops, the diver can empty his vest and descend with the raft. After collecting the sample, the diver can ascend with the raft to the surface and then reinflate the inner tube. The tube is filled gradually to prevent over-filling; once the tube starts to rise it usually continues to the surface without more air. The diver can float downstream or swim across current with the raft to the next sampling site. The diver should practice with the floating anchor system before attempting to use it in sampling.

In summary, the use of scuba eliminates traditional problems in sampling the benthos in large rivers. In very turbid water, the diver can swim to the river bottom to observe and delineate habitats by actual observation, and he can accurately position sampling devices on any or all of the substrates he finds. Rocks on the river bottom can be dislodged by hand and cleaned with a self-contained suction sampler. Widely dispersed organisms can be hand-sampled from large areas of river bottom marked off by a quadrat frame.

Ancillary Uses of Scuba

There are many ways the use of scuba can be expanded. In our study of the Susquehanna, scuba was quickly incorporated into ongoing programs. In some instances, because of scuba, new programs were initiated to ask questions we could not contemplate answering a few months earlier.

Water Chemistry

We initiated a study of iron deposition (Gale et al. 1976) using scuba to situate "detritus-free" substrate holders on the river bottom. Scuba was then used to retrieve test plates on a monthly basis throughout the year. The holders remained intact and free of detritus for the duration of the study and longer (more than 31 months). In 1975 the holder and its plates survived a major flood unscathed. Without scuba the study could not have been conducted using substrate holders in deep water.

Periphytic Algae

At the onset of our periphytic algae study in 1971, we wanted to know how many and what kinds of algae were growing on stones in the near-darkness of the river bottom. Because of our inability to work on the river bottom in deep water, at that time, we turned to the use of artificial substrates (glass slides and styrofoam spheres). We discarded our original question and asked instead, "How many and what kinds of algae will grow on clean, artificial substrates suspended for a few weeks in the photic zone?" Ecologically speaking, the answer to the second question was of much less interest than an answer to the first.

Predictably, we were dissatisfied with our results; both types of substrate were sometimes lost to, or forced out of position by, floating debris. The styrofoam spheres often shrunk, negating one of their most important advantages: providing a known amount of surface area for colonization.

Later, with scuba and a bar-clamp sampler (Gale 1975; Fig. 10) we could sample any cobble on the river bottom. More recently a "chain" sampler (Fig. 10) was developed to sample small boulders. The sampling cup enclosed the area sampled for return to the laboratory without disturbance or loss of cells. In the laboratory cells were dislodged inside the cup by scraping, brushing, or ultrasonic vibration.

Several samples could be collected at a station within a few minutes; samplers with stones in them were sent to the surface attached to inflatable floats as the diver obtained additional samples. Small boulders could be lifted by inflatable floats, by a submersible raft, or by the boat operator with a hand-winch.

Fish Reproduction

We used "scuba searches" as one method of locating fish spawning grounds in the river and adjacent streams (Gale and Mohr 1976). In spite of poor visibility, some fish eggs were found that were not collected by other sampling methods. Scuba proved to be and excellent method of observing the miscrodistribution of eggs on the substrate.

Scuba was also used to situate and retrieve artificial spawning devices (Gale and Gale 1976); by snorkeling we were able to approach to within a few centimeters of spawning spotfin shiners (*Notropis spilopterus*) to observe and photograph their reproductive behavior (Gale and Gale 1977).

Other Uses

In our fishery program we used scuba to evaluate the sampling effectiveness of a wheeled trawl. We used it in our larval-fish and macroinvertebrate-drift pump sampling program to determine the position of the intake on the river bottom and to conduct dye tests establishing that we were not pumping from the substrate. Without these observations, we could not be certain of the area from which the sample was drawn. In a discipline filled with probablies, likelies, maybes, and other evasions, it is a relief to speak with certainty.

At various times we used scuba to gather submerged aquatic plants, to collect bottom sediments for radiation analysis, and to obtain macroinvertebrates for many purposes. Other utilitarian uses included locating a variety of lost sampling gear, underwater repair of docks and fish cages, and the installation of underwater monitoring devices.

We are now investigating colonization rates of chironomids using scuba and a modified bar-clamp sampler (Fig. 11) to collect samples from acrylic plates on the river bottom (a modified chain sampler that can be used to sample benthos inhabiting the surfaces of boulders is also shown). We are preparing to use scuba in a study of the sounds produced by the spotfin shiner in its natural environment.

Future Role of Scuba in River Research

At this point, it should be obvious that scuba is neither fad nor gimmick. It is a serious tool by which the biologist can perform tasks that might otherwise yield unreliable data or that would prove completely impossible. The use of underwater equipment with scuba in freshwater research is growing, but continues to be hampered by some overly-cautious administrators who are unwilling to incur any risk, and by a few short-sighted persons who are willing to economize by "making do" with long-outdated sampling gear and techniques.

Because scuba allows implementation of sampling methods so vastly superior to conventinal methods, its eventual acceptance seems assured. In fact, scuba's growth rate should rise sharply because of an increasing demand for (and a willingness to pay for) ecological information from "impossible-to-sample" waters that have been too long ignored.

At this time, the use of scuba in freshwater research might best be promoted by the establishment of short training courses to teach certified divers preliminary sampling techniques, especially ones that are used in rivers with strong currents and low visibility. There is too little time in basic scuba training courses to train the new diver to function in large, turbid rivers, even if the instructors had the expertise to do so.

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Acknowledgments

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Figure 1. A lead-filled anchor (right) for rocky substrates. The wraparound handle is for easy manipulation. The "creeper" dveice (left) is used by the diver to move across rocky substrates in strong currents.

Figure 2. Ways in which a diver uses the "creeper". The diver (left) advances upstream by moving the handles forward in alternate turns. He uses the creeper as a pivot (right) to swing in widening arcs.

Figure 3. Modified vise-grip pliers for attaching the diver to underwater objects in strong currents.

Figure 4. A ladder with "open steps" for small boats. The diver kneels (left) or stands (center) on the ladder to rest. The ladder's slope allows him to lean forward (right) leaving the water.

Figure 5. A submersible raft and floatable anchor. The inner tube was slipped, uniflated, through a 6 mm slot in the anchor handle. The diver fills and empties the tube from the raft's stern. Tube and anchor size depend upon the combined resistance of diver and raft and on anchor line length.

Figure 6. A diagrammatic view of the way Bar-B-Q baskets (attached to underwater ropes) can be relocated by divers and put into protective bags.

Figure 7. A dome suction sampler made floatable with an inner tube.

Figure 8. Support stockings containing sand and lead shot being used to seal crevices between the serrated band of the suction sampler and the substrate (left and center). The bags closely fit irregular contours (right).

Figure 9. Diagrammatic view (semi-exploded of a floatable anchor system. The snap on the upper branch of the "Y" shaped bridle attaches to a ring on the raft's bow and the other branch goes to the raft's stern.

Figure 10. Two epilithic-algae samplers with 23 mm diameter sampling areas. The bar-clamp sampler (right) is suitable for cobbles but the chain sampler (left) is needed for boulders.

Figure 11. Two new devices for sampling benthos on solid surfaces with scuba. A modified bar-clamp sampler (right) is on an acrylic plate and a modified chain sampler (left) is on a boulder; both have a 70 mm I.D. and black-rubber sealing discs. A turkey baster is used to pipette organisms from the sampler.

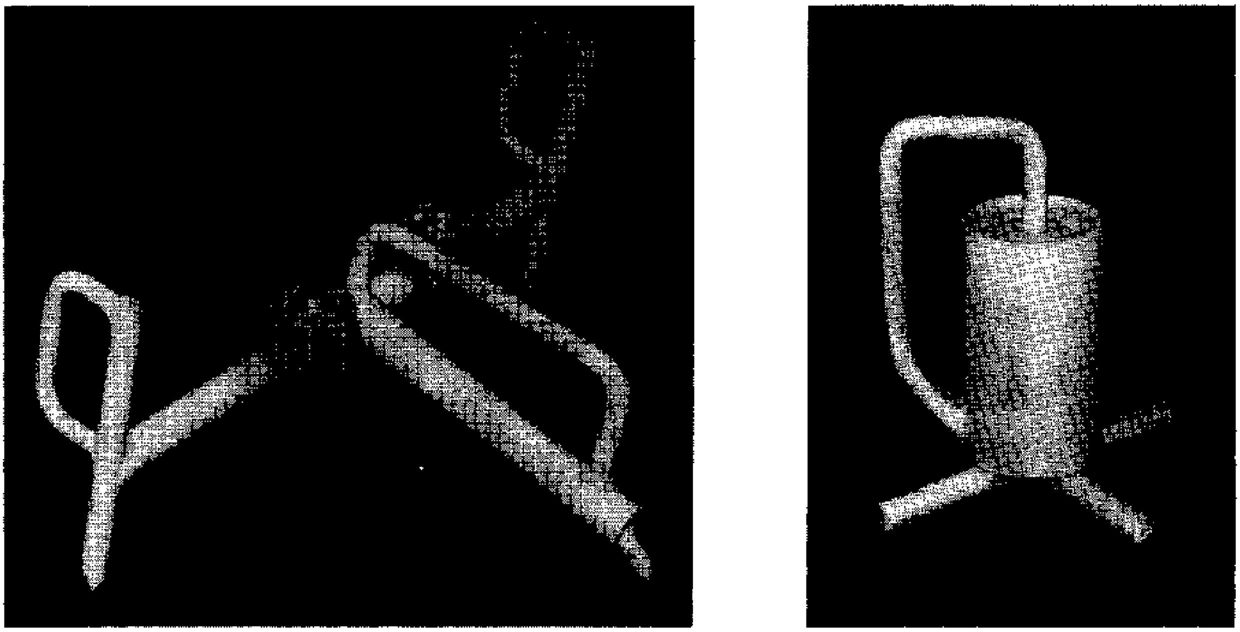
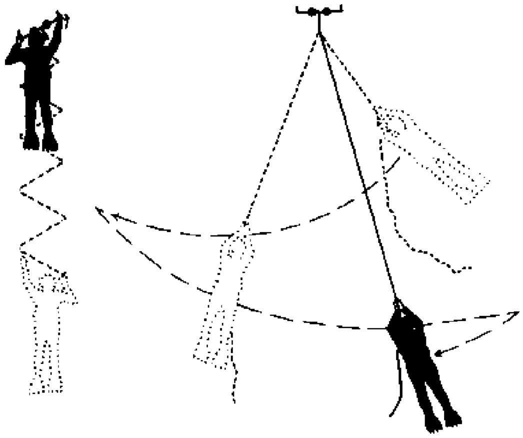


Figure 1



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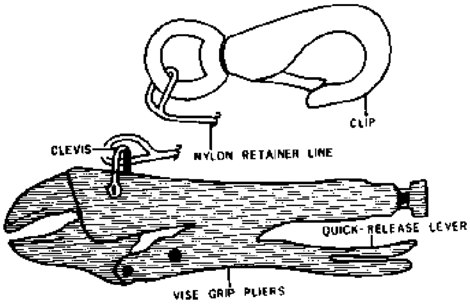

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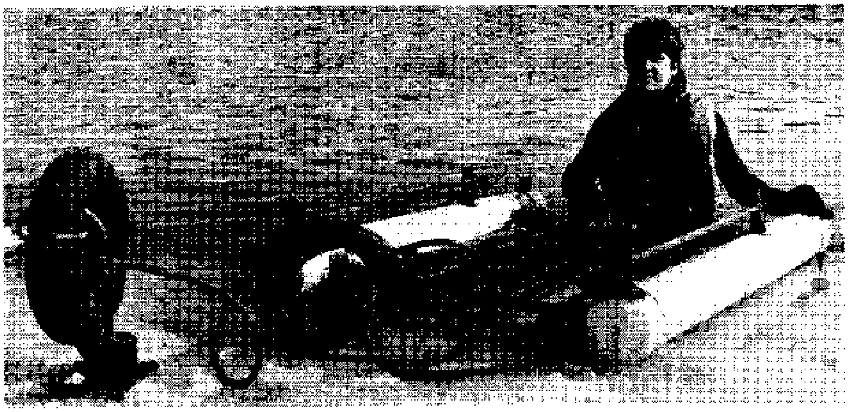

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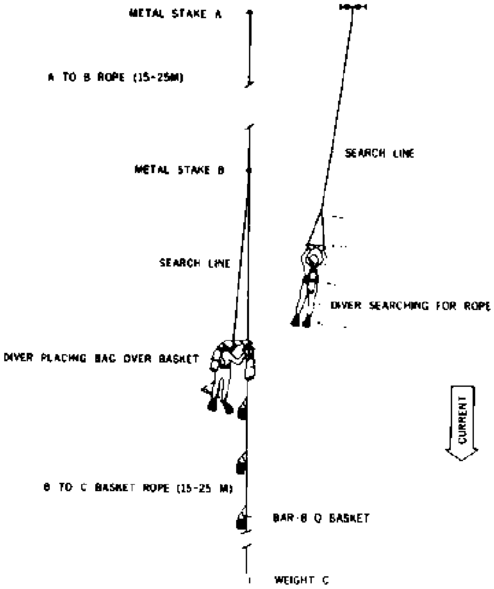
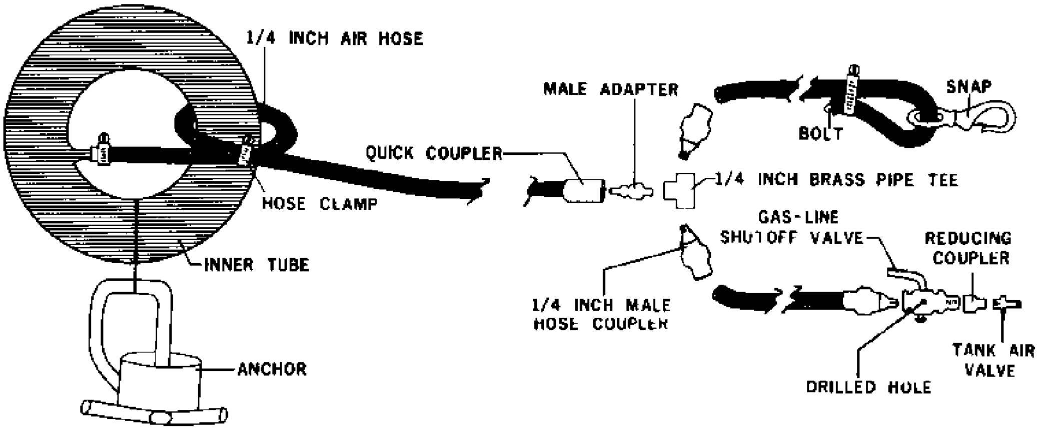


Figure 6

Figure 7

Figure 8



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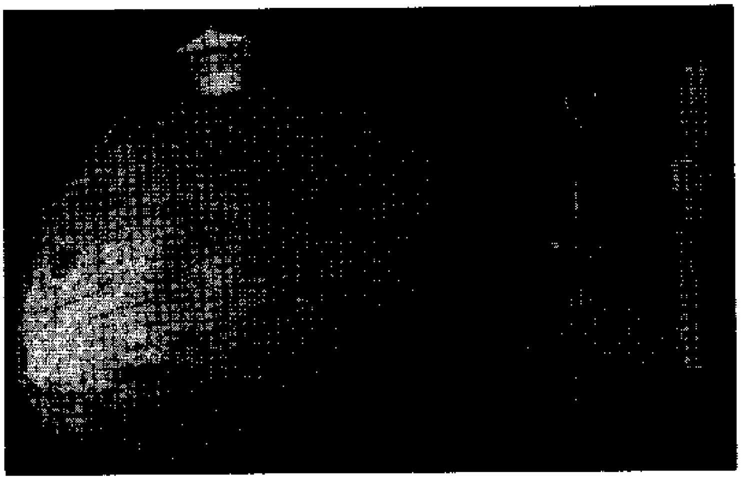

Figure 10

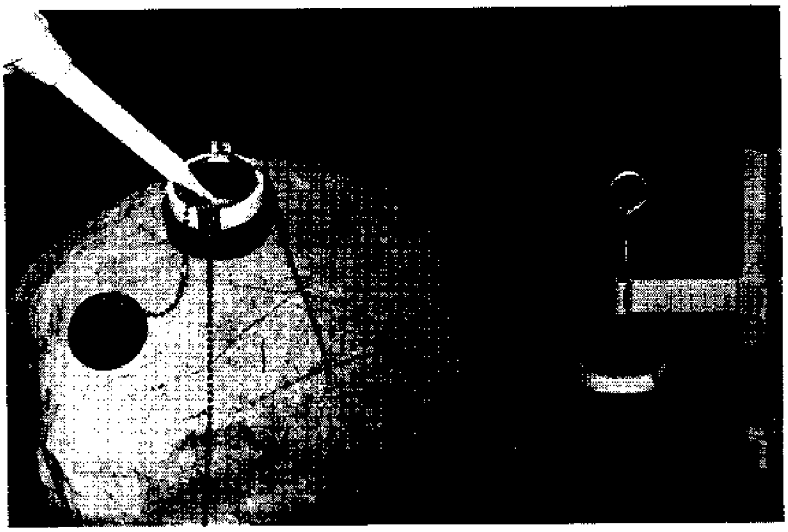

Figure 11

THE USE OF UNDERWATER RESEARCH EQUIPMENT IN TEMPERATE LAKES AND RESERVOIRS

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ABSTRACT

In this paper several common problems faced by limnologists when using benthic sampling gear in the standard way are outlined. Five studies are described in which the researchers effectively utilized underwater breathing apparatus and modifications of standard sampling equipment to obtain better samples and valuable supplemental visual data. These studies point out that, while underwater breathing apparatuses are not the ultimate solution to all sampling problems, their potential value as an additional tool to a limnologist should not be overlooked.

THE USE OF UNDERWATER RESEARCH EQUIPMENT IN TEMPERATE LAKES AND RESERVOIRS

Introduction

Data from studies of benthic plant and animal communities can provide valuable insight into the status of aquatic systems. The quality of data obtained from such studies depends upon the effectiveness of the sampling method. Therefore when evaluating an impact it is important that comparable samples be obtained from the same places at the different times during the study. (Beak, 1973)

There are six standard types of equipment currently in use for sampling benthic communities in temperate lakes and reservoirs. These are:

1. nets (dip nets and surber square foot samplers)
2. mechanical grabs (ponar dredge, petersen dredge and ekman dredge)
3. sediment corers
4. suction samplers
5. artificial substrates
6. periphyton samplers (actually a type of artificial substrate)

Each of these has specific advantages and disadvantages. All, however, suffer from certain problems common to remote-operated sampling devices.

SAMPLING PROBLEMS IN TEMPERATE LAKES AND RESERVOIRS

Terrestrial ecologists have the advantage over aquatic ecologists in being physically at the sampling site to assure both uniform operation of the equipment and the best location of sampling areas. Aquatic ecologists, however, are faced with one or more of the following problems while studying the benthic communities of lentic waters (Fig. 1).

1. Abrupt changes in temperature, oxygen, biological communities, or substrate. These make the collection of uniform samples very difficult while using surface-operated equipment.

2. Steeply sloped bottoms which produce rapid changes in depth and on which sampling devices may easily tip over or roll to a greater depth.

3. Surface wind which makes the collection of repeated samples from exact locations from a boat very difficult.

4. Lack of visibility which precludes the collection of large numbers of samples at precise depths on different days.

5. Vandalism and recreational boat traffic which make it impossible to use surface floats for marking sampling stations.

6. Hard substrate which prevents the collection of samples by grabs or corers.

7. Small objects which clog the jaws of mechanical grab samplers and cause the partial loss of the sample.

8. Surface ice which makes winter sampling of precise locations very difficult.

9. Benthic populations of low density or highly motile organisms which may not be collected in remote-operated samplers.

10. The inability to evaluate the sampling effectiveness of remote-operated methods or to obtain valuable supplemental data through visual observation of the bottom during such sampling.

SOLVING THE PROBLEMS: SPECIFIC STUDIES

Many contemporary aquatic researchers are adding underwater breathing apparatuses to their list of research techniques as a means of circumventing many of the problems form the preceding list. Five studies will be discussed to illustrate ways in which underwater research equipment can help aquatic acologists.

A Study Using An Ekman Dredge

My first introduction to the use of underwater breathing apparatus for research purposes was in Mountain Lake, Virginia. I wished to expand the study by Edmunds, et al (1973) and test the hypothesis that the lake's rooted macrophytes were responsible for the unusual oxygen maximum in its metalimnion (Dubay, 1976). Substrate variability, steepness of slope and the precise depths with which samples needed to be collected all precluded the use of remote sampling. Hand operation of an Ekman dredge along underwater transect lines using underwater breathing apparatus was considered to be the best method of sampling (Fig. 2). This method kept the dredge penetration into the substrate uniform while assuring sufficiently precise macrophyte sampling to make a valid correlation with the lake's narrow metalimnion which changed position slightly on a monthly basis during the thermal stratification period (Fig. 3). It also eliminated the chance of sample loss due to incomplete closing of the dredge and afforded an opportunity to obtain supplemental visual data on the condition of the lake's macrophyte community.

In this study the following results were obtained:

1. The species composition of Mountain Lake's littoral macrophyte community was determined.

2. The distribution of the rooted aquatic vegetation standing crop with depth was determined.

3. The effect of position of the transects around the lake's basin on the depth distribution of rooted aquatic plants was evaluated.

4. The lake's rooted aquatic plants (rather than the phytoplankton as was previously hypothesized) were shown to be responsible for the lakes unusual metalimnetic oxygen maximum and for the partial alleviation of the hypolimnetic oxygen deficit.

A Study Using a Surber Square Foot Sampler

In a similar situation, Abbot (1973) studied the distribution of an Asiatic clam population (Corbicula manilensis) in a Tennessee reservoir. These populations, according to observations of underwater swimmers, appeared to be concentrated in two very narrow bands, one between the 7-9 meter depths and the other between the 13-15 meter depths.

The very steep, rocky basin posed conditions under which remote sampling with dredges would not have allowed sufficient precision to collect a large number of samples from pre-determined depths on the bottom. After repeated attempts to use a dredge failed, hand placement of a Surber sampler while using underwater breathing apparatus proved to be the only feasible method for obtaining the sampling accuracy required by conditions of the study.

Sampling data verified the initial observations of underwater swimmers. Clam densities were found to increase offshore with the highest densities between the 7 - 9 meter depths and again between the 13 - 15 meter depths (Fig. 4). The patterns of distribution were attributed to substrate effects. In areas of bedrock and cobblestones there was less space for colonization, whereas the softer sediments provided a greater area for colonization.

An Artificial Substrate Study

Reservoirs are often very difficult environments to sample with dredges for all of the previously listed reasons. In particular, the clogging of dredges, steep sides, and wind often combine to produce very difficult sampling problems. Voshell and Simmons (1977) were confronted with the responsibility of collecting numerous samples on a monthly basis from a new reservoir. The data were to be used to evaluate the future influence of heated water effluent from a near by nuclear power plant. Therefore, the samples had to be collected at very specific depths, at specific stations on a repeated basis and the samples had to be independent of substrate influence in order to evaluate the future impact of the heated water. The variability of the substrate plus the problems illustrated in Figure 1 led the researchers to consider the use of artificial substrates in lakes. They compared three different types of material with the standard ponar grab.

The investigators needed to know:

1. Which method would provide the most reliable data concerning density and community structure with the fewest number of replicates.

2. Which method would require the least amount of time for field collection and laboratory processing.

3. Which method would allow the investigators to operate independently of weather conditions in the field.

The types of material which they used were rocks (mineral), Conservation Webbing (inert thermoplastic fibers) and leaves (organic). These substrates were placed in baskets (Fig. 5) at three depths in a grid pattern (Fig. 6), in a Virginia piedmont reservoir. Three replicate samples were collected at each depth on a monthly basis for the period of a year. The researchers found that:

1. The leaf and web artificial substrates collected more taxa and a greater density of animals with less variability than the grab.

2. The number of replicate samples of leaves and web artificial substrates needed for statistical treatment were less than the grab samples.

3. All the artificial substrate samples required much less time for field collection and laboratory processing than a comparable number of grab samples.

4. Collection of artificial substrates with scuba allowed the investigators to operate independently of weather conditions.

5. The artificial substrates insured replicate samples from the exact depth and same area each month.

The use of the artificial substrates facilitated the efforts of the investigators and allowed them to make detailed studies on the temporal, spatial and horizontal distribution patterns of the lake macrobenthos over the period of several years (Voshell, 1977).

A Study Involving A Suction Sampler

This study, while being estuarine, was selected since it illustrates the use of a suction-type sampler which could be used in the same manner in a lake or reservoir. In this study Haven et al. (1966) designed an experiment to test the effect of two chemical pesticides (Polystream and Sevin) on oysters and other benthic marine life for the possible application in controlling populations of oyster drills. In the course of their study the quantitative sampling of benthic invertebrates from very specific areas within a 2/3 m^2 ring was essential. Due to substrate variability and the difficulties of sampling hard-shelled organisms by dredge a suction sampling device was the best choice.

Quantitative sampling of precise locations with this suction dredge necessitated the use of divers using underwater breathing apparatus. In this manner the dredge was hand-held and placed by the researcher exactly over the area of sampling as described by Brett (1964) (Fig. 7).

Haven et al. (1966) noted the additional values of underwater breathing apparatus in conducting direct visual observations of the substrate. As part of their project, a qualitative list was made of all organisms sighted while swimming on the bottom along a 45 m chain.

As a result of this research the investigators were able to conclude that these two pesticides had an adverse effect on most species of macroinvertebrates with no increase in oyster production or significant decrease in drill populations.

An Artificial Reef Study

Underwater research equipment has been very useful in studies on artificial reefs. As an example of such studies, Prince (1976) made an extensive ecological study of a freshwater artificial tire reef in a Virginia piedmont reservoir. Much of the data collected was due to direct underwater observation by scuba divers swimming pre-placed transect lines. Of particular importance were the observations on the migration of fish (Figure 8) in the reef area. Direct underwater observation also helped define details concerning the food web associated with the reef and showed the importance of periphyton and fish fry. Without the availability of direct observation such a detailed study could not have been made.

As a result of these direct underwater observations, Prince (1976) was able to make the following conclusions pertaining to freshwater artificial reef fish populations:

1. Fishes (especially sport fishes) were observed to be significantly more abundant on experimental reef sites after reef construction than before.

2. In winter months the fishes confined themselves to areas deeper than 6.1 m. As the water temperature rose to approximately 12°C and higher, fishes migrated onto the reef.

3. Centrarchid basses demonstrated a clear preference for deeper high-profile reefs while centrarchid sunfish showed a preference for simpler shallow-water reefs.

4. Centrarchid bass nest adjacent to tires of the reef while centrarchid sunfish nest closer to shore and away from the reef. Only the white catfish seem to spawn in the tires of the reef.

5. The reef periphyton was observed to be the major source of energy to the reef community. The sunfish were observed to feed continuously on periphyton, particularly bryozoan colonies and white catfish eggs. The bass were observed to feed on fish fry and mainly during early morning and late afternoon.

6. Centrarchid bass were observed to spend 80% of their active hours during the day and 20% at night with their greatest period of activity at 8 a.m. (E.S.T.). The bluegills spend 90% of their active hours during daylight and only 10% at night with their greatest period of activity at 6 p.m. (E.S.T.).

7. Most tagged reef fish were observed to confine their activity to their reef with relatively few straying to other parts of the lake (Fig. 8).

Summary

In addition to the studies cited in this paper many other persons and organizations engaged in aquatic benthic sampling have used, or recommended the use of, underwater breathing apparatus as a means of better deployment of standard sampling equipment (Environmental Protection Agency, 1973; Somers, 1972; Schmid, 1965; Wood, 1963; Fager et al., 1966; Westlake, 1969; Edelstein, 1969; U. S. Dept. of Commerce, 1975; etc). Such underwater breathing apparatus does, however, have three drawbacks. These are:

1. The initial equipment cost which may be prohibitive unless the study is of a long-term nature (> 1-2 years or more), requires a large number of samples, or is used recurrently in similar studies;

2. A certain level of swimming skill and training by a nationally recognized organization (YMCA, NAUI, PADI, etc.) and advanced training for research diving is a necessary safety requirement;

3. Establishing underwater transects is rather time-consuming if the study is of short-term nature (Voshell & Simmons, 1977).

The addition of underwater breathing apparatus to a limnologist's research equipment is not, therefore, the ultimate solution to all benthological sampling problems. However, the lack of underwater breathing apparatus from a limnologist's research tools would certainly detract from the quality and validity of many studies.

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FIGURE CAPTION LIST

FIGURE 1 Sampling problems in lakes and reservoirs

FIGURE 2 Use of a diver-operated Ekman dredge in Mountain Lake, Virginia (Dubay, 1976)

FIGURE 3 Mean summer rooted macrophyte standing crop compared with (A) the monthly metalimnion and (B) the mean summer metalimnion in Mountain Lake, Virginia (Dubay, 1976)

FIGURE 4 Vertical distribution of *Corbicula manilensis* in Dale Hollow Reservoir (Abbott, 1973)

FIGURE 5 Wire basket samples in place at one of the numbered stakes on a transect (Voshell & Simmons, 1977)

FIGURE 6 Scuba system for using artificial substrates in a reservoir (Voshell & Simmons, 1977)

FIGURE 7 Sampling with a diver-operated suction sampler (Brett, 1964)

FIGURE 8 Recaptures (multiple underwater sightings) of largemouth bass and smallmouth bass marked with peterson disc tags on the multicomponent reef in Smith Mountain Lake, Virginia, June thru September, 1974. (Prince, 1976)

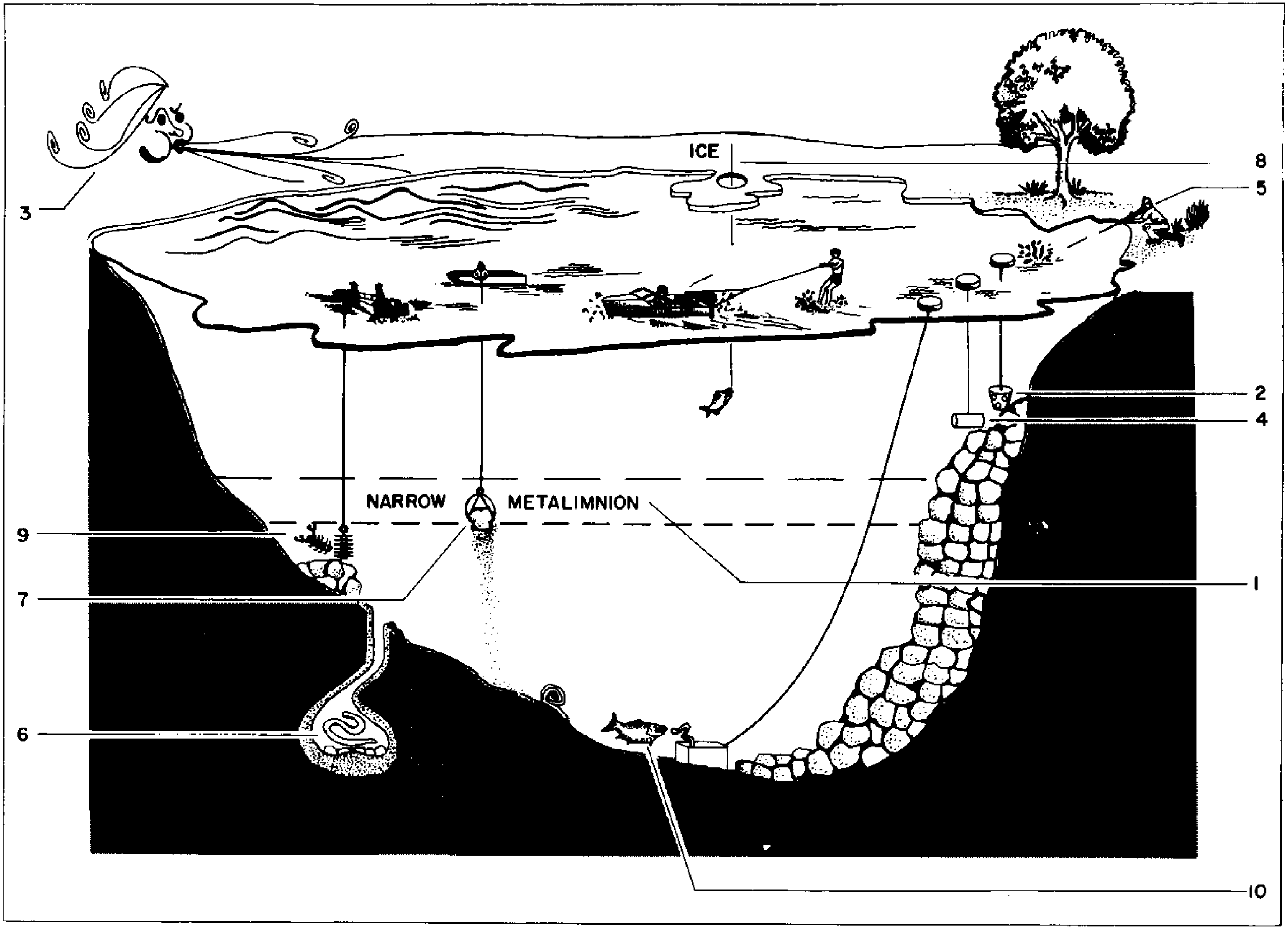
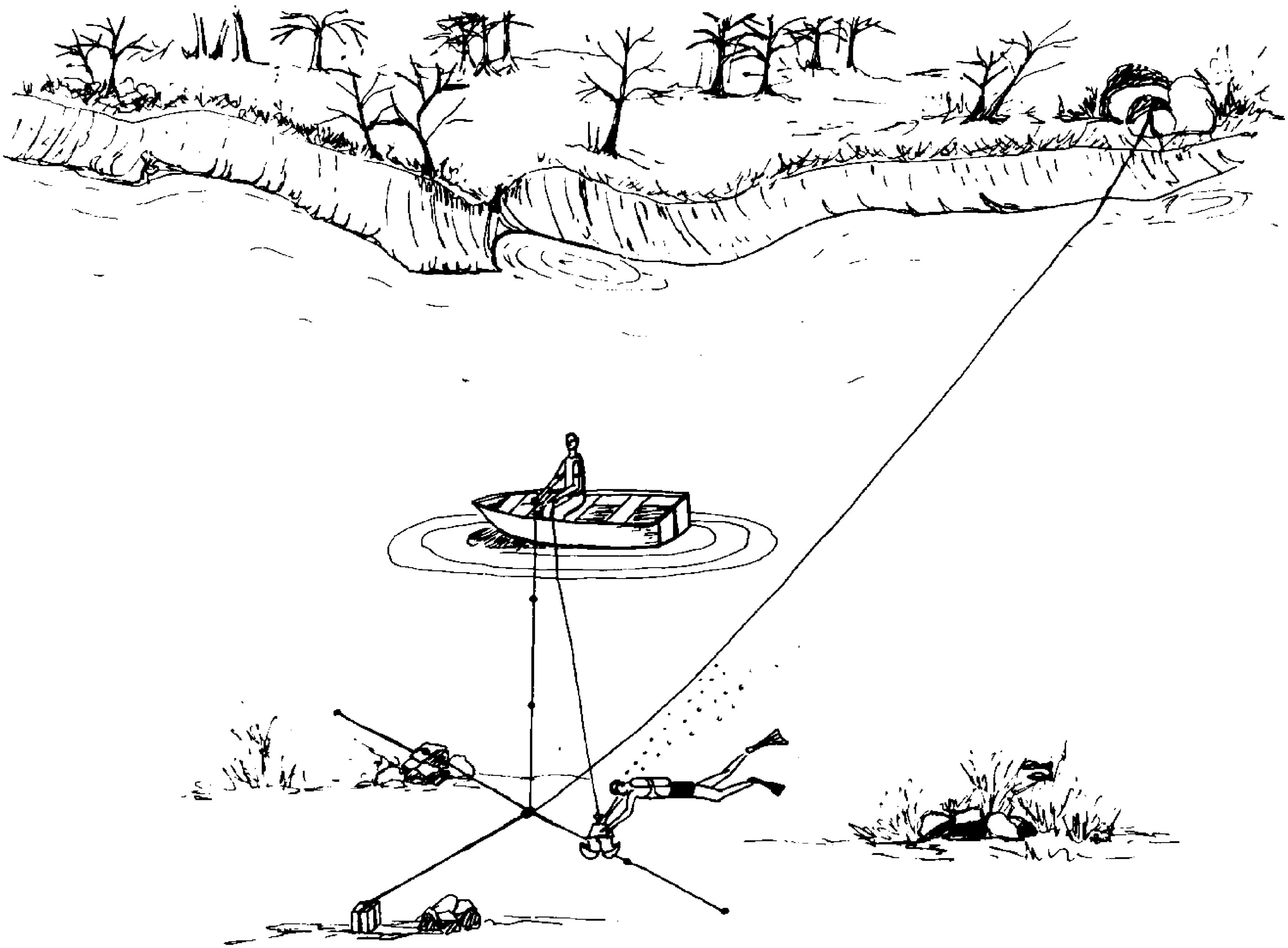
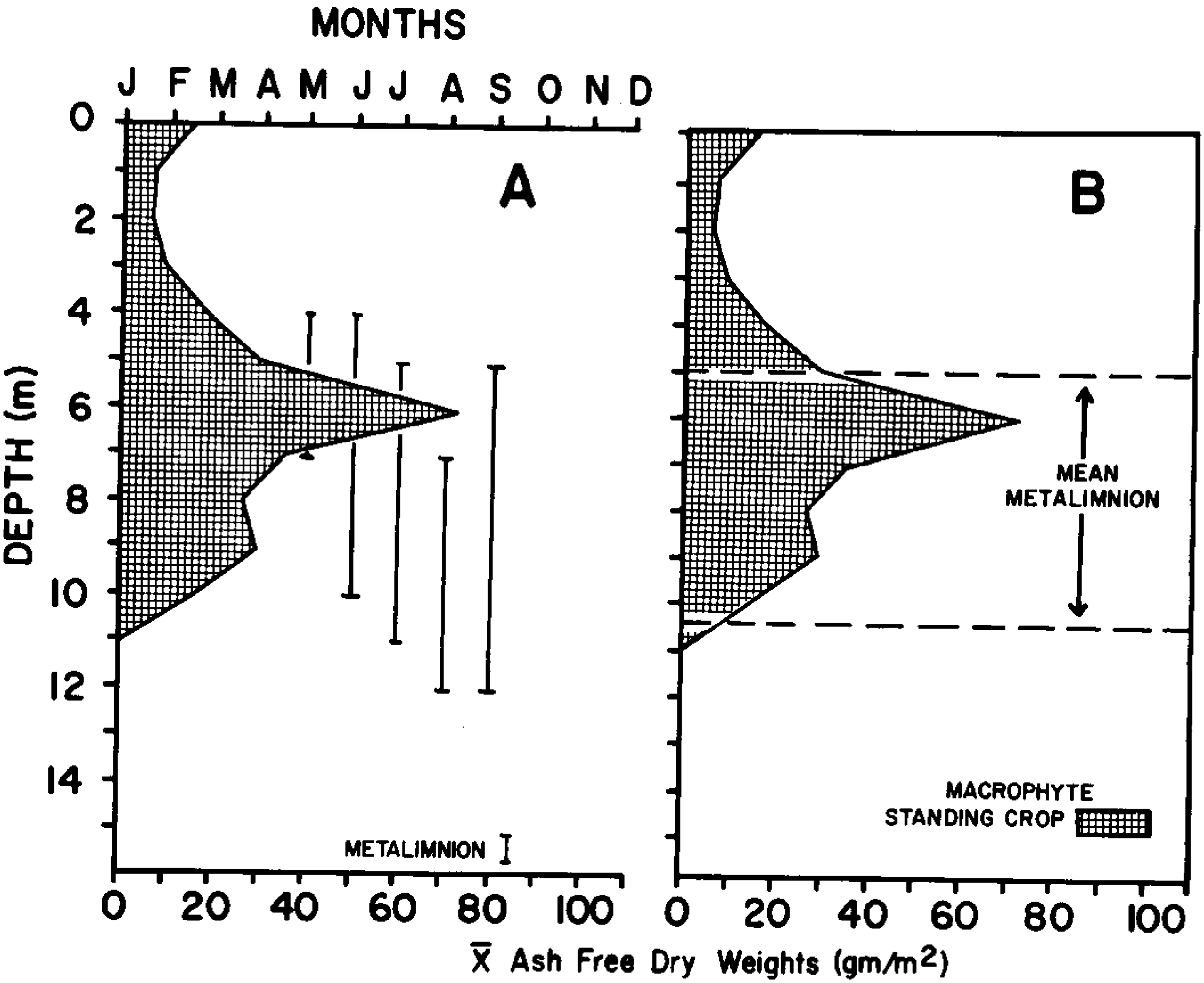
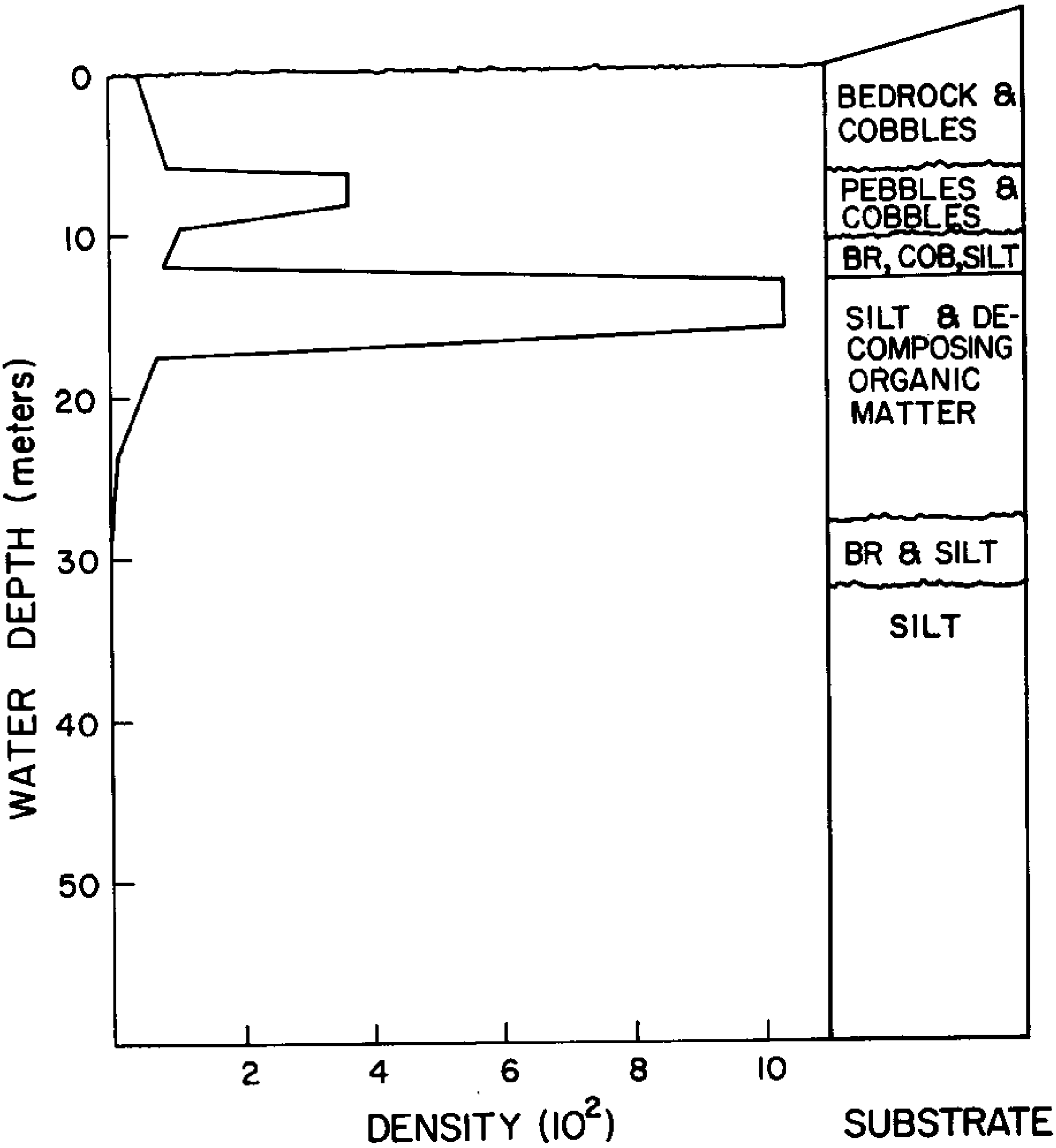


