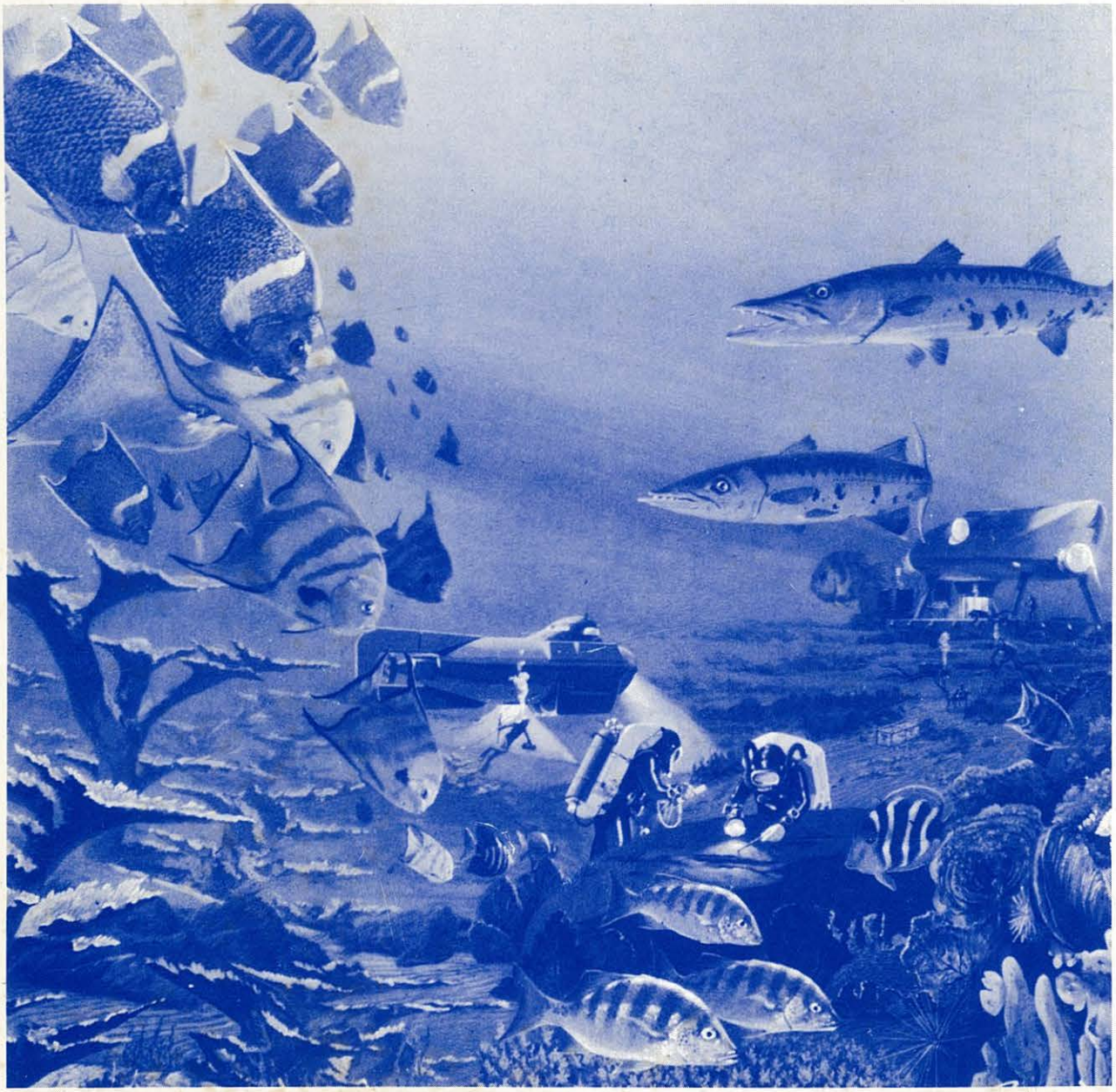
Manned Undersea Science and Technology Fiscal Year 1975 Report

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration



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Rockville, Md.
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U.S. DEPARTMENT OF COMMERCE
Elliot L. Richardson, Secretary

National Oceanic and Atmospheric Administration
Robert M. White, Administrator

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Introduction and Summary

This is the fourth annual report of the Manned Undersea Science and Technology (MUS&T) program of the National Oceanic and Atmospheric Administration (NOAA). It describes the purposes, objectives, and results of the managerial, technical, and scientific endeavors that form the program.

The purpose of the program is primarily to foster those manned underwater scientific investigations that meet the needs and requirements of NOAA and to encourage studies that may increase the safety and versatility of manned undersea operations. Also, the program includes liaison, advice, and support for Federal, State, and academic bodies performing manned undersea work.

A variety of continuing and new missions and programs accounted for about 65% of the overall $1 million budget in fiscal year 1975 and included support for the National Marine Fisheries Service's (NMFS) Northeast Fisheries Center research and surveys, the Bahama Banks research program using the Perry *HYDROLAB,* diver safety studies, coastal zone environmental and ecological research, and support of *ALVIN* operations in project FAMOUS and other collaborative foreign programs.

Also in fiscal year 1975 the NOAA Diving Manual was issued, and programs in diver safety and physiology were continued.

Sea bottom analysis for heavy metal contaminants was begun as a joint endeavor with the Atomic Energy Commission (AEC),[1] the Geological Survey, and other agencies. A submersible project in the Long Island Sound took place in July 1975.

Internationally, liaison and activities were continued with French, German, Japanese, and Canadian underwater research groups for mutual participation in submersible and underwater habitat programs. The U.S.-French FAMOUS Mid-Atlantic Ridge investigation, involving the *ALVIN* submersible and the French submersibles *ARCHIMEDE* and *CYANA,* was completed in midsummer 1975.

Background

Progress was made in intra- and intergovernmental underwater survey and research during fiscal year 1975, and the basis was laid for future scientific missions on fish and herring ecology, mineral and fossil fuel search, and trace contaminants.

The policy of the MUS&T office is to start, encourage, or act as technical liaison for or to manage underwater research and survey missions. In order to adequately meet these policy objectives, the MUS&T office relies on the formal advice and program review of such bodies as the National Academy of Sciences-National Academy of Engineering (NAS-NAE) and on informal advice by other marine groups. In particular, technology review and transfer are extended by information and data exchange with the U.S. Navy.

[1] Now Energy Research and Development Administration (ERDA).

Objectives

The basic objectives of the Manned Undersea Science and Technology (MUS&T) program are as follows:

—Support to NOAA investigations involving marine resources and environmental problems for which manned, subsurface observations and data collection are required.

—Develop, support, and manage a NOAA diving program to insure safer diving and more efficient operations for prolonged manned missions near coastal regions and on the Continental Shelf.

—Synthesize the data from MUS&T-supported investigations for dissemination to users in order to improve understanding of the nature and availability of marine resources.

—Foster and coordinate manned undersea science and applied science projects with other Federal and State agencies, industry, institutes, and universities and support man-in-the-sea aspects of international programs.

—Develop scientific and technical criteria for characteristics of civilian undersea facilities and platforms through the experience gained by using available habitats and submersibles.

—Encourage and coordinate the transfer of undersea technology, including advances in diver technology, from the U.S. Navy when in the best interest of the Navy and NOAA. Also, keep abreast of general scientific and technological developments, both civilian and military, U.S. and foreign.

These objectives were achieved by a small staff of technical personnel with a recognized standing in the marine science and technology community and acquainted with Federal, industrial, and academic institutions.

NOAA Diving Activities

NOAA has had a close association with diving operations, safety, and technology since 1970. The first organizational meeting of NOAA divers was held in Boston in May 1971 to develop a formal diving program. At that time, there were less than 25 recognized NOAA divers. By mid-1975 more than 300 NOAA divers were certified. The center for planning, administering, and controlling the NOAA diving program is the MUS&T program office. The program includes a formal set of diving regulations for certification at different levels of proficiency and operating instructions for all forms of diving, including research submersibles and habitats.

Shortly after program funding began in late 1971, the MUS&T office assumed its stewardship of NOAA diving activities. These have included 25 projects involving the use of 9 U.S. research submersibles and 6 ocean floor habitats-laboratories for 125 missions involving about 500 diving scientists. MUS&T has closely cooperated with the U.S. Navy, especially in diving physiology and biomedical programs involving NOAA diving. Included have been programs to make saturation diving with nitrogen-oxygen mixtures more useful and to support several Navy diving developments such as bubble detectors, subminiature decompression meters, and a portable recompression chamber. NOAA has reached an agreement with the Federal Aviation Agency (FAA) whereby FAA doctors give diving physical examinations to NOAA divers using NOAA medical forms. A Medical Review Board has been established to review all specialized medical aspects related to NOAA diving. NOAA has been working also with the Coast Guard and the National Institute of Occupational Safety and Health in developing information on fatal scuba diving accidents and establishing criteria and standards for diving safety. MUS&T has also developed standards, operational plans, and safety requirements for using research submersibles and is establishing standards for the use of recompression facilties, since three such facilities will be operating in 1976.

In addition, efforts related to diving have been sponsored by the NOAA Sea Grant program and included the support of projects in nine States. Also under Sea Grant is a program at six universities on diving safety research, human performance in the sea, undersea technician training, and underwater technology.

NOAA's sponsorship of diving research and use of available undersea technology and applied science

projects has produced much diving data and information; for example, the new diving tables for air-breathing excursions from habitats and lockout submersibles. These tables have permitted deeper dives for longer periods of time on air than previously possible. The results of these efforts are beginning to be used in U.S. offshore oil operations.

The NOAA Diving Manual was published in 1975, providing in one book the latest information on diving for science and technology. It includes contributions from diving scientists, technologists, and other experts.

Studies on Underwater Fatalities

In a continuing study funded by NOAA and the Coast Guard, the University of Rhode Island had compiled in 1973 a list of diving accidents involving U.S. citizens, using a clipping service and queries to various Federal, State, and local agencies and to scuba divers and instructors in high-activity regions. Based on these and similar data acquired from 1970, 1971, and 1972, the MUS&T office of NOAA estimated for 1971–72 a 15–25% increase in diver population but a less than 2.6% increase in the number of fatalities. Thus the annual fatality rate appears to be decreasing.

In general, no large change in accident pattern was detected in 1973. The total of 147 fatal accidents (123 compressed air, 24 skin diving) is only slightly higher than 1971 and 1972 totals. Geographic distribution of fatalities is also similar to past years, with Florida and California accounting for almost half. Weather was found to contribute to about 25% of the accidents, and there were more Florida cave accidents in 1973. Fewer beginning divers were involved in accidents this year, and fewer of the accidents involved training. Most of the divers used the "buddy system," but buddy separation remained a serious problem. Several cases involved the failure of the victim to remain on the surface following a dive, his inability to help himself, or to notify his partner of his problem.

Of the 49 autopsies, most showed "drowning" as the cause of death. However, there were nine detected embolisms and six heart attacks in this group, suggesting that a third or more may have suffered an incapacitating injury at some point in their dives. No serious equipment problems were detected, and relatively few of the accidents were equipment caused.

Almost a quarter of the scuba group were involved in multiple accidents, 10 involving two victims and 1, three. The bulk of these were cave deaths, although two involved boats dragging their anchor offshore.

The pattern of skin diving deaths remains variable, although fewer skin divers use the buddy system. One skin diver was killed apparently by a great white shark off Baja California, Mexico.

Technology Studies, Development, and Transfer

Introduction

The purpose of the technology program is to review and establish technical criteria for civilian manned underwater activities; provide safe and versatile submersibles, undersea laboratories, and ancillary equipment in support of undersea operations; and to formulate safe and effective procedures for man to operate in the ocean environment.

During fiscal year 1975, three submersibles, two underwater laboratories, and one unmanned tethered vehicle were used on MUS&T projects. Under-

water facilities for these projects were selected from the existing inventory by competitive procurement. No new facility developments were needed to meet the technical requirements of these missions, but assessment of undersea platforms developed by industry and the Navy continued.

Also, the Federal civilian agencies' requirements for these facilities and their use, as recommended by the Interagency Committee on Marine Science and Engineering (ICMSE), are being coordinated in the MUS&T program. The MUS&T office is maintaining close liaison with the Navy to transfer technology from military to civil undersea applications.

This section covers MUS&T activities in the following five general areas during this period, including technology-oriented projects sponsored or cosponsored by NOAA.

- Diving technology and physiology
  - Doppler bubble detection
  - Portable, inflatable recompression chamber
  - Digital decompression computer
  - Bubble detector comparison tests
- Undersea habitats and laboratories
  - Status and utilization
  - *HYDROLAB* system
  - *HELGOLAND* system
- Research submersibles (status and utilization)
- Instrumentation
- Technology transfer

Diving Technology and Physiology

Doppler Bubble Detector

Principal investigator.—Dean Haugen, Applied Physics Laboratory (APL), University of Washington.

The presence of bubbles in the blood stream is thought to be a more sensitive indicator of possible decompression sickness than physical symptoms. Evidence indicates that bubbles have been detected prior to and even in the absence of decompression sickness symptoms. It is possible that such bubbles may be related to long-term diving illnesses such as aseptic bone necrosis. Since divers have different physiological reactions to decompression, a device to monitor bubbles in the blood stream may prove effective in evaluating decompression profiles.

An integrated, self-contained bubble detector operating on the Doppler frequency shift principle was developed by the Applied Physics Laboratory. This unit was used at *HYDROLAB* as an indicator of decompression sickness after excursions and during decompression. The *HYDROLAB* operating crew trained the diving teams in its use so that the bubble detector could become an integral part of the saturation missions. This use also gave the unit a tough field test that would not be possible otherwise.

During its use at *HYDROLAB,* the bubble detector monitored diving teams and showed no indication of bubbles in any of the divers. This was expected from the conservative decompression schedule used at *HYDROLAB*. However, this unit did prove its practicality for use in the field and in monitoring a wide variety of divers.

The bubble detector was used to monitor divers during the chamber verification dives of the deep-excursion decompression profiles developed for the Bahama Banks Research Program's SCORE mission. (The results of these dives are described in this report under "Marine Science and Applications.")

Portable Inflatable Recompression Chamber

Principal investigator.—Ron Seiple, Naval Undersea Center, Hawaii Laboratory.

A portable, inflatable recompression chamber is being developed at the Naval Undersea Center under the joint sponsorship of the Marine Corps, Navy, and NOAA. A prototype has been developed to prove the feasibility of the project, and U.S. Navy certification requirements have been established. The chamber is not intended to replace other portable recompression chambers, but to supplement them on vessels or wherever there is no room or facilities to operate them. The Marine Corps needs an easily operated emergency chamber to support its underwater swimmer training exercise in places that have no treatment facility. Lack of adequate facilities has severely curtailed their operations.

The recompression chamber consists of a cylindrical body manufactured from a Kevlar fiber-rubber composite. Kevlar is a new high-strength organic compound which has been used in applications from cables to bulletproof vests. The door of the chamber is a specially designed leakproof "zipper." The

chamber will withstand an internal pressure of 75 psi or the equivalent of 165 ft of seawater. When inflated it will measure 30 in. in diameter by 90 in. long, which will allow a medical attendant in the chamber with the patient. The entire chamber will pass through standard double-lock recompression chamber doors so that the patient can be directly transferred to a larger, more complete facility. When not in use, the chamber can be collapsed to fit into a 36×8×8-in. carrying container. The weight of the chamber will be approximately 50 lb. The chamber will use standard scuba tanks for its pressurization and life support. A high-efficiency recirculating device will circulate the chamber air through a CO_2 scrubber, allowing a single 72-ft^3 scuba tank to provide life support for approximately 1 hr.

Meetings have been held with the Navy to determine certification requirements and to decide upon a certifiable final design. As no procedures exist for this type of chamber, certification requirements are a considerable step in advancing the state-of-the-art and will serve as a guideline for future use of exotic materials in manned undersea systems. A certifiable design will be completed in fiscal year 1976, and fabrication of a number of units for testing purposes is expected after that.

Decompression Computer

Principal investigator.—Ron Seiple, Naval Undersea Center, Hawaii Laboratory.

A wrist-worn diver's digital decompression computer is being developed by the Naval Undersea Center's Hawaii Laboratory under a grant from NOAA. The computer is designed to monitor the diver's depth and dive time and give a continual display of his decompression status. A prototype was demonstrated early in fiscal year 1975. Plans are to produce a number of diver-worn units, to be ready for field testing and evaluation in fiscal year 1976.

The decompression computer consists of four principal electronic subsystems: A pressure transducer, an electronic "clock," a programmable read-only memory (PROM) storage, and a digital information display. The pressure transducer measures the diver's depth while the electronic clock monitors the diver's time. These two signals are used as inputs to the PROM. The PROMs have the mathematical model for inert gas absorption programmed into them. With the time and depth inputs the computer can calculate the diver's decompression status continuously, even in multidepth or repetitive dives not covered by the standard decompression tables. The readout on the computer consists of two digital light-emitting diode displays. One tells the diver the depth and the other the safe-ascent depth, the depth to which he can safely return with decompression. The unit can be converted for mixed gas diving by simply replacing the PROM with one programmed for the gas mixture used.

The computer can easily compute the gas absorbtion of seven different tissues, compared with present decompression meters that use three tissues for computation. These meters work by measuring the pressure of the gas as it diffuses through a tissue-simulating membrane. They are subject to error, especially if poorly maintained or handled roughly.

The unit was demonstrated in October 1974 to the Navy's Experimental Diving Unit and to MUS&T. Several simulated decompression dives were found to exactly match the standard decompression tables. Also, the unit was used to run a simulated, 3-day saturation mission using excursions that would be encountered during SCORE of the Bahama Banks Research project (SCORE is described under "Marine Science and Applications.")

The digital decompression computer represents a great advance in the use of electronics to monitor free-swimming divers.

Bubble Detector Comparison Tests

Two bubble detectors were used during the hyperbaric chamber verification of the decompression tables at Duke University for the SCORE mission. One was the APL detector that has been used at *HYDROLAB;* the other was a unit belonging to the Navy's Submarine Medical Center, New London, Conn. Both units were doppler type and used external chest probes placed in the vicinity of the pulmonary artery. Tape recording and listening capabilities were present on both units. Bubble detection with each unit was limited to the discrimination of the human operator. The APL unit had a second set of headphones so that the subject also could monitor his own signal.

Readings were taken on each diver with both units during the decompression following the 250- and 300-ft excursions and during the final decompression from the 60-ft saturation depth. Only one

mild case of decompression sickness was reported, and it could not be correlated with any bubble signals.

Positioning the doppler probe to get a good signal from every diver and high background noise were the two major problems encountered with both doppler units. The quality of the signal depends strongly on proper positioning of the probe, and the best position will vary from diver to diver. However, it appears that the signal is enhanced when a sitting diver bends forward at the waist or stands up and poor when the diver is supine. The cause of this is unknown.

The detection of bubbles relies upon the subjective analysis of the operator. Future work should be directed toward enhancing the signal-to-noise ratio to enable better detection of bubble-related signals.

Undersea Habitats and Laboratories

The status of available undersea habitats and laboratories, as of June 30, 1975, appears in table 1. Of these seven facilities *HYDROLAB* was utilized during fiscal year 1975. The *HELGOLAND* facility was used in a German-U.S. program.

HYDROLAB System

NOAA awarded a grant to the Perry Foundation, Riviera Beach, Fla., to support *HYDROLAB* during fiscal year 1975. The habitat (fig. 1) was refurbished by Perry in 1973 for improved operations. Its characteristics are:

Depth capability	100 ft
Size	8 ft diameter by 16 ft long
Volume	730 ft^3
Weight	134,000 lb
Number of divers accommodated	3–4

The habitat is supported via an umbilical cable to an unmanned surface life support boat providing the following:

7.5 kW, 100 V AC by diesel-electric generator
Compressed air supply
Potable water supply
Habitat vent hose
CB radio link to shore
Emergency battery power, 3-day supply

TABLE 1.—*Status of U.S. habitats and laboratories, June 1975*

Name	Owner	Operational depth (ft)	Status
EDALHAB	University of New Hampshire	45	Inactive. Last used in project FLARE, Florida, Jan.-Apr. 1972. Located ashore at Woods Hole.
HYDROLAB	Perry Foundation	50	Active. Used in Bahama Banks research program during fiscal year 1975. Located offshore at Freeport, Bahamas.
TEKTITE	General Electric	80	Inactive. Last used in 1970 *TEKTITE II* project in Virgin Islands. Located ashore at Philadelphia Navy Yard.
LA CHALUPA (PRINUL)[1]	Marine Resources Development Foundation.	100	First mission Nov. 1972. Inactive since June 1974, but available for use. Located offshore at Mayaguez, Puerto Rico.
AEGIR	Makai Range	550	Active. Currently being used for testing at dockside in Hawaii.
PORTALAB	University of Rhode Island	50	Inactive. Located at the university.
LAKELAB	University of Michigan	50	Tested in fiscal year 1973 in Lake Michigan.

[1] Puerto Rico International Underwater Laboratory.

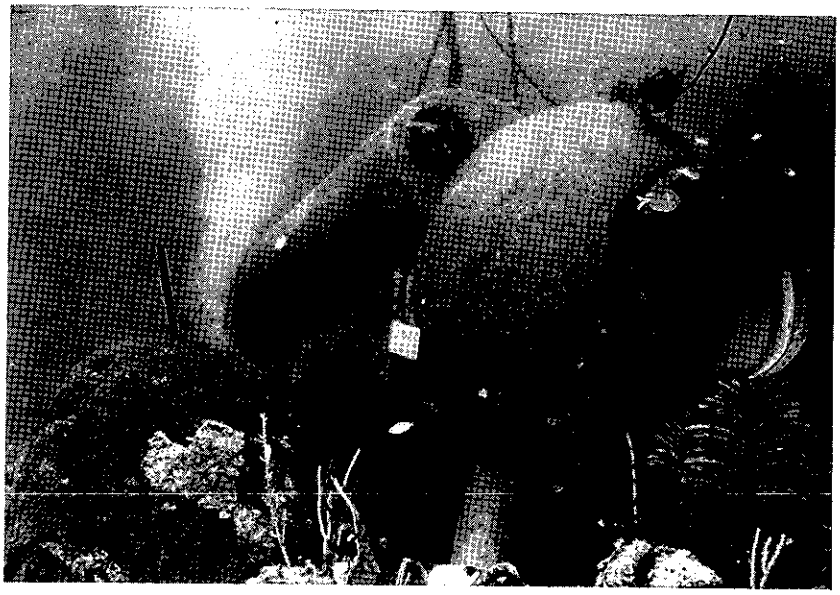


FIGURE 1.—Habitat *HYDROLAB* at Bahamas site.

The *HYDROLAB* was used for 21 missions off Freeport, Grand Bahama Island, during fiscal year 1975 and has compiled some impressive statistics. Since 1972 there have been 82 saturation missions involving 310 individuals. NOAA has supported all but 33 of these missions. These dives account for 1,680 days or over 40,320 man-hr spent in saturation during the facility's 50 months of use.

HELGOLAND System

The *HELGOLAND* underwater laboratory was conceived in 1966 by the Institute of Flight Medicine and the Biological Institute of Helgoland. The project was funded by the Ministry for Education and Science of the Federal Republic of Germany (FRG). The facility was designed and constructed in 9 months in 1968 and used in its first mission in 1969. It was overhauled and modernized in 1971 and operated in Eckenförde Harbor. In 1972, technological responsibility was transferred ot GKSS [2] which operated it at Helgoland in 1973.

The *HELGOLAND* system (fig. 2) consists of the underwater laboratory with its energy station buoy, the "Igloo," "Depot," a personnel transfer capsule (PTC), deck decompression chamber, and one-man rescue chamber. The "Igloo" is an independent underwater station containing compressed air bottles underwater communications, CO_2 scrubbers, lights, and an acoustic pinger where divers may take refuge for rest periods or emergency. The "Depot" (fig. 3) is an underwater station where divers can stand in a bubble of air, remove their mouthpieces, and converse. The one-man rescue chamber acts as a backup to the PTC and enables one person to be transferred to the surface under pressure and dry.

[2] Gesellschaft für Kernenergieverwertung in Schiffbau und Schiffahrt, Geesthacht, FRG.

Research Submersibles—Status and Utilization

Table 2 lists and shows the activities of 12 U.S.-owned, civilian-operated research submersibles capable of 600 ft or greater during the period July 1, 1974, to June 30, 1975. Beginning in fiscal year 1973, MUS&T continued its policy to lease only American Bureau of Shipping (ABS)-classed or Navy-certified submersibles for use in its projects. Of the 19 U.S. civilian-operated submersibles available for use, only 12 are ABS-classed or Navy-certified.

During fiscal year 1975, the MUS&T program utilized four submersibles—*NEKTON GAMMA*,

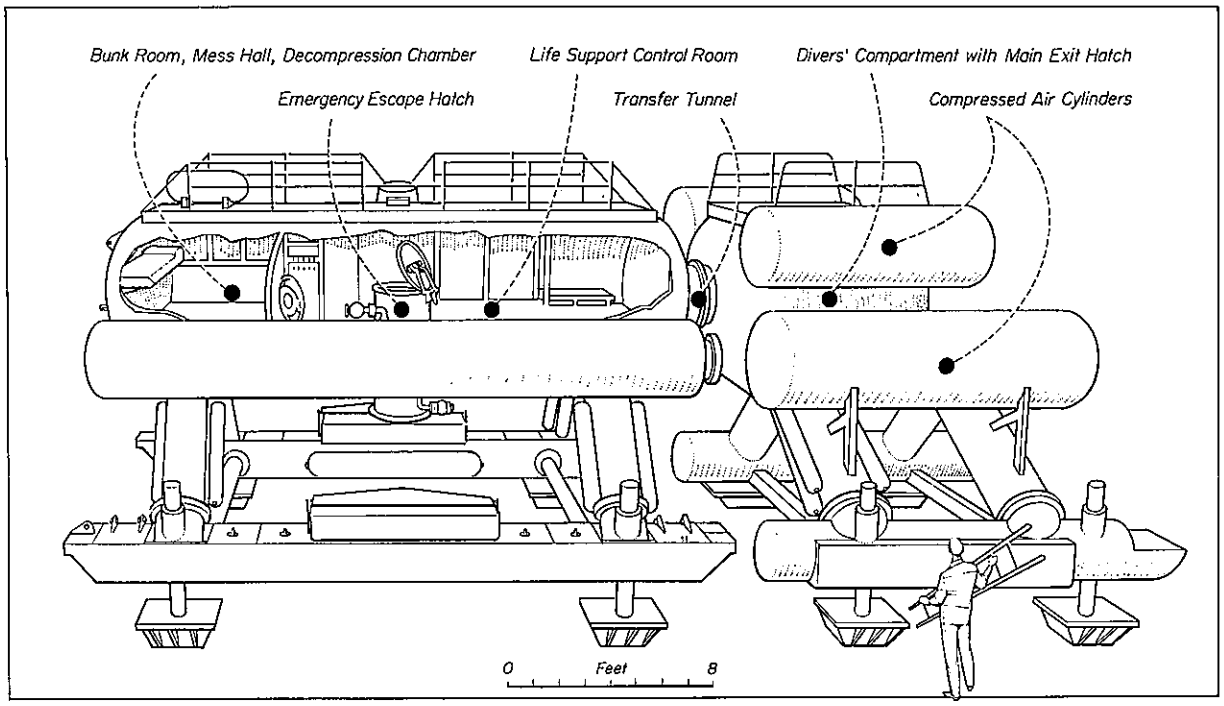


FIGURE 2.—Underwater laboratory *HELGOLAND*.

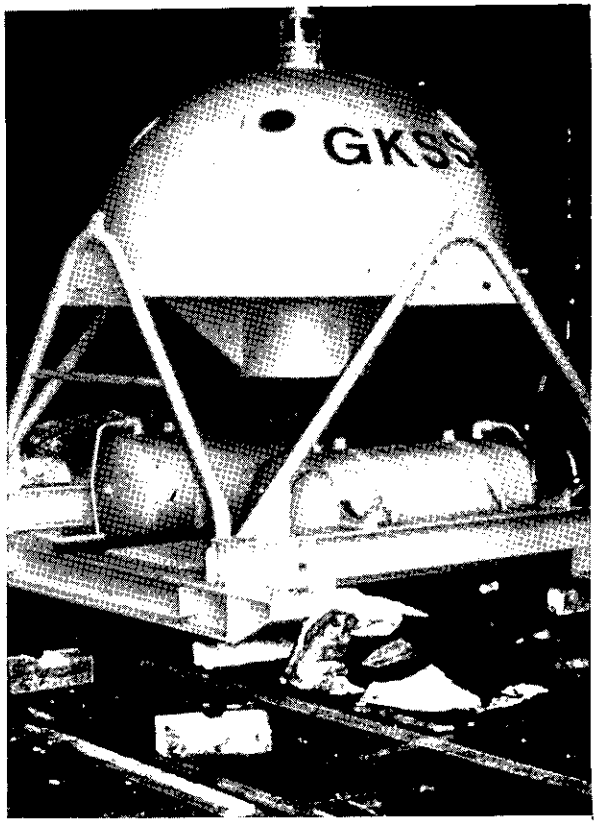


FIGURE 3.—*HELGOLAND's* "Depot."

ALVIN, JOHNSON SEA LINK I, and the *BEAVER MARK IV*. Their characteristics are included in table 3. The missions employing them are described under "Marine Science and Applications."

Instrumentation

Neutron Activation Analysis: Project IGUANA [3]

Program coordinator.—Joseph R. Vadus, NOAA/MUS&T.

Program advisor.—Kurt R. Stehling, NOAA/MUS&T.

Program participants.—William Forster, AEC (now ERDA); Richard W. Perkins, Ned A. Wogman, H. George Rieck, and John R. Kosorock of Battelle Pacific Northwest Laboratories.

Project IGUANA, which took place in Long Island Sound July 22–27, 1974, was a joint venture by NOAA, AEC, Geological Survey, and National Aeronautics and Space Administration (NASA) to evaluate the effectiveness of in-situ neutron activation and X-ray fluorescence in detecting heavy metal

[3] Intergovernmental Undersea Atomic Neutron Activation.

TABLE 2.—*Activities of U.S. civilian-operated submersibles, July 1, 1974, to June 30, 1975*

Submersible	Date	Mission	Location	No. of dives	Dive days	Depth
						Ft
NEKTON ALPHA	Sept. 1974	Relaunch and test	Catalina Island, Calif	6	1	225
Do	do	Geological	California Continental Shelf	5	2	250-480
Do	Oct. 1974	Backup	Gulf of Mexico			
Do	June 1975	Pipeline inspection	do			
NEKTON BETA	July-Oct. 1974.	do	do		56	100-360
Do	June 1975	do	do			
NEKTON GAMMA	May 1974	Salvage	Pt. Mugu, Calif	17	7	60-1,000
Do	July 1974	Lobster survey [1]	Gulf of Maine	39	14	100-1,000
Do	July-Aug. 1974.	Dump site survey [1]	New York, Delaware	24	5	80-190
Do	Aug.-Sept. 1974.	Backup	Gulf of Mexico			
Do	Oct. 1974	Dam inspection	Libby, Mont	2	1	40
Do	do	Pipeline inspection	Santa Barbara, Calif	13	4	100-225
Do	do	Geological	California Continental Shelf	24	6	120-350
Do	Apr. 1975	Training	San Diego, Calif	100	10	25-1,000
PC-14 (02)	June 1975	Test	Florida			600
PC-12 (01)	Mar. 1975	do	do			1.000
PC-12 (02)	Apr. 1975	do	do			1.000
JOHNSON SEA LINK I.[1]	July 1974-May 1975.	Scientific operations.	Caribbean	69	49	To 1,000
SNOOPER	July 1974	Promotional	Catalina Island, Calif	23	7	250
Do	Sept. 1974	Biological	Oxnard, Calif	13	4	200
STAR II	July 1974	Research and coral harvesting.	Hawaii	88	88	1,200
BEAVER MARK IV[1]	do	Evaluation of neutron techniques.	Western Long Island Sound		3	50-80
TS-1	July-Sept. 1974.	Pipeline inspection	North Sea			150-460
ALVIN	June 1974	Test	Woods Hole	1		70
Do	do	Test	Azores	1		2,540
Do	June-July 1974.	FAMOUS [1]	Mid-Atlantic Ridge	13		9,240
Do	July 1974	Inspection	AFAR Range, Azores	1		1,940
Do	Aug. 1974	FAMOUS [1]	Mid-Atlantic Ridge	4		9,030
Do	do	Inspection	do	1		6,150
Do	Aug.-Sept. 1974.	Geology	New England, seamounts	7		9,975
Do	Sept. 1974	Biology inspection [1]	Hudson Canyon dump sites	2		4,070
Do	Oct. 1974	Biology	South of Martha's Vineyard	1		5,910
Do	Mar. 1975	Test	Woods Hole	1		Tethered.
Do	Apr. 1975	Test and certification.	Bahamas, TOTO [2]	2		8,220
Do	do	Biology	do	4		6,700
Do	Apr.-May 1975.	Geology	do	10		9,770
Do	May 1975	Engineering	do	9		5,905
Do	do	Geology	Great Abaco, Bahamas	8		11,480
Do	do	Current meter recovery.	Off Charleston, S.C	2		328
Do	June 1975	Biology	Off Cape Hatteras, N.C	3		6,560
Do	June-July 1975.	Biology inspection [1]	Hudson Canyon	11		12,005

[1] NOAA-sponsored.
[2] Tongue of the ocean.

TABLE 3.—*Characteristics of U.S. submersibles utilized in MUS&T program, fiscal year 1975*

Submersible	Builder	Year launched	Operator and location	Depth	Certification or class	Speed-time sustainable		Energy source [2]		Life support	
						Cruise	Maximum			Normal	Maximum
				Ft		*Knot-hr*	*Knot-hr*	*V* [a]	*A-hr*	*Thousand hr*	*Thousand hr*
NEKTON GAMMA	General Oceanographics, Irvine, Calif.	1971	General Oceanographics, San Diego, Calif.	1,000	ABS	2/3.5	3.5/	24	190	.....	150
JOHNSON SEA LINK I. [1]	Aluminum Company of America (ALCOA).	1971	Harbor Branch Foundation, Ft. Pierce, Fla.	1,000	do	1/10	2/5	28	1,200	16	480
BEAVER MARK IV [1]	North American Rockwell.	1968	International Underwater Contractors, City Island, N.Y.	2,700	do	2.5/8	5/5	64 28	250 260	120	144
ALVIN	General Mills Inc.	1964	Woods Hole Oceanographic Institution, Woods Hole, Mass.	12,000	USN	1/8	2/3	60 30	450 450	216	216

TABLE 3.—(Continued)

Submersible	Crew	Observers	Payload	Weight	Length	Beam	Height	Pressure hull		Hull material	Viewports/ Manipulators	
								Type	Size			
	No.	*No.*	*Lb*	*Lb*	*Ft*	*Ft*	*Ft*				*No.*	*No.*
NEKTON GAMMA	1	1	460	4,700	15	4	6	Cylinder	42×96 in.	Steel	17	1
JOHNSON SEA LINK I.[1]	1	3	1,200	21,000	23	8	11	Sphere; cylinder.	[4]66 in. 5×9 ft	Acrylic G 5456 Aluminum	4 4	1
BEAVER MARK IV [1]	2	3	2,000	34,000	25	8.5	9.5	Spheres (2)	[4]84 in. [4]65 in.	HY-100	12	2
ALVIN	1	2	1,500	32,000	23	8.5	12.5	Sphere	[4]7 ft	Titanium	4	1

[1] Lockout capability.
[2] Lead acid type.
[3] DC.
[4] Diameter.

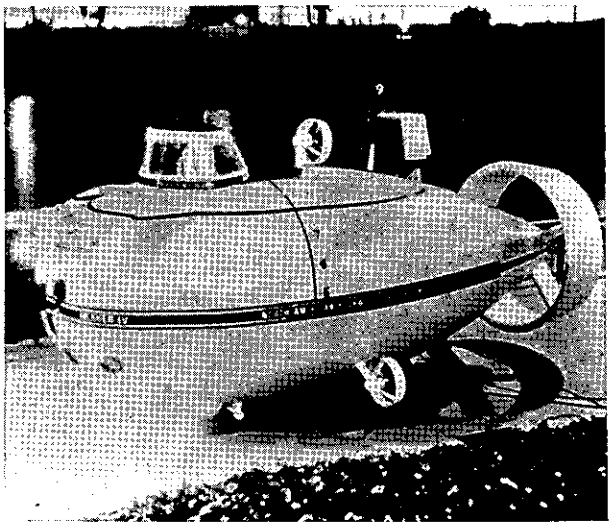


FIGURE 4.—Research submersible *BEAVER MARK IV*.

pollution in seafloor sediments. Instrumentation was on the *BEAVER MARK IV* submersible (fig. 4) and its support barge.

The objectives mainly were to evaluate the effectiveness of the two techniques rather than to detect and chart pollution levels in Long Island Sound. However, accurate location fixes were made so that the data obtained can be used in the future.

X-ray fluorescence and neutron activation techniques both employ a radiation source and a sensor (fig. 5), mounted on the submersible in these tests. With both techniques, heavy metals that may be on the seabed are irradiated by the energy source. Each metal then emits its own radiation signature.

The aft part of *BEAVER* held the sensor and cadmium-109 source for the X-ray fluorescence, and the submarine's two articulating arms were used for the neutron activation system. For the latter, a californium-252 source was secured to one arm, the sensor to the other, and both were remotely operated from inside the craft. The source was pressed briefly into the bottom sediment, then removed, and the sensor pressed into the same spot. Scientists in the submersible then recorded the signature response.

A passive detector, mounted externally beneath the submersible, measured the minute background radiation that is present everywhere in varying degrees.

Signals detected by the three external detectors were transmitted to a central processing system including minicomputer, displays, and data recording equipment in the aft sphere compartment of *BEAVER*.

Scientists from the Battelle Institute Northwest, Richland, Wash., under contract by the Atomic Energy Commission, performed the mission aboard the submersible. *BEAVER* was used at various locations in the Sound and to depths of about 100 ft. While the submersible was deployed from the support barge and operating on the seabed nearby, a second neutron activation system was deployed over the side from the barge. In this system the sensor is in the same housing and very close to the californium-252 source in order to detect gamma energy that is instantly emitted when the sample is activated.

A mobile van containing instrumentation for signal processing and analysis, computation, display, and data recording was used on the barge with the second neutron activation system. The data obtained from the barge will be compared with that obtained from the submersible, and both will be compared with data obtained from samples processed independently in a laboratory.

Results.—The primary result of this mission was the experience gained in using nuclear techniques for in-situ analysis. Several problems were encountered, and recommendations were made.

For example, the signature of the chlorine spectrum, which is obtained from seawater, can mask the spectrum of the desired material. The influence of the chlorine spectrum was investigated through statistical methods, but good resolution was difficult to obtain. There are several solutions to this problem. One is to change the geometry of the source and detector in such a way as to enhance the spectral statistics. Another would be to use a pulsed neutron generator and by proper training to increase the instrument's selectivity. The latter solution is being pursued by NASA and planned for use in fiscal year 1976.

Figure 5 shows the seabed probe system as it was installed on the *BEAVER MARK IV*. With this system, X-ray spectra such as that shown in figure 6 were observed. Instrumental problems and electrical limitations imposed by the submarine decreased the undersea probe resolution to 400 eV; however, subsequent work indicates that very good resolution is possible. Samples of the Long Island bottom sediments were analyzed also by the laboratory system, and the spectra comparisons shown in the lower portion of the figure. (See also table 4.) This comparison indicates that even this initially poor-resolution in-situ system measured chromium, iron, nickel, copper, bromine, arsenic, lead, zinc, zirconium, strontium, and rubidium at their ambient concentra-

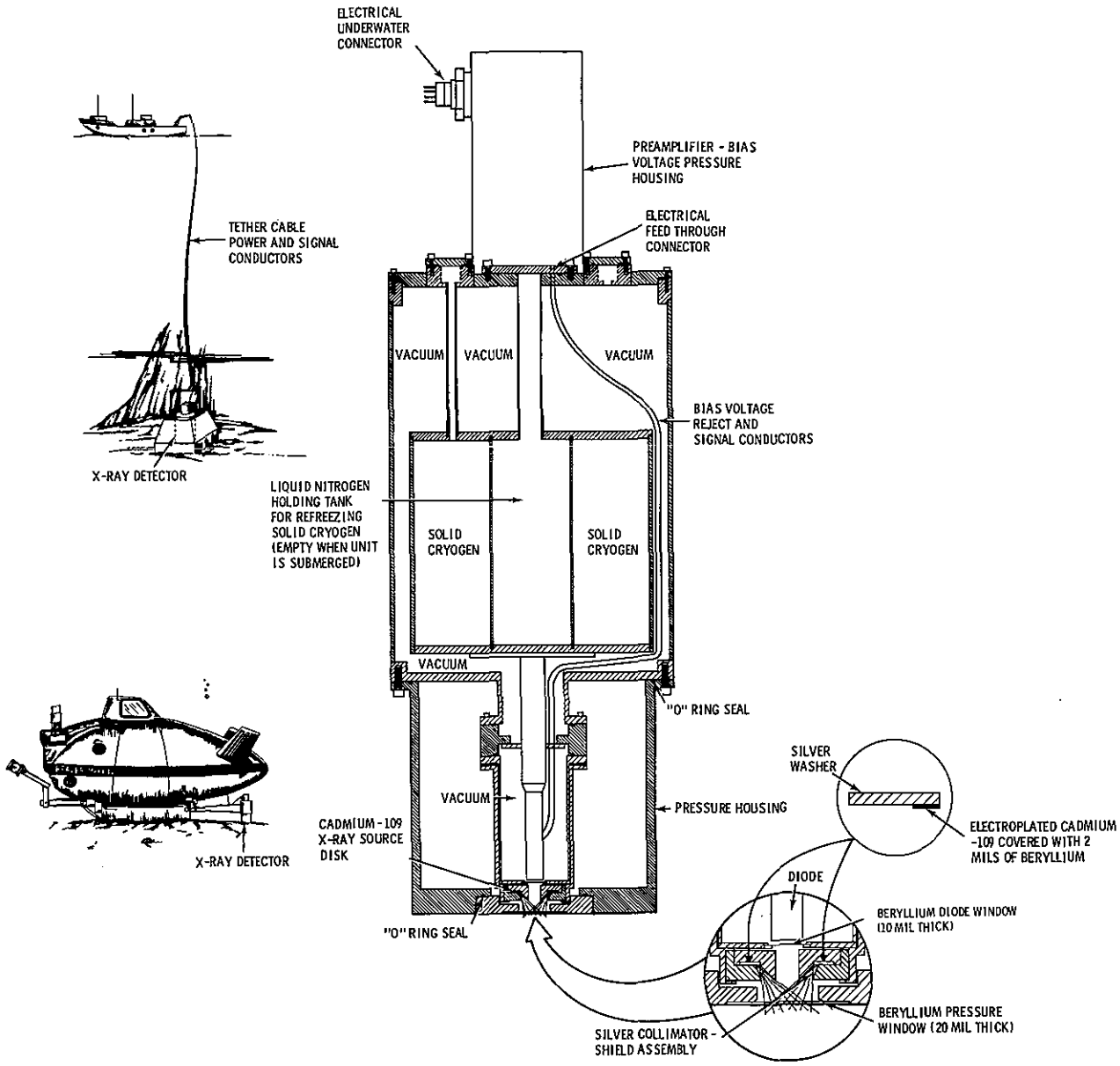


FIGURE 5.—In-situ X-ray fluorescence analyzer probe.

tions in polluted Long Island Sound sediments. For elements with X-ray energies above that of chromium, the laboratory and X-ray analysis gave the same elemental concentration within experimental error. The high temperatures of the submarine interior (94°F) interfered with the electronics, allowing only low-dead-time analyses to be used. Thus, only 10 μCi of cadmium-109 was used, requiring long counting periods of 48 min.

In general, the data in table 4 illustrates a fairly uniform concentration of pollutants in the Long Island Sound and in the areas studied. As shown in figure 7, the polluting elements can be measured almost as well with the in-situ system as with a laboratory-based system, if the concentrations are sufficient. Although the sedimentary material in Long Island Sound varied from colloidal suspensions at a water depth of 25 ft to a thick, pudding-type sediment at 100 ft, satisfactory analyses were possible with the in-situ instrument.

With the in-situ system, 10 samples per hour could be analyzed. With a 100μCi cadmium-109

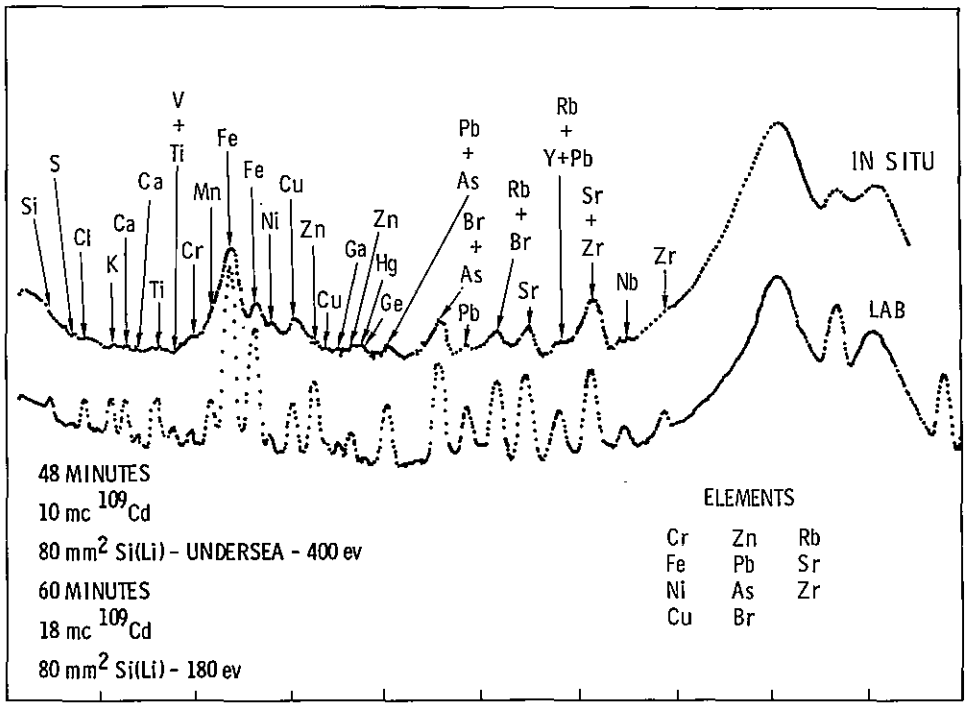


FIGURE 6.—X-ray fluorescence spectra from Long Island Sound, July 25, 1974.

source and a bottom time of 8 hr per day, 80 data points could be obtained for contour mapping of pollutant elements on the sea floor. With faster-response electronics, this performance could be improved.

Summary and conclusions.—This experiment demonstrated the feasibility and practicality of in-situ X-ray fluorescence analysis. The system can measure major pollutants in the top few millimetres of surface of the undisturbed sediments at concentrations down to 20–50 ppm, allowing real-time measurements within an actual marine system. Analysis of sediment surface pollutants is important in mapping the extent of elemental pollution and in determining concentrations at the sediment-seawater interface. It has been shown that in-situ pollutant analysis with this system can be used from both surface vessels and a submarine for rapid mapping of the elemental pollutant concentrations in fresh water and marine environments.

A similar approach could be employed on a roving, unmanned vehicle for deeper submergence studies; however, the thickness and strength of the required beryllium window will be the limiting factor. Changes in concentration within the sediment probably could be measured by modifying the probe so it could be pressed to increasing depths without excessively disturbing the sediments. Future development of the in-situ system will include all the developments noted here to produce a system with resolutions of better than 200 eV.

Technology Transfer

During fiscal year 1975, the MUS&T staff kept abreast of the latest undersea technology developments in the Navy and industry by attending briefings, review meetings, and symposia, reviewing reports and proposals, and continuing surveys and assessments of submersible systems and underwater laboratories and their ancillary support systems, diving equipment, physiology, instrumentation, and undersea power sources.

NOAA joined with the Navy and National Science Foundation in 1975 to support the operation of the *ALVIN* research submersible for 3 years as part of the University-National Oceanographic Laboratory System (UNOLS), thus making the *ALVIN* available to civilian scientists.

Despite considerable knowledge of undersea systems and equipment developed by the Navy, utilization of the technology has been limited by the small number and modest scale of MUS&T projects conducted in this period. Nevertheless, part of the technology program is to work closely with the Navy on

TABLE 4.—*Elemental concentrations of selected marine and freshwater sediments analyzed by X-ray fluorescence*

[Parts per million unless percent]

Element	Laboratory [1]			In situ		
	July 24	July 25	July 26	July 27 [1]	Sample 5 [2]	Sample 12 [3]
Si	28%	27%	18.5%	...	...	...
Cl	3.7%	8.9%	3.5%	...	...	...
K	2.3%	1.9%	1.8%	...	...	...
Ca	0.50%	0.83%	1.2%	...	2.3%	1.59%
Ti	0.40%	0.44%	0.49%	...	<0.02%	0.3%
Cr	190	230	450	400	...	...
Mn	760	1,190	820	...	1,800	...
Fe	4.7%	4.7%	6.9%	5%	22%	5.2%
Ni	100	94	100	100	...	...
Cu	300	290	200	200	1,500	250
Zn	530	430	315	300	1%	0.1%
Ga	20	<3	...	...	...	...
As	24	10	18	20	3.900	...
Br	150	300	150	200	<9	30
Rb	160	160	120	150	30	30
Sr	150	165	245	200	350	350
Y	50	45	53	...	200	220
Zr	230	190	215	200	150	190
Nb	23	18	27	20	10	15
Hg	<9	<9	<9	...	<10	<10
Pb	210	245	175	200	4,300	5,500

[1] From Long Island Sound.
[2] Analyzed in Puget Sound, Point Defiance, Wash.
[3] Analyzed in the ship canal, Lake Washington, Wash.

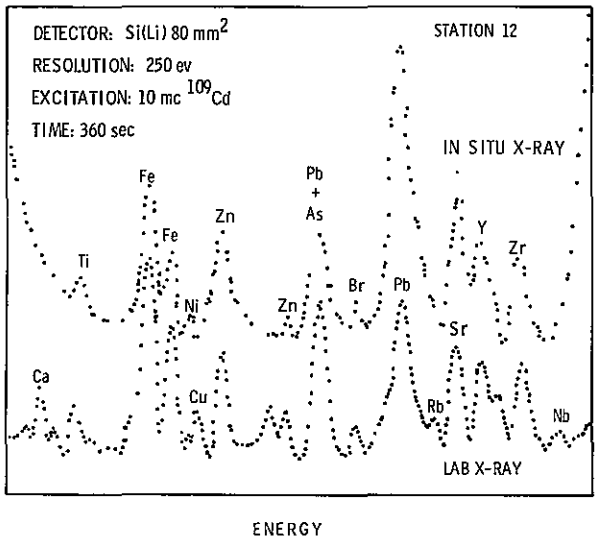


FIGURE 7.—Laboratory and in-situ X-ray fluorescence of Ship Canal sediments from Seattle, Wash.

behalf of the civilian agencies' undersea requirements and needs. Systems and equipment already developed by the Navy and industry will be used or adapted whenever possible.

Also, MUS&T has participated in undersea science and technology exchange programs with France and the Federal Republic of Germany. These programs have involved direct utilization by visiting scientists and engineer diving teams of equipment designed and built by the host country and have resulted in exchange of habitat systems technology and operational methods with Germany and seabed instrumentation with France. These international exchanges are expected to continue in fiscal year 1976.

Remote-Controlled Underwater Vehicle Usage in Fisheries Research

Principal investigators.—Richard Cooper, National Marine Fisheries Service; John Robinson, MUS&T, NOAA.

The remote-controlled, tethered, underwater television platform "Electric *SNOOPY*" was leased from the Naval Undersea Center for use in the 1974 National Marine Fisheries Service's herring survey. The herring survey takes place during September and October of each year off Gloucester, Mass., to study the herring spawning. In previous years, diver lockout and nonlockout submersibles have been used to supplement scuba divers for the in-situ investigations. This year *SNOOPY* was used to provide real time, in-situ observations and to decrease the cost of operating manned vehicles. Its principal use was to investigate various areas of bottom for sign of spawn before sending divers down. The depth at the site (130 ft) precluded any diver from making more than one 10-min dive per day. The results of the herring survey are described under "Marine Science and Applications." This section covers the operational evaluation of *SNOOPY*.

SNOOPY (fig. 8) is a small vehicle, 3 ft long by 2 ft wide by 1½ ft high, and weighing about 100 lb in air. Its tether consists of two ¼-in. coaxial cables that conduct power and control commands. The vehicle is powered by three ¼-horsepower DC motors. Two are used for propulsion and one to provide depth control. The vehicle's main body consists of two pressure-proof housings. One contains a closed-circuit TV camera; the other a color 8-mm movie camera and electronics. The vehicle has a depth capability of 1,500 ft and a maximum speed of 1½ knots. A surface TV monitor gives the operator visual reference, and a video tape recorder is used to record the TV signal. Direction of the vehicle is maintained with the aid of a small compass mounted in view of the TV camera.

Bad weather hindered the diving operations during the 3 weeks that *SNOOPY* was used on the herring mission. On such days, with swells reaching 12 ft, operations were impossible at the spawning site and so moved to protected waters for training exercises and evaluation of *SNOOPY*.

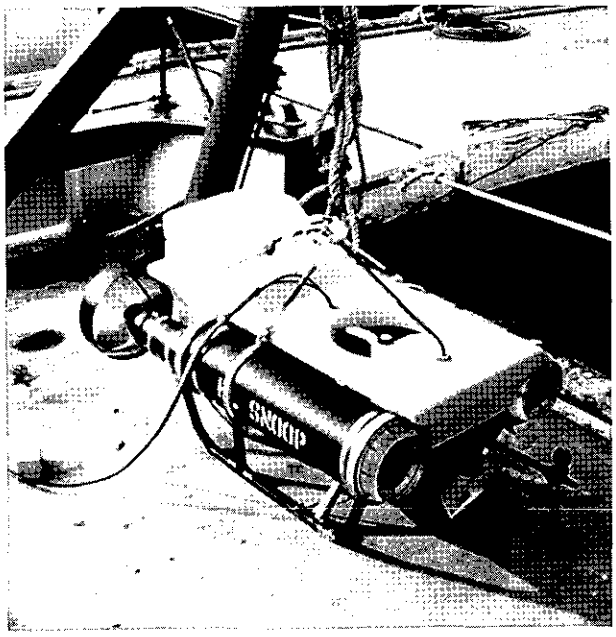


FIGURE 8.—*SNOOPY*, a remote-controlled, underwater TV platform.

Except for problems in locating the vehicle once submerged, *SNOOPY* was determined to be a valuable fisheries research tool. Its light weight and compact size allow it to be launched and retrieved from small vessels without sophisticated equipment. Its primary advantage is to enable scientists to look at the bottom before sending divers down, especially when the no-decompression limits are short or dives cannot be repeated. For shallow water, this type of vehicle can reduce diver time by eliminating unnecessary dives and placing the divers in the area of interest. For deep work requiring a manned submersible, the vehicle could be used to select dive sites and thus determine how expensive submersible time may best be utilized.

Marine Science and Applications

This section summarizes MUS&T-sponsored endeavors that dealt with such practical and scientific matters as ocean dumping analysis, environmental assessment, shellfish and other fish ecological surveys, and reef studies at various locations off the U.S. east coast. MUS&T supported or was involved in the following activities:

Megabenthic survey
Underwater radiation studies
Herring egg studies
Project FLARE
MESA cruise
Bahama Banks research program

Megabenthic Survey

Principal investigator.—Richard Cooper, National Marine Fisheries Service (NMFS), NOAA.

Associate investigators.—John Culliney, Harvard University; Theodore Loder, University of New Hampshire; Lance Stewart, University of Connecticut.

NOAA MUS&T liaison.—Lt. Comdr. L. Bussey.

Dates.—July 11–29, 1974.

Facilities used.—Support vessel *ATLANTIC TWIN* and submersible *NEKTON GAMMA*.

Purpose of survey.—To observe, photograph, and assess by direct observation the megabenthic faunal complex associated with selected Continental Shelf submarine canyons. To assess similarly the species distribution and ecology at selected sites in the area of Georges Shoals. A secondary objective was emplacement of duplicate racks of wood and tile test panels (marine boring and fouling studies, Harvard University) and minibales of compacted solid refuse (marine degradation processes, University of New Hampshire). The survey was the second of a series designed to assess the distribution, abundance, and ecology of commercially important benthic species inhabiting the slope waters of the Continental Shelf submarine canyons.

Geographical Areas

The principal area of investigation was the southeastern margin of the New England Continental Shelf and specifically the heads and flanks of Veatch Canyon, Hydrographer Canyon, Oceanographer Canyon, Gilbert Canyon, Lydonia Canyon, and Corsair Canyon over the depth range 80–166 fathoms. Secondarily, scuba and submersible dives were executed at four sites in the area of Georges Shoals.

Submarine Operations

Thirty-nine submarine dives were made during the course of the cruise; 20 during the first part and 19 during the second part (fig. 9). Number of dives by canyon area were: Veatch—12, Hydrographer—5, Oceanographer—8, Corsair—4, Lydonia—6, and Gilbert—2.

Immediately prior to a given dive, a fathometer tracing was made over the proposed submarine transect to determine depth change and slope over the transect range. This strategy permitted launching the submersible at a point that would maximize the depth range covered and minimize long trips over the shoaler, low-gradient bottom. This predive operation worked well in most instances and permitted extensive survey of the canyon slope depths to the maximum depth capability (1,000 ft) of the submersible. Temperature profiles were established at each dive site from a thermistor thermometer readout during descent and ascent. On-bottom temperature, visibility, current speed and direction, and topographic features were recorded at touchdown level and subsequently at 100-ft depth intervals. Meanwhile, the observer and pilot directed the dive transect to permit the most photographic

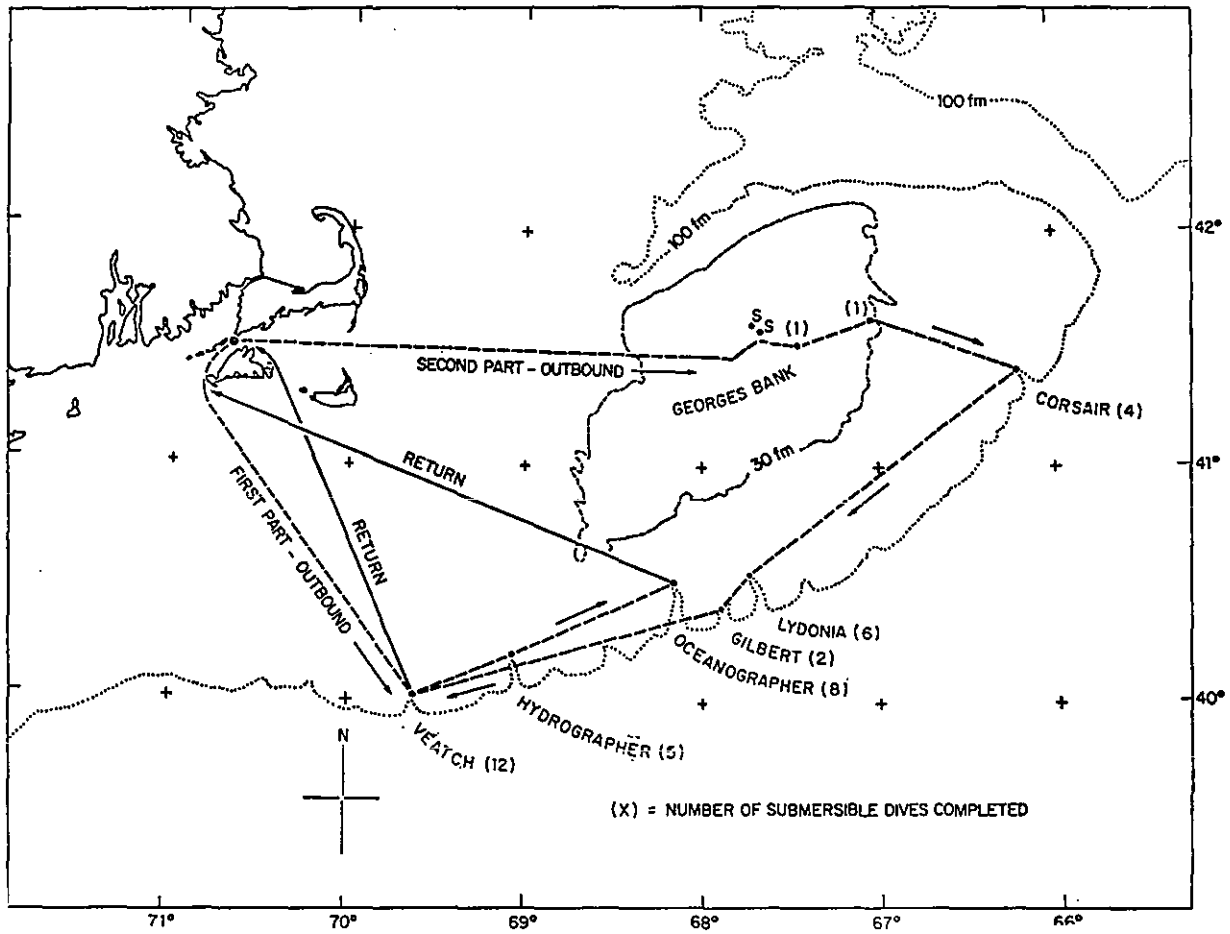


FIGURE 9.—Cruise tracks of the *NEKTON GAMMA* submersible and *ATLANTIC TWIN* for the 1974 megabenthic survey.

and video documentation of faunal arrays, behavior, and species interactions. Further observations of species counts, topographic features, and allied information were recorded on audio tape.

Georges Shoals Operations

Operations at Georges Shoals and Georges Bank dive sites (10–30 fathoms) were intended to assess distribution and behavior of expected aggregations of adult lobsters. Dives were planned at locations where commercial draggers had made significant catches of tagged lobsters released during the period 1968–71 along the edge (±100 fathoms) of the Continental Shelf between Oceanographer and Corsair Canyons.

Failure to locate the expected summertime concentrations of lobsters in these areas was partly because of marginal visibility and incapability of the submersible to maneuver within or even stem prevailing tidal currents in excess of 1 knot. Both submersible dives were uncontrolled sweeps over the bottom with only marginal visibility.

Two scuba dives were conducted in a drifting mode over the west flank of Georges Shoals at depths of 60–80 ft. The diver pairs trailed a small float from which their position was closely followed from a small tender boat. These dives were more controlled, but did not yield any sightings of lobsters. The adverse diving conditions in this area indicated that further activity would be unproductive; so the time was redirected toward submersible dives at Lydonia and Gilbert Canyons—hence extending the coverage from four to six canyons.

Results.—The submersible dives yielded an extensive body of qualitative and quantitative data on submarine canyon fauna, ecology, and geology. Documentation in the form of video tapes, audio tapes, and still photographs will provide a sound baseline

assessment, by canyon, from which to extrapolate and to plan future submersible activities in these areas more strategically. These data and observations will be developed into a final report following summation and analysis.

A highlight of the dive series was the discovery of additional "pueblo communities" at Veatch, Oceanographer, and Lydonia Canyons. These biologically rich areas appear to be slumped terminations of canyon-facing ridge ends which result in steep slopes and terraces of exposed clay substrate extensively burrowed by lobsters, cancer crabs, galatheid crabs, tilefish, cusk, ocean pout, conger eels, octopus, and several species of shrimp. These complex communities of burrowing crustacea and fishes result in far greater populations than in surrounding areas, where the overburden of sandy silt maintains itself in relatively low-gradient slopes. These slopes, over a short term, are relatively unstable bottoms that preclude buildup of high population densities so strikingly evident in the "pueblo" sites.

Significant resident populations of lobsters were seen at Veatch, Hydrographer, Oceanographer, and Lydonia Canyons. Lobster pot trawls were abundantly distributed about the heads and flanks of these canyons. The traps and connecting groundlines were often encountered during the course of dives. Many "ghost traps" were seen, with most being degraded beyond the point of effective fishing or holding and having become artificial habitats in that lobsters, cancer crabs, conger eels, ocean pout, hakes, and lesser forms had burrowed beneath or beside the trap remains. Lobsters were also observed within, beneath, or beside all manner of artifacts including oil drums, paint buckets, wads of trawl netting, and various lengths of trawl towing cable.

Red crabs, a potentially important commercial species, were seen in small numbers on one dive each at Lydonia Canyon and Gilbert Canyon near the 1,000-ft level. Considering the number of dives made and the area coverage, our depth capability appeared to barely overlap the upper depth distribution of red crabs, at least in July. These findings agree with the observations during our June 1973 diving at Veatch Canyon and the supporting trap catch data from that operation. Productive studies on behavior and distribution of red crabs must await availability of a deeper diving submersible such as *ALVIN*.

Underwater Radiation Studies

Principal investigators.—Peter Kotzer, Western Washington State College; Jere J. Lord, University of Washington.

Associate investigator.—Terrance Koss, University of Washington.

Dates.—April–June 1975.

Facilities and equipment used.—A marine interfacing glass sphere, which housed a Geiger "tray" counter and recording apparatus.

Location.—Puget Sound, 200 ft deep.

Objectives:

To design, construct, and test a remote underseas flux monitor of cosmic rays for measuring at one location the intensity of various radiations in order to correlate time-synchronized bursts of gravity waves, neutrinos, X-rays, or gamma rays as reported by other groups. And to provide a reference point or baseline for radiation flux variations and possible variations in activity or physiology of microbio-organisms.

Results:

Despite recorder and count-integrator circuit difficulties, several significant muon collisions were discerned and a sidereal correlation was established.

No secondary collision processes were observed, but anomalous rise of flux density with increasing depth was noted. This phenomena can be interpreted after further analysis supported by varying depth experiments.

Observations of Herring Egg Beds on Jeffreys Ledge

Principal investigator.—Richard Cooper, NMFS, NOAA.

Dates.—Sept. 15–Oct. 30, 1974.

Facilities used.—A surface ship, scuba gear, and remote-controlled, underwater TV platform *SNOOPY*.

Purpose.—The study of the spawning and early life history of the North Atlantic herring (*Clupea harengus harengus* L.).

Procedures:

—Locating spawning sites.
—Defining the spatial distribution of the beds.
—Describing the egg bed-stratum relationship.
—Defining the density of eggs and larvae by depth and substrate type.
—Determining the kinds and numbers of predators.
—Observing the hatching and immediate fate of the yolk sac larvae.
—Defining the timing and associated bottom water temperatures during spawning and hatching.
—Determining the relative success of hatching.

Diving Operations

Scuba operations totaled 25 man-dives at stations A, B, C, and D (fig. 10), all sites of herring spawning. Divers were not able to work beyond a depth of 42 m (23 fathoms) because of NOAA scuba diving regulations. Samples were collected at greater depths with Smith-McIntyre grabs. Initial indications of spawning came from adult herring and herring eggs in the stomachs of cod, bluefish, and pollock that were caught commercially at stations A–D with bottom-placed gill nets. Commercial gill nets are set at these locations each fall (September–November) in anticipation of the migrating predators.

Diver tasks were (1) photographic documentation of the substrate and attached organisms before and after spawning and larval hatching, (2) direct sampling of the substrate with attached eggs, (3) observing predation on the eggs, and (4) setting larval herring nets over the eggs to capture hatching larvae and assess success of hatching relative to substrate type, depth, and thickness of egg cover.

Surface Sampling

One hundred and fifty Smith-McIntyre grab samples were made at stations A–D during October to define the spatial distribution of two (station A and C–D) of the three egg beds. Approximately 15% of the grabs did not obtain a sufficient substrate sample because of a rock wedged between the blades of the grab. Repeated grabs were made at such stations until a decision on egg presence or absence could be made. Quantitative assessments of substrate type and egg abundance on a hard substrate were not possible with this type of grab.

Plankton Tows

Ten surface plankton tows with a 1-m net were made at station A, the egg bed location permitting the most detailed study by the divers, to determine the time of larval hatching and dispersal. Tows were between 1200 and 1800 hours for 15 min durations.

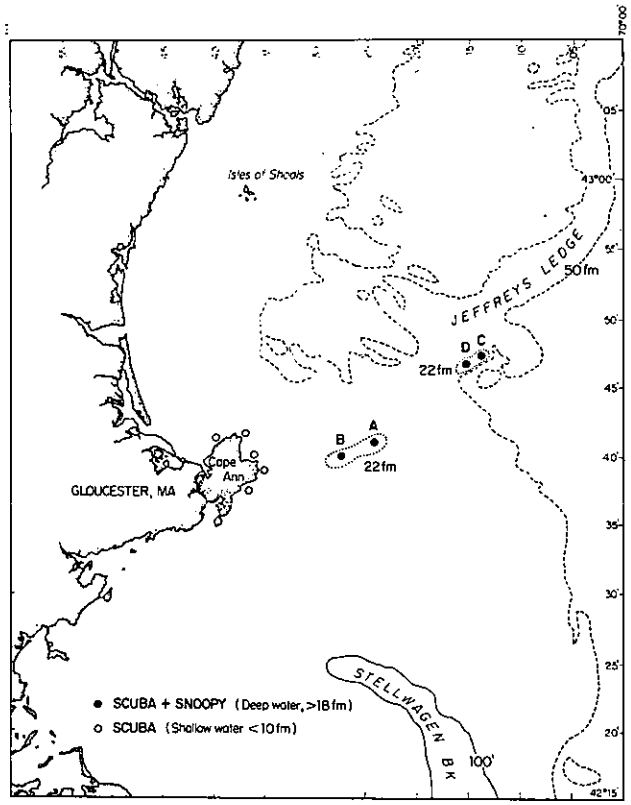


FIGURE 10.—Sites of herring egg bed observations.

Results:

General Characteristics of Spawning and Egg Bed

Table 5 presents the pertinent information describing the herring spawning and egg bed characteristics at three locations. From discussions with commercial fishermen (gill netters), spawning at stations A and B was from September 29 through October 3, when bottom water temperature was 9.6°C. (BT cast on October 2.) Bottom grab samples (October 6–12) indicated the egg bed at Station A was elliptical in shape, covering approximately 0.23 nm^2. Substrate type was boulders, rocks, and gravel from the crest of a submarine rise at 35 m to a depth of 50 m. The shape of the egg bed at Station B, which appeared to be discontinuous with the egg bed at station A, was not determined. Depth profiles at both stations are similar. Primary substrate at station B was boulders and rock up to 1.5 m in diameter.

TABLE 5.—*General characteristics of herring spawning and egg beds at three locations*

Spawning location (station)	Dates of spawning (1974)	Bottom water temperature at spawning	Substrate	Depth range of eggs	Area of egg bed and shape	Dates of hatching	Egg density	Predators (finfish)
		°C		*M*	*Nm*²		*No./m*²	
A	Sept. 29–Oct. 3	9.6	Boulder, rock, gravel; 70–80% *Ptilota serrata.*	35–50	0.23, elliptical	Oct. 6–10	161,000	Cunners, pollock, bluefish, cod, haddock, hake.
B	do		Boulder, rock, gravel; no *P. serrata.*			Oct. 6–10 (assumed).		
C–D	Oct. 23–25	9.5	Bedrock, boulder, rock, gravel, shell; 10% algal cover.	40–55	0.41, irregular	Nov. 1–3 (probable).		Cunners, pollock, cod, haddock.

Approximately 70% of the substrate at station A was covered with clumps of the red alga *Ptilota serrata.* This alga was not observed on the substrate at station B. The remainder of the substrate was encrusted with bryozoans, sponges, colonial hydrozoans, and coralline algae. Small rocks and gravel were relatively free of encrustation. No evidence of siltation was observed at either station. Observed bottom currents were from 0 to 1.0 knots.

Spawning at stations C and D occurred between October 23 and 25 when bottom water temperature was 9.5°C. Eggs were deposited from a depth of 40 m near the 37-m crest of a seamount, and down the 20°–40° slopes to the talus at the base (53 m) and beyond to 55 m. Substrate type ranged from bedrock with attached red alga *Ptilota serrata,* hydrozoans, and brachiopods with encrusting sponge at 37–43 m, boulders and rocks from 43 to 49 m, rocks and gravel from 49 to 53 m, and mixed fine gravel, coarse sand, and broken shell with attached polychaete worm tubes from 53 to 55 m. Beyond 55 m depth the substrate was fine sand with no evidence of herring eggs.

At stations C and D, as indicated from the grab samples, the rock-gravel substrate appeared to contain 90% or more of the eggs. The gravel-shell-coarse sand substrate ranked second in egg abundance; the lowest concentrations of eggs were on the bedrock-boulder and coarse sand substrates.

Larval hatching at station A began on October 6 and was complete by October 11. Direct observations and sampling by the dive team documented the presence of newly hatched larvae on the substrate on October 6 and the absence of all eggs, excluding the opaque dead eggs, by October 11. Hatching time is assumed to have been the same at station B. Grab samples of the substrate at station B on October 12 were free of eggs. Hatching time at stations C and D is not known.

Egg Bed-Substrate Relationship

The following discussion of egg-substrate relationship is based on the direct observations and sampling by divers within the 35–40-m depth interval at station A between October 6 and 12. At 35–40 m was a relatively uniform thickness of eggs with discontinuous clusters associated with clumps of red algae, *Ptilota serrata,* which covered about 70% of the ocean floor. Between 80% and 90% of the eggs were adhering to the red algae. Algal clumps were attached to the dorsal surface of all rocks 6 cm in diameter and larger, up to boulders 1.5 m in diame-

ter. A given algal branch held from one to three layers of eggs. The larger algal clumps, rising as much as 20 cm from the substrate, had the greater concentrations of eggs. Deposition on nonalgal surfaces of the boulders and rocks was discontinuous and one egg layer thick. The remaining 30% of the ocean bottom was characterized by small (less than 5 cm) barren rocks, gravel, and an occasional patch of coarse sand with a sparse occurrence of eggs. Overhangs and vertical substrate surfaces had very few attached eggs. It is not known whether the herring spawned selectively over the algal clumps or the algae was an egg trap for the spawn that was settling to and drifting over the bottom with the tidal current.

Large numbers of yolk sac larvae were discovered among the algal clumps during examination of the diver-collected substrate samples. These larvae were not visible while examining the substrate prior to collecting the sample.

Density of Eggs and Larvae

Table 6 presents data on egg and larval density, egg maturity stage, length of larvae and their condition in relation to absorption of the yolk sac, presence of prematurely hatched larvae, and area of substrate from which the eggs and larvae were sampled by the dive team at station A. Divers did not collect samples from the other stations. All samples were taken from a depth of 35–40 m. Differences in egg and larval densities were not apparent over this depth range. These samples, because of the method of collection discussed above, are considered to quantitatively and qualitatively represent actual egg and larval conditions on the spawning grounds. Unfortunately, the weather conditions and limited bottom time available to the divers at 34–40 m prevented the collecting of more substrate samples.

Visual examination of the rock surfaces and algal clumps suggested that the major hatching began on October 7 and 8 at station A (table 5). It appears that newly hatched larvae are retained for one to several days among the algal branches, during which time the yolk sac is partially absorbed. Three to five days after peak hatching the algal clusters were free of larvae and viable eggs. Egg and larval densities varied from 1.4 to 16.3 eggs per cm^2 and 0.9 to 19.5 larvae per cm^2 regardless of depth. Variability in density estimates is partly a function of date of sampling and size of rock or boulder obtained in the sample. The largest boulder had the largest clumps of algae and thus the greatest density of eggs and larvae. Density of eggs and larvae combined was from 3.7 to 22.3 per cm^2.

Predators

The fish predator most abundant on the egg bed at stations A, C, and D during daytime was the cunner, *Tautogolabrus adspersus.* Cunners were observed on several dives (October 6, 8, and 10) feeding upon clusters of eggs among the branches of algae.

The stomachs of approximately 1,000 cod, *Gadus callarias,* bluefish, *Pomatomus saltatrix,* and pollock, *Pollachias virens,* were examined by NMFS biologists and commercial gill netters. These fish were taken at stations A, B, C, and D in gill nets that fished overnight (September 28–October 10). Adult spawning herring were found in the stomachs of approximately 90% of the bluefish and pollock; eggs were found in 70% of the cod. Bluefish had up to eight adult herring in their stomachs. Cod fed primarily on the eggs; their stomachs were enlarged with clusters of red algae and attached eggs. Predators were from 30 to 65 cm (12–26 in.) in length.

Schools of cod and pollock were observed swimming over the egg bed during daytime but not observed feeding. The high catches of predators at night with partially decomposed adult herring and eggs in their stomachs suggest that predation on the eggs, and probably on the adults, is primarily at night.

Hatching Success

Rock samples taken on October 11 and 13 with 1,344 cm^2 of surface had 18 dead eggs. If the average density were 5.5 eggs/cm^2 on October 6, then 1,344 cm^2 would have contained about 7,392 attached eggs. Thus, hatching success would be greater than 99%. Since mortality from predation is not known, the 99% is an overestimate of hatching success. Divers noticed that less than 1% of the eggs on the substrate on October 6 and 8 (hatching period) were dead, as evinced by an opaque appearance.

Project FLARE (Follow-on)

This project was a continuing study that began in January 1972 to compare manmade and natural (coral) reefs.

Principal investigator.—Richard B. Stone, NOAA.

TABLE 6.—*Density and general condition of eggs and larvae sampled by divers from ocean bottom at station A*

Sampling date	Substrate area	No. of eggs	Egg density	Egg maturity stage [1]	No. of larvae	Larval density	Yolk sac presence	Length of larvae	Total eggs and larvae	Egg and larval density
	Cm²		*No./cm²*			*No./cm²*		*Mm*	*No.*	*No./cm²*
Oct. 6	145.1	900	6.2	Late 6	177	1.2	Complete	4–5	1,077	7.4
Do	38.7	111	2.9	do	33	0.9	do	4–5	144	3.7
Oct. 8	580.5	9,483	16.3	do	[3]3,491	6.0	Complete to partially absorbed.	5–6	12,974	22.3
Do	206.4	300	1.4	do	4,031	19.5	do	5–6	4,331	21.0
Do	464.4	987	2.2	do	3,674	7.9	do	5–6	4,661	10.0
Oct. 10	522.5	1,838	3.6	do	163	0.3	Partially absorbed	6–7	2,001	3.8
Oct. 11	484.0	10	0.1	[2]4–6	[2]9	0.02	50% absorbed; latest stage larvae found on substrate.	6–7	19	0.0
Oct. 13	860.0	8	0.00	[2]5–6	0	0.0			8	0.0

[1] Judged as 1–6. Fully mature is stage 6.
[2] Dead.
[3] Few aborted.

Associate investigators.—H. Pratt and R. Parker, NOAA; G. Davis, Everglades National Park.

Date.—August 1974.

Facilities and personnel used.—Five boats and 20 divers.

Location.—Biscayne National Monument, underwater reef area, near Miami, Fla.

Objective.—To compare the number of fishes, species composition, and behavior of fishes on an artificial and natural reef and determine the feasibility of using artificial reefs to increase the fish-carrying capacity near natural reefs.

Results.—The artificial reef was surrounded with a net, poisoned with rotenone, and removed from the bottom. Visual counts of fish collected after treatment with rotenone were compared with those on a nearby natural reef (fig. 11). Of prime importance in this sampling program were the survey techniques developed that compare special populations with the true resident population.

Visual counting, artificial reef	1,098
Collected by rotenone, artificial reef	1,493
Visual counting, natural reef	1,163

Diver counting techniques are considered reasonably accurate.

After 7 months the carrying capacity of the reef was established. After this, both the natural control reef and the artificial reef showed seasonal variations.

Recruitment on the artificial reef was primarily through juvenile fish and not migration of adults from neighboring reefs.

The final carrying capacity of the artificial reef was found to be 487 lb/acre, higher than reported in Eniwetok, Puerto Rico, Bermuda, and Hawaii and lower than reported for other reefs in Hawaii and the Virgin Islands.

Artificial reefs thus represent a reasonable method of increasing the fish production of otherwise sparse areas.

NEKTON GAMMA Cruise–MESA (Project support)

Principal investigator.—G. L. Freeland, Atlantic Oceanographic and Meteorological Laboratory (AOML), NOAA.

The *NEKTON GAMMA,* with the *ATLANTIC TWIN* as support vessel, was used by AOML and NMFS (Sandy Hook laboratory) personnel from July 30 to August 5, 1974, in making bottom observations in the New York Bight. Sediment grain size and composition and bottom microtopography were to be assessed as part of the Marine Ecosystem Analysis (MESA) project's environmental studies of the proposed midshelf interim alternative dumping areas. The benthic fauna was to be assessed in some MESA areas and in an area around Tiger Scarp (15 nautical miles southeast of the southern alternative dumping area) for the U.S. Geological Survey.

Because of support vessel equipment failure and inclement weather only two of the six diving days were suitable for diving, but nine dives were made: five in the southern alternative dumping area (MESA Area 2D2) and four in the Tiger Scarp area.

From the geological standpoint the dives materially assisted in evaluating and understanding bottom conditions in Area 2D2, which in turn aided our report to the MESA Project Office of our assessment of these areas for offshore dumping. We discovered early Holocene lagoonal clay in the axis of a deep trough which we did not find by bottom grab sampling or photography on previous cruises. This strongly supported previous ideas that there were strong bottom currents during severe storms that caused erosion of troughs and buildup of ridges. The dives made us vividly aware of the pristine nature of the bottom and confirmed our recