dition of each tube increases the total length by almost exactly 5 feet. A machine bolt is threaded into a hole in the lower part of the coupling to serve as a setscrew to prevent the piston from moving when the corer is withdrawn after the core has been cut.

The instruments are made of stainless steel for strength and to avoid corrosion. The weight of the separate components is:

Large bore barrel and tube	5.0 pounds (2.3 kg)
Piston and attached rod and handle	5.4 pounds (2.5 kg)
One extension tube	3.5 pounds (1.6 kg)
One extension rod	3.3 pounds (1.5 kg)

The complete assembly including four extension tubes and rods (sufficient to core to a depth of 25 feet) and the template is about 40 pounds (18.2 kg). Rods and tubes made of aluminum to reduce weight have not stood up in use.

A tool useful in pushing the corer down and withdrawing it is shown in Fig. 3. It is made from a 0.375-inch (0.95 cm) steel plate to which a handle of steel rod is welded. A slot in the plate slightly wider than the outside diameter of the extension tube permits the tool to be slipped over the tube. Vertical pressure on the handle then causes the tool to jam. Two such tools applied to opposite sides of the tube permits the weight or strength of two men to be used in forcing the corer down or pulling it up after the core has been cut.

Alfred C. Redfield

Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543

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Underwater observations of blue-water plankton: Logistics, techniques, and safety procedures for divers at sea[1]

Abstract—The results of more than 800 h spent in offshore dives in the eastern Florida Current near Bimini, Bahamas, in the Gulf of California, and in the Sargasso Sea to observe living, undisturbed plankton in the open sea suggest that the technique has much potential. The logistics of this type of research, particularly safety procedures, are reviewed in detail.

Most of our information about oceanic organisms is inferential; it is derived from data collected by ships on the surface of the sea, or from data collected in shore-based laboratories. Occasionally direct observations have been made by scientists within the sea itself, from bathyscaphes, research submersibles, or from viewing ports affixed to ships. Direct observations by divers in the open ocean of live, undisturbed animals of any kind are exceedingly rare (Bainbridge 1952). Because oceanographic ships are expensive, cruises are often organized years in advance and stations are made at sea according to rigid schedules that maximize efficiency; it is not surprising that research vessels do not regularly stop while someone swims around the ship looking at jellyfish. Yet direct observation of free-swimming oceanic animals is needed badly. This need has been recognized for years by fisheries biologists, who have spent vast

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quantities of money and time in mostly abortive efforts to see pelagic fishes (Nakamura 1972). Now, however, due to recent advances in diving technology and to the increasing reliability of small boats, it is possible to work in selected areas of blue water without the economic constraints of large ships and research submarines or the inflexibility of rigid collecting schedules.

The advantages and limitations of obtaining direct observational data on planktonic animals with SCUBA techniques in blue water are reported here. This research has focused on the biology of the major groups of gelatinous, transparent zooplankters commonly found near the surface of tropical oceanic waters during the day—primarily medusae, siphonophores, ctenophores, salps, larvaceans, chaetognaths, heteropods, and pteropods. Although they probably are important to the natural economy of the sea (Ryther 1969), these animals have not been studied extensively because they are frequently hard to find, difficult to collect, or awkward to maintain alive in the laboratory. Because traditional methods of investigation have proved unsatisfactory, direct underwater studies of these poorly known organisms could be exceptionally informative.

Although several recent publications discuss various aspects of the methodology of underwater science (Kenny 1972; Woods and Lythgoe 1971), they do not consider the unique problems of diving offshore over depths of 100 fathoms or more. This report focuses only on those problems of special interest to offshore, blue-water diving.

The ideas for this project were developed aboard the RV *Proteus* in 1970 in the Gulf of California. Cadet Hand, J. Tinkass, B. Splaine, and their associates at the Bodega Bay Marine Laboratory provided initial help. A. Giddings designed the housing for the underwater tape recorder and later took many pictures for the project. R. Mathewson and the Directors of the Lerner Marine Laboratory of the American Museum of Natural History, Bimini, Bahamas, provided later help. P. Brimberry and H. Boyd provided technical assistance throughout the project. The Boston Whaler Corporation loaned the project a 21-foot (6.4 m) boat for the duration of the study.