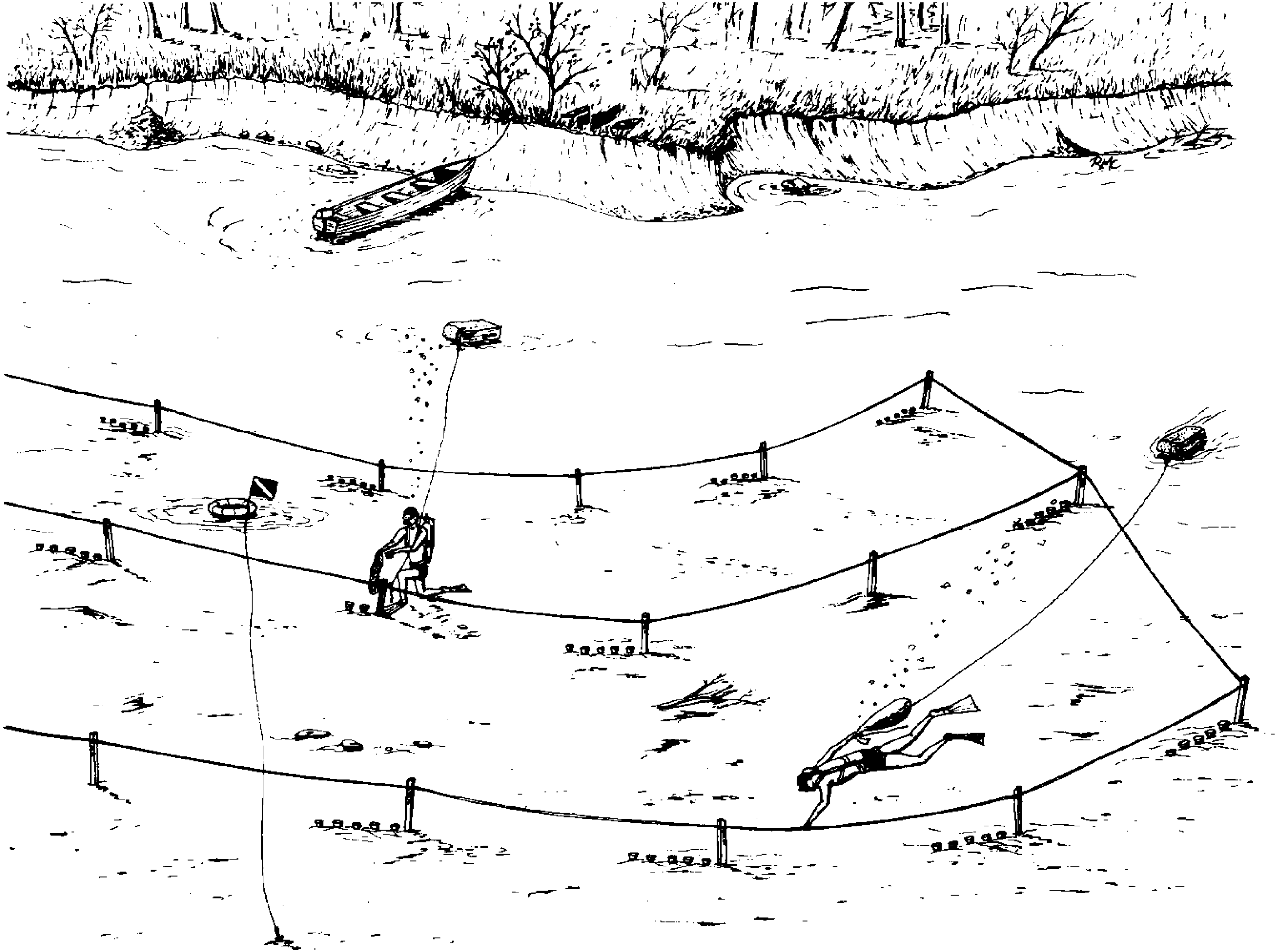
FIGURE I . SAMPLING PROBLEMS IN LAKES AND RESERVOIRS



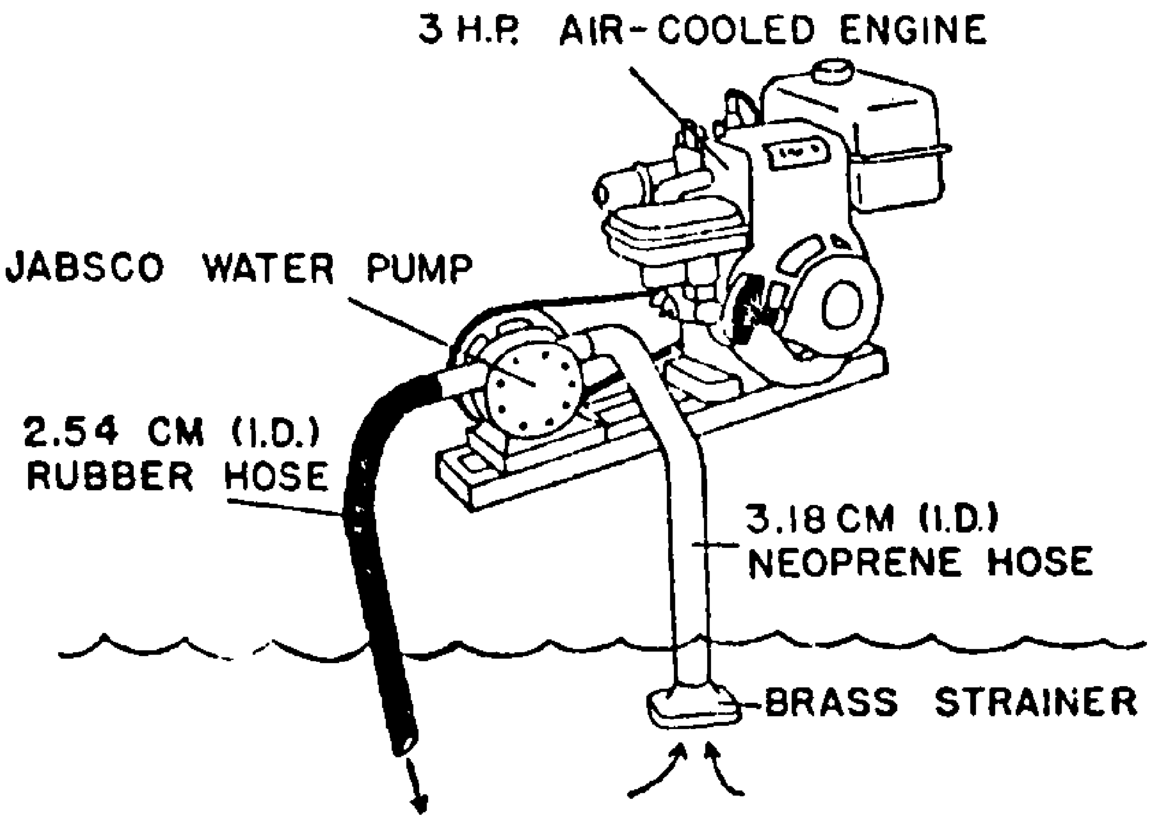
MONTHS
J F M A M J J A S O N D
A
B
DEPTH (m)
0
2
4
6
8
10
12
14
METALIMNION
MEAN METALIMNION
MACROPHYTE STANDING CROP
0 20 40 60 80 100
0 20 40 60 80 100
$\bar{X}$ Ash Free Dry Weights (gm/m²)

