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BLUE WATER DIVING GUIDELINES

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I. INTRODUCTION

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The introduction of modern scientific diving in the late 1940s allowed researchers to work directly in the underwater environment. Rather than collecting data, often indirectly, from the surface of large water bodies, scientists became able to set up experiments underwater, determine the distribution and abundance of subtidal organisms, make behavioral observations, take photographs, and carry out many other scientific investigations that were previously impossible.

A wide variety of scientific literature has resulted from diving techniques that allow scientists to explore the nearshore environments of the world's oceans and bodies of fresh water. Initially, researchers were mainly interested in benthic communities of the inner sublittoral zone. More recently, they have become interested in the direct observation and sampling of pelagic organisms and particulate matter of the open ocean (e.g., Trent et al., 1978; Harbison et al., 1978; Biggs et al., 1981; Alldredge and Madin, 1982; Alldredge and Silver, 1982; Caron et al., 1982; Martinez et al., 1983). Many of these organisms are difficult, if not impossible, to study via conventional collection techniques (nets and niskin bottles) because of their patchy distribution and fragile nature. Consequently, the need to dive in the euphotic zone of deep oceanic water became apparent.

In 1970 W. M. Hamner and his students at the University of California, Davis, considered the unique problems associated with this type of underwater methodology, termed *blue water diving*. Diving in the Gulf Stream off Bimini, they developed the first set of procedures for safely diving in this type of environment (Hamner, 1975), although they were not the first persons to use diving techniques in the open ocean.

As far as can be determined from the literature, the French conducted the first true blue water dives in 1962–1963 (Ceccaldi, 1962; frontispiece in Totton, 1965), during which they collected organisms in plastic bags. Photographs show that they did not use buoyancy compensators, submersible pressure gauges, or dive lines, but they did use double tanks, watches, depth gauges, and knives. An English group of physical oceanographers used diving to study thermocline structure and internal waves in the Mediterranean Sea off Malta in 1964 (Woods, 1971), and Russian divers investigated krill populations in Antarctic waters in 1969 (Ragulan, 1969). They used double tanks, but no dive lines.

II. GENERAL BLUE WATER DIVING PROCEDURES AND GUIDELINES

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These earlier projects were not further pursued.

Today blue water diving is a specialized technique that involves important perceptions, considerations, and hazards not experienced in any other type of diving. Sometimes likened to a "space walk," diving in the open ocean often means diving in very clear water without a functional bottom and with no fixed objects for reference. These factors can create a feeling of disorientation, which can be compounded if the diver is concentrating on small organisms or nearby objects. In this situation there is a considerable decrease in the diver's awareness of depth, buoyancy, current, surge, other divers, large organisms, and even surface direction to some extent. Therefore, coincident with the increasing use of blue water diving techniques for scientific research is a need for proper training and guidelines that will facilitate the safe use of this specialized type of diving.

Literature concerning blue water diving techniques has not been widely available in the past. Thus, the guidelines contained here are an attempt to achieve a wider distribution of such techniques within the scientific diving community. These guidelines are a result of a blue water diving workshop held at the Moss Landing Marine Laboratories in April 1984 with financial support from the California Sea Grant College Program. Blue water diving techniques, like all research diving techniques, are constantly evolving and reflect changes in equipment technology, training procedures, and scientific research requirements. Therefore, the guidelines as presented here are not intended to be rigid standards. They serve rather as a reference for those individuals interested in blue water diving techniques, giving recommendations for such concerns as diver training, diver equipment, small boat equipment, emergency procedures, and constraints associated with blue water diving. A section on general blue water diving procedures is followed by specific techniques submitted by active blue water diving research groups (see appendices). Finally, those persons interested in initiating a blue water research program should contact active researchers with the appropriate experience for consultation and training.

Although the reason for doing blue water diving is to answer scientific questions where *in situ* manipulations are the only feasible way to get results, scientific considerations must always be secondary to the health and safety of the divers doing the research. Thus, both the scientific and safety aspects of all procedures must be carefully considered when one designs a blue water technique for a specific application. Changes made in any technique to meet a requirement of the science must be carefully scrutinized for safety implications. And the technique itself must have enough flexibility to allow a variety of scientific uses.

This section will first describe a series of requirements common to most blue water applications. Following will be some general guidelines for safe implementation of these procedures. The guidelines are intended to be general enough to allow a variety of permutations of the technique while still preserving the high level of safety that is required of any blue water diving application.

The following goals of blue water diving techniques to ensure diver safety will be discussed: (A) extensions of the "buddy system" to ensure quick and effective communication between divers; (B) maintenance of correct and safe depths in a referenceless environment; (C) provisions for a safe surface platform, including ease of entry and exit, availability of emergency supplies on the platform, and access to extensive help (ship or shore); (D) divisions of tasks and distributions of scientific equipment and other weight that are both efficient and safe; and (E) provisions for safe responses to difficulties that are encountered, whether expected (e.g., weather and sharks) or totally unexpected.

A. Extensions of the Buddy System

In blue water diving, the buddy system has been altered to provide for a single "safety diver" whose full-time job is to ensure the safe execution of the dive. The safety diver communicates with the "working divers" by safety tethers—long (about 30 ft.), thin (about 1/4-inch diameter) lines. These safety tethers allow the safety diver to get any working diver's attention immediately by simply tugging on the tether. Signal tugs can be prearranged or

simply serve to get the diver's attention so that communication by commonly understood hand signals can be achieved.

Tethers of a fixed length would tend to droop and become tangled around divers and their gear. They must be designed so they remain somewhat taut at all times, which also ensures quick signaling of the working divers. This can be done by weighting the end nearest the safety diver with a 4 to 8 oz. fishing weight. The tether then passes freely through the metal loop on the end of a swivel clip (see Figs. A4, B3, and C1 in appendices). These clips are then attached to a "trapeze" located near the safety diver (see below for details). Thus, as the working diver swims away from the safety diver, the tether smoothly plays out, and upon returning, the tether retracts as the weight sinks. By ensuring that the diameter of the tether weight is wider than the loop on the clip, the tether is prevented from extending beyond its 30-ft. length. In conditions of low visibility, the tethers can be shortened by tying a knot on the weight side of the tether, shortening the length that can play out.

The other end of the tethers should be connected to the diver with some form of quick-release shackle, which enables divers to quickly disengage themselves from the apparatus. The tether should never be attached to the weight belt, as this would add excessive weight to the array in the event that one or more divers ditched (or accidentally lost) a weight belt. Instead, the tether should be attached by a quick release to the diver's buoyancy compensator or to a separate harness. If the quick-release shackle is attached to the diver's buoyancy compensator or harness (rather than the tether), it can be released by a pull away from the diver's body, ensuring that it releases. The safety diver should also be attached to the trapeze by a short (3-ft.) tether, so that all of the divers are always attached to each other.

The trapeze can be any bar or ring that accepts numerous clips and allows them to be easily repositioned by the safety diver (see Figs. A4, B3, and C1 in appendices). As the working divers move around at their various tasks, they will often change relative positions in the water. The safety diver unclips and rearranges the tethers on the trapeze to prevent tethers from tangling.

B. Maintenance of Correct and Safe Depths

By definition, there is no bottom in blue water diving. In fact, any diving where the maxim "if you drop it, it's gone forever" holds true, even if the bottom is only 150 ft. deep, could probably be considered "blue water." The most common applications, however, are in places where the bottom is far deeper than one can see or go while breathing air on SCUBA. In these cases, especially in very clear water, it is difficult to tell how deep you are and often whether you are ascending or descending (even for those with sensitive ears). While diving unattached, it is easy to go below your planned depth without realizing it. For this reason, it is a good idea to have a depth gauge that records maximum depth, especially on long or repetitive dives.

The common way to provide some reference point in blue water applications is to hang a line from a float. This provides a frame of reference attached to the surface. If depths are marked at regular intervals on this "down line," the diver can glance at the line, get an estimate of depth, and, more importantly, tell if he or she is rising or sinking and compensate accordingly. Most blue water diving is done from small boats (see Section II, C), and the down line is ultimately attached there (see Figs. A1, B2, and C1 in appendices). The attachment at the boat should be very secure, and the line should be fastened at more than one location on the boat. In some applications this line is hung directly from the boat, while in others the down line passes through a buoy or float and descends from there. The opposite end of the line should be weighted just enough to cause the line to sink and no more (not exceeding 10 lb. and usually much less). In all cases the down line should be a continuous line from the boat to the weight at the lower end of the line. Depths below the surface float are usually marked clearly with plastic labels above knots in the line, which are also useful for attaching gear. (See Figs. B1 and B2 in the appendices.) The trapeze is attached to this down line, providing a means of communication between the "boat person" and the dive team. The boat person can terminate the dive by pulling the apparatus out of the water.

There are two major physical phenomena that affect the down line: wind and waves. Windage on the boat moves it along the surface, dragging the down line after it—a problem naturally

greater on high profile boats and in stronger winds. The movement through the water will affect the safety of the dive and the efficiency of the work. Some groups approach this problem by decoupling the windage on the boat from the down line. To do this the down line must be very long (150 to 200 ft.) and the surface float secured at about the midpoint. This leaves a large amount of rope between the float and the boat, which must be kept slack by rowing into the wind toward the float (Fig. A2). The windage on the float itself is minimal, so the underwater segment of the down line is usually vertical. In this application, the rope used for the down line must float (see Section III) to avoid entangling the divers below.

If the down line hangs directly from the boat or if the segment of line from the boat to the float is short, a sea anchor can be used to retard the boat's motion through the water (see Figs. B1 and B2). The down line and the divers are themselves acting as a sea anchor, so the addition of a sea anchor will reduce drag. If a sea anchor is to be deployed routinely, even in light or inconsistent winds, it should have a small float of its own so it does not sink and interfere with the divers if the wind dies.

Waves also affect the down line, causing a vertical bounce that is uncomfortable for the safety diver who is usually the only one holding onto or closely attached to the down line. Wave motion is also a problem for any applications where the down line must remain still, such as *in situ* incubations. To decouple the bounce of the surface float from the line, a segment of bungy cord or surgical tubing can be incorporated into the line just below the buoy by securing it between two loops, so that the continuity of the down line is maintained. The addition of "flopper stoppers" (flat disks or plates) to the bottom of the line provides vertical drag to the down line, also helping to damp out wave motion. If the disks are negatively buoyant, their underwater weight should be taken into account. For "heavy" materials like PVC, no additional weight may be necessary. Examples of various down line and tether configurations are depicted in the appendices.

C. Provisions for a Safe Surface Platform

Blue water diving is usually done from a small boat such as a Zodiac or Boston Whaler. Large boats present a lot of windage and are harder to maneuver, and much smaller boats cannot

accommodate the people and gear required. Since the diving platform (from now on referred to as the "boat") is at some distance from shore or the mother ship, it is necessary that it contain a certain level of safety gear of its own. What is actually aboard the boat is in part determined by space limitations and by the rapidity with which advanced emergency care can be obtained.

Section III, on equipment, lists a large number of safety items that could be carried on the boat. Each safety item should be carefully considered in the context of the emergency situations for which it is used. In some cases, the choice of a boat will affect this decision. For example, a secondary motor cannot easily be mounted on a small Zodiac. Other items such as a radio are probably mandatory under any circumstances. Any equipment carried on the boat should be conveniently arranged and waterproofed when necessary. All divers should know where all equipment is located and how to use it. The boat should not be overloaded. If multiple dives are planned or if there is a large number of divers, a second boat to hold extra gear and possibly ferry divers should be considered. This boat could then cruise around or drift at a safe distance from the dive boat and be recalled when necessary. In any case, the dive platform should be large enough to carry all divers in an emergency. To allow re-entry into the boat, equipment lanyards with terminal clips can be hung from the boat. Tanks, weight belts, and other equipment can be attached to the lanyards before climbing into the boat.

One person should remain on the dive boat at all times. This "boat person" can monitor surface conditions, keep a lookout for sharks, and assist divers in entering and exiting the water. It is recommended that the boat person be a diver so he or she is aware of what is happening below, is sensitive to the divers' needs, and can identify diving-related maladies should they occur. Some dive teams recommend that the boat person be able to lift a fully equipped diver out of the water and into the boat.

D. Division of Tasks and Distribution of Equipment

The maximum number of divers that can work together in a single blue water team with only one safety diver is probably about five (one safety diver and four working divers). The safety diver must keep track of the depth and condition of each of the

divers, monitor the tethers, and visually scan the water in all directions. With more than four working divers, the ability of the safety diver to adequately perform all these tasks is seriously impaired. To aid the safety diver, each working diver should visually scan the working environment whenever the scientific task allows. The presence of a full-time safety diver in no way relieves the other working divers of the responsibility of keeping some track of each other and their own dive status (air, body temperature, depth, bottom time, etc.). The responsibility for the continuation of the dive rests with the safety diver; however, at any time and for any reason, any diver or the boat person can (and should) terminate the dive if he or she feels it is unsafe.

Blue water diving usually has a scientific goal. The work that is being done varies and so does the equipment being used. Much of this equipment is not neutrally buoyant and can be quite heavy (especially glass collection jars). The distribution of equipment is an important consideration when planning where the weight will go once everyone is in the water. If each diver is carrying a large amount of gear, it will affect his or her buoyancy, both underwater and on the surface. If the gear is attached to the down line, it frees the divers but adds weight to the down line. Each piece of gear can have its own flotation device or weight to render it neutral at the working depth. If gear is hung on the down line, it can be attached at the appropriate depth as the down line is deployed rather than being carried down by the divers. Sensitive instruments, such as cameras and photometers, can be hand-carried, but no diver should be overloaded with gear. Gear hung on the down line should be above the trapeze and safety diver. Working divers below the trapeze risk entanglement in the weighted tethers and envelop the safety diver in a cloud of bubbles, reducing vision. Alternately, a second down line can be deployed (see Fig. B1), and all the gear can be attached to this line. Care should be taken that this gear line be kept separate from the tethers, and no diver should ever attach to it.

E. Provisions for a Safe Response to Difficulties

As part of both pre-dive planning and training, the techniques and procedures used should be closely examined for their safety. Possible alternatives should be thought of and compared with the

safest, most effective technique adopted. The development of new techniques (or even the re-evaluation of old ones) should be discussed with other experienced blue water divers, and their advice and suggestions should be considered seriously within the context of the particular sampling requirements.

During the pre-dive planning, strategies should be worked out for any anticipated emergency situation, such as sudden storms, sharks, and diver accidents. Techniques for aborting a dive should be standardized within the dive team, and all divers should be familiar with these techniques. The order of events for a fast or unexpected termination of the dive should be practiced often. The dive team should consider what its response would be to emergency situations, such as a diver's becoming unconscious underwater, and every technique should be compared to worst-case scenarios. Through a constant and critical examination of the dive protocol, many marginal or unsafe situations can be corrected or planned for in advance.

The exact protocol used in blue water diving is not something that can be rigorously dictated. There are differences created by different scientific needs and by differences in philosophy of the dive programs and the people involved. The dive protocols listed in the appendices are those generally and recently used by the indicated groups. Groups beginning a blue water operation should contact others actively involved in blue water research for aid and advice. They should evaluate the commonly practiced procedures and tailor a protocol to suit their research needs, always making conscious decisions about any alterations of an established technique and thinking through the repercussions of the new protocol.

III. BLUE WATER DIVING EQUIPMENT

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Blue water diving necessitates the use of an array of equipment different from other research diving. The following is a list of equipment used in most blue water diving applications. It is extensive and can be used as a checklist of items that are or may be necessary. Section III, C discusses materials and the construction of some of the more specialized pieces of equipment.

A. Small Boat Equipment and Safety Equipment

1. Radio
2. First aid kit
3. Drinking water
4. Oxygen resuscitator
5. Outboard motor with sufficient fuel
6. Oars
7. Flares and strobe
8. Compass
9. Tool kit
10. Spare parts and patch kit
11. Coast Guard approved personal flotation devices
12. Spare tank with backpack and regulator
13. Radar reflector
14. "Diver down" flag
15. Sea anchor
16. Launch/recovery sling
17. Equipment lanyards with clips

B. Diving Equipment

1. Standard SCUBA Equipment
 - a. Exposure suit sufficient for local environment
 - b. Mask, snorkel, and fins
 - c. Weight belt with quick release
 - d. Buoyancy compensator (with power inflator)
 - e. SCUBA tank and backpack
 - f. SCUBA regulator with submersible pressure gauge
 - g. Depth gauge (with maximum depth indicator preferred)
 - h. Underwater time-keeping device
 - i. Sharp knife
 - j. Spare parts (O-rings, straps, etc.)
 - k. Dive tables
2. Specialized Equipment
 - a. Down line
 - i. sturdy continuous length of line of the appropriate material
 - ii. float
 - iii. elastic wave damper
 - iv. depth markers

- v. points (loops) of attachment
 - vi. weights and/or flopper stoppers
- b. Gear line (same as above)
 - c. Trapeze
 - d. Safety tethers
 - e. Shark billies
 - f. Safety harness
 - g. Tank and regulator (with octopus) at decompression stop

C. Materials and Construction

Lines. Lines can be of either braided or twisted rope. Twisted lines tend to kink and chafe more readily than do braided lines but are less expensive. Braided lines are easier to handle and are preferable. Dacron double braid and braided nylon are the strongest commonly used lines. Nylon stretches, while Dacron does not; both are negatively buoyant. For applications where the lines must float, braided polypropylene can be used. Polypropylene lines should be greater in diameter than either nylon or Dacron, because they are not as strong and are more susceptible to chafing.

Trapeze. The trapezes used come in a variety of configurations and are made from many different materials. See the appendices for complete descriptions.

Tethers. Tethers should be made of braided materials only. Twisted tethers will kink and catch in the clips. Nylon or Dacron double braid are preferable. The weights on each tether should be shaped so that they will not jam in the clips when they are fully extended. The diver end of the tether should end in a ring or a clip.

Weight. The weight at the end of the down line should never exceed 10 lb. and can be much less. Flopper stoppers can be fashioned from Secchi Disks or PVC plates. These materials are negatively buoyant and additional weight is probably not necessary. Flopper stoppers can also be made from the plastic lids of 5-gal. buckets. These have the added advantage that the bucket can be used to store the down line when not in use (see Appendix B).

Shark Billies. Shark billies should be thin and/or short enough to allow rapid lateral movement through the water. They can be made from broom sticks, pole spears, or thin fiberglass poles. Bang sticks are discouraged because of the potential danger to other divers both in the water and in a crowded boat.

IV. DIVER TRAINING

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Blue water diving in clear, blue oceanic water is considerably different from bottom-oriented nearshore diving. Some divers have initially found that the lack of a bottom or any fixed objects can be distracting and discomfiting (Hamner, 1975). Furthermore, much of the science being conducted at present in this environment centers on small, planktonic organisms, which requires that the eyes focus on an area very close to the face mask. This can make it difficult for the working diver to be aware of such things as changes in buoyancy and depth, proximity of other divers, and sharks. For these reasons, even experienced divers require additional training before participating in blue water diving in deep water. Inexperienced divers should be encouraged to gain more experience in nearshore bottom diving before attempting blue water diving on a large scale.

Pool sessions provide a useful introduction to blue water diving equipment and procedures. As with all diving skills, repetition is the key to successful learning. Divers should first become highly proficient at buoyancy control, an important skill to master in diving efficiently in the blue water environment. A good drill is to have the divers achieve neutral buoyancy in midwater and have them control their buoyancy through breath control.

Divers should practice clipping and unclipping their tether lines, communicating with the safety diver via jerks on the line and hand signals, simulating emergency procedures such as entanglement and shark presence, and retrieving an untethered diver drifting away from the group. All divers should have an opportunity to act as the safety diver to gain appreciation of this important position. The pool is also an excellent location in which to test scientific sampling gear that will be used in open water.

Inshore open water training sessions that closely simulate blue water diving, but with a bottom depth of 30 to 60 ft. are useful as an introduction to conditions approaching open ocean diving. Divers will gain an appreciation for such factors as currents, surge, limited visibility, and manipulation of lines and equipment in (possibly) cold water. Training at an inshore location allows divers to become comfortable and confident without the disorientation of diving in blue water for the first time. Also, if something goes wrong or is dropped accidentally, it can be easily retrieved from the bottom.

Initial blue water dives for divers in training should be conducted under relatively benign conditions. Scientific work should not be attempted on the initial dives, or until the divers in training are comfortable with the procedures. No minimum number of dives can be established as sufficient to qualify someone as a "certified" blue water diver, since this will vary with individuals. Ultimately, it is the responsibility of the person in charge to determine when blue water divers in training are qualified to begin scientific research.

V. CONSTRAINTS ASSOCIATED WITH BLUE WATER DIVING

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Common constraints associated with blue water diving are strong winds, heavy swells or strong currents, turbid waters, bad weather, and aggressive predators.

