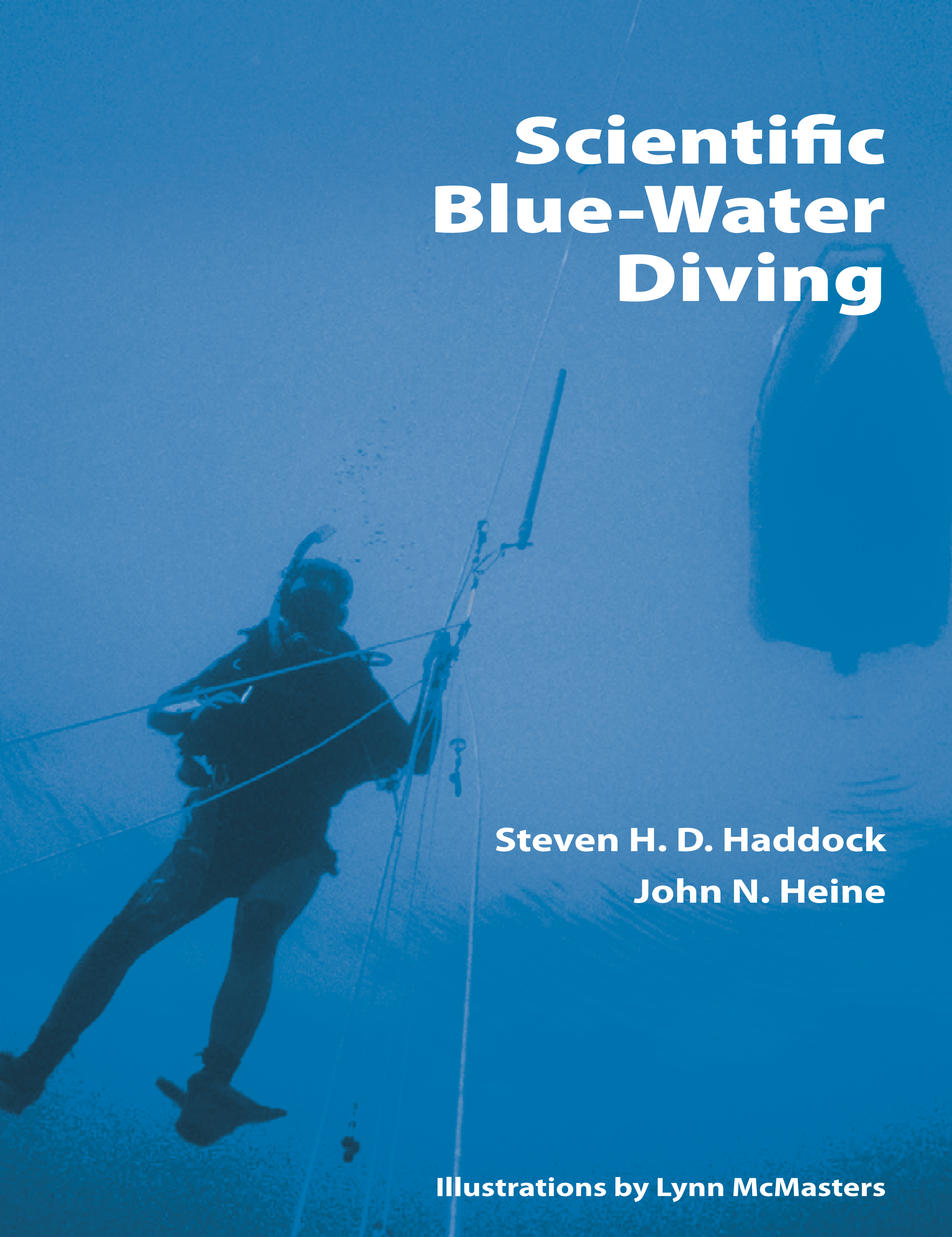
Scientific Blue-Water Diving



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Scientific Blue-Water Diving

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Acknowledgments

Scientific Blue-Water Diving is a revision of *Blue Water Diving Guidelines*, which was published by California Sea Grant in 1986. The first book was a collation of the blue-water diving equipment and procedures of the major research groups at the time, namely from the University of California at Los Angeles (William Hamner), University of California at Santa Barbara (Alice Alldredge and James King), University of California at Santa Cruz (Kenneth Coale, Anthony Michaels and Robin Pinto), and the Woods Hole Oceanographic Institution (Larry Madin, Richard Harbison and Terry Rioux). Many of the participants in the blue-water diving workshop held at the Moss Landing Marine Laboratories on January 27, 1984 contributed to the original work as well.

In the nearly 20 years since *Blue Water Diving Guidelines* was published, some of the equipment and procedures have changed, as well as some of the research groups using this diving mode. However, portions of the original book have been retained, and we thank the original authors for their contributions.

Figures, including some adapted from the original volume, were drawn by Lynn McMasters and by Steve Haddock, who also took the photos.

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Introduction

The goal of this book is to open the world of blue-water diving to a larger scientific community, without compromising the safety of the procedure. It is not meant to impose excessive restrictions on the methodology, but to provide guidelines for conducting blue-water dives, to assist in the construction of a blue-water rig, and to present lessons learned from past experiences.

Throughout the book, tips to improve safety ⚠ *or convenience* 🤿 *are denoted by icons in the margin.*

History

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 & Madin, 1982; Alldredge & Silver, 1982; Caron *et al.*, 1982; Martinez *et al.*, 1983; Mills, *et al.*, 1996).

Many of these organisms are difficult, if not impossible, to study via conventional collection techniques (*e.g.,* 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.

early pioneers

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 cylinders, 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 cylinders, but no dive lines. In Japan, Bieri (1966) made *in situ* SCUBA observations of neustonic (near-surface) plankton.

In the early 1970s, the University of California, Santa Cruz blue-water diving technique was used in the collection and counting of marine snow samples for nutrient analysis (Silver *et al.*, 1978; Trent *et al.*, 1978). In 1984, the technique was modified and was used on early VERTEX and marine chemistry cruises to the central North Pacific 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 (Silver & Bruland, 1981; Bruland & Silver, 1981). Collections of *Rhizosolenia* mats and marine snow incubated *in situ* and hand collections of salps, pteropods, and doliolids were also taken, along with flow meter estimates of specimen densities. Other recent applications are mentioned below.

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.

* * *

goals of this book

This revision of *Blue Water Diving Guidelines* (Heine, 1986) provides a comprehensive and updated guide to the scientific applications, equipment, and methods utilized in this specialized mode of diving. Blue-water diving techniques, like all research diving techniques, are constantly evolving and reflect changes in equipment technology, training procedures, and scientific research requirements. We have chosen to present one overall method for blue-water diving, as opposed to the several overlapping variations that were published in the first edition. Therefore, the guidelines presented here are not intended to be rigid standards. They serve rather as a reference for those individuals interested in open-ocean diving, giving recommendations for such concerns as diver training, diver equipment, small boat equipment, emergency procedures, and constraints associated with blue-water diving. There is no single right way to conduct a blue-water dive; on the other hand, experience has shown that there are some procedures that should *not* be followed. We have attempted to explain the rationale for the methodology we present. Finally, those who are interested in initiating a blue-water research program should contact active researchers with the appropriate experience for consultation and training.

Scientific Applications

organisms for study

Blue-water diving makes it possible to address oceanic research topics that are not tractable by other means. Primary among these is the ecology of *gelatinous zooplankton*. Animals in this group are not necessarily taxonomically related, but they share the traits of fragility and transparency that make them largely inaccessible to standard devices (Haddock, 2004). Some of the organisms that are especially amenable to SCUBA studies are introduced below.

Marine Organisms

Radiolarians, Foraminiferans, and other protists

These macroscopic protistan groups can reach high numbers in surface waters. They are somewhat like amoebae, but bearing siliceous (Radiolaria; Fig. 1A) or calcareous (Foraminifera; Fig. 1B) “shells.” Shallow polycystine radiolaria contain symbionts, and while their molecular phylogeny has been examined (Amarl Zettler, *et al.* 1997), little is known of their ecological impact (Swanberg, 1983).

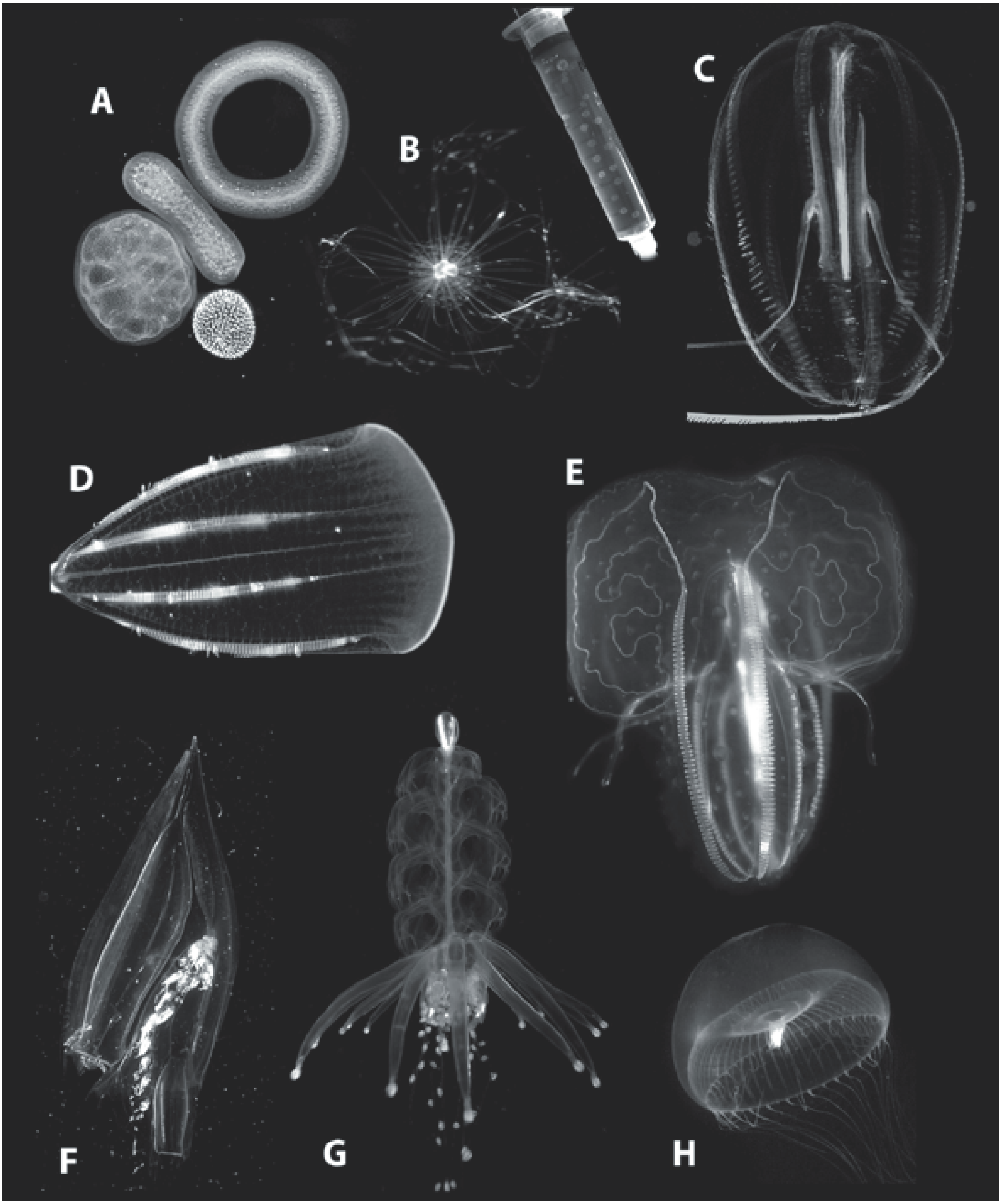


Figure 1. Blue-water plankton A. Radiolarian colonies. B. Foraminifera (collection syringe in background. C. Cydippid ctenophore. D. Beroid ctenophore. E. Lobate ctenophore. F. Calycophoran siphonophore. G. Physonect siphonophore. H. Hydromedusa.