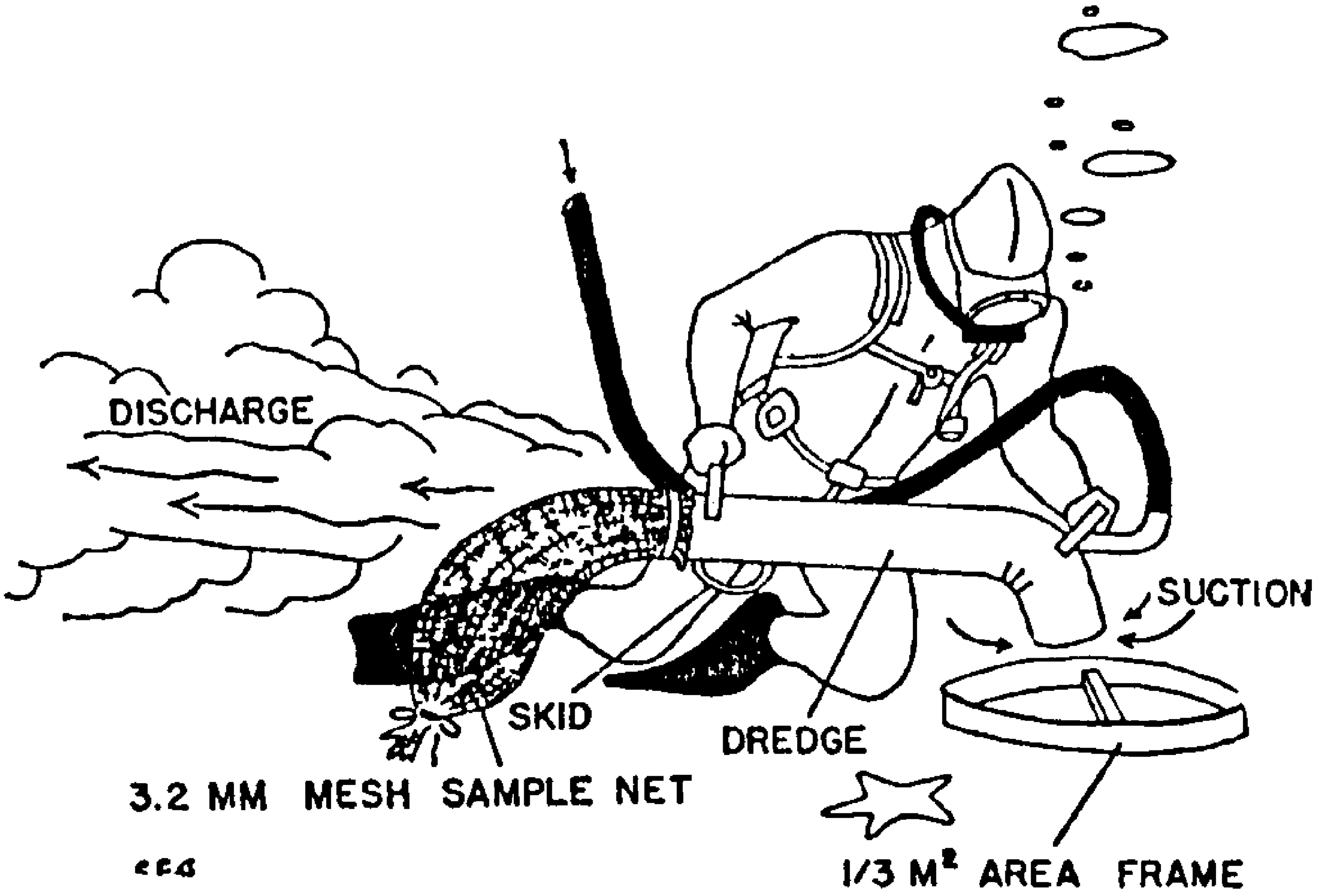

WATER DEPTH (meters)
0
10
20
30
40
50
DENSITY (10^2)
2
4
6
8
10
SUBSTRATE
BEDROCK & COBBLES
PEBBLES & COBBLES
BR, COB, SILT
SILT & DE-COMPOSING ORGANIC MATTER
BR & SILT
SILT

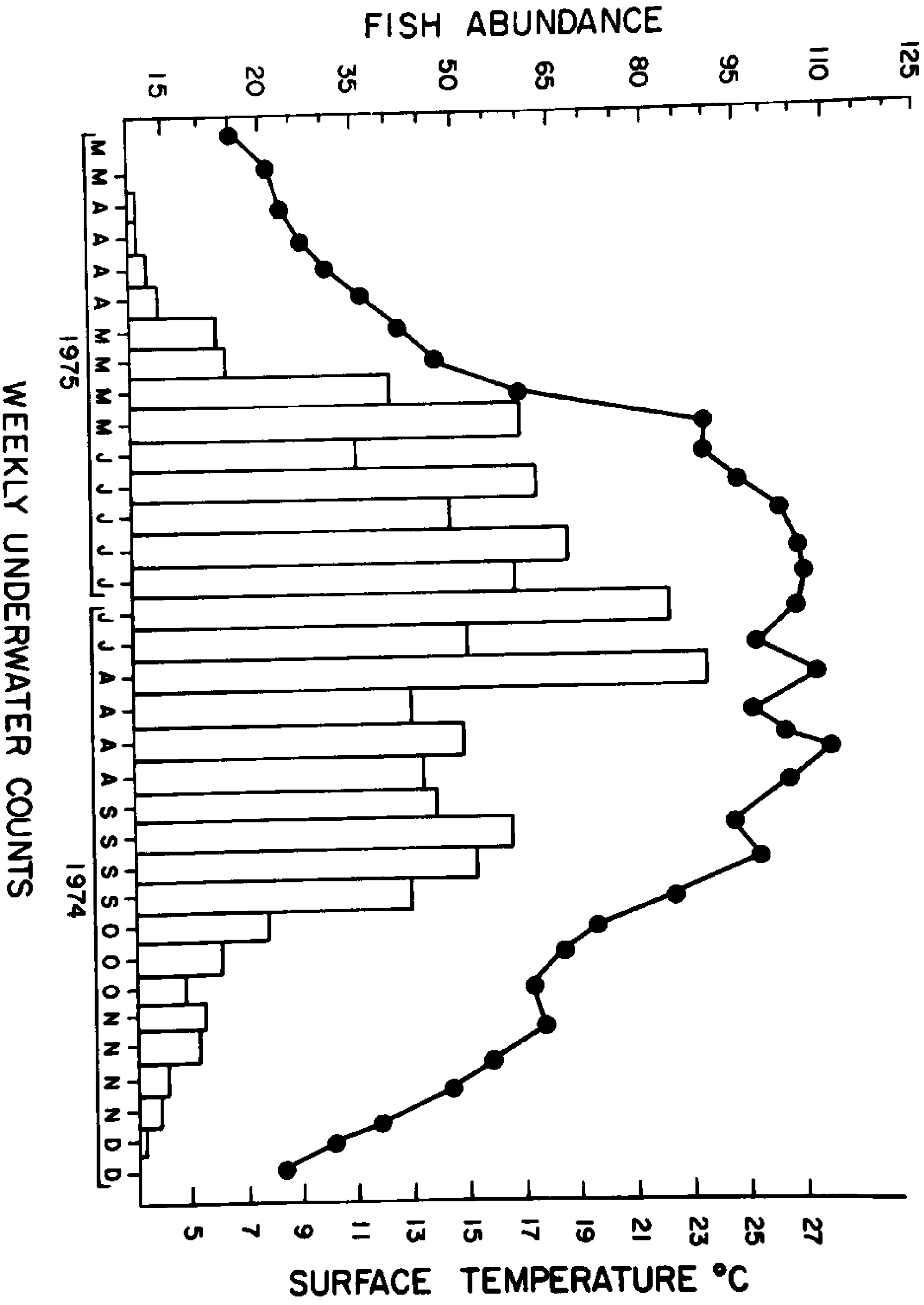

2
1
7



RMc


3 H.P. AIR-COOLED ENGINE
JABSCO WATER PUMP
2.54 CM (I.D.) RUBBER HOSE
3.18 CM (I.D.) NEOPRENE HOSE
BRASS STRAINER


DISCHARGE
SUCTION
SKID
DREDGE
3.2 MM MESH SAMPLE NET
1/3 M² AREA FRAME
ccA


FISH ABUNDANCE
15
20
35
50
65
80
95
110
125
WEEKLY UNDERWATER COUNTS
D D N N N N O O O S S S S A A A A J J J J J J J M M M M A A A A M M
1974
1975
SURFACE TEMPERATURE °C
5
7
9
11
13
15
17
19
21
23
25
27

THE USE OF UNDERWATER RESEARCH EQUIPMENT IN LARGE LAKES AND COLD WATER

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ABSTRACT

The application of underwater diving techniques for biological research in large, cold water lakes is relatively limited when compared to ocean research. Basic problems relative to diver training, equipment, and techniques are identifiable. Basic procedures for quantitative sampling, transect sampling, data recording, and underwater photography in turbid water are discussed. Specific examples of research projects utilizing divers are included to demonstrate the significance of underwater research methodology.

THE USE OF UNDERWATER RESEARCH EQUIPMENT IN LARGE LAKES AND COLD WATER

Introduction

During the past two decades diving with self-contained underwater breathing apparatus (scuba) has gained recognition as an important aid to scientific investigation. The underwater scientist does not have to depend solely on conventional surface sampling techniques and "educated guesses" for shallow-water studies. He can work directly in the underwater environment to observe, sample, photograph and conduct field investigations in a manner similar to his dry-land colleagues. Working underwater the scientist may record evidence which might be completely missed using conventional surface sampling and remote recording techniques. The concepts of underwater experimentation are discussed by Ott (1973).

The first documented dives for scientific research purposes are credited to H. Milne-Edward of Sicily in 1844 according to Dugan (1956). Diving has been used by scholars and scientists since that time. However, it wasn't until 1949 that scuba diving began to exhibit influence on the American scientific community. Unfortunately, the over-all impact of diving on the field of marine science remains to be sufficiently identified. A review of approximately 1500 marine science papers published in selected American scholarly journals during 1974 revealed that diving was a contributing factor in only 2.2 percent of the research. This figure is certainly misleading. The papers reviewed encomposed all facets of marine research including deep-sea. If the survey had been limited to only research in the water depths accessible to the scuba diving scientist, the percentage would have been much higher.

A general review of the literature and discussions with aquatic biologists suggest that the use of diving for benthological research in large freshwater lakes is relatively limited. Some marine biologists consider direct underwater observation and sampling as a major means of field investigation. Yet few, if any, aquatic biologists advocate diving as a major field method. Why? In an attempt to answer this question I offer the following comments:

1. During the years of 1950-1970 when scuba diving was gaining popularity among marine biologists, freshwater researchers tended to retain a more clasical approach to field studies.

2. Young researchers and graduate students have been guided in the direction of more traditional field methodology by many established researchers and professors. In many cases those who have desired to use scuba diving in field studies have been actively discouraged.

3. The early public image of the underwater researcher was cast in a background of warm, tropical waters and coral reefs, not the cold, turbid waters of northern lakes. Both young and established researchers were attracted to an environment that was less physically demanding and more aesthetically pleasing.

4. The Cousteau TV program have placed emphasis on the ocean environment rather than the lake environment.

This paper will address some selected problems and solutions relative to biological studies in large cold water lakes. Emphasis is placed on the study of the benthic environment.

SELECTED SAMPLING PROBLEMS IN COLD WATER LAKES

Diving, Equipment and Techniques

Realistically, one must consider the techniques and equipment currently employed by the diving scientist. Until recently the diving scientist has been more or less limited to the equipment and techniques used by the recreational scuba diver. In warm tropical waters open-circuit scuba and standard foamed-neoprene wet suits have been relatively satisfactory. The diver is less susceptible to cold stress with associated increased air consumption and fatigue. On the other hand, the cold water environment of the northern lakes increases the physical demands on the diver. Cold stress alone significantly reduces diver work efficiency and comfort. For many who have attempted underwater studies in northern lakes, cold combined with limited underwater visibility has been sufficient motivation to seek more traditional surface-oriented field methods for their research. The rigors of diving have also discouraged many traditional researchers, especially those over 35 years of age, from venturing underwater.

Quantitative Sampling

Quantitative sampling is of considerable importance to the aquatic biologist. In the study of benthos, classical dredges or grab-type samplers are commonly deployed from surface vessels. Dredges have some disadvantages such as the inability to retrieve burrowing organisms or quick-moving organisms. For this and other reasons quantitative sampling of any significance cannot be accomplished with dredges.

Semi-quantitative samples may be obtained with grab-type samplers such as the Pertersen. Generally, only shallow infaunal animals may be recovered by this type of sampler. Quick-moving animals can avoid the sampler in response to the pressure wave generated as it approaches the bottom. More importantly, large rocks or shells may prevent the sampler from completely closing and smaller organisms can be washed out of the sampler during ascent to the surface vessel.

A very limiting feature of many grab and dredge type samplers is their inability to penetrate deeply into the substrate. Most samplers rarely penetrate beyond a depth of 10 cm. Holme (1964) suggests that " the majority of benthic animals may be found in the top 10 cm of sediment." On the other hand, Keegan and Könnecker (1973) state that "an important fraction of the standing crop can and does occur much deeper within the deposit. In fact, where marl substrates are concerned, as much as 98% of the standing crop may be found in the 20-40 cm zone."

Despite the disadvantages of classical sampling apparatus, many researchers are still reluctant to use diver-operated apparatus. Comparisons between quantitative grab samples and diver collected samples, in some cases give significantly different results. In my opinion, some investigators question the validity of underwater quantitative sampling because of the relatively limited number of applications evident in the literature.

Transect Sampling and Data Recording

Collecting samples and making observations along a predetermined transect are probably two of the more common techniques used in underwater research. The investigator generally fixes a measured line relative to topography or compass orientation. Samples are collected and observations are recorded at given intervals and/or for a given distance on each side of the line. The sample collection equipment and procedure will depend upon the organisms under investigation. Observations are generally recorded manually on a slate. Transects requiring detailed manual observation recording are somewhat difficult in cold water where the diver wears foamed-neoprene gloves. Also, handling data recording equipment can be somewhat awkward.

Underwater Photography in Turbid Water

Underwater photography is commonly used in clear water as a data collecting technique. However, the application of photography in turbid water is limited due to the problems associated with large quantities of particulate matter between the lens and the subject, low light levels, and back scatter associated with artificial light photography.

SOLVING SELECTED PROBLEMS OF UNDERWATER SAMPLING AND DATA AQUISITION

Equipment and Techniques for Scientific Diving in Cold Water

Modern diving equipment and techniques which will reduce or eliminate the problems of cold stress and significantly increase working efficiency in turbid waters are now available to the underwater scientist. Somers and Anderson (1971) introduced the use of surface-supplied diving apparatus and hot water diving suits in Great Lakes research in 1968.

Self-contained underwater breathing apparatus (scuba) allows the diver considerable advantages in portability, underwater mobility, and simplicity of operation. In addition, training in the use of open-circuit scuba is readily available for most research personnel. In order to utilize the advantages of scuba, the diver has sacrificed dive duration, physical (thermal) comfort, reliable communication capabilities, and safety under limited visibility conditions.

Recognizing inherent disadvantages and limitations imposed by the use of scuba diving techniques, University of Michigan scientists now employ surface-supplied diving techniques in underwater research. The diver wears a steady-flow/demand mask or lightweight helmet and is connected to the surface by an unbilical which consists of an air hose, hot water hose, safety line and communication cable. Air is supplied in virtually unlimited quantities by a compressor or high pressure cascade system located on the support vessel. A hot water circulating diving suit is used to maintain a high degree of thermal comfort. Heat loss is no longer a limiting factor of dive duration regardless of the water temperatue. A wire type communications system provides excellent diver-surface voice communications. Self-contained wireless type communication systems have been used in the past. However, compared to wire type systems, these self-contained units lack the reliability, clarity and over-all performance characteristics necessary for transmitting precise data to the scientist on the surface. Use of the wire types system enables surface personnel to maintain constant communication with the diver and record all data on tape. This procedure increases the accuracy of recording diver observations and the general safety of the diver.

Operational efficiency has always been relatively low when using self-contained diving techniques. In addition to the limiting factors previously mentioned, scuba diving required that at least two divers be committed to all operations for safety purposes. Frequently, the task could be as effectively accomplished by a single diver. Also, when working under limited visibility conditions common in the lower Great Lakes, two scuba divers easily became separated and could offer each other little or no assistance in an emergency. In fact, scuba diving under zero visibility conditions actually consitutes a hazardous situation. Using surface-supplied diving techniques only one diver enters the water at a time for most tasks. A tender handles the umbilical on deck and maintains constant communications with the diver; a stand-by diver is available for emergency assistance. Committing only one diver to the underwater task at a time compared to the two diver requirement for scuba diving increases operational efficiency by a factor of two. The virtually unlimited air supply and the degree of control for safe decompression increases dive durations for shallow and moderate depth operations. Consequently, dive timing and decompression procedures must be precise and an on site decompression chamber is recommended. Finally, the thermal protection provided to the divers by the open-circuit hot water suit system eliminated diver inefficiency and time limitations due to heat loss. Considering these factors, diver efficiency or operational capability is increased by at least a factor of four.

The diver is limited in lateral range by the length of his umbilical. However, for a diver wearing fins vertical and lateral movement within this range is comparable with movement when using scuba. The steady-flow/demand mask and lightweight helmet provide the diver with the large quantity of air required during periods of heavy exertion, thus allowing him to accomplish tasks that would be marginal or impossible when using scuba.

The application of modern surface-supplied diving techniques to research operations is a revolutionary advancement in underwater research. Diving operation capabilities are greatly extended and higher standards of safety are maintained. For additional information on surface-supplied diving consult Somers (1972).

Scuba diving in cold water is greatly facilitated by the use of variable-volume dry suits. A number if these improved dry-type suits are currently available. These suits are particularly applicable to diving operations conducted from small vessels or shore bases where the use of hot water heating systems is imparactical or impossible. For additional information on cold water diving consult Somers (1973).

Diver training is also a very important consideration. Most scientists receive their training in recreational diving courses. Although most of these courses are satisfactory for the recreational diver, they are inadequate for training the working diver. The scientific diver is an underwater worker that must complete his underwater task within the scope of greatest safety and efficiency. An increased emphasis on specific research diver courses is significant to the advancement of underwater research.

Underwater Quantitative Sampling

Quantitative sampling of the epifauna may be accomplished by counting the animals within a randomly located circle of $0.25m^2$ area (Fager, et al, 1966). A circle template, fixed center rod, and movable arm are constructed of brass; the center rod and movable arm are marked with grooves at 1 cm intervals. The position of an animal within the circle can be defined by three numbers: the distance along the center rod from a standard end, the distance from the center rod along the movable arm, and the half of the circle within which the animal was observed. To study details of the pattern of distribution of individuals of sedentary species the "distance to the nearest neighbor" technique may be used (Clark and Evans, 1954). A large lightweight, metal square is preassembled and dropped on an appropriate location. Within the square, divers place short brass or plastic rods with fabric flags on them at predetermined positions in relation to individual species being examined. After the position of all individuals has been marked, distances to nearest neighbors are measured and reflexives counted.

Another device used for studying epifauna is the diver operated fish-rake. It has been used by Fager, et al (1966) to obtain information on the small scale distribution patterns and estimates of population densities of demersal fishes and invertebrates. The apparatus consists of a metal tubular frame fitted with a handle, a roller of rigid polyvinyl chloride tube into which stainless steel wire "staples" are fixed, and an odometer made of a plastic tracking wheel and removable Veeder-Root direct-drive revolution counter. It is pushed along the bottom by a diver who makes visual counts, size estimates, and other observations on animals that occur within the path traversed by the roller.

Samples of the substrate and infauna can be collected with no observable loss of sediment or organisms using a simple coring device with a wide mouth sample container attached to the top. The corer is pushed a given distance into the sand, i.e., 5 cm, tipped slightly and an aluminum plate is slid through the sand under it. The apparatus is inverted and the sediment is allowed to settle into the jar. Once all sediment and organisms have settled into the jar, the coring attachment is removed and the jar is capped.

A multilevel corer is used for studying the depth distribution of infauna. This corer samples an area of about 45 cm^2 to a depth of 6 cm.

It consists of a square brass box fitted with a funnel adapter at the top to accept widemouth sample containers. The front side of the corer is slotted to permit thin metal slide plates to be inserted for separating the sample into 5 separate layers which may be transferred underwater to separate sample containers. Details for the construction and use of the above apparatus are given by Fager, et al (1966).

Most underwater investigators have used transect or simple quadrant methods for the analysis of underwater plant communities. A reasonable desscription of the change in vegetation relative to depth and other factors can be readily obtained by subjective assessment of the percentage of cover along a strip transect. Accurate quantitative data on standing crop can be best obtained by collecting the entire vegetation from a quadrant and then sorting this into component species in the laboratory for subsequent analysis. Larkum, et al (1967) developed a suitable implement for quadrant sampling.

The air lift, the "shovel" of underwater archaeology, has been successfully used as a quantitative benthos sampler (Keegan and Könnecker, 1973). Essentially, the air lift or, in the case of the marine biologist, the diver-operated suction sampler is a simple instrument consisting of a rigid or part rigid and part flexible tube into which air is introduced at the lower end. The air breaks into small bubbles and mixes with the water resulting in a gas-liquid mixture of less density than the liquid outside the pipe. Since the density of the mixture inside the pipe is less than the density of the water outside the pipe, the air-water mixture will rise until the pressure of the column at its equals the pressure of the water at the same level. The suction created at the lower end of the tube displaces unconsolidated materials and carries them up the tube. The sample can be collected in the water using a bag attached to the upper end of the pipe or in appropriate containers on-board the support vessel. The use of the suction sampler for collecting epifauna and infauna is discussed in detail by Barnett and Hardy (1967), Brett (1964), Della Croce and Chiarabini (1971), and Finnish IBP-PM Group (1969).

Use of a suction sampler for quantitative work requires that the operator be able to discretely "confine" a known volume of substrate. Brett (1964) used a steel frame which was hand-pushed into the substrate. For compacted sediments and coarse-grained deposits such as shell-gravel Keegan and Könnecker (1973) used a "cylinder of reference" such as described by Masse (1970).

Keegan and Könnecker (1973) also devised an instrument which permitted the collection of "intact" columns of deposit 60 cm in length and 15 cm in diameter. This sampling method is significant to the study of vertical distribution of infauna. The development of the sampler is based on Mackereth (1958). Basically, the sampler consists of a cylinder which is forced into the substrate under hydrostatic pressure. This cylinder concentrically encloses and rigidly confines a core tube of smaller dimensions. Details of construction and use are given by Keegan and Könnecker (1973).

Underwater Transects and Advanced Methods of Data Recording

The belt transect has been used by Cvancara (1972) to study lake mussel distribution. In this study a 20 m long transect line paralleling depth contours was established. The diver collected all mussels that could be reached on either side of the transect line, a 1.7 m wide belt or band. In general, transects of this type appear to be widely used by scientists in many underwater studies. Most often the diver simply moves along a pre-established transect line and collects samples, photographs, and/or records data on a writing slate. Modern diving technology can enhance the effectiveness of transect studies through the application of diver carried underwater television systems. These systems are designed primarily as an inspection, observation and data logging tool for the commercial diving industry. The system consists primarily of a small, rugged, highly sensitive underwater television camera with corrected water contact optics and self-contained lighting,mounted in a housing and connected via a cable to an above water control unit, television monitor and video tape recorder. The camera may be hand-held or mounted on the diver's helmet. All visual data and verbal communications are recorded on the surface as the diver moves along the transect line. This system is probably best suited for use by surface-supplied divers.

In some areas the collection of large numbers of macroinvertebrates on long transect lines can present logistical problems for the diver. Bailey, et al (1967) solved this problem by clipping bags weighted with rocks at 25 m intervals along 150 m lines arranged in parallel transects across the collecting area. The diver would start with a hand-carried bag at the beginning of the transect and exchange it for a new one at 25 m intervals.

Underwater Photography

Close-up underwater photographic techniques are commonly and successfully used in turbid waters. Frey (1965) published an excellent popular journal article on turbid water flash photography. Church and Church (1972), Strykowski (1974) and Church (1971) have published excellent manuals which include discussions of underwater close-up photography.

Many investigators have devised special techniques of turbid water photography. Rhoads and Young (1970) photographed the sediment-water interface in profile using an underwater camera fitted onto the apex of a truncated plexiglass pyramid filled with clear water. A focal length of 25.4 cm was obtained by fitting the camera with a 6x diopter close-up lens; the field of view at this magnification was 18 cm by 21 cm. The camera unit was inserted into the sediment by a diver. The sharp ventral edge of the transparent face plate cut a relatively undisturbed profile through the upper few centimeters of sediment. The sediment profile was illuminated from outside the plexiglass housing by a flash unit. Similar apparatus and techniques have been used for photographing aerial views of bottom features and organisms.

Additional Underwater Sampling Techniques

In some studies of benthic animals it is necessary to determine specific chemical conditions at or near the water-sediment interface. Aarefjord (1973) describes a diver-operated water sampler for sampling close to the bottom surface. An interchangeable 100 ml dissolved oxygen bottle is fitted with a special rubber stopper. The rubber stopper is penetrated by a gas hose an a large syringe needle attached to a water sampling hose. The gas hose ends in a funnel which makes the bottle easier to fill with gas and also holds the hose vertical when sampling. A hose clip prevents gas from accidentally escaping from the bottle. On the surface the bottles are filled with water and glass stoppers are inserted. On the bottom the diver positions himself away from the sampling site, preferably down slope, to prepare the apparatus. The glass stopper of a pre-labeled bottle is replaced by the sampling device. The bottle is turned upside down and filled with nitrogen from a small cylinder through the funnel and gas hose. When the bottle is completely filled with nitrogen, the gas hose is sealed with the clip. The diver moves to the sampling site, inverts the bottle to an upright position, and removes the clip. As the gas escapes through the gas hose, water is sucked into the bottle through the other hose. The diver moves the sampling hose along the bottom as required. A hand-held, stoppered syringe can also be used for similar sampling purposes.

Divers can hand place various types of artificial substrates for periphyton studies as well as quantitatively sample natural substrates. By encasing an artificial substrate in a plastic bag prior to removal, the diver can assure a relatively undisturbed sample. Information on the natural substrate obtained during exploratory dives can significantly aid in the design of the artificial substrate.

Special equipment for collecting underwater benthos has been devised or fabricated by individual investigators. Everson (1969) modified a square frame conical clip net for sampling epifauna in the Antarctic. Wilkinson (1967) describes methods for use of benthic quadrant scraper. A small hand operated suction device or "slurp gun" is useful for collecting mobile benthic macroinvertebrates. This commercially available device consists of a plastic tube with a hand drawn piston inside.

Evaluation of the significance of benthic algae to primary production may be measured by estimating the rate of carbon fixation. Carbon fixation measurements are made in situ using light and dark plexiglass chambers. These chambers are positioned by divers and C-14, in the form of sodium bicarbonate, is injected into each chamber with a syringe through a rubber port and stirred with a vane assembly. This entire process was developed to impart minimum distrubance to the benthic community. After a specified time interval, all algae are collected from the chamber for laboratory analyses.

Environmental factors which must be considered when studying the establishment and growth of underwater plant communities include exposure to wave or swell action, type and slope of substrate, water temperature, availability of dissolved nutrients, and grazing by herbivorous animals. It is often necessary to determine these factors accurately within a given plant community, and observation or measurement by divers may be indispensable.

Probably no other single environmental factor, however, approaches the importance of the variation in intensity and spectral composition of light underwater as an influence on the plant community. Drew (1971) indicates that an accurate estimate of the illumination at or within a given plant community can only be obtained by actual measurement in situ. The use of photographic light meters for this purpose is considered generally unsatisfactory. Instruments for underwater light measurement have been devised by Kitching (1941) and Boden, et al (1960); however, Drew (1971) describes what are probably the most promising instruments, a direct reading underwater spectral photometer and a miniature integrating photometer.

The Finnish IBP-PM Group (1969) designed the diver-operated Tvärminne quantitative sampler for use in soft sediments, a bag for quantitative sampling of fucoid biocoenoses, and a quantitative suction sampler for use on hard substrates. For details of apparatus construction and use consult the above paper.

SUMMARY

Underwater techniques for biological research are highly individualized to meet the needs of individual investigators and specific environmental conditions. In general it is evident that underwater quantitative sampling can be more precise than classical surface oriented methods. The diving biologist can use special photographic techniques even in turbid waters to document his studies. The trained diver-scientist, using modern techniques and equipment, can safely and confortably work to 40 m using compressed air breathing apparatus. Specially trained divers with proper diving and support equipment can work to depths of 60 m on compressed air. However, deep dives require highly specialized mixed gas diving equipment and techniques for safety and efficiency.

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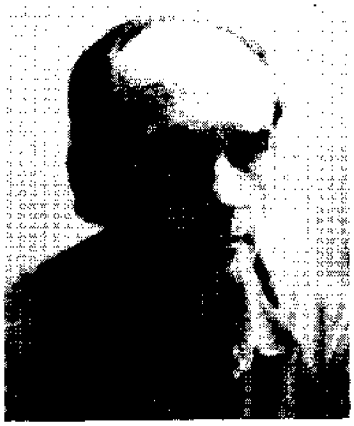
Dr. Simmons is an associate professor of Zoology in the Biology Department at Virginia Polytechnic Institute and State University in Blacksburg, Virginia where he teaches courses in aquatic ecology at the graduate and undergraduate level. His primary research interests deal with the evolution of lake communities, effects of perturbation on stream and lake ecosystems, and the development of underwater sampling techniques. He was instrumental in the development of an artificial substrate system for sampling the benthos of temperate lakes and reservoirs. He also manages a research dive team and trains research divers when necessary for participation in research projects. He holds active instructor status with the National Association of Underwater Instructors and the Young Mens Christian Association, and teaches courses in basic and advanced scuba at V.P.I. and S.U.



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Dr. Gale is currently Director of Research at Ichthyological Associate's laboratory in Berwick, Pennsylvania. He earned his Ph.D. degree in fishery biology from Iowa State University in 1969. Bill is a member of honorary, professional and semiprofessional societies.

Bill became involved in river research in 1966 when he began a two-year investigation of the benthos inhabiting Pool 19 in the Mississippi near Ft. Madison, Iowa. Since 1971 he has been part of a research team investigating the ecology of the Susquehanna River in northeastern Pennsylvania. In his work on the Susquehanna, Bill has been instrumental in the implementation of several innovative scuba sampling programs. His most widely recognized contribution is the development of the dome suction sampler. Bill has authored or co-authored over 20 scientific publications dealing with a wide variety of topics ranging from the study of iron in a river receiving acid-mine drainage to the burrowing behavior of fingernail clams in laboratory experiments. His present research interests include sound production in minnows, colonization rates of chironomids, and population dynamics of periphytic algae.

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Mr. Dubay is currently a biology teacher at Lafayette High School in Williamsburg, Virginia. He earned a B.S. degree in biology from the University of Virginia in 1976. Between these two periods, he served as a communications officer with the United States Army in Thailand during the Viet Nam conflict.

In addition to his academic persuits, Charles earned national certification as a scuba instructor in 1966. He is currently recognized as an instructor in the National Association of Underwater Instructors, the Young Mens Christian Association, and the Professional Association of Diving Instructors. Charles teaches basic scuba classes at the College of William and Mary.

His proficiency in diving enabled him to conduct the necessary underwater research on the macrophyte community of Mountain Lake, Virginia for his masters degree. Additionally, he has assisted a research dive team from Virginia Polytechnic Institute and State University in their studies on the macrophyte communities of a piedmont Virginia reservoir.

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Dr. Somers is an Assistant Professor in the Department of Physical Education and an Associate Research Oceanographer in the Department of Atmospheric and Oceanic Science at the University of Michigan, Ann Arbor. He is director of the University's Underwater Technology Laboratory which includes a double-lock recompression chamber and is the University's Diving Safety Coordinator. His primary research efforts are presently in the field of diving technology, diver education, diver safety standards, and the study of reef fishes in the Caribbean.

Dr. Somers has held positions on 14 major scientific diving and oceanographic projects or expeditions since 1963 including an Arctic Expedition and HYDROLAB saturation dives. Dr. somers has authored or co-authored more than 50 publications ranging from environmental studies to articles on underwater habitats, diving equipment and techniques for improving diver training. He is the author of the Research Diver's Manual and Cold Weather and Under Ice Diving. He holds professional or honorary memberships in eight societies including the American Society of Limnology and Oceanography and the Marine Technology Society. He is chairman of the Underwater Education Committee of the American Alliance for Health, Physical Education and Recreation and a member of the Scientific Committee of the Confederation Mondiale des Activities Subaquatiques (CMAS). Dr. Somers currently holds active instructor status with National Association of Underwater Instructors, Professional Association of Diving Instructors, and theYMCA. He currently conducts courses in basic scuba, research diving, scuba instructor training, hyperbaric chamber operation, underwater technology, general oceanography, and Caribbean marine environments at the University of Michigan. He is a member of the National Association of Underwater Instructors Board of Directors and a member of the Advisory Board for the National YMCA Underwater Activities program. In 1975 Dr. Somers received the Lenard Greenstone Award for contributions in diving safety.