A. Strong winds, generally greater than 20 knots, cause excessive windage on an inflatable boat, which drags divers through the water. This makes it extremely difficult for the divers to work underwater and can present a safety problem with regard to recovery of the divers after the dive. Strong winds also create problems in launching a small boat from the mother ship and recovering it.

B. Heavy swells create excessive vertical jerking of the down line, making it difficult to accomplish work, and usually necessitating termination of the dive. The dive should also be terminated if the current is excessive and divers are unable to work safely.

C. Turbid waters having low light levels necessitate short safety lines. Divers must be able to see the safety diver (and vice versa) clearly. If the visibility requires very short tether lines, effective work may not be practical. It may also be difficult to establish and maintain orientation in the water.

D. In heavy rain, snow storms, or fog, small boats can become separated from the mother ship or possibly from the divers.

E. Known presence of aggressive predators, such as sharks, killer whales, and leopard seals, makes it difficult to concentrate on the task at hand, and the possibility of attack is a strong consideration.

VI. EMERGENCY PROCEDURES

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All diving activities have the potential for serious accidents. In addition to the physiological considerations that apply to diving while breathing compressed air, there are other risks that should be discussed and comprehended by all individuals involved. Emergency situations such as a diver out of air, an unconscious diver, diver entanglement, shark attack, or equipment failure may require different responses in a blue water dive than they would in a nearshore bottom dive. The following items should be considered by all participants for each diving location and/or vessel used:

A. Have an emergency plan. Make sure that the captain of the vessel knows how to make emergency calls and whom to contact in case of serious diver injury. He or she should know the location of the nearest recompression facility and the fastest method of transportation to it. Have a first-aid kit and oxygen available, with personnel trained to use it. All personnel should be trained in cardiopulmonary resuscitation (CPR).

B. Use prearranged signals (hand waving, flares, or radio) for communicating emergencies between small boats and the mother ship.

C. Give training regarding an underwater diver out of air. Establish priorities among the options a diver in this situation can exercise. The first choice is for the diver to swim to the safety diver, to signal that he or she is out of air, and then to breathe from the safety diver's secondary air supply (i.e., octopus or pony bottle) or to buddy breathe using the safety diver's primary regulator. The safety diver then signals all other divers to abort the dive and ascend to the surface. An emergency swimming ascent is also possible, but the diver usually must release from the safety tether to reach the surface. A diver making a positive buoyant ascent risks lung overpressure and decompression sickness and could drop his or her weight belt onto another diver below.

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APPENDIX A: BLUE WATER DIVING EQUIPMENT AND PROCEDURES USED AT THE UNIVERSITY OF CALIFORNIA, LOS ANGELES AND SANTA BARBARA

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A. Procedures

These procedures are presently being used by William Hamner and his research group at UCLA in the Bering Sea and in Antarctica. The same system (with some minor modifications) is also being used by Alice Allredge at UCSB.

1. A small inflatable boat or Boston Whaler is deployed from the mother ship according to ship's procedures.
2. Divers review dive plan before entering the water.
3. All lines, knots, clips, and buoys are inspected prior to deployment.
4. The down line is lowered into the water, the buoy is attached to a loop in the line at the 100-ft. (30-m) length, and the remainder of the line (about 100 ft.) is secured to the boat. In other words, there is one continuous line, with a buoy connected in the middle and the bitter end secured to the boat (see Figs. A1, A2, and A3).

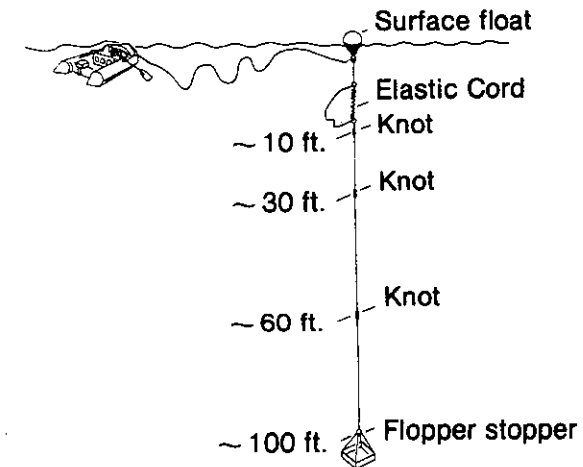


Figure A1. Typical down line array utilized in blue water diving operations. One continuous line, 100-200 ft. in length, is tied off at the boat and run through the surface float, terminating with a flat stock PVC "flopper stopper." Groups of two knots each are tied into the line at specific depth intervals, in between which the safety diver and trapeze are connected. (Adapted from Hamner, 1975).

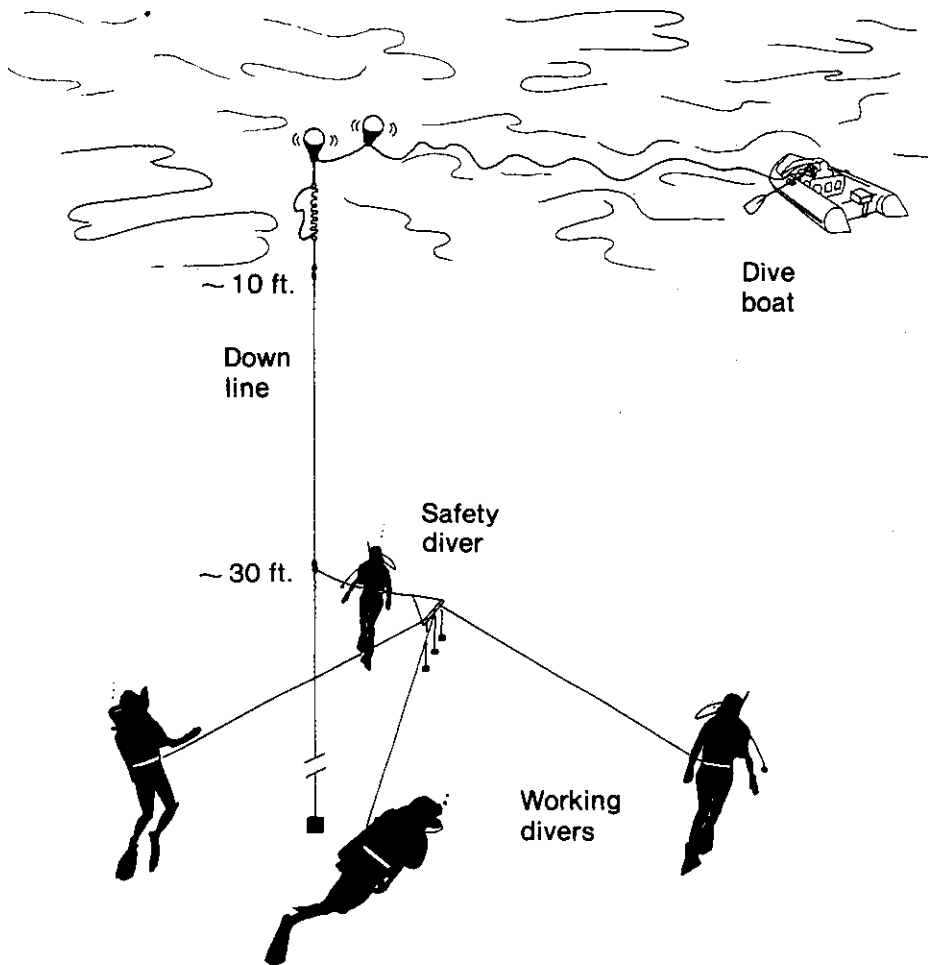


Figure A2. Surface dive boat with operator, down line array, safety diver and three working divers conducting a blue water dive. (Adapted from Hamner, 1975).

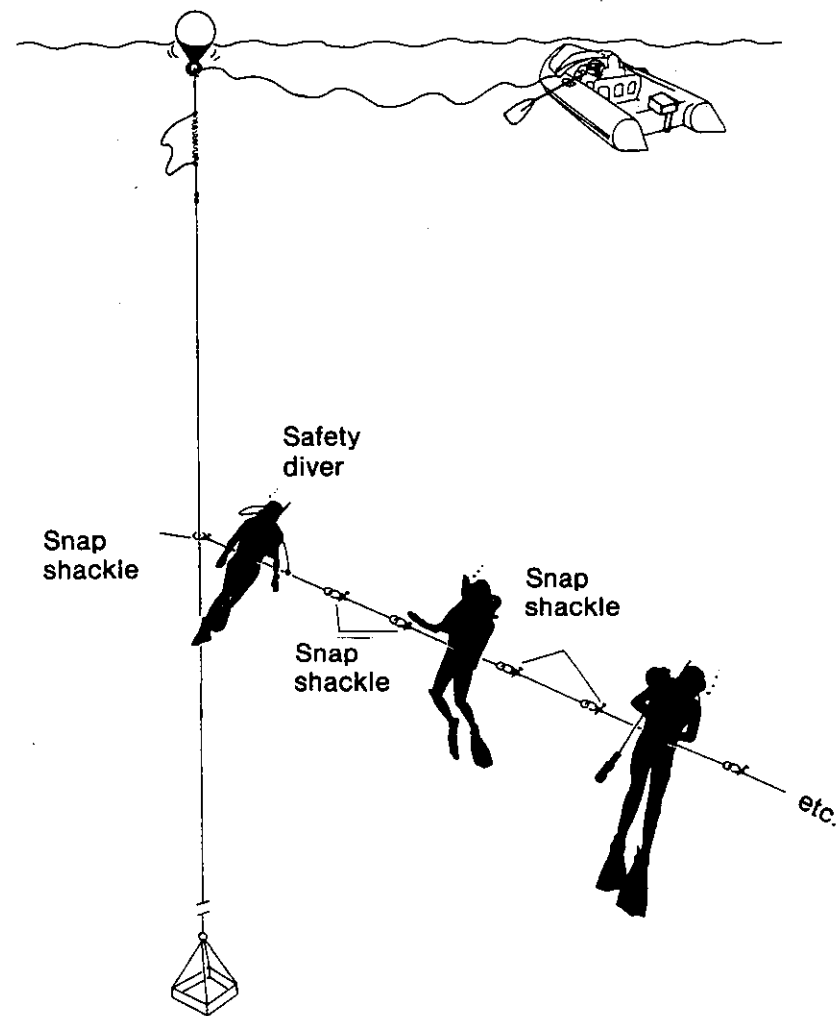


Figure A3. Modification of the typical blue water diving operation used to sample a horizontal transect. Note that no trapeze is used and that the divers are tethered to each other via quick-release snap shackles.

5. The minimum number of divers required is two, one safety diver and one working diver. The maximum number of research divers that can be tended adequately by a safety diver is usually four, but under ideal conditions, as many as six.
6. All divers suit up. Divers attach safety tether line to quick-release snap shackle on buoyancy compensator and drop an approximately 8-oz. lead sash weight and safety line over the side behind each diver. *No lines are ever to be connected to the weight belt.*
7. Divers enter the water and swim to the surface buoy. When all divers are assembled at the buoy, the safety diver signals OK to the boat operator, who keeps the surface line slack by rowing or motoring toward the buoy. This line must remain slack throughout the dive so that the divers will not be pulled through the water. If it is not possible to keep the line slack, the dive should be aborted.
8. When the boat operator signals (with the OK signal) to the divers that the line is sufficiently slackened, the divers can begin the dive.
9. The divers descend together down the line, usually to a depth of about 10 ft. (3 m). Each diver attaches his or her safety line to the trapeze. When the safety diver signals OK, the divers descend to the predetermined depth. The safety diver attaches the trapeze to the down line and attaches his or her short tether line to the trapeze. All divers adjust buoyancy and signal OK to the safety diver before beginning work. Working divers should orient themselves so that they can see the safety diver. A good practice is to run the safety line through the palm of one hand so that tugs on the line can be easily detected.
10. The safety diver acts as a buddy for each of the other divers, and therefore must keep all working divers within good visual range. He or she monitors the safety tethers—unclipping, untangling, and reattaching the lines to the trapeze as needed. The safety diver can adjust (shorten) the length of the safety lines by tying knots in the lines between the small weights and the trapeze. The safety diver also surveys the surrounding area for

potential hazards and supervises the entire dive. He or she has the ultimate underwater control over the dive and can terminate the dive if conditions warrant. He or she communicates with the research divers by tugging on their tether lines using, for example, the following types of signals: one tug on the line means "Are you OK?"; two tugs, "I want your attention"; and three tugs, "Return to the safety diver."

11. The boat operator can also communicate with the safety diver by pulling on the down line or by using an underwater recall system. Also, if necessary, the boat operator can terminate the dive by slowly pulling up the whole system toward the surface.
12. The procedure used as a defense against large predators, such as sharks, killer whales, or leopard seals, is for the safety diver to signal all working divers to return to the down line, unclip their tethers and hold them in one hand, and ascend to the surface as a group, facing outward if necessary. The safety diver utilizes the "shark billy" to ward off curious predators if necessary.
13. The dive is terminated when the first diver has approximately 600 psi of air remaining. This allows time for other divers to discontinue their sampling and to converge at the safety diver. All divers release safety lines simultaneously and ascend the down line together, leaving the trapeze and tether lines attached to the down line below. With a large group (five divers total), divers can be sent up to the surface in pairs by the safety diver, leaving their safety lines hanging from the trapeze. All divers should be alerted to the fact that a pair of divers is surfacing, and the divers should wait at the surface float for the others.
14. Once at the surface, divers swim along the surface line to the boat, which is idling in neutral if the engine is running.
15. To facilitate entry, divers can attach weight belts to clips hung on short lines from the boat, and they should exit the water as rapidly as possible.
16. Down line and surface buoy gear are retrieved.

A modification of this procedure may be used to sample a horizontal transect in blue water (see Fig. A3). There is no trapeze used, but the safety diver is connected to the down line via a quick-release snap shackle. Each successive diver added to the system is connected to the previous diver via the snap shackle.

B. Specialized Equipment for Blue Water Diving

Down line (Fig. A1). The vertical down line is 100 to 200 ft. long, the length depending on the amount of line desired for the slack line from the surface buoy to the boat. Typically, 100 ft. of the line is used underwater and approximately 100 ft. on the surface. Commonly used materials are 1/2-in. polypropylene line or 3/8-in. nylon or Dacron double-braided line. The surface float should be sufficiently large to provide positive buoyancy for the entire array. Elastic "bungee cord" is often attached on the down line just below the surface buoy to act as a wave damper. Two knots are tied closely together on the down line at depths of approximately 10, 30, and 60 ft. The trapeze is connected between these knots and will not slide over them, thereby limiting the depths at which the divers are able to work. The lower end of the down line is lightly weighted by a shackle, a 5- to 10-lb. weight or length of chain, or a flat PVC "flopper stopper" that weighs 5 lb. in water. Its large surface area provides resistance and reduces vertical movement of the down line.

Trapeze and Safety Tethers (Figs. A4, A5, and A6). The trapeze is a small aluminum bar about 3 ft. long with approximately five holes drilled through it to accommodate the safety lines. The trapeze is connected to the down line by a 3-ft. long nylon line (usually 1/4 in.), with a brass snap clip (see Fig. A4). Brass swivel snaps hook onto the holes in the trapeze. The safety lines (1/4 in. nylon) are approximately 30–50 ft. in length. They pass through the snaps, with the lead sinker hanging below the trapeze to keep the line taut (see Fig. A4). The other end of the safety line is attached to the buoyancy compensator (usually on a D ring) via a quick-release snap shackle (see Figs. A5 and A6). The safety diver is attached to the trapeze by a short 3-ft. line, so that his or her hands are free to manipulate the safety lines.

Shark Billy. Some type of slender rod, such as a broom stick or short pole spear, should be carried by the safety diver. This shark billy should not be too long or too wide, as this limits its mobility in the water—important when fending off fast-moving sharks.

Scientific Sampling Equipment. All sampling equipment should be close to neutrally buoyant underwater. It is also prudent to have some type of lanyard on each piece of equipment so that it can be carried looped on the diver's arm or can be attached to the down line. It is important not to overload (overweight) the diver or the down line with additional scientific equipment in case the rope fails or equipment becomes detached from the surface flotation system.

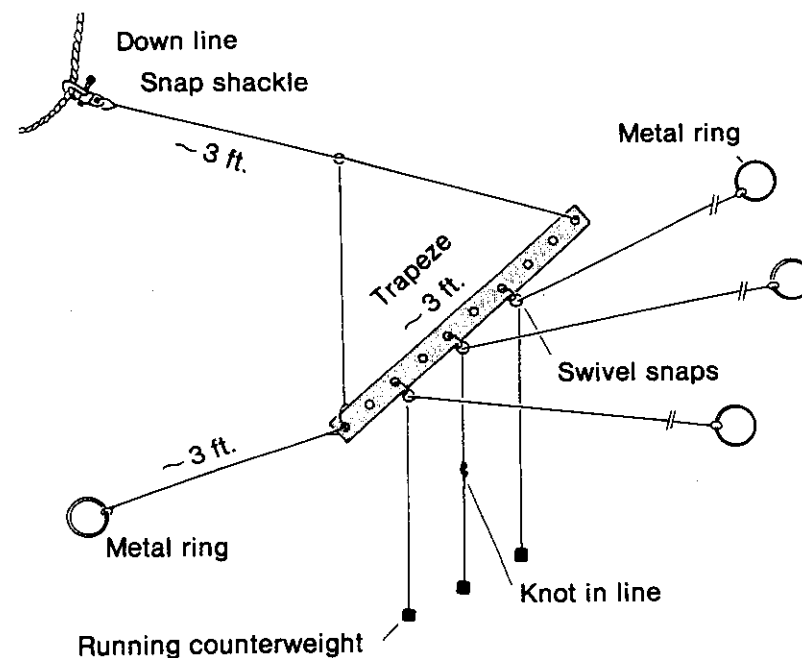


Figure A4. Typical trapeze, showing quick-release snap shackle and weighted safety tether lines. (Adapted from Hamner, 1975).

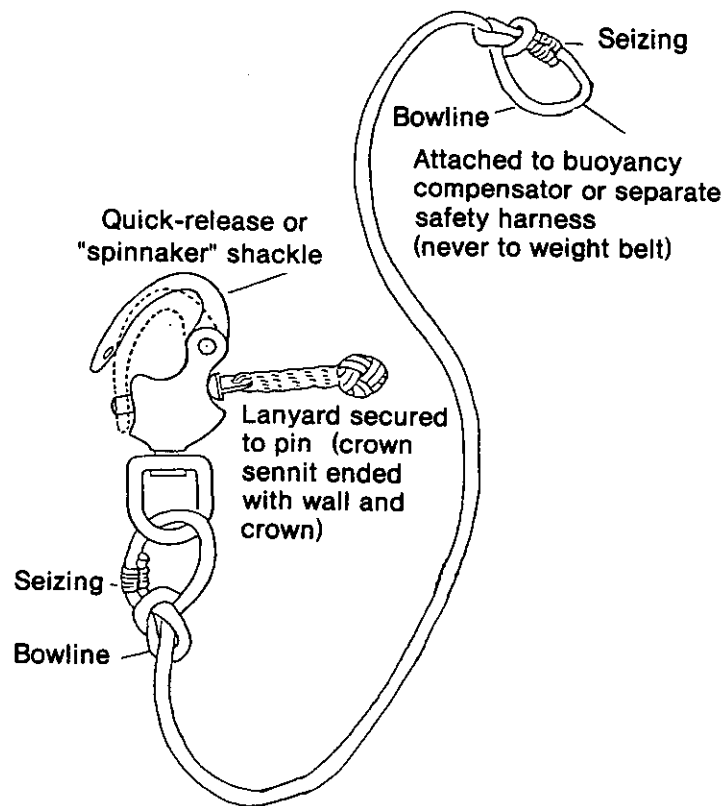


Figure A5. Typical safety line. Free end of line attaches to diver's buoyancy compensator or separate harness and terminates in a quick-release snap shackle. Line is short enough that diver can easily grasp shackle and pull away from his body to release. (Drawing modified by D. Divins from original by T. Rioux.)

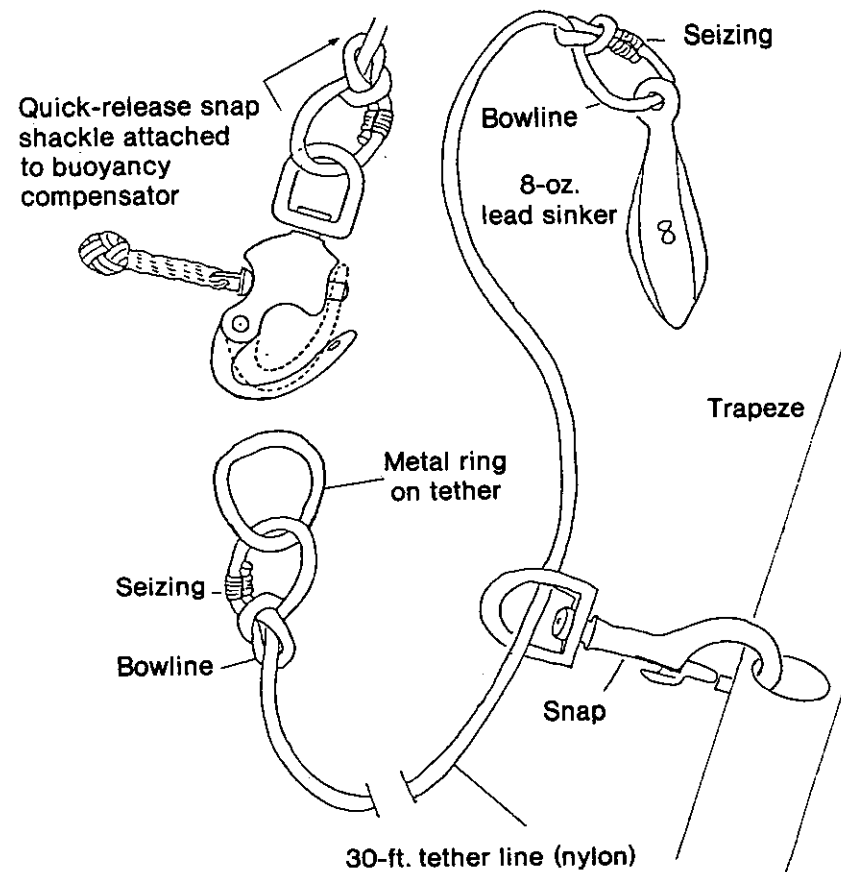


Figure A6. Safety tether line. Metal ring attaches to quick-release snap shackle on diver, and tether line runs through the trapeze or pivot ring, terminating in a small lead sinker that keeps the line taut. (Drawing modified by D. Divins from original by T. Rioux.)

APPENDIX B: BLUE WATER DIVING EQUIPMENT AND PROCEDURES USED AT THE UNIVERSITY OF CALIFORNIA, SANTA CRUZ

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University of California, Santa Cruz

The University of California, Santa Cruz (UCSC) blue water diving technique was originally adopted in 1973 by Jonathan Trent and Alan Shanks. Similar to that of Hamner (1975), this method was used in the collection and counting of marine snow samples for nutrient analysis (Trent et al., 1978; Silver et al., 1978). Since that time, the technique has undergone a substantial amount of redevelopment and improvement by Kenneth Coale, Jim Cowen, Robin Pinto, and Anthony Michaels to accommodate a wider variety of sampling requirements.

Our first modified technique was used on early VERTEX and marine chemistry cruises in the collection of pelagic macroplankton samples. This type of sampling involved collecting marine snow or organic aggregate samples for species abundance counts, microbiological characterizations, aggregate densities, and trace metal analysis. This work resulted in publishable data in three areas: (1) photographic documentation ("UFOs," 1982 exhibition at the Scripps Aquarium-Museum by Jonathan Trent; and cover of December 1982 *BioScience*, photograph by Kenneth Coale); (2) gelatinous zooplankton fecal pellet composition and sinking rates (Silver and Bruland, 1981; Bruland and Silver, 1981); and (3) natural series radionuclide analysis of salp fecal pellets (Coale, in prep.).

The system described below (Fig. B1) was used during the 1984 VERTEX V cruise to the central North Pacific. Collections of *Rhizosolenia* mats and marine snow incubated *in situ* and analyzed for nitrogen fixation activity (acetylene reduction and ^{15}N uptake), hydrogen evolution, and pigment and nutrient composition. Hand collections of salps, pteropods, and doliolids were also taken along with flow meter estimates of specimen densities.

A. Equipment

The apparatus used by the UCSC blue water divers is described below. The considerations that prompted this specific construction for this kind of array are presented so as to allow the reader to evaluate the design.

Down Line Construction. The down line is constructed from a continuous 150-ft. length of 3/8-in. double-braided Dacron line.

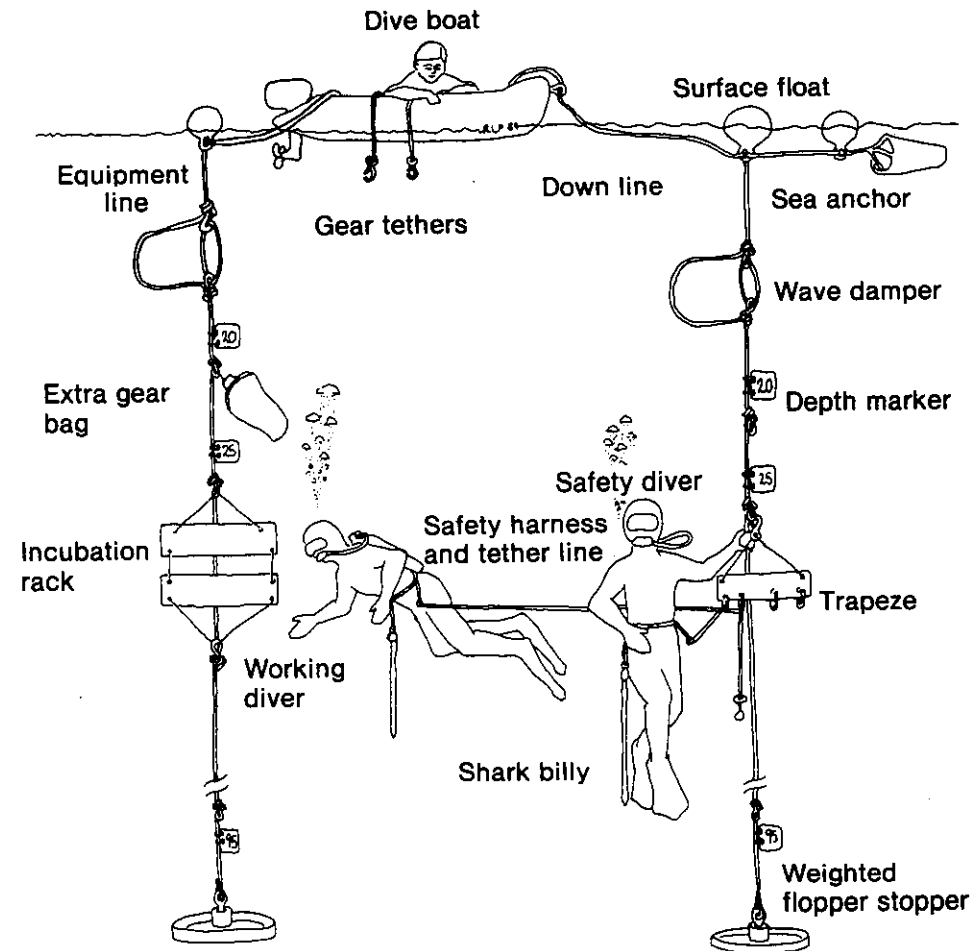


Figure B1. A schematic representation of the UCSC blue water diving apparatus. The down line and equipment line are depicted in a typical configuration. Only one working diver is shown, although there may be as many as four (not to scale).

Loops 3 in. in diameter are tied in this line every 5 ft. Loops at 10-ft. intervals are clearly marked with 3 x 3 x ¼ in. white polypropylene plaques. These plaques, clearly labeled on both sides with the appropriate depth, are secured to the down line with nylon cable ties. The bottom of the down line (100 ft.) is shackled and seized at a small, 3-lb. weight that is eye-bolted to the lid of a 5-gal. white polyethylene bucket (Fig. B2). An elastic wave damper made from a 3-ft. loop of 3/8-in. surgical tubing is secured between two loops about 2 ft. directly below the surface float. A 1-ft. diameter international pink inflatable boat fender serves as the surface float. This is shackled and seized to the surface loop in the down line. About 10 ft. up the line from the surface loop is another loop that is secured to the bow of the dive boat. The bitter end of the down line is securely fastened at one or more other locations inside the dive boat and within the boat operator's sight and grasp.

The down line must be accurately positioned in the water column, with small depth variations resulting from the sea and swell. Therefore, the surface portion of the down line, the wave damper loops, and the surface float loop positions must be adjusted such that the average working load extension of the wave damper is consistent with the depth increments on the down line.

We chose 3/8-in. double-braided Dacron as the down line material because of its high strength and ease of handling. It is more resistant than polypropylene and nylon to chafing, twisting, and stretching. Knots in this material can tolerate considerable strain and still be untied or retied easily. Loops tied at 5-ft. intervals accommodate a wide variety of equipment configurations. Depth markers are made from chemically inert polypropylene to be durable and noncorrosive. Increments on these markers are in feet rather than meters so that there is a direct correspondence to standard depth gauges and U.S. Navy dive tables.

The bucket lid used on the bottom of the down line serves a variety of purposes. Slightly weighted, it serves as a flopper stopper to oppose the vertical wave-driven oscillations of the down line. It doubles as a Secchi Disc and in clear water as a good lower visual reference point. In our design the down line is

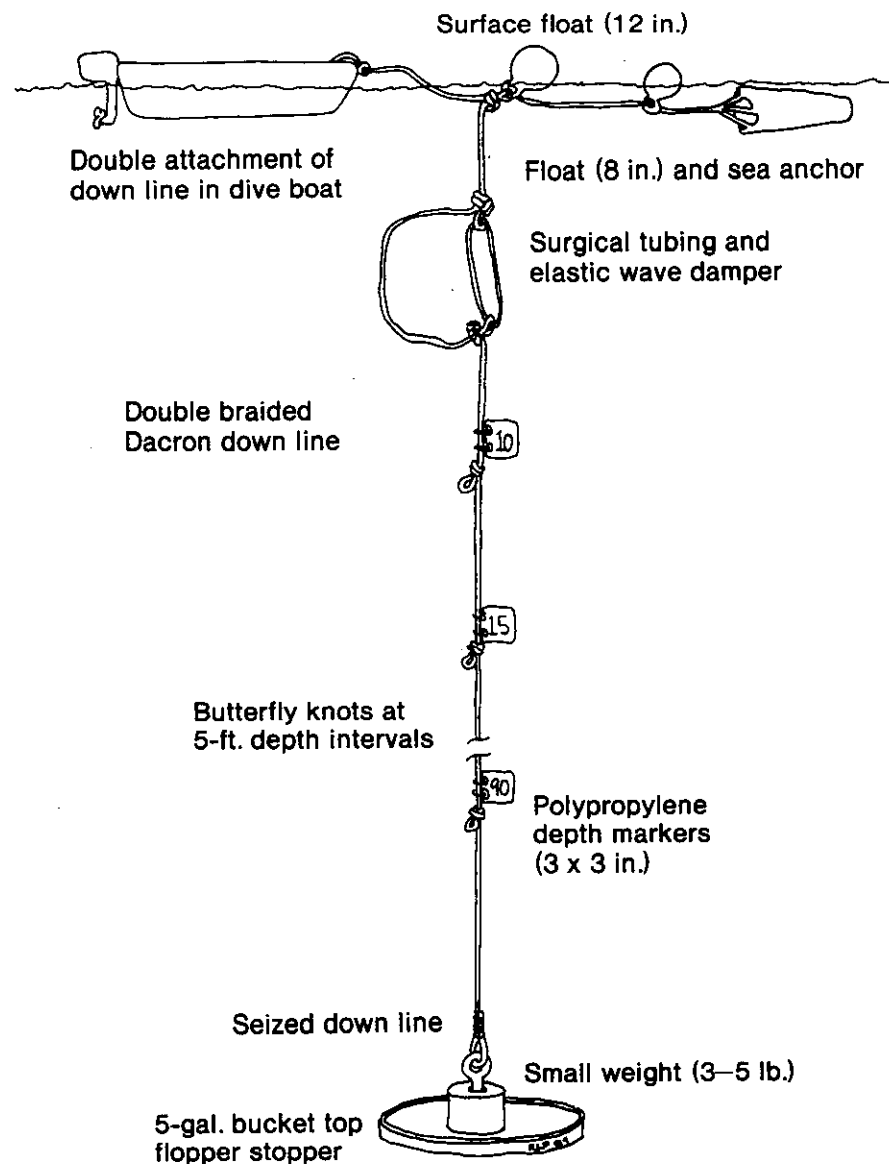


Figure B2. The down line. The down line and sea anchor are shown in deployment configuration (not to scale).

stored as a fair lead random coil inside a 5-gal. plastic bucket. Conveniently, the down line bottom serves as the top of the bucket. With this arrangement, the down line can be deployed directly from the bucket and recoiled upon recovery into the bucket. This arrangement facilitates convenient transport, use, rinsing, and storage of the down line.

Trapeze. Our trapeze is constructed of a 3/8 x 3 x 24 in. piece of white polypropylene with six holes drilled 1/4 in. from the bottom edge and evenly spaced from one end to the other (Fig. B3). These holes accommodate the pins of 2-in. deep D stainless steel shackles to which the diver tether clips can be fastened. Two holes in the top of the trapeze accommodate the trapeze harness. This harness attaches to the down line loop by means of a large, spring-loaded clip permanently fastened at the harness apex. The edges of the trapeze are rounded smooth to avoid snagging or chafing of the trapeze against the down line or tethers.

White polypropylene was chosen for its unreactive and durable qualities in seawater. If lightly sanded, it can be written on underwater, doubling as an emergency slate. The cleanliness and nonreactive chemical behavior of the materials used in this construction are of prime importance when trace metal or hydrogen gas analyses are to be made. It is also important that there are more locations on the trapeze to secure the diver tether clips than there are divers. This facilitates untangling or repositioning of the tether clips.

Tethers. Tethers for the working divers are 30-ft. braided Dacron lines, whereas the safety diver's tether is only 3 ft. long. One end of the tether passes through a polypropylene washer and is secured to a coated 4-oz. fishing weight. The other end passes through a swivel clip eye and terminates in a 2-in. stainless steel ring (Fig. B3).

The diver tethers must pass smoothly through the swivel eye. In our experience, twisted nylon or polypropylene tether lines may kink, twist, and jam when passing through these clip eyes. For this reason a smooth, braided line was chosen. When diving where the visibility is poor, the extension of the tether must be restricted. This is done by tying an overhand knot in back of the polypropylene washer. In this way tether travel through the swivel eye is stopped at the knot without the knot becoming jammed in the swivel. We recommend that the tether length be restricted to 50 to 75% of the nominal visibility.

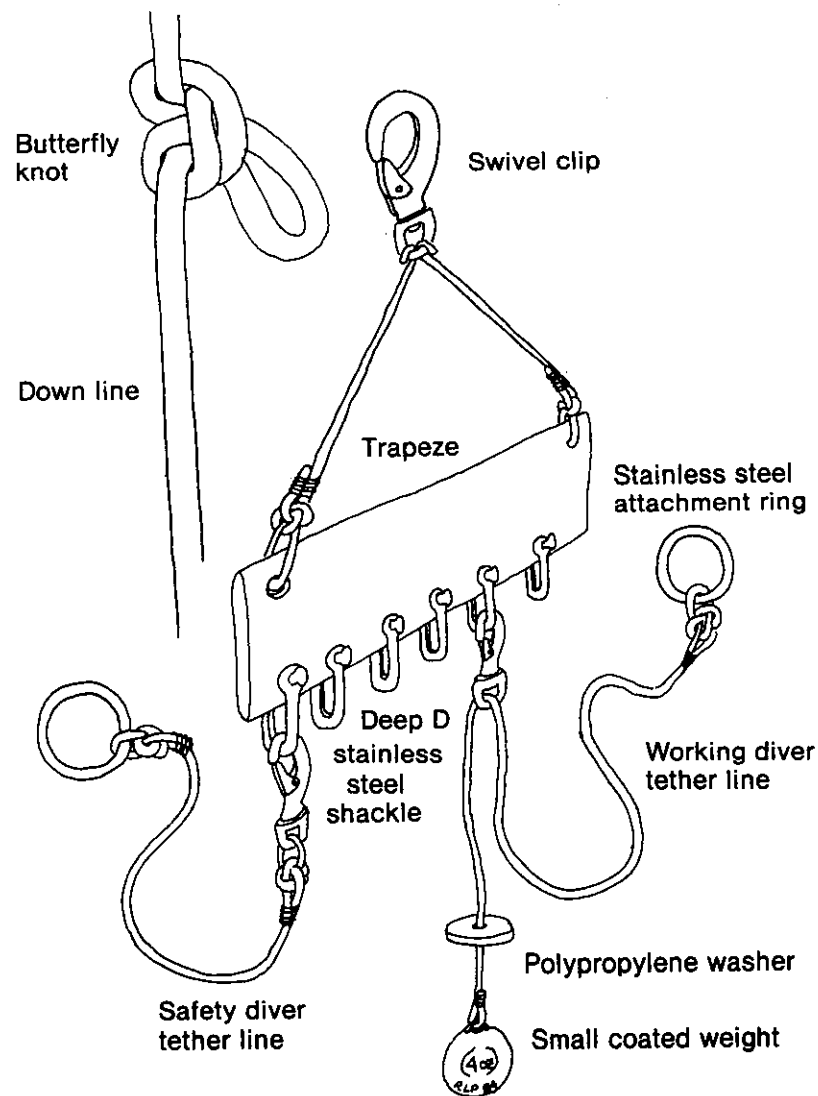


Figure B3. The trapeze and tethers. For clarity, only one working diver tether is shown. A butterfly knot is typically used to create attachment loops (not to scale).

Diver Safety Harness. We use a diver safety harness (Fig. B4) for the convenient and safe attachment of lightweight equipment and the safety tether to each diver. The advantage of the harness is that it affords good signal reception by the working divers. If the safety tethers are attached to other points on the diver (e.g., buoyancy compensator), signals from the safety diver may be attenuated. It is our opinion that the attachment of safety tethers and vital equipment should be independent of any other standard piece of dive gear. Safety tethers should never be attached to the weight belt. The safety harness can be worn by divers wearing either buoyancy compensators or dry suits.

The safety harness provides an attachment or detachment point that is readily visible and identifiable (because of the color coding of the attachment lanyards) and that can be released easily and quickly, even under strain. In our design, one lanyard is used for safety tether attachment only (no other equipment is attached to this lanyard), and the other lanyard is used for a shark billy and possibly a camera. This ensures that the weight of diver equipment (weight belt, tank, buoyancy compensator, camera, shark billy, or scientific equipment) cannot be inadvertently transferred to the down line when the diver is released from the tether.

The safety harness is constructed from 1-in. tubular nylon webbing that is fastened around the diver's waist with a Fastex plastic squeeze clip. Color-coded attachment lanyards, about 1-ft. long made of 1/2-in. nylon webbing, are secured to right and left sides of the harness. The attachment lanyards terminate in a stainless steel swivel spinnaker shackle (Schaffer) onto which a short release lanyard is secured. The resistance required to operate the release mechanism is generated by pulling the release lanyard away from the diver's body. The mechanism can readily be activated by a single jerk with one hand.

Shark Billies. About 20% of all the blue water dives performed by our group in the central North and South Pacific gyre systems and the eastern tropical Pacific were aborted because of the persistent presence of sharks, specifically oceanic white tip sharks. In all cases they were spotted first by the safety diver. This underscores the value of the safety diver and a routine abort plan and the utility of the shark billy.

Shark billies are made from 3/4-in. round fiberglass stock and are 4 ft. long. A hole is drilled in one end to accommodate a

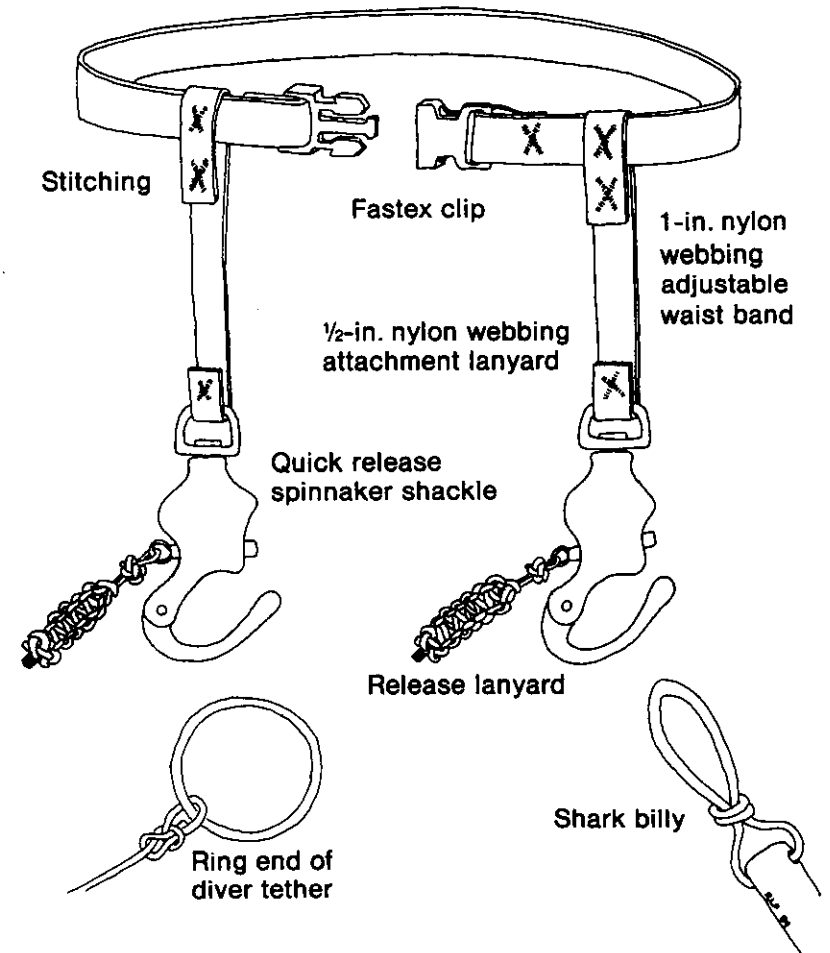


Figure B4. Diver safety harness. The safety harness with quick-release spinnaker shackles is shown as well as the attachment points of the tether and shark billy (not to scale).

lanyard and a loop of surgical tubing. The other end is ground to a point and coated with fiberglass resin. An instrument of this length and diameter can be moved quickly in a lateral direction because it has little drag underwater. Shark billies are routinely carried by all divers.

When a shark is tightly circling a diver, the billy is used in a prodlike manner, with the butt end kept against the diver's body and the sharp end toward the shark. This defense discourages the shark from coming closer than 4 ft. from the diver. A sharp prod to the shark will usually result in a hasty but always temporary retreat. This retreat, however short, usually provides the diver with sufficient time to leave the water. Emergency exiting procedures are discussed in the procedures section in this appendix.

Equipment Line. The purpose of the equipment line is to prevent overloading and congestion of the down line with sampling equipment. It also ensures easy access to and proper weight distribution of the sampling gear. Divers should never attach themselves to this line. It is typically deployed from the stern of the boat and secured at two or more locations within reach of the boat operator.

The equipment line is constructed in a manner identical to the down line with some exceptions. When heavy equipment is needed, a larger surface float (18 in. diameter) and a stronger wave damper can be used. When the line must remain stable in the water column (e.g., during incubation experiments), additional flopper stoppers can be added near the bottom of the line (Fig. B5). A more flexible wave damper can also be useful.

Gear Tethers. Gear tethers are short lines with snaphooks at one end. These are secured to the dive boat and hang approximately 3 ft. underwater. Tanks, weightbelts, or any other equipment the diver may want to unload can be attached to these tethers to facilitate entry into the boat. Since the dive boat can become somewhat crowded once all divers exit the water, tanks are often left hanging on gear tethers until the boat is ready to leave station.

Sea Anchor. During blue water dives, we commonly deploy a 4-ft. diameter sea anchor to reduce the movement of the boat resulting from windage. This is attached to the loop in the down line at the float. The sea anchor is also attached to a small

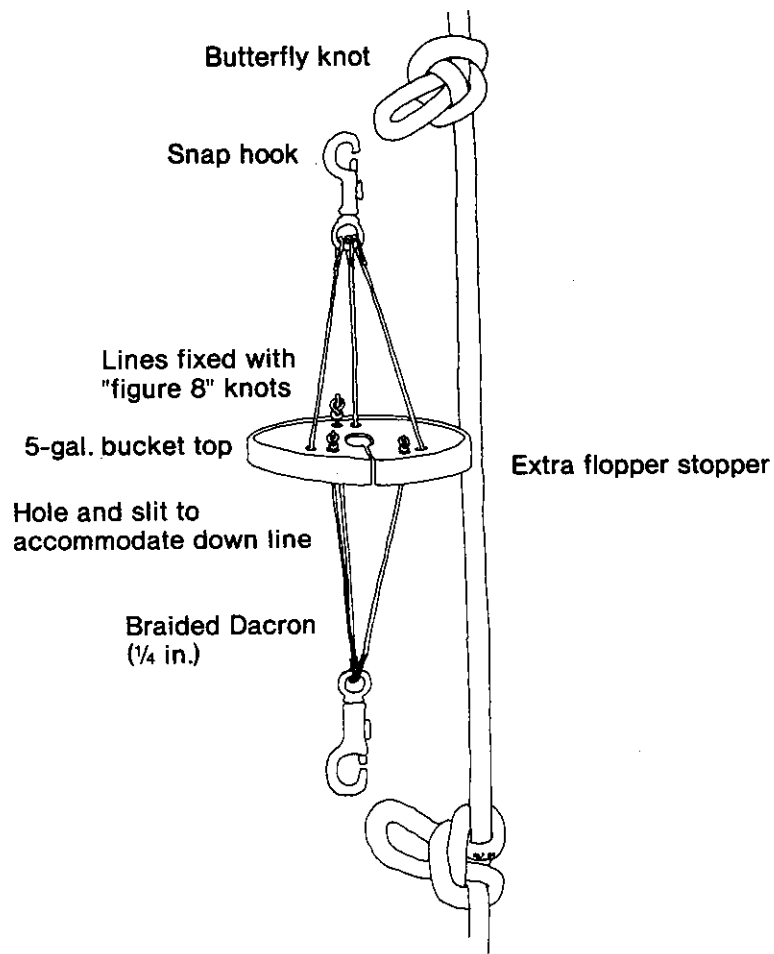


Figure B5. Additional wave damper. This "flopper stopper" is suspended between two butterfly knots near the bottom of the equipment line (not to scale).

separate float that keeps it from collapsing and sinking should the wind die.

B. Blue Water Diving Procedure

This section describes the procedure most commonly used by the UCSC blue water divers. The majority of these dives have been conducted within the context of other large oceanographic sampling programs, and the methodology described below reflects this experience. These procedures were developed for use in conjunction with a large mother ship from which one or more small dive boats are deployed. These procedures can be easily modified if diving is done from small boats originating from a port or marine lab.

Preparation and Launch. When the tasks to be performed have been determined, the dive plan is discussed with the chief scientist and captain of the vessel. The mate(s) on watch during the dive are also informed of the dive schedule. All dive gear and sampling equipment is readied at least one-half hour prior to the scheduled launch time. This preparation includes the following tasks: (1) all down lines are tied in place; (2) tanks and weight belts are tied in the bottom of the boat(s); (3) scientific diving and safety gear, oars, floats, and the sea anchor are safely secured; (4) the outboard motor with gas tank is tested and the engine warmed before launching; and (5) the lifting sling and tag lines are secured and the boat positioned for launch. Care must be taken to ensure proper balance of the dive boat with this added weight.

When the ready signal is given by the bridge, the boat is launched from a quick release and positioned where convenient for boarding by the boat operator and diver. Typically, the boat operator, wearing a PFD and radio, boards first and starts the engine, leaving it in neutral while the divers board. Divers board wearing their exposure suits and/or buoyancy compensators. When the boat operator signals "all clear," the tag lines are withdrawn and the dive boat casts off. The mother ship and dive boat steam and motor to their respective stations, usually between 0.5 and 3 miles apart.

Equipment Deployment and Dive. On station, the motor is shut off and the down line is deployed from the bow, weight first. The trapeze with diver safety tethers is clipped on at the working

depth, and the down line equipment is attached 5–10 ft. above the trapeze. The rest of the line is fully deployed and the sea anchor set. At no time is the down line weighted with more than that which a single diver could carry to the surface. When the sea anchor is set, the boat operator radios the bridge so that a fix of the dive boat can be taken. The equipment line is then deployed weight first from the stern. As the equipment line is deployed, sampling gear and incubation racks are secured at the appropriate depths. Thus, divers are not encumbered with gear on their descent or ascent.

Divers don the rest of their gear and clip shark billies to their safety harnesses. When everyone is ready and checked out, the safety diver enters the water first and from the surface immediately scans the surroundings for sharks, down line entanglement, and other hazards. When the safety diver signals "all clear," the rest of the divers enter the water and swim to the float. The boat operator marks the time and radios the bridge that the divers are in the water. The divers then descend directly to the trapeze along the down line. The safety diver goes first, attaches him- or herself to the trapeze, and readies the tethers for the working divers. The working divers clip themselves in immediately on arrival at the trapeze, signal OK to the safety diver, then move off horizontally, and wait and watch until the last diver is safely clipped in. At this time all divers signal OK and begin sampling.

The working divers generally work in an area (or, more accurately, a volume) "up stream" of the trapeze, allowing divers to collect fresh, undisturbed samples and to maintain themselves in one general area in sight of the safety diver. As the scientific task allows, the working divers occasionally scan their surroundings and visually check the safety diver. The safety diver constantly monitors the entire surroundings. He or she checks for sharks, keeps an eye on the divers and the down line, and monitors the progress of the dive. During the course of the dive, the safety diver maintains contact with the divers by making periodic tugs on their tethers to check on their comfort, air supply, and tug response. Should a working diver require minor assistance, the safety diver should signal another working diver to go to his or her aid. If the safety diver becomes involved in helping another diver, he or she must first signal another diver to

act as temporary safety diver. There must always be someone acting as safety diver.

Dive Termination. As the dive progresses, the safety diver signals the working divers more frequently to determine which are lowest on air. When one diver reaches 500 psi, the safety diver may signal the diver next lowest on air to buddy up with that diver, unclip, and head for the surface. This action minimizes congestion at the boat and is a more efficient use of air. If all divers have similar air consumption, or if there are only two working divers, the safety diver signals everyone when the first diver reaches 500 psi, and the dive is then terminated.

To terminate the dive under normal circumstances, the safety diver tugs on each diver's tether, signaling each to ascend ("thumbs up"). The working divers respond by clipping their equipment to the down line or equipment line, swimming to the trapeze, and releasing their tethers. A second "thumbs up" signal is given and the divers ascend directly up the down line, scanning the water around them while keeping one hand in contact with the down line. The safety diver brings up the rear, notes the time, and ensures that all divers enter the boat safely before leaving the water.

Anyone who perceives an emergency or unsafe situation can terminate a dive at any time. In the event that a shark is sighted, a working diver may signal the safety diver with a sharp tug on the tether or by swimming to the trapeze and giving the "jaws" hand signal. In our experience it is usually the safety diver who sees a shark first. The safety diver signals all other divers and gives the "jaws/thumbs up" hand signal. All divers then immediately swim to the trapeze and release their tethers. Forming a circle around the down line, the divers ascend with shark billies pointing outward or at the shark and proceed directly to the boat. The first diver to surface tells the boat operator that a shark is nearby, and the boat operator quickly assists the divers out of the water. The first diver out of the water can then also assist the rest into the boat. The safety diver again brings up the rear but enters the boat at the same time as the last working diver. Since all of the divers may enter the boat at the same time, it is useful for each diver to make a practice of entering the boat at the same position from which he or she entered the water.

Should the boat operator wish to terminate the dive for any reason, he or she simply pulls the down line up until the divers

take notice. In general, when the wave damper is taken aboard, the rocking of the boat will be felt by the safety diver. Anyone on the mother ship can also terminate the dive by radioing the boat operator.

Once everyone is aboard the dive boat, the boat operator informs the mother ship that the divers are out of the water. The down line, equipment line, and equipment are recovered and stowed. All tanks and gear are tied into the dive boat and the boat operator radios the bridge that the dive boat is leaving station. The bridge instructs the dive boat to come alongside. Tag lines are secured, and the divers exit the boat. The boat operator attaches the lifting harness to the crane and then climbs out of the boat. The boat is then lifted on deck, the dive completed, and the bridge notified.

Orchestration. The safe execution of a blue water dive from a large ship requires coordination and communication between all parties involved. It is essential that the divers, boat operator, chief scientist, captain, and mate(s) on watch are aware of the dive plan and the hazards involved in its execution. It is helpful if one diver is appointed "head" for a particular dive or series of dives to facilitate communication between the bridge, chief scientist, dive team, and the deck hands or boatswain. The head diver informs the watch of the procedures and, if there is a change in watch during the dive, the relief watch as well. The head diver briefs the dive team and makes sure that all equipment is ready for launch.

Safe execution of the dive also depends on the proper handling of the mother ship before, during, and after the dive. Typically, any object in one place for any period of time—such as sediment trap arrays, productivity arrays, and ships—will attract sharks. For this reason blue water diving near such objects is not recommended. The bridge and the mess deck should be notified that no garbage is to be dumped, no fishing to be allowed, and no bilges to be pumped in the vicinity of the dive. If the ship has been on station for a period of time prior to a dive, the bridge should be instructed to steam away from station at least 5 miles. The boat is then launched and the ship steams about 1 mile back in the direction of the last station. When doing horizontal transects, the dive boat can be launched and the ship can resume the transect course for 1 mile or so. To minimize the sonic

attraction of sharks to the divers, the dive boat motor should be shut off and the mother vessel instructed not to come closer than ½ mile to the dive location.

Upon retrieval of the dive boat, the mother ship must also steer a steady course to keep the ship stable until the boat and equipment are secured. The boat operator should maintain frequent contact with the bridge. This brings the bridge up-to-date with the progress of the dive and also serves as a radio check.

In our experience, blue water diving is not the only sampling operation conducted while the dive boat is deployed. Often the chief scientist will schedule shallow plankton tows or hydrocasts from the mother ship during a blue water dive. This provides a more efficient use of ship time. It must be understood, however, that during such dual operations, the divers' safety demands top shiptime priority.

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APPENDIX C: BLUE WATER DIVING EQUIPMENT AND PROCEDURES USED AT WOODS HOLE OCEANOGRAPHIC INSTITUTION

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Blue water multiple-tethered diving is a technique that allows a small group of divers to work in midocean, suspended in the upper water column. The system was developed in 1970 by W. M. Hamner and his students. It was first used at WHOI in 1973 and, after more than 1200 open-ocean dives, is included as a standard practice in the WHOI Diving Safety Manual. At present, the technique is primarily used by Madin, Harbison, and co-workers while collecting and observing gelatinous zooplankton.

Blue water diving is conducted in clear, open water where there are no overhead obstructions or danger of entanglement. A system of tether lines ensures that divers cannot become separated from the group and allows communication among the divers and the boat operator.

A small boat, usually an inflatable, is launched from the mother ship and serves as the diving platform. A boat operator is aboard the small craft at all times, maintains visual and radio contact with the mother ship, and assists the divers as needed. A 100-ft. vertical line, lightly weighted by a shackle or 9- to 10-lb. chain, is suspended from a surface float (see Fig. C1). The float is secured to the boat with about 15 ft. of polypropylene line. The vertical line is knotted at 10-ft. intervals. A stainless steel ring is clipped to the vertical line by a brass snap hook and is the central pivot point of the system. The tethers consist of a 33-ft. nylon line, secured to a brass snap at one end and to an 8-oz. lead sinker at the other. The snap is clipped to the diver, usually at a buoyancy compensator D-ring. The tether line passes through the eye of another brass snap that connects to the ring. Thus, the tethers are counterweighted to eliminate slack as the divers move about. The diver can easily disconnect from the tether for ascent, but he or she is securely connected during the dive. This system allows free mobility within a radius of about 30 ft. but sets limits on the divers' depth.

The pivot point is manned by a safety diver, whose duty is to act as "buddy" for the other divers. The safety diver is the first to enter the water to connect the pivot ring to the vertical line and to prepare the tethers and is the last to exit the water. This diver's tether is short, about 3 ft. in length. He or she monitors the tethers, keeps a lookout for hazards, and generally supervises the dive. The safety diver can gain the attention of the other divers by tugging at their tethers, and the boat operator can signal the

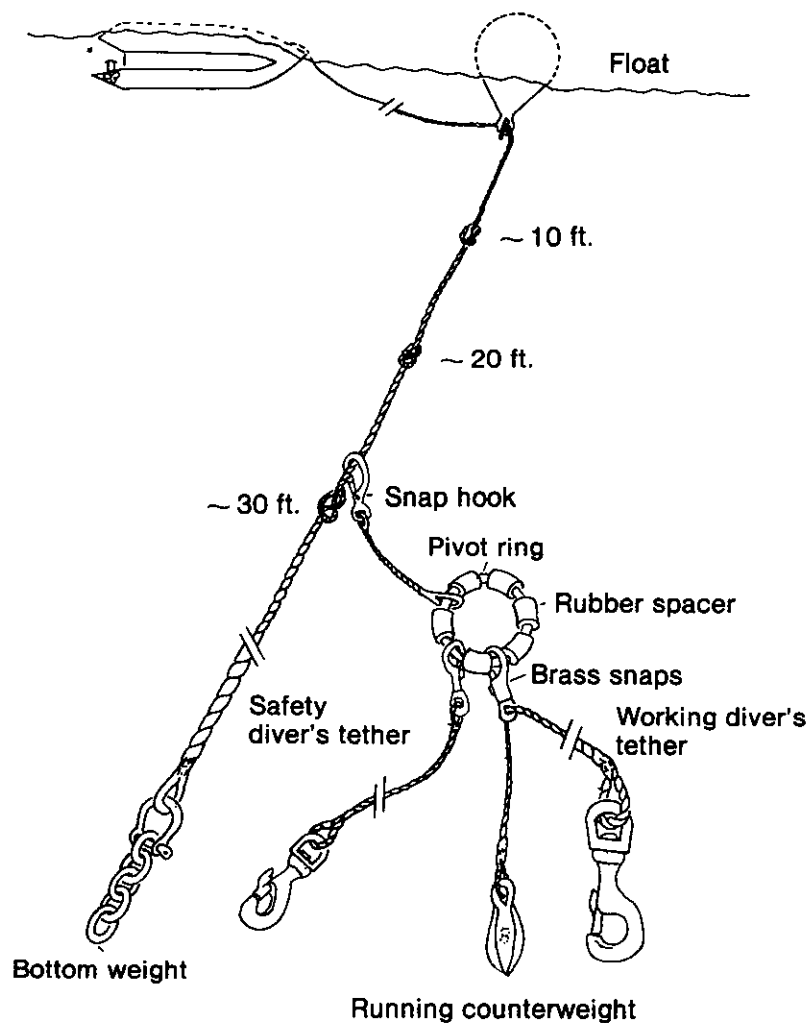


Figure C1. Blue water multiple-tether system used at Woods Hole Oceanographic Institution. Knots are spaced at about 10-ft. intervals, and a stainless steel ring is clipped between knots at the desired depth interval. (Drawing from T. Rioux at WHOI.)

safety diver by pulling on the vertical line. The safety diver is in visual contact with the other divers at all times. In this way the entire group can communicate and can be alerted to ascend at any time during the dive. The safety diver can move the pivot ring up or down the vertical line to any of the knotted stops, as required by the situation, and can thus control the potential maximum depth of the other divers. He or she can also terminate the dive or send any diver up if he or she feels the situation warrants such action. The other divers can ascend when they wish to by signaling their intent to the safety diver, unclipping their tethers when they arrive at the pivot ring, and going up the vertical line to the boat.

All divers are required by WHOI regulations to have a submersible pressure gauge, depth gauge (the type indicating maximum depth is preferred for blue water), bottom timer or diver's watch, and buoyancy compensator (autoinflatable type preferred). An oxygen resuscitator unit is to be available in the boat and on the ship (with at least several hours' supply). Accident management information has been added to the WHOI Diving Safety Manual, which must be available on the ship. The safety diver must have an alternate second stage, e.g., an "octopus," and wear a knife (although entanglement in the tether line is unlikely).

There is a shark defense procedure for use in the event a passing predator displays any interest. The divers swim toward the pivot point, unclip their tethers, and ascend as a group, facing outward. Shark billies are sometimes carried.

All divers are required to surface with a safe air supply margin, generally 300–500 psi. All divers must monitor their depth, bottom time, and repetitive data. It is the responsibility of the principal investigator or designated cruise dive master to ensure that all divers adhere to safety regulations and that all necessary data be recorded.

The procedure and equipment are different for night diving. Since effective visual communication is not possible, a hard-wired communication system is used among the divers and the boat tender. The communication wires serve as tethers. Divers wear AGA full face masks and helmets with headlamps, as well as wrist-mounted lights (e.g., "Super-Q" lights). All divers can talk to each other and to the tender, who is in radio contact with the

ship. Divers' conversations are recorded for later extraction of data. Two to four divers can be supported for night diving.

The minimum experience level required for participation in a blue water diving operation is certification for diving down to 70 ft. Our regulations follow the Scripps Institution of Oceanography standard in that a 70-ft. level diver is permitted to exceed 70 ft. if he or she is accompanied by a diver certified down to 100 ft. or greater. A depth of 100 ft. is the maximum allowed for a 70-ft. level diver. A depth of 130 ft. is the maximum authorized for the operation, but the usual range is 20–80 ft. U.S. Navy decompression and repetitive diving procedures must be followed.

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BLUE WATER DIVING GUIDELINES

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