Some species are small enough to be collected with syringes, while other colonial forms (often mistaken for egg masses) may reach tens of centimeters in length. Foraminifera ("forams") are important indicators of past climate change. Their shells hold a record of the isotopic composition of seawater in which they were formed, and thus they are of great interest to paleooceanographers. Live forams have been collected in snap-cap vials, then cultured and studied in the lab (*e.g.*, Spero *et al.*, 1997).

Cnidarians

Many planktonic cnidarians, principally the Hydrozoa, may be obtained using SCUBA. Siphonophores, fragile colonial forms that are rarely seen intact (Fig. 1F, G), are especially suitable for blue-water collection (*e.g.*, Biggs, 1977), and shallow specimens collected by hand have contributed to a recent molecular phylogeny of this group (Dunn, *et al.*, 2005). Hydromedusae (Fig. 1H) are readily collected using glass jars (Johnsen & Widder, 1998), and even larval anemones (particularly ceriantid larvae) may be encountered. Large scyphomedusae (Fig. 2G) may be collected in larger plastic buckets, if available.

Ctenophores

Comb jellies (Fig. 1C, D, E) are among the most fragile of plankton, and as a result only hardy species such as *Pleurobrachia* and *Beroe* are typically seen. Using jars, divers can collect the most fragile of lobates (Fig. 1E), and these types of samples have revealed new facets of their ecology (Harbison, *et al.* 1978; Matsumoto & Harbison, 1993), their bioluminescence (Haddock & Case, 1999), and their molecular phylogeny (Podar, *et al.*, 2001).

Salps, Doliolids, and Larvaceans

Pelagic urochordates feed directly at low tropic levels and demonstrate rapid population explosions. They form an important component of many productive food webs (Madin, 1974; Alldredge, 1977). While some salps (Fig. 2A) are hardy enough to be enumerated from plankton tows, their ecology, and that of their fragile cousins, may be difficult to appreciate without carefully collected living specimens. Larvaceans (Fig. 2B), in particular, build elaborate feeding webs ("houses"), which cannot be observed in net-caught specimens.

Molluscs (Pteropods, heteropods, nudibranchs)

Pteropods (especially *Corolla* and *Clione*) may occur in large numbers (Fig. 2D, I), along with diverse species of heteropods and other pelagic molluscs (Lalli & Gilmer, 1989). Holoplanktonic nudibranchs such as *Phylliroe* (Fig. 2F) prey on

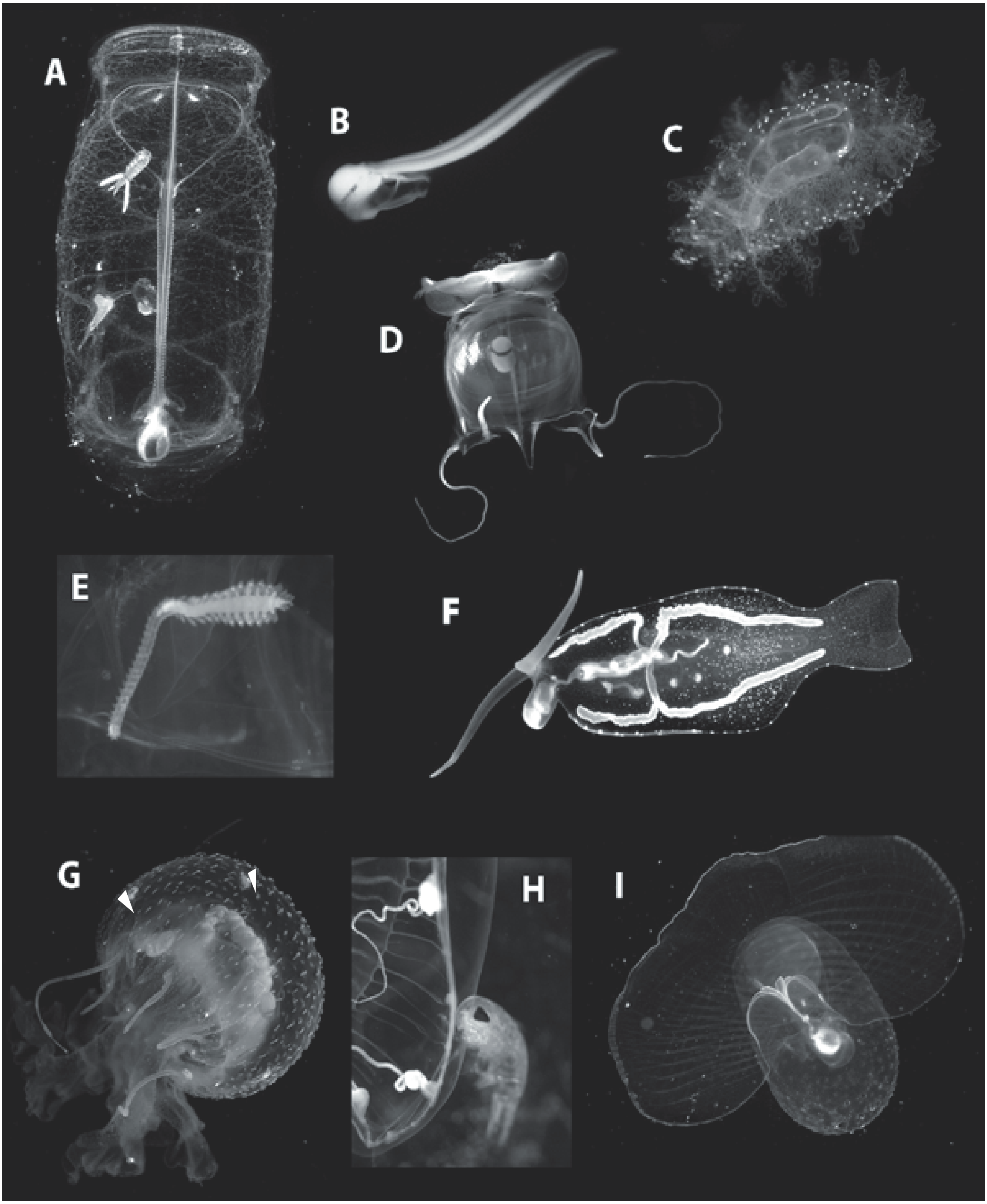


Figure 2. Blue-water plankton A. Salp with symbiotic copepod. B. Larvacean. C. Echinoderm auricularia larva. D. Pteropod. E. Alciopid polychaete on ctenophore. F. Pelagic nudibranch. G. Scyphomedusa with amphipods (arrows). H. Amphipod on hydromedusa. I. Pteropod.

planktonic cnidaria, and all are readily caught by divers. Ommastrephid squid may occasionally be observed, with their large gelatinous egg-masses.

Worms (Chaetognaths and Annelids)

Many arrow-worms (Phylum Chaetognatha) are large enough to be observed by divers, and they may be among the most important predators on other plankton. Diverse polychaetes are found, both free-living and in association with other gelatinous plankton (Fig. 2E).

Pelagic fish

Open-ocean adult species, such as the sunfish *Mola mola*, can be charismatic visitors during dives, and larval fish are frequently encountered. In addition, some fish are often found in association with large gelatinous species such as scyphomedusae.

Symbiotic Relationships

One of the most exciting realms that is made available by direct observation is that of parasitic or commensal relationships. Most commonly, one will find amphipods (Fig. 2G, H) or other crustaceans (Fig. 2A) living on a variety of gelatinous hosts (Harbison, *et al.*, 1977), and even rearing their broods (Gasca & Haddock, 2004). These relations will rarely, if ever, persist under standard net-based sampling.

Larval invertebrates

Some plankton spend their entire life in the water column (holoplankton), but many benthic or otherwise sedentary organisms may spend a portion of their life-cycle as "meroplankton." Unique larval crustaceans, worms, echinoderms (Fig. 2C), and fish are frequently encountered on blue-water dives.

Other Applications

Marine snow

In most environments, the feeding webs produced by many of the organisms listed above, as well as phytoplankton aggregations, form a softly falling procession of *marine snow*, which is a primary mechanism for carbon flux (Alldredge & Silver, 1988). These macroparticles can be collected by syringes and used in a variety of studies (*e.g.*, Villareal, *et al.*, 1999). The base constituents of the marine snow and associated microbial or invertebrate populations may also be observed.

Other environments and research subjects may also call for the application of blue-water diving techniques. These include large pelagic organisms, fish-attracting devices, open-ocean instrumentation, and even diving under ice.

General Procedures and Guidelines

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 resultant technique itself should have enough flexibility to allow a variety of scientific uses.*

Overview of Procedures

This section will first describe a series of requirements common to most blue-water applications. Following will be some general guidelines for 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.

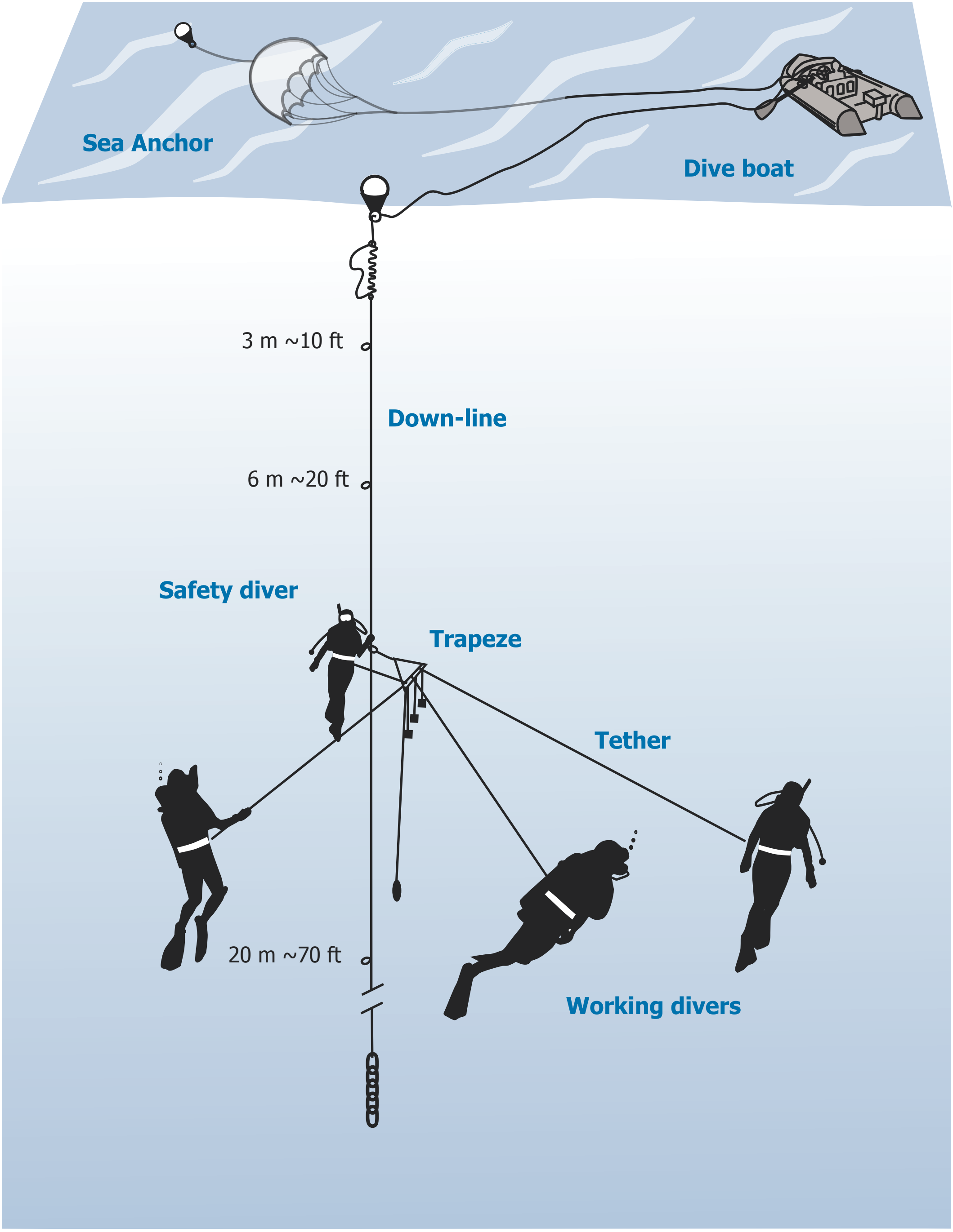


Figure 3. Overview of a blue-water dive

In a typical blue-water dive, working divers are connected to a surface platform (and indirectly to each other) by tethers attached to a central hub, which is tended by a safety diver (Fig. 3). This hub is connected to a down-line, providing a vertical point of reference. A surface float allows the divers to drift freely through the upper water-column, focusing on their work while the safety diver acts as a buddy for everyone.

The following goals of blue-water diving techniques to ensure diver safety will be discussed: (1) extensions of the "buddy system" to ensure quick and effective communication between divers; (2) maintenance of correct and safe depths in a reference-less environment; (3) 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); (4) divisions of tasks and distributions of scientific equipment and other weight that are both efficient and safe; and (5) provisions for safe responses to difficulties that are encountered, whether expected (*e.g.*, weather and sharks) or unanticipated.

"One Buddy for All"—The Safety Diver

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 10 m; 30 ft), thin (about 6 mm; ¼-in diameter) lines. These individual 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.

safety diver

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 100 to 150 g (4 to 6 oz) fishing weight. The tether then passes freely through the metal loop on the end of a swivel clip (see Figs. 4, 6). These clips are then attached to a "trapeze" located near the safety diver. 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. 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.

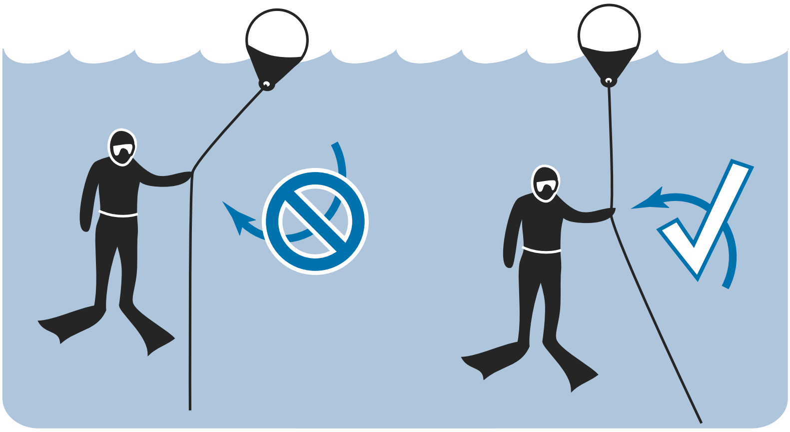
tethers

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 (BC) or to a separate harness. If the quick-release shackle is attached to the diver's BC (rather than to the end of the tether), it can be released by a pull away from the diver's body, ensuring that it releases even when the line is not under tension.

quick release

Some procedures call for the safety diver to be attached to the trapeze by a short 1 m (3 ft) tether. In our experience, there are two disadvantages to this method, and we do not know of any compelling advantages. For example, if the safety diver needs to swim to the assistance of a diver, with a short tether they would have to endanger themselves by unclipping. In addition, once all the divers have reached a level of experience and comfort, it is often convenient to "take turns" at the safety diver position. With all divers using standard length tethers, there is no need to unclip and re-clip underwater each time an exchange is made.

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. 4, 5). 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 them from tangling.



One mistake commonly made by inexperienced safety divers is the tendency to use the down-line for a free ride. Under calm conditions, it is fine, and perhaps even advised, for the safety diver to hang relaxed with their arm on the trapeze. However during moderately windy conditions, as the boat is blown across the surface of the water, the divers must swim to maintain their position relative to the down-line. If divers, including the safety diver, allow themselves to be dragged along by the down-line or their tether, then the apparatus begins to "kite" upward, and all the divers are brought to a shallower depth. In extreme cases, the trapeze may be dragged nearly to the surface. It is therefore important that the safety diver is aware of how the down-line is hanging in the water column, and takes action to keep it as vertical as possible. This is mainly achieved through careful buoyancy control, and by swimming along with the down-line as it moves, rather than allowing it to pull them along.

Working divers should maintain some slack in their lines to avoid kiting and also to have full range of motion in collecting samples. If the motion of the boat across the surface requires that the divers swim vigorously to keep up, then the conditions are unsafe, and the dive should be terminated. A sea anchor will greatly alleviate this potential problem.

working divers

The safety diver should not collect or work during the dive. If they spot a rare or unusual specimen, they should alert another diver by tugging on their tether, and point out the organism of interest. The natural tendency is to point a finger directly at the animal, but the working diver has no way to know where the organism lies along this line. Therefore it is most informative to point using two hands and triangulate on the position of the animal in the water column.

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 50 m (165 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 dive computer that records maximum depth, especially on long or repetitive dives.

The common way to provide some reference point in blue-water applications, and to insure connection to the boat, is through the use of a central *down-line*. This is a continuous line attached at one end to the boat, a horizontal portion along the surface to a float, and a vertical section terminating in a moderate weight or chain. 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 next section), and the down-line is ultimately attached to this platform. This attachment should be very secure, and the line should be fastened at more than one location on the boat. Problems have arisen from down-lines being detached from either the boat or the buoy. The opposite (deep) end of the line should be weighted just enough to cause the line to sink and no more (not exceeding 5 kg or

down-line overview

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 below knots or loops in the line (see Figs. 3, 4). The trapeze is attached to this down-line, providing a means of communication and attachment between the "boat person" and the dive team. The boat person can terminate the dive by pulling the apparatus out of the water. The boat tender may also signal a recovery by revving the boat engine in neutral, or activating a horn or other audible diver recall system.

There are two major physical phenomena that affect the down-line: wind and waves. Windage (the area of the boat exposed to the wind) causes the boat to move along the surface, dragging the down-line after it. This problem is naturally greater on high profile boats and in stronger winds, and may be the limiting factor while evaluating diving conditions. Depending on the boat and other conditions, a cut-off of 30–45 km/hr (18–25 kts) may be the limit for reasonable underwater operations. This number needs to be agreed upon by the lead diver and ship operator, but a simple anemometer is no substitute for experienced evaluation of the sea state.

sea anchor

The movement of the boat 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. This may be accomplished by rowing, in the case of a small boat or intrepid boat operator. The most effective way to reduce wind-induced drift is by using a sea anchor to retard the boat's motion through the water (see Fig. 3). The sea anchor should ideally be deployed on an independent line from the down-line to avoid unnecessary strain, and should be attached to a line that floats, such as polypropylene. The sea anchor should be deployed beyond the down-line, using a line longer than the segment of the down-line that runs from the boat to the surface float. In this way, the risk of entanglement is limited to the short surface swim at the beginning and end of each dive. 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.

swells

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. Unless the divers are deploying an *in situ* incubator or similar apparatus, this is typically not a limiting factor for a dive. To decouple the bounce of the surface float from the line, a segment of bungie 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 (see Fig. 4B). We do not advise the use of "flopper stoppers" on the down-line itself for two reasons: they add to the kiting tendency and keep the line from hanging vertically in the event of wind, and most importantly, they add virtual weight to the down-line itself. The down-line should only be weighted in such a way that a single diver may drag its weight to the surface in the event of entanglement. Nonetheless, flopper stoppers (disks such as bucket lids, or PVC segments) may be useful at the end of an equipment line that is used for *in situ* incubations.

Examples of some down-line and tether configurations are depicted in figures 3 and 4.

Provisions for a Safe Surface Platform

Blue-water diving is usually done from a small boat such as a Rigid-Hull Inflatable Boat (RHIB; i.e., Zodiac™ or Avon™) or a skiff (such as a Boston Whaler™). Large boats present increased windage and are harder to maneuver, and much smaller boats cannot accommodate the people and gear required. Fiberglass boats up to 8 m (26 ft) are also suitable platforms provided they have an easy means for divers to enter and exit the water, and they do not have excessive drift (achieved through low windage, or a sea anchor, as described above). These larger vessels may be especially appropriate platforms for dives occurring further offshore from a shore-based station. 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.

small boat

The single most important piece of safety equipment is the oxygen kit, which should be kept aboard the small boat at all times, not back on the main ship. All divers, as part of their general research-diver training, should be ready to administer oxygen in the event of an emergency, or even if there is a suspicion of diving-related malady.

Appendix 1, on equipment, lists a 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 RHIB. Other items such as a radio are probably mandatory under any circumstances, and GPS navigation units should typically be included. Optional equipment includes radar reflectors and dive flags. 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.

boat safety

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 reentry into the boat, equipment lanyards with terminal clips can be hung over the side of the boat. SCUBA units, weight belts, and other equipment can be attached to the lanyards while divers climb into the boat.

On cruises where the boat is launched from a larger ship, it should generally move 1.5 km (one mile) to the leeward side of the ship to avoid encounters during the dive. The presence of fog or limited cross-water visibility should be considered before setting out on a dive, and before deciding on an operating distance. One person should remain on the dive boat at all times. This "boat tender" 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.

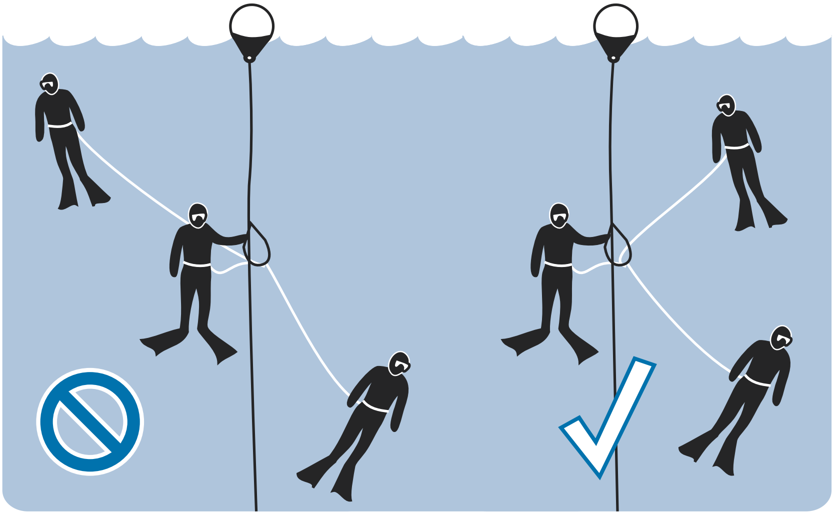
boat tender

The same conditions that may make it unsafe to dive may make it unsafe for the boat operator. Strong winds, especially coupled with large swells, may increase the likelihood that the boat gets swamped or even capsized (all of which have happened during the short history of blue-water diving). These dangers, and the safety of the boat tender, should not be overlooked at the time when the decision to dive is made. Provision for safe launch and recovery of the boat must also be evaluated prior to each dive. If dives are conducted near a reef, island, or shipping lane, the projected drift of the boat (and attached divers) must also be evaluated.

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. Each diver should also be mindful of their position relative to the other divers and their tethers. In situations of limited visibility, it is difficult for

working divers



the safety diver to monitor the divers if they spread at all points of the compass and across the entire range of attainable depths. 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, dive 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.

sampling gear

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. Divers working 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 as an equipment line, 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.

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.

pre-cruise planning

The phases of dive planning may be divided into basic training and preparation of equipment, pre-cruise planning, and immediate pre-dive planning. Equipment preparation should be especially mindful of the safety guidelines presented below—most decisions were made based on accumulated experience of various blue-water diving groups. Pre-cruise planning will ensure that all the necessary equipment has been assembled, and the ship and science teams are fully informed. The captain of the ship and the chief scientist or lead diver should have clear vision of the procedures that will be followed. Pre-dive planning involves evaluating environmental conditions immediately prior to each dive, and this should take place with the lead diver, the captain, and the mate on watch.

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.

shark procedure

Dangerous organisms, potentially including sharks, leopard seals, and even swordfish, may necessitate the early termination of a dive. If a sighted shark is persistent or aggressive, divers typically congregate near the trapeze, and if necessary, ascend together. Some groups recommend unclipping from the tethers to avoid entanglement, but if an attack *were* to occur, an unclipped diver would be at high risk of being lost from the group, especially if unconscious or injured. All divers should be briefed on the agreed-upon procedure before any dive. After a forced ascent, the safety diver should be sure to keep watch below as the boat tender helps divers into the boat.

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 here are those generally and recently used. 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.

Dive Training

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 discomforting (Hamner, 1975). Furthermore, much of the science being conducted at present in this environment centers on small, transparent planktonic organisms, and this 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 skills

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 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.

tether skills

The necessity of a tether adds a level of complication to the basic diving procedures. One must be aware of its path relative to the other divers and one's own equipment. Tethers may easily become tangled on cylinder valves, fins, or other lines, so divers should be aware of their surroundings and calmly disentangle each other when this happens. 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 10 to 20 m (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 an item 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 new divers 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. Divers may be comfortable with the procedures in a pool, or in clear tropical waters, but adverse conditions may rapidly create feelings of discomfort. Ultimately, it is the responsibility of the person in charge to determine when blue-water divers-in-training are qualified to begin scientific research.

Collecting Procedures

sampling gear

Sampling devices are routinely kept in mesh bags attached to clips on the weight belt. Heavy bags and other gear should be attached to dedicated lines, belts, harnesses, or perhaps the BC, but should not be clipped directly to the quick release or other safety tethers. Small mesh bags (often red-colored, ~30 cm or 1-foot deep) may be easier to work out of than the longer ones (often yellow, 60 cm or 2-feet deep), though this is a matter of personal preference.

Most gelatinous plankton can be collected by hand using wide-mouth jars between 470 ml (16 oz) and 1 liter (32 oz). Glass jars have the primary advantage of being negatively buoyant, making it easier to remove them from the mesh bag without having them float away. However, they are more susceptible to breakage. Teflon-sealed lids are not recommended, as they form vacuum seals and become difficult to unscrew at depth. The only way they can be used is if a small hole is drilled through the lid and the inner seal. Any jars must be filled with water before the dive, by submerging them completely in a bucket. Even a small air bubble will create a strong vacuum seal at depth, rendering the jar useless.

clear jellies

Ctenophores, siphonophores, and medusae are often transparent and difficult to see, especially when divers are looking down on them from above. To enhance

their contrast, it helps to look at a slight angle up, with the sun in the background. This lighting may be enhanced by using the boat or a diver's dark wetsuit as a backdrop.

Capturing a fragile jelly into a small jar is a skill that comes with practice. Rather than removing the lid and pushing the jar at the animal, divers should experiment with cracking the lid at the top as they move the jar up toward the animal. By this water motion, the animal can be gently swirled into the jar. Jelly-eating animals (especially the ctenophore *Beroe*) should be kept in separate jars, or they will consume many prized specimens by the time divers have returned to the boat. As jars are filled, the lids, frequently prepared with a strip of masking tape, may be marked to avoid re-using the same jar, and to insure that small specimens are not inadvertently discarded during sorting after the dive. These marks can be made with a lead pencil or grease pencil ("china marker") attached by a short length of line to a band of elastic or rubber tubing around the wrist or to the mesh sample-bag itself for convenience.

protists

Small plankton such as foraminifera and radiolaria can be collected individually with small plastic snap-cap vials. Multiple specimens, up to 20 at a time, may also be sampled with 15 to 50 ml plastic syringes, strung in bunches onto plasticcoated wire. (Fifty ml syringes may be difficult to operate at depth). The plastic tips that come with the syringes should be reattached underwater after the sample is taken, to prevent samples from leaking out during the surface ride back to the boat or laboratory. For larger particles like marine snow, syringes can be specially prepared by cutting off the tapered section, and inserting another plunger as a removable cap.

On occasion, it is helpful to have large plastic buckets to collect especially large scyphomedusae, siphonophores or ctenophores. These may be attached to the down-line or equipment line using "longline snaps" or similar clips (see Appendix 3).

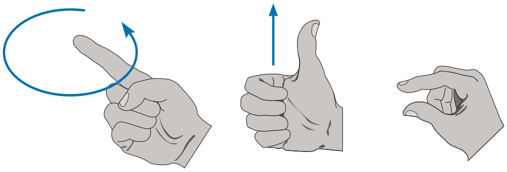
For all these sampling devices, a cool chest on the boat will keep the sample jars from breaking, leaking or overheating.

Communication

Hand signals are the quickest and easiest way to communicate between divers, but the messages are generally restricted to simple pre-arranged gestures. These should be agreed-upon by participating divers before the beginning of the dive; more complex communication calls for dive slates. A quick tug on a diver's tether—either from the safety diver or from a working diver—is used to attract attention. It is sometimes easiest to use the safety diver as an intermediary. Giving a "line-tugging" signal while pointing at the other diver should convey the message for the safety diver to send the other diver over.

hand signals

The gesturing diver should be aware that under many conditions black gloves will not show up well against a black wetsuit. Commonly used signals should be part of the vocabulary of all participating divers. For example: "Divers and trapeze moving to the next working depth" may be indicated by (1) waving the index finger in a circle (="everyone"), (2) thumbs up (= "go up"), (3) index and thumb slightly separated (= "a little").



Often a diver will want to point out a small jelly to another diver. This is best done using both hands to "triangulate" on the animal. Otherwise, if one finger is used, the natural instinct is to look far off in the direction the finger is pointing, while expecting to see something large looming in the distance. For the larger organisms, it is useful to determine signals for other animals that are expected to be seen, such as sharks (hand making a fin on the head), sea lions, or even the ocean sunfish *Mola mola.*

If the safety-diver duties are going to be exchanged during a dive, then a signal should be prearranged for this message. For example, moving one hand away from the chest while moving the other toward the chest can signify such an exchange, although the safety diver should not begin working until their replacement has settled into position. It is also common for the safety diver to inquire about remaining air pressure, by pointing at their own pressure gauge.

Specialized Applications

Night Diving

Blue-water diving may be safely conducted at night, provided that all divers are experienced and comfortable with day-time diving procedures, and the conditions are benign. In fact, for some types of research, night-time may provide optimal viewing conditions because many animals migrate to the surface at sunset, and many transparent animals will be more visible when starkly illuminated against a black backdrop.

The dangers of separation of individual divers from the small boat, or of the small boat from the mother ship, are magnified in conditions of darkness. Divers are encouraged to clip and unclip only when safely at the surface. During night dives, because underwater flashlights may run out of charge or fail to turn on, it may be useful for each diver to have at least one back-up flashlight or a chemical light-stick. "Safety sausages" (inflatable emergency signals), which convey visibility from long distances, may be required by some dive operations. Because orientation and depth perception are especially difficult at night, it is also useful to attach different colored light-sticks to the bottom of the down-line, the trapeze, and to the surface float. The small boat should have running lights, and back-up flashlights, as well as emergency flares, to ensure visibility from the mother ship.

For collecting, effective working illumination may be obtained if divers have a small flashlight strapped to the inside of each wrist. The size that operates on 4 C-cells is sufficient, and high-intensity discharge lamps are becoming more widely available. New brighter LED lamps are also bright enough for most use, with the advantage that the batteries last many times longer than incandescent bulbs. Larger "lantern-style" flashlights are generally too cumbersome to operate while working. In addition, surface-based floodlights may be deployed over the side of the boat to illuminate a curtain of water, although this is not typically practical or necessary unless the operation requires it.

Collecting with jars at night will be facilitated by the use of two dive bags, one with empty jars and one for jars that have been filled. This minimizes groping in the dark for a usable container, and reduces the chance of losing specimens. It is also helpful to secure all pencils and other small items with a short line so they are easily found and are not inadvertently dropped.

Diving under Ice

Diving under ice when the bottom depth exceeds normal diving conditions can be done with blue-water diving techniques. Most blue-water diving techniques in ice have been done in areas of seasonal pack ice using an inflatable boat as a basic platform. In this realm, space among the ice floes may vary from nonrestrictive in areas of newly forming pancake ice to near nothing in 10/10 pack (frozen together with no water visible), which may necessitate cutting entry/exit holes through ice floes. Therefore, modifications of standard procedures are necessary to accommodate variable conditions. In all instances, however, a modified blue-water procedure can help minimize risks during the dive.

Variations in the techniques of blue-water ice diving have mostly to do with ice and weather conditions. Though the basic blue-water set up from the surface boat remains the same, there is variation in the launch and recovery of the boat and divers, whether a boat is used at all, number and type of safety holes, and use of additional weather protection over dive holes. For example, in pancake ice, an inflatable boat can be launched, driven to a boarding ladder and motored away from the ship with no concern about the ice "closing in". In thicker ice cover, the divers may be most safely launched and recovered after boarding the boat at the rail of the ship, and then swung with a crane out to a dive hole between floes. In 10/10 pack ice or on large floes divers may enter the water through holes cut into the ice, essentially diving from a "solid" platform. In these cases, where entry and exit areas are not plentiful between floes, one to two additional holes will need to be cut to ensure the divers can exit if one hole closes.

Air temperature and wind chill always need to be monitored before and during a dive. During ice-diving training, divers and tenders are trained in the symptoms and signs of hypothermia. Pack ice diving has been done successfully in temperatures as low as –50°C, but more often in winter conditions ranging from –10°C to –30°C. When diving in pack ice, the ship's bridge needs to be constantly monitoring wind direction and speed, as well as the two dive tenders in the boat. The bridge is left instructions to notify the tenders if there is either a change in the wind direction by 10 degrees or a 16 km/hr (10 mph) increase in the wind speed. While either of these situations may not result in terminating the dive, either situation alerts the tenders that conditions may be changing. In addition, tenders are constantly monitoring the pressure on the pack ice, especially when diving between floes. Pack ice may close from increased pressure due to meteorological conditions occurring far from the dive site, so constant vigilance is necessary.

For diving in pack ice and working immediately on the underside of the ice, a typical blue-water system of tethers may be used, but with a down-line only 3 meters deep, and deployed through a hole in the ice. In addition, only two divers (tethered in the traditional manner) are in the water, acting as a buddy team in place of a safety diver. This allows the removal of a minimum number of divers when a sudden change in ice conditions requires it. In addition, because a safety diver remains relatively immobile, they would be susceptible to becoming overly cold during the dive. Since dives are generally no deeper than 8 m (25 ft) in pack ice, samples may be brought more or less continuously back to the boat. This frequent topside exchange is an additional safety factor.

The lone signal from the surface boat to the divers at depth—whether in response to tightening ice conditions, high winds, or predators in the area—is to slowly retrieve the down-line and tethers. Upon feeling this slow but constant tug the divers immediately swim together back to the Zodiac.

The underwater aspect of diving in pack ice is relatively simple since depths are shallow, water is clear, and the ice ceiling provides orientation. Managing the tethers is the most difficult aspect of ice diving. However, the tethers provide the safety benefits as in any blue-water dive, in addition to providing an immediate orientation to the dive hole when the diver is “out of sight” behind some ridging.

Managing a dive also involves consideration of air supply and distance from the exit hole. Given the typical water temperature of –1.8°C, regulators may freeze and free flow. It is often advisable to begin the dive furthest from the entry hole, and work back toward the opening. In addition, because the apparent current relative to the ice increases with depth (or distance away from the ice), a diver doing traditional blue-water capture techniques should try to remain up-current of the dive hole, in case the current worsens. This orientation is a good general precaution to take.

Ship Operation

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 recomsafe vessel operation

mended. The bridge and the mess deck should be notified at the outset, and reminded regularly, 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 8 km (5 mi). The boat is then launched and the ship steams about 0.6 km (1 mi) 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 0.6 km (1 mi) 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 0.3 km (0.5 mi) to the dive location.

Constraints Associated with Blue-Water Diving

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

- 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 and heavy swells also create problems in launching a small boat from the mother ship and recovering it.

- 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.

- In heavy rain, snow storms, or fog, small boats can become separated from the mother ship or possibly from the divers. Far from shore, it may be difficult to establish where the main ship lies, even with the use of radios.

- 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.

Emergency Procedures

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:

- 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 on the small boat during each dive, with personnel trained to use it. All personnel should be trained in cardiopulmonary resuscitation.

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

- 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.

Recommended diving procedure

Each group will develop the methodology that is most suitable to their operations. Below is a step-by-step account of one potential dive procedure. These procedures will change (more or less conservatively) depending on conditions.

Pre-dive

1. Collecting jars are filled with seawater; dive gear, cameras and scientific equipment are prepared.
2. A small inflatable boat or skiff is loaded with dive gear, jars, blue-water down-line and tethers, oxygen, and emergency equipment before being deployed from the mother ship according to ship's procedures.

Deployment

3. Divers enter the small boat, and it proceeds away from the main ship, in a direction that will lead to them drifting apart, not together. (This will depend on the operations aboard the ship.) "Currents" as measured by the ship's instrumentation will have little effect on the path of the divers, whose drift is determined almost entirely by the wind.
4. Divers review dive plan before entering the water, especially depth at which trapeze will be initially clipped. Typical dive profile will work from deep to shallow: *e.g.*, clip trapeze at 15 m (50 ft) for 15 minutes, 10 m (30 ft) for 15 minutes, and 3 m (10 ft) for 15 minutes.
5. All lines, knots, clips, and buoys are inspected prior to deployment. Knots made secure with seizing or zip-ties.
6. Sea anchor, if desired, is deployed first to set the orientation of the boat.
7. The down-line is secured to the boat at one end, then tied to the rail, cleat, or loop. Weighted end is lowered into the water. 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. 3, 4). At no time is the down-line weighted with more than a single diver could carry to the surface.
8. The trapeze is clipped to the rail (loss of the trapeze could spell the end of diving operations).
9. Individual tethers are clipped to the trapeze, and paid out over the side of the boat.
10. Shark-billy is attached to the trapeze, or each diver brings their own.
11. Trapeze is clipped to the down-line between the boat and the buoy.
12. 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.

13. All divers gear up, check air, and check quick-release on buoyancy compensator.

Working dive

14. Divers enter the water and swim to the surface buoy. As the divers arrive at the trapeze, they receive the loop end of their tether and clip into the rigging.

15. The divers descend together down the line, with the safety diver bringing the trapeze. The trapeze should be clipped to the line, and slid along its length, not carried in the safety diver's hand. Divers are arrayed around the safety diver, who monitors their descent, looking for signs of incorrect buoyancy (divers too light or heavy), trouble clearing ears, and other potential problems.

16. At the pre-determined depth, the trapeze is clipped to the loop or above the knot.

17. Divers double-check their buoyancy, distribute themselves at convenient distance, working mainly at the same depth as the trapeze if possible (or necessarily, if visibility is poor). 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. Divers must swim as necessary to avoid dragging the apparatus into shallower depths; tethers are not effective as towing lines, and should be slack during most of the dive.

Deviations from the planned dive

18. 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 behind the washers (if present) or between the small counterweights and the trapeze. The safety diver also surveys the surrounding area for potential hazards and supervises the entire dive. They have the ultimate underwater control over the dive and can terminate the dive if conditions warrant. They communicate with the research divers by tugging on their tether lines. For example, if it is time to ascend to the next depth, the safety-diver communicates this individually to each diver (typically by a circling motion followed by thumbs up).

19. 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.

20. 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. Divers remain clipped to their tethers (in the event that one is attacked or loses consciousness) and all ascend to the surface as a group, facing outward if necessary. The safety diver utilizes the "shark-billy" to ward off curious predators.

Ending the dive

21. The dive is terminated when the first diver reaches the agreed upon amount of air remaining (but see #22 below). This allows time for other divers to discontinue their sampling and to converge at the safety diver. All divers remain clipped in, and ascend the down-line together. The safety diver brings the trapeze slowly along with the group, if possible.
22. In benign or clear conditions, divers may ascend to the surface individually when their dive is completed, provided they notify the safety diver of their intention, and stay in physical contact with the down-line during the ascent and safety stop. They should not unclip and then perform a free ascent.
23. Once at the surface, divers swim along the surface line to the boat to exit the water. To facilitate re-entry into the boat, divers can attach weight belts and gear bags to clips hung on short lines from the boat. Divers should not linger at the surface, except to assist others as needed.
24. In the boat, tethers are coiled up and stowed, down-line is recovered, and sea anchor is retrieved and stowed. Any gear or samples over the side are recovered before the engine is started.

* * *

Despite the extra training and equipment required, blue-water diving can be one of the most rewarding underwater endeavors. Those who participate in a blue-water dive gain first-hand experience of the open ocean—a rarely seen environment with many frontiers for discovery.

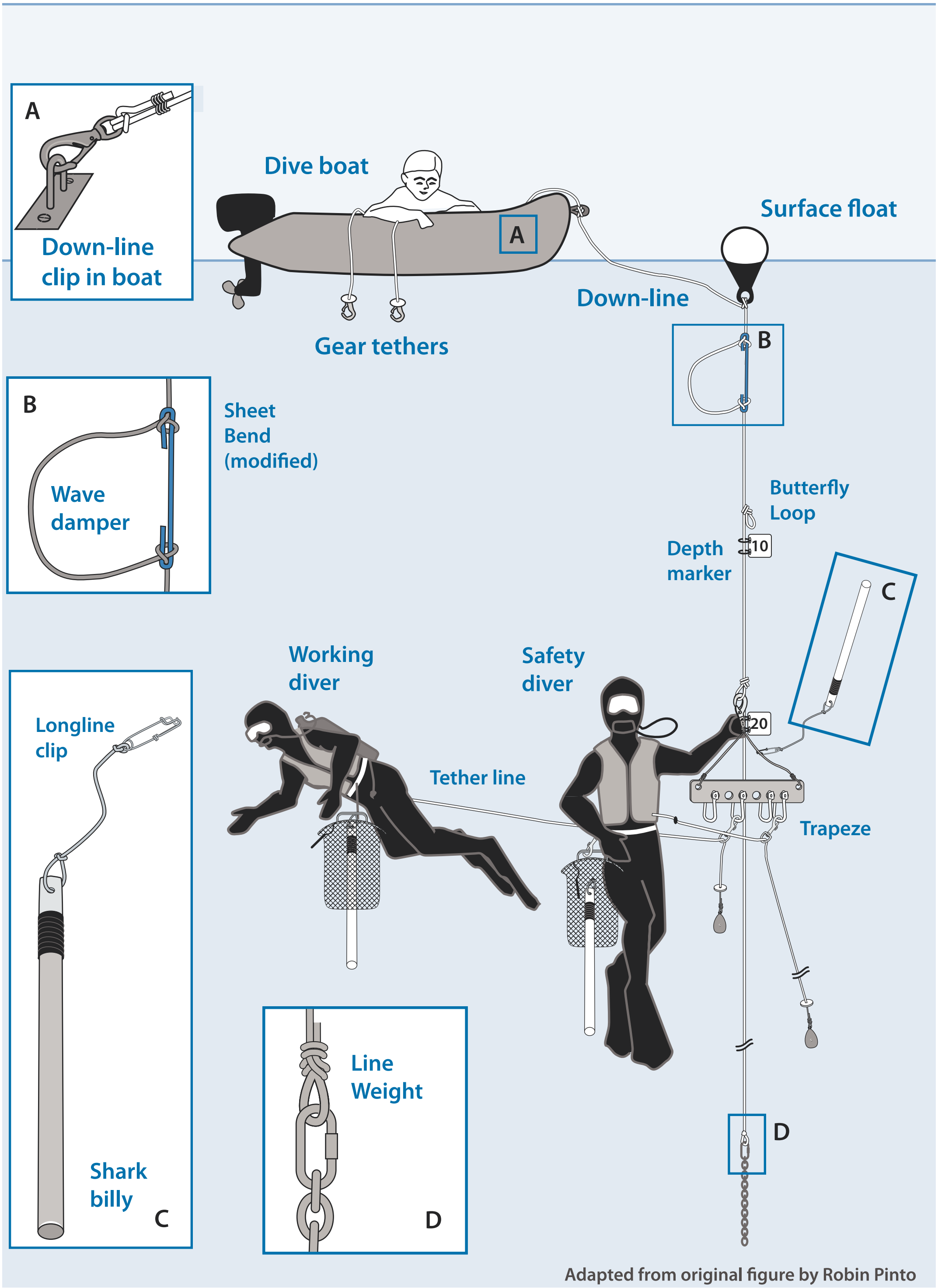
Specialized Equipment and Tips for Construction

One of the most difficult aspects of beginning a blue-water diving operation is simply gathering and assembling the equipment required. This section explains the function and design of each component, and gives guidance toward the construction of a complete rig.

Components of a Blue-Water Rig

Once assembled, a blue-water diving rig will provide many years of use. It is convenient to store all the parts in a large plastic bucket with holes drilled in the bottom. Like a well-packed parachute, carefully stowed blue-water lines will be rapidly deployed at the beginning of each dive.

In Appendix 3 is a discussion of how to choose and work with the many types of rope that may be used for making lines and tethers, as well as a guide to some useful knots.



Adapted from original figure by Robin Pinto

Figure 4. Details of blue-water diving apparatus

Down-line. The down-line serves as the backbone of the connection between divers and the boat, and as the main vertical point of reference in the water column. It is constructed from a continuous 45 m (150 ft) length of 10 mm (⅜ in) double-braided Dacron line (Fig. 4). A portion of this line (15 m or 50 ft) runs from the boat to the surface float. A large clip securely fastened to one end (Fig. 4A) may be used as the first point of attachment to the small boat, and the line should be secured at a second point within the boat operator's sight and grasp.

down-line

A 0.3 m (1 ft) or larger diameter inflatable boat fender serves as the surface float. The line should be attached to the float while remaining continuous, not tied to it in two segments. Thus it may either be looped through the eye of the float (with a binding hitch or figure 8 knot), or alternately a loop (figure 8 or Butterfly Loop) may be tied in the down-line, and the float may be securely clipped to this loop with a carabiner.

An elastic shock absorber (Fig. 4B) made from a 0.6 m (2 ft) segment of 1.2 cm (½ in) shock cord or rubber tubing may be secured between two loops about 0.6 m (2 ft) below the surface float. The down-line should not be cut to accommodate the elastic cord. This segment may be tied to the main line using a modified sheet bend (see Fig. 4B, detail) so that the down-line remains continuous.

The vertical portion of the down-line below the float is 30 m (100 ft) long. Loops ~8 cm (3 in) in diameter are tied in this line every 3 m (10 ft), usually to about 21 m (70 ft). The Butterfly Loop (Appendix 3E) is an excellent knot for this application, as it resists strain in all directions, and can be tied in the middle of a continuous length of line. The depth of each loop is clearly marked with white plastic plaques (*e.g.*, 80 x 80 x 6 mm [3 x 3 x ¼ in] polypropylene). These plaques, clearly labeled on both sides with the appropriate depth, are secured to the down-line with nylon cable ties, typically below the knot to avoid wear by the trapeze.

This last loop is the deepest depth at which the trapeze will be secured, but the line continues to 30 m (100 ft) to serve as a reference point. The bottom of the down-line (30 m/100 ft) is connected by a shackle or quick-link to a length of chain or a small, 1.5-kg (3-lb) weight (Fig. 4D).

The down-line may be made of three-strand twisted line if preferred, although in that case, stopper knots should be used in place of loops as sites for placing the trapeze.

The down-line must be accurately positioned in the water column. Therefore, the shock-absorbing loops and the attachment of the surface-float must be well planned. As long as the sub-surface loops are accurately spaced relative to each other, if the surface float is found to be poorly adjusted in comparison to depth

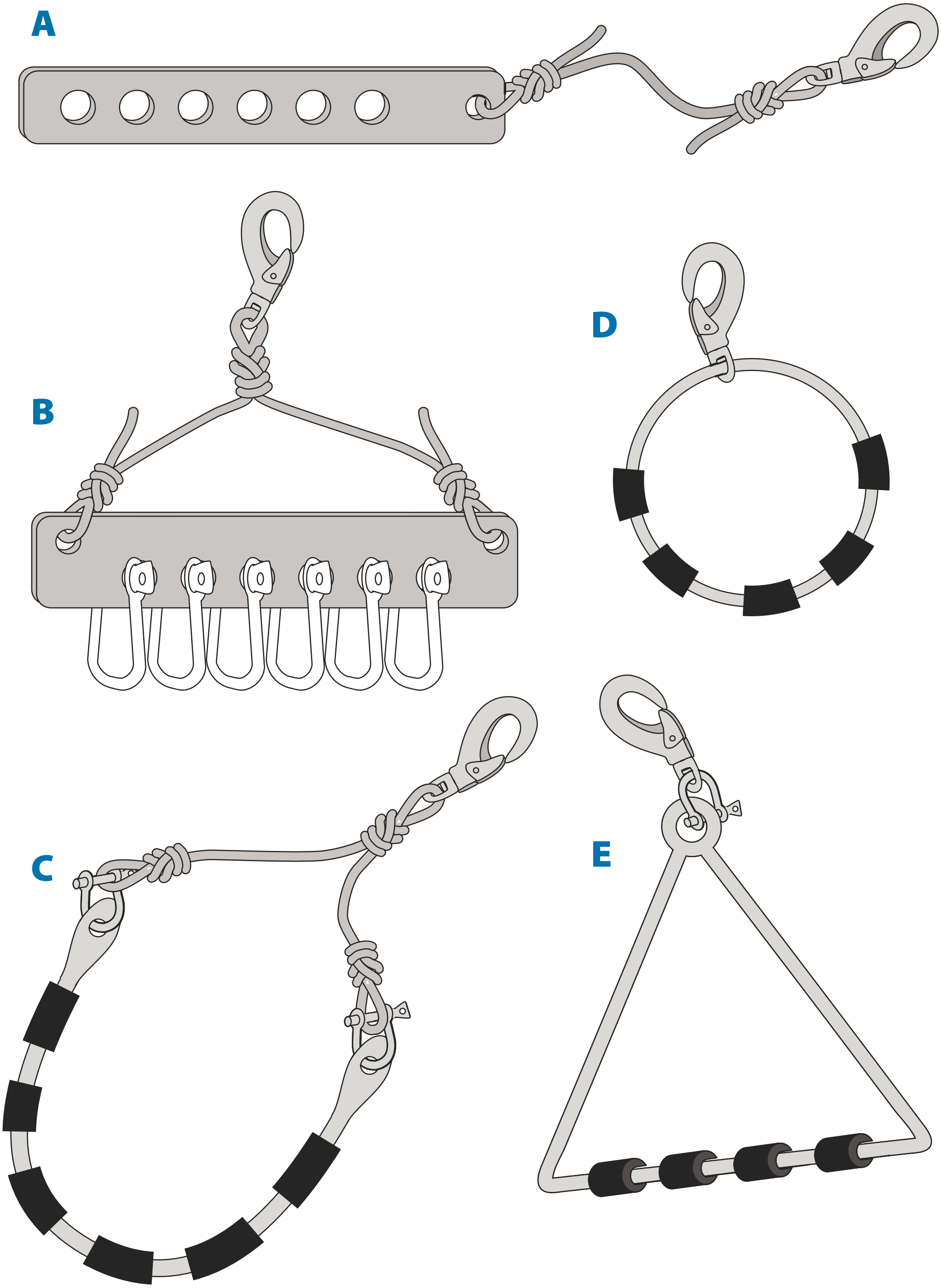


Figure 5. Views of trapeze designs

gauges, the depth may be adjusted on dry land by moving the point of attachment of the float.

Trapeze. The trapeze (Fig. 5) is the central hub of the diving operations, keeping the divers connected to the down-line with minimal restrictions on their movement. The trapeze is clipped to the down-line at the main working depth, typically with a large, bronze spring-loaded clip. Each diver's tether is connected to the trapeze by a swiveling bronze snap shackle. Unlike the attachment of the tether to the diver, this connection should not be a quick release. There are many variations of trapeze designs, five of which are shown in the adjacent figure. The choice of a trapeze design depends largely on the materials and fabrication methods available. Basic features to consider are strength, rust-resistance, and a design that makes it easy to keep the divers' tethers separated. It is convenient to have more locations on the trapeze to secure the diver tether clips than there are divers. This facilitates untangling or repositioning of the tether clips.

trapeze designs

Design A. Perhaps the simplest design consists of a small aluminum bar about 1 m (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 0.3 m (1.5 ft) long nylon line (usually 5 mm or ¼ in), with a bronze snap clip (see also Fig. 4). Bronze swivel snaps hook directly into the holes in the trapeze.

Design B. A variation of the bar is constructed of a 10 x 75 x 600 mm (⅜ x 3 x 24 in) piece of white polypropylene with six holes drilled 6 mm (¼ in) from the bottom edge and evenly spaced from one end to the other. These holes accommodate the pins of 50 mm (2 in) deep-D stainless steel shackles to which the diver tether clips can be fastened.

Design C. A U-shaped piece of sailing hardware, known as a "boom bail,"may be readily modified for use as a blue-water trapeze. Lengths of rubber tubing may be slid over the ends of the bar, and possibly wrapped in rubber electrical tape, before affixing the shackles.

Designs D & E. A hoop of brass or stainless steel rod (approximately 7–10 mm [¼–⅜ in] diameter) may be welded into a loop or triangle (6–9 in or 15–24 cm across). If tubing is used rather than solid rod, holes should be drilled to allow pressure equilibration. Swivels are clipped directly to the frame, and spacers may be welded on, or simply made from rubber tubing, wrapped in rubber electrical tape.

Tethers. (Fig. 6) Tethers connect the diver's quick release to the trapeze. They should be made of double braided 5–6 mm (¼ in) Nylon or Dacron line.

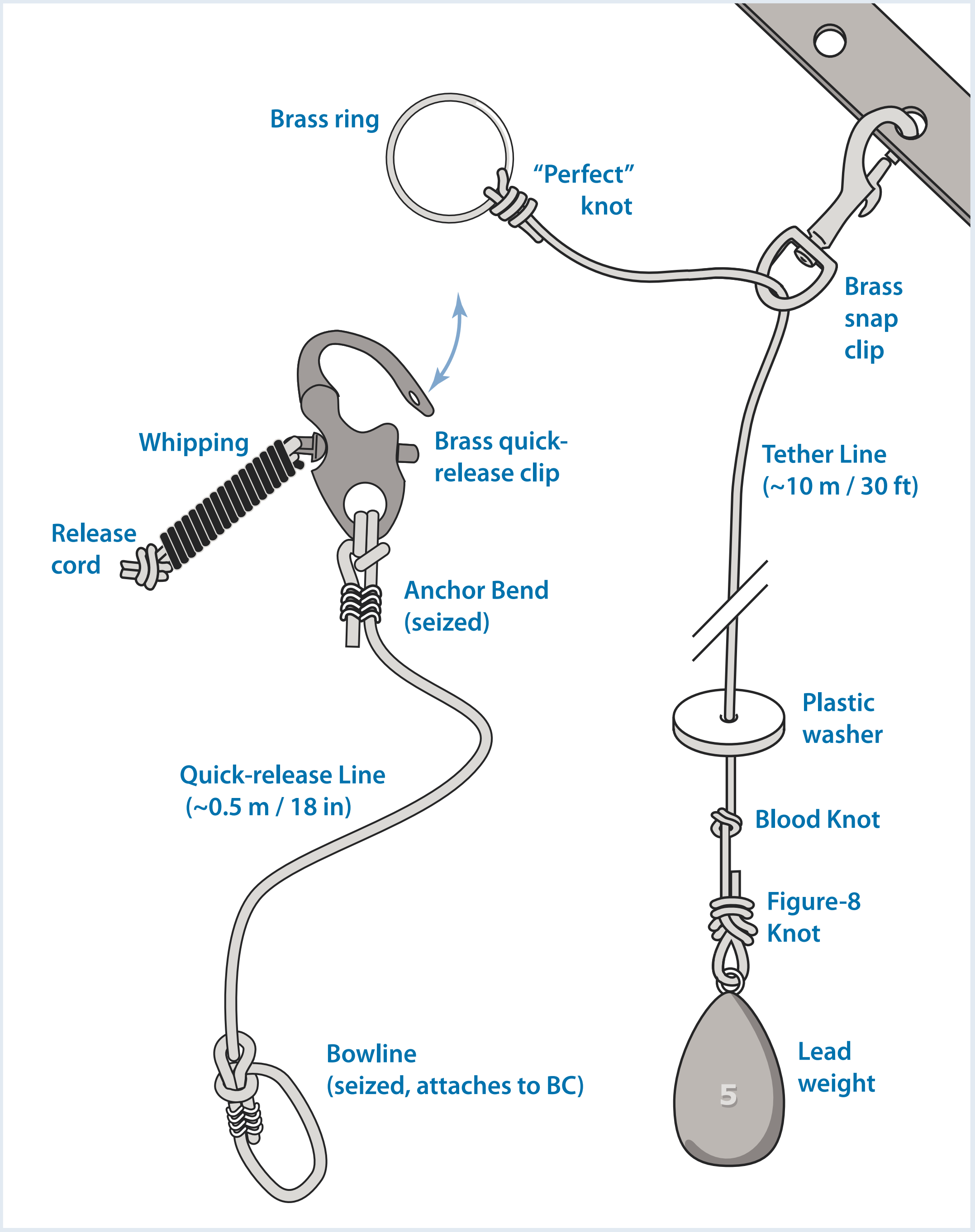


Figure 6. Detail of the tether and quick-release lines

Twisted nylon or polypropylene lines will be more likely to kink, entangle, or catch in the swivels. The safety lines are typically 10 m (30 ft) in length. At one end is a brass or stainless steel ring approximately 2–4 cm (~1 in) in diameter. The lines pass through the eye of a bronze swiveling clip, with a 100–150 g (4–6 oz) lead sinker at the end. The sinker should be heavy enough to take up slack in the line, but not so heavy as to constantly draw the diver toward the trapeze in calm conditions.

diver tethers

A plastic or acrylic washer between the clip and the weight will prevent the weight from jamming when the line is fully extended. This washer can also be used as a backstop for shortening tether lines during conditions of low visibility, by tying an overhand knot in the line below the washer. Typically the tether length should be restricted to 50–75% of visibility.

The other end of the safety line is attached to the buoyancy compensator (usually on a D-ring or through a strap) via a quick-release snap shackle (see Figs. 4, 6). As described above, in the present scheme the safety diver uses the same full-length tether as the other divers.

Quick release. The quick-release clip is the point of connection between the tether and the diver (Fig. 6). Quick-release "snap shackles" are used for these releases. Bronze shackles are recommended, as they engage and release more easily than their stainless steel counterparts. Some groups have tested plastic compression clips, such as those used to secure a BC or backpack, and they appear to be suitably strong and easy to release under tension.

A normal swivel hook is not recommended for this purpose because it must be possible for the diver to disengage themselves from the apparatus even if it is under tension. Similarly, if the quick release is on the tether, rather than attached to the diver, it is not easy to release by a quick tug against the body—the tether must be under tension for it to operate. Although it sounds unlikely, there have been incidents where the surface boat has capsized, or the down-line has become detatched from the float and begins sinking. It may also be important to be able to release rapidly in the event of extreme entanglement.

quick release clips

The quick release is attached by a short length of 5 mm (¼ in) line to the diver's buoyancy compensator, ideally through a permanent strap or sturdy D-ring. The line should be affixed at a short enough length that the diver can trigger the release at arm's length. A bowline by itself is not sufficiently secure for tying this line, unless the free end is seized. The attachment point should be consistent (right or left side) between divers within a particular working group, so that the safety diver knows where to find the clip when needed. It should be fixed between the armpit and waist—if too high on the shoulder, it becomes a distraction when trying to focus on collecting.

Shark-Billy. Some type of slender rod, such as a broom stick, short pole spear, or ~12–18 mm (~½–¾ in) round fiberglass stock should be carried by the safety diver or clipped above the trapeze using a "longline snap" (Fig. 4C, Appendix 3C). Other divers may carry individual shark-billies as desired. The rod should be about a meter long (3 ft) with a hole drilled in one end to accommodate a lanyard or a loop of surgical tubing. 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. Bang sticks are not to be used because of the potential danger to other divers both in the water and in a crowded boat.

response to sharks

When a shark is tightly circling a diver, the billy is used in a prod-like 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 close to the diver. A sharp prod to the shark will usually result in a hasty but temporary retreat. This retreat, however short, usually provides the diver with sufficient time to leave the water.

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.

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 (diameter 450 mm/18 in) can be used. When the line must remain stable in the water column (*e.g.*, during incubation experiments), a flopper stopper (a large disk of wood or plastic) can be added to the bottom of the line, although this is not recommended for the divers' down-line.

Gear Tethers. Gear tethers are short lines with snaphooks or longline snaps at one end (Fig. 4). These are secured to the dive boat and hang approximately 1 m

(3 ft) underwater. SCUBA units, weight belts, goody bags, 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, SCUBA units are often left hanging on gear tethers until the boat is ready to leave station.

Sea Anchor. During blue-water dives, a roughly 2 m (6 ft) diameter sea anchor may be used to reduce the movement of the boat resulting from windage. This is attached by a separate polypropylene line to the small boat, and deployed beyond the main down-line. The sea anchor is also attached to a small, separate float that keeps it from collapsing and sinking should the wind die.

Appendix

Appendix 1. Blue-Water Diving Checklists

Blue-water diving requires the use of an array of equipment different from other research diving. The following is a list of items used in most blue-water diving applications.

A. Small Boat Equipment and Safety Equipment

- GPS
- Radio
- First aid kit
- Drinking water
- Oxygen kit—resuscitator
- Outboard motor with sufficient fuel
- Oars
- Flares and strobe
- Compass
- Tool kit
- Spare parts and patch kit
- Coast Guard approved personal flotation devices
- Radar reflector
- Dive flag
- Sea anchor
- Launch/recovery sling
- Equipment lanyards with clips

B. Diving Equipment Checklist

- Standard SCUBA Equipment as appropriate for the conditions

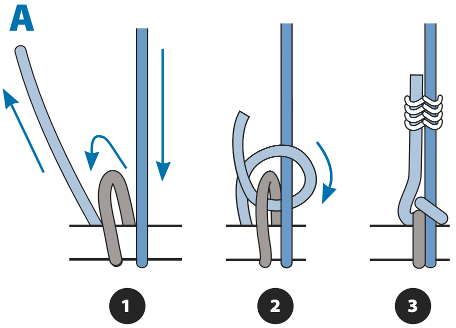
- Specialized Equipment
    - Down-line
    - Trapeze
    - Tether for each diver
    - Quick-release for each diver
    - "Safety sausage" inflatable marker
    - Shark-billies, if desired
    - Gear line
    - Scientific gear
        - Jars, Syringes, Buckets
        - Writing Slates
        - Cameras

Appendix 2. Parts List

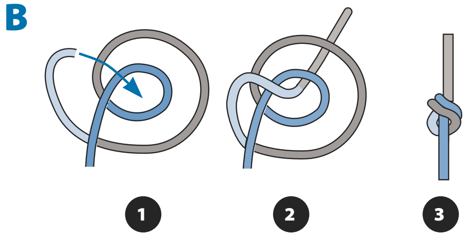
The following list of parts is meant to serve as a checklist or starting point for constructing a blue-water rig. We do not endorse any particular brand, supplier, or manufacturer. Most parts will be available at any marine hardware store or chandlery.

Name	Mfg. Part # or Descr	Size	Qty.
DOWN LINE			
Large clip to boat	any bronze/stainless	variable	1
Line (Dacron/Nylon)	double-braid	7/16 in / 11 mm dia	150 ft / 45 m
Shock cord	bungee or rubber tubing	½ in / 12 mm dia min	3 ft / 1 m
Surface float	round boat fender	~12–15 in / 30–40 cm dia	1
Plastic depth placards	scrap, salvage PVC	~2 x 2 in / 5 x 5 cm ea	~7
Quick-Link (to chain)	big enough to fit chain link	~ 5/16 in / 8 mm stock	1
Down-line chain (galvanized)	⅜ in / 1cm link thickness	20 in / 50 cm	1 x ~16 links
TRAPEZE (parts variable)			
Swivel-eye Snap Clip	Various; e.g., size #2	~3 7/8 in, 10 cm	1
Captive-pin shackles	e.g., Wichard #1443	depends on design	~2
Rubber tubing (stoppers)	depends on design	6 inch for cutting	1
var C: Boom bail (u-shape)	e.g., Schaefer #90-12	5¾ x 8⅜ in deep	1
var D/E: Welded loop/triangle	bronze/stainless rod/tube	~¼ in / 7 mm dia	1
TETHERS (recommend at least 4, up to 7 or more for spares)			
Ring	brass or stainless steel	1–1.5 in /2.5–3.5 cm	1 ea
Tether Line (Dacron/Nylon)	double-braid	¼ in / 6 mm dia	30 ft / 10m ea
Swivel-eye bolt snap	~3.5 in long; 1 in/2.5 cm eye	7/16 in / 11 mm jaw open	1 ea
Plastic washer for tether line	~1.5 in / 4 cm outer dia	inner dia for tether line	1 ea
Lead weight	variable (with brass loop)	4–6 oz, 100–150 g	1 ea
QUICK-RELEASE TETHER (recommend at least 5, up to 8 or more for spares)			
Bronze fixed-bail snap shackle	e.g., Ronstan #RF6002	for ⅜ –½ inch line	1 ea
(Or plastic BC quick-clip)			
Quick-release line (& pull cord)	double-braid Dacron	¼ in / 6 mm dia	3 ft / 1 m ea
MISCELLANEOUS AND OPTIONAL			
Sea anchor (float and 60 ft/20 m polypropylene line)	e.g., Para-Tech 6-ft dia	6–9 ft (2–3 m)	
Waxed whipping line (whipping) and waxed lacing tape (seizing and whipping)			
Black rubber tape, zip-ties	misc. for seizing, etc.		
Plastic bucket (for rig)	5 gal/ 20 liter		
Over-the-side clips and lines, and Long-line clips (for underwater gear)			

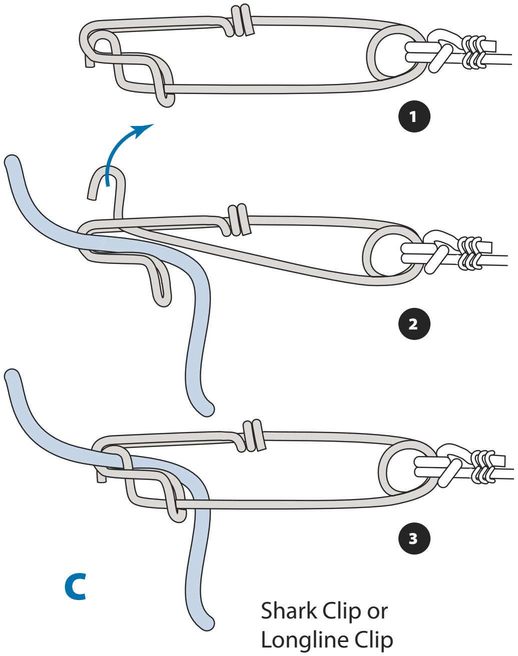
Appendix 3. Knots and Lines



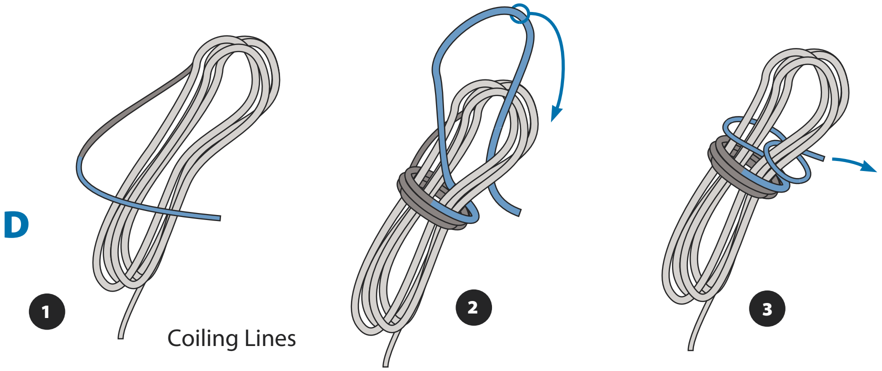
Anchor Bend



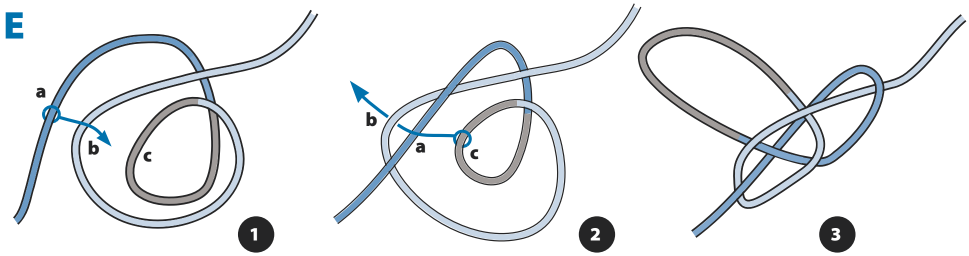
Blood Knot



Shark Clip or
Longline Clip



Coiling Lines



Butterfly Loop (Lineman's Loop)

Appendix 3. Knots and Line Handling

Choice of Rope. 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 and can be more easily spliced. Braided lines are easier to handle and are preferable for most applications. Dacron double braid and braided nylon are the strongest commonly used lines. Nylon stretches, while Dacron does not; both are negatively buoyant. For applications such as sea-anchors, where the lines must float, 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.

types of line

Working with lines. To cut lengths of lines without causing fraying at the ends, first wrap masking tape tightly around the line at the point you wish to cut. With a sharp knife, cut through the middle of the taped segment, leaving both ends with tape wrapped around them. Burning the ends of the line can form a stable termination, but for additional protection against fraying, whip the ends (Knot I) using waxed lace (available at marine supply stores) or even dental floss. The same material may be used for seizing the lines (Knot J).

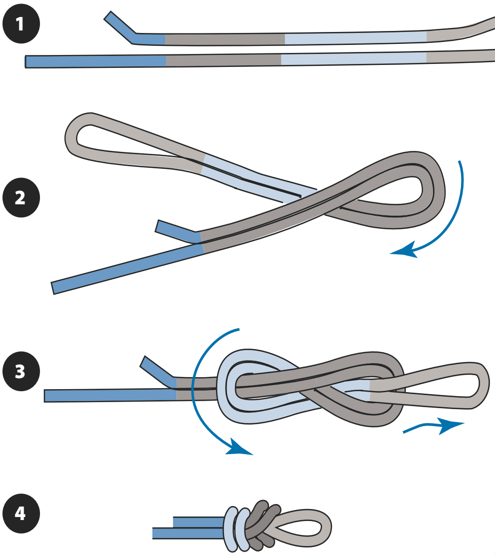
Knots. Using the right knot will make your blue-water rig hold together for many years. Several examples are shown in this appendix with illustrations to indicate how they are tied. Some, like the “perfect” knot, may require a little bit of interpretation and practice to accomplish. Knots used in blue-water diving, where safety depends on their staying attached, should be “seized” by connecting the two ends to each other, using line or plastic zip-ties where indicated in the diagrams. This connection is not contributing to the overall strength of the knot, but merely prevents it from coming untied, especially when not under tension. The tendency for knots to relax and become untied is more prevalent underwater.

Notes on particular knots.

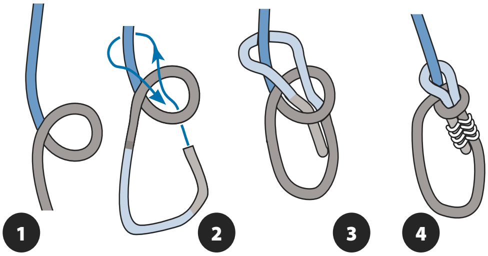
A. The Anchor Bend is a good for securing a line to a fixed eye, but it will *not* stay tied unless the ends are seized.

B. The Blood Knot is a good stopper knot for the tethers. It is tied just like an overhand knot (most basic knot), but before passing through the hole, you wrap the line twice. To make it lie nicely, pull the second loop to cross over the first.

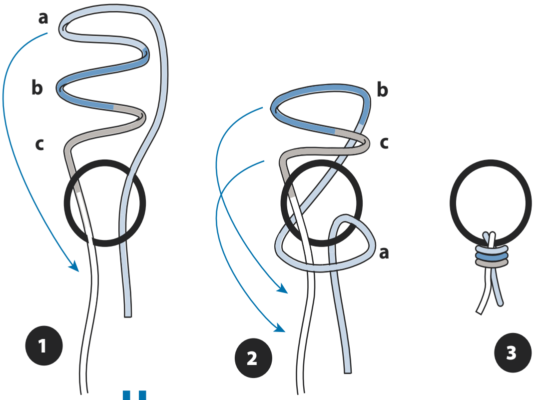
C. Long-line clips are used to quickly attach fishing gear to another piece of line. They may be used to attach a shark-billy to the trapeze, or to attach scientific gear to an equipment line.



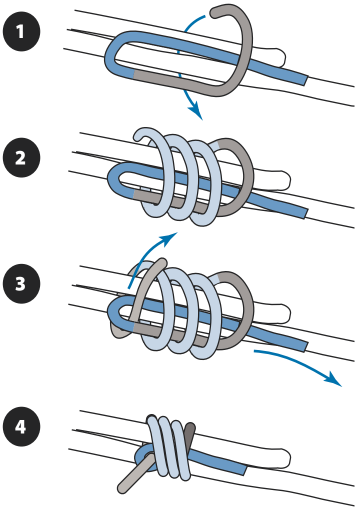
F Figure-8 Loop



G Bowline

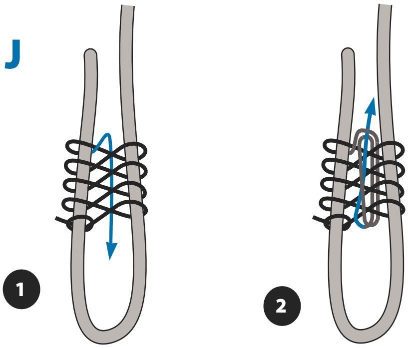


H “Perfect” Knot

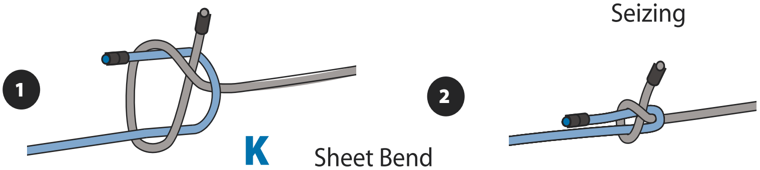


I Whipping

J



Seizing



K Sheet Bend

D. Coiling Lines, if done properly, makes uncoiling and deployment tangle-free. (1) Make a loose coil, leaving 2 ft (0.6 mm) of free line. (2) Wrap tightly around the larger coil, and pass a loop of the remaining strand through it. (3) Flip the loop back over the top of the coil, and pull tight.

E. The Butterfly Loop is convenient because it can be tied in the middle of a line, and resists pulling in all directions. It is useful for the down-line, but measure the interval between each successive knot only after the previous loop has been tied. To tie, (1) wrap the line three times around your hand, with the third wrap between the first two. (2) Lay strand **a** over strand **b**. (3) Then insert strand **c** between **b** and **a** (over **a**, and under **b**).

F. The Figure-8 Loop is a secure way of forming a loop at the end of a line. It is a little bulky, but extremely strong.

G. The Bowline is the most popular way to form a loop in the end of a line, but it does *not* stay tied unless under tension, so the free end must be seized to the loop, as shown.

H. The Perfect Knot is a fishing knot that is also a clean way to connect tether lines to the metal ring. It is a little bit difficult to tie from the illustration, but each of the loops "above" the ring is laid down along the strand and tightened together. In the final knot, the loops have the same sequence that they had above the ring.

I. Whipping is used to lightly secure the ends of two lines (not as strong as seizing) or to prevent the end of a thicker line from unravelling, when done using flat waxed line. With thicker round line, it can also make a somewhat decorative wrapping for the handle of a shark-billy (Fig. 4C) or on the pull cord for the quick release (Fig. 6). Pull the loops tight before securing by pulling the free end.

J. Seizing is similar to whipping, but more securely fastens two lines to each other. This can be used on many knots, including the anchor bend and bowline. (1) Tie a thin waxed line or floss at one end and then do figure-8 motion between the two strands, working toward the free end. (2) After several passes, pull the loops tight, and wrap across the middle of the 8s. Finish by tucking the free end under these final loops. (A quick but less secure seize may be achieved with a zip-tie.)

K. Sheet Bend. A classic knot used to secure two lines. Figure 4B shows how this may be used to connect the shock-absorbing cord while leaving the down-line uncut. Note: bitter ends of both lines should end up on the same side of the knot, as shown.

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Scientific blue-water diving is a method used to explore the open-ocean environment and to study and collect the organisms that live there. This book hopes to bring these techniques to a wider audience of researchers, especially those interested in plankton biology and biogeochemistry. It describes the applications, methods, and equipment involved in the procedure, including instructions for fabricating a complete blue-water diving apparatus.

Cover photo:
Kevin Raskoff takes a turn as the safety diver in the mid-Pacific Ocean. (©: Steven Haddock 2003)