This note is a report of how my colleagues and I did our work. The advantages of directly observing plankton are discussed elsewhere.

To see some organisms, water conditions must be almost ideal. Any condition that impairs visibility makes it difficult to see gelatinous, transparent organisms. Some animals, like chaetognaths and small doliolids, are difficult to see even under ideal conditions. Others occur only in water masses where conditions are never ideal. However, danger and expense can be reduced by selecting a location where blue water comes in close to shore. The lee of a tropical offshore island often is good for continuous diving programs in blue water. A reasonably large island is preferable, since the wind shadow is extensive.

Our studies in the Florida Current were conducted on the Grand Bahamian Bank, an elevated submarine platform off the southeast tip of Florida. Bimini sits near the northwest corner of the bank, about 80 km east of Miami. The prevailing winds at Bimini are from the east so that even on windy days there is limited protection offshore in the island's western lee. Water 800 m deep is found about 2 km offshore, making it possible to reach clear oceanic waters on a regular basis in small boats. We often worked 30 km offshore and occasionally we crossed the 80 km Strait of Florida, usually in less than 2 h.

Most of the excellent locations for blue-water diving in the Gulf of California are associated with islands in the southern gulf along Baja California. The gulf is elongate, relatively shallow at the upper end and very deep at its mouth; a chain of islands in its midriff almost entirely occludes the gulf and partly separates the northern and southern water masses. When the tides change, currents are violent and rapid. I have personally seen currents of nine knots along Isla Cardenoza, south of the large island of Angel de la Guarda. These currents apparently mix the water in the channels all

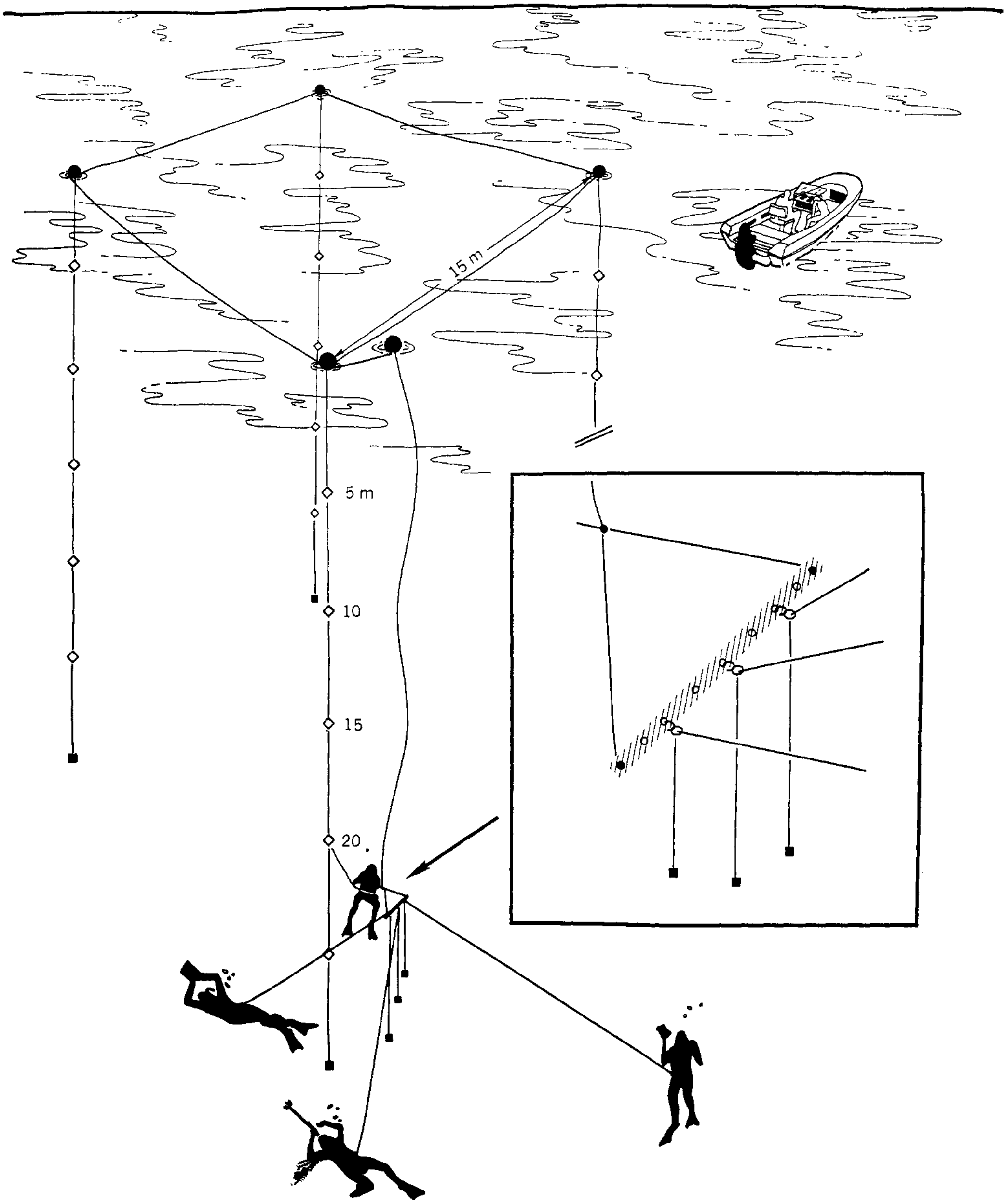

Fig. 1. Diagram of procedure for diving at sea. Small floats at surface support weighted vertical lines marked at 5-m intervals with metric white markers. Vertical lines are variously arranged, spacing floats with floating plastic pipe. Boat operator stands by but does *not* tie boat to diving grid. Safety diver descends to selected depth and is secured to surface via two vertical lines and two floats. Safety trapeze is attached directly to surface float and to divers via sliding 0.25 kg sashweight on diver's safety line. Note that all diving lines are taut. Safety lines are attached to the trapeze via heavy snaps; this permits rapid release and reattachment of lines to other holes on trapeze when lines get twisted.

the way to the bottom, enriching the water, and the subsequent blooms of phytoplankton drastically reduce visibility underwater. Poor visibility and treacherous currents in the upper gulf limit the diving possibilities. Winds can be exceptionally strong and unpredictable.

We have dived successfully near the southern islands of Carmen, Danzante, and Espiritu Santo. Here underwater visibility is often 30 m; poor visibility for this region is still 6–7 m. Currents of two to three knots are common near shore. In these locations we worked from inflatables and from homemade sailing outrigger canoes.

Although we normally work relatively close to shore, L. P. Madin has dived from a Woods Hole oceanographic vessel in the Sargasso Sea, and L. P. Madin, A. Alldredge, and I have worked similarly from a vessel in the North Pacific gyre. We were not formally allocated ship time; the ship did not halt normal operations for our work. A loaded dive boat was put over the side of the ship on calm days when the ship was on station, and divers worked in the open sea while the ship continued to perform its specific mission. It is important to insist that the small dive boat is not tied to the research ship. If the dive boat is in radio contact with the research ship during the dive, operating schedules of the cruise can be maintained.

It is necessary to have a relatively large number of diver-researchers, both for safety and efficiency. SCUBA diving in the open sea is both distracting and dangerous. An untethered diver in clear, blue, oceanic water often experiences great psychological discomfort. There is no bottom for visual orientation nor any of the fixed objects that normally aid in focal readjustment of the eye. The great clarity and brilliant blue of tropical oceanic water severely aggravate this condition. Furthermore, the diver must be neutrally buoyant, and if one is absorbed in watching some small planktonic animal it is easy to become dangerously disoriented.

A pool or inshore training session is a valuable prelude to blue-water diving, for even highly trained, experienced divers often become disoriented and disturbed by sensory isolation and feelings of extreme vulnerability when diving in blue water for the first time. Divers should always work at least in pairs, and for blue-water SCUBA research a team of three persons is the minimal number required: one *must* remain in the support boat which maintains station near the divers, one acts as a safety diver, and one concentrates on the research. The research diver is tied to the safety diver by a 15-m line and the safety diver in turn is tied to a line hung from a surface float (Fig. 1). The surface float is *never* tied to the support boat unless there is absolutely no wind; even the gentlest breeze will cause the boat to drift and drag the divers. It is inefficient for a single research diver to have two assistants, so we usually have three researchers per safety diver, plus the boat-person. We have found that four is the maximum number of researchers that can be tended satisfactorily by one safety diver. If five or more divers wish to collect data, we form teams, each with its own safety diver.

Orientation in blue water is a constant problem and in order to obtain estimates of depth and distance we suspend a series of weighted 30-m vertical lines from surface floats with white markers on the lines at 5-m-depth intervals. The vertical lines are spaced about 10 m apart at the surface by floating sections of plastic pipe. The divers thus can work within a visual grid at sea. The distance between vertical lines can be adjusted according to water visibility. Usually we use a linear array, and with one team, we often use only one line and surface float. A 12-man rubber liferaft (not shown in Fig. 1) with the canopy removed is tied to one of the surface floats directly overhead when it is windy; it contains safety equipment. The small support boat usually stands by within several hundred meters or takes plankton tows nearby while the divers are in the water.

Safety lines between the researchers and the safety diver are each 10–15 m long. Their nature and arrangement are surprisingly important. Lines that can compress or flex, or which expose individual fibers in the weave will foul the divers. Each type of line seems to behave differently underwater; one must be selected that does not tangle or float, and in which knots will not work loose; 0.64–1.3-cm diameter is best. A small, sturdy aluminum trapeze keeps the safety lines separated. Swivel snaps are separated by 10–15-cm lengths of rubber tubing and hook over the separation bar of the trapeze or are hooked through holes drilled in the bar. The line from each diver passes through a closed ring in the end of one of the snaps and then descends to attach to a lead weight, just heavy enough to keep the line taut without pulling the diver back to the separation bar (about 0.25 kg). A separation bar 1 m long will keep four safety lines apart.

The safety diver is attached to the trapeze by a short line, about 1 m long, so that his hands are free to manipulate the safety lines. The trapeze is suspended separately from one of the surface floats which also supports a vertical marker line. Thus, if the weighted grid line breaks, it will not pull the divers toward the bottom as it sinks. The trapeze line unwinds from a reel so that the safety diver can control the depth of each dive. At the start of a bluewater dive each diver while still at the surface attaches himself to a safety line hung from the trapeze to prevent drifting. The research divers then swim out to about half the length of their lines to wait until the safety diver signals the start of the dive, unreeling the trapeze line as he descends to a predetermined depth, usually 10 to 15 m. Each research diver is now free to concentrate fully on his work. As each diver moves slowly through the blue water, his sash weight rises, stops against the separation bar, and falls slowly again as the diver returns to the vicinity of the orientation lines. Dives usually last 40 to 50 min if the safety man is tied at 15 m. By wearing single air tanks, regulating the depth of our dives, and diving no deeper than 10 m on our second dive, we avoid decompression stops and the need for repetitive dive schedules.

For diving far offshore I recommend boats primarily in the 5–8 m range. Larger boats can withstand heavy seas, but have excessive windage and often are slow. Boats shorter than about 5 m are fast but cannot carry a heavy load on rough seas. Most adequately powered 7-m boats are fast enough to outrun sudden bad weather carrying a full load of divers and gear.

Since the support boat is usually separated from the diving floats to reduce windage, the boat operator must be sufficiently competent to return and collect the divers when they have surfaced at the end of the dive. On one occasion engine problems developed while divers were below; fortunately our boat operator was able to repair the engines in time and return. Those who use small boats at sea need a set of two engines or at least an additional smaller backup engine for safety.

Our work in the Florida Current was always opportunistic because the animals we were studying drifted 90–115 km northward each day, and often different communities of animals were present off Bimini on successive days. One day, for example, we saw only foraminifera and medusae and the next day only heteropods and salps. Often the weather would change and we could not dive as planned, or we might be bothered by sharks and our efficiency would deteriorate. We thus studied whatever happened to be present, and we accordingly have many qualitative observations on an exceptionally wide variety of organisms.

In addition to varied scientific gear, each diver has a safety vest and carries a sharkbilly of some type. We use various types of vests to achieve neutral buoyancy; even divers who do not routinely use vests should seriously reconsider their advantages when diving in blue water. We see sharks regularly; they usually swim by only once. When sharks are particularly persistent, they often swim in a large circle around the divers, moving in and out of visual range. We were chased from the water once by a 1.5-m White-Tip shark; a 2-m gray once tried to bite one of us. However, we do not abort a dive each time sharks appear. We usually cluster near the safety diver, unhook our safety lines to avoid entanglement, and watch. Usually the shark leaves and we resume our dive. Sharks are often present, and occasionally they will attack, but they are seldom an immediate hazard. Sharks usually don't bother divers actively moving under the water.

We collect planktonic animals individually or in groups in numbered clear jars. The jars are carried in a mesh collecting bag which is attached by a snap to a short cord knotted into several loops hanging from the vest. Volumetric samples of water or animals can be obtained (up to 20 liters) by using the heavy plastic collapsible water containers. These can be expanded slowly underwater and filled with precisely selected water samples or a particular kind of animal. We occasionally carry slurp guns, plankton nets, and hand pumps to fill containers.

We also carry large plastic syringes and meter sticks attached to the shark-billies. The syringes or squirt-guns are filled with various dyes which not only mark specific locations in the water column but also stain animals of particular interest. Some dyes are specific for particular substances and L. Madin and A. Alldredge have stained the interior mucus filters of both salps and larvaceans with carmine dyes; water motion is visualized with urinine dye. Dyes can be released also to measure swimming speeds of various plankters by recording on a tape recorder when a spot of dye is initially released next to an animal and again when it is released after the animal has moved a measured distance. If the bursts of dye encompass the swimming plankter, the animal often is also dyed, and it is therefore more easily located again for successive measurements. A graphic demonstration of the effectiveness of fluorescent dyes such as urinine in the sea is provided by Woods (1968) in his investigation of the Malta thermocline (*see also* Woods and Lythgoe 1971).

We record data with a pencil on a hard rag paper (such as lithographic) held in a clipboard. Exposed photographic printing paper does not deteriorate underwater either, nor does the expensive underwater paper produced by the Nalgene Corporation. We also use 90-min cassette tape recorders in underwater housings. The housing fits over the recorder snugly, has an O-ring seal, and has one penetration into the housing for the microphone lead and one for the on-off switch. Use of a magnetic reed-switch can eliminate one of these holes. We use waterproof throat microphones. Most divers speak directly into the mouthpiece and they learn after several tries to decipher their own garbled sounds. One diver preferred to take out his mouthpiece and talk into the water. I prefer to use a full face mask to eliminate incoherence, but a full face mask causes many divers discomfort. Various underwater communication devices are available commercially. Diver-to-boat devices permit the recording of observational data on a tape recorder kept in the boat.

It is perhaps too early yet to evaluate fully the importance of this direct observational approach to biological oceanography, but it is already clear from our own work that thoughtful contributions can be made in many areas (Alldredge 1972; Gilmer 1972; Madin 1974; Swanberg 1974; Hamner et al. 1975). It is also possible for divers in blue water to carry out valuable investigations on aspects of physical oceanography (Woods and Lythgoe 1971). Perhaps this report will stimulate other researchers to consider using this approach.

William M. Hamner[2]

Department of Zoology
University of California
Davis 95616

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[2] Present address: Australian Institute of Marine Sciences, Townsville, Queensland 4810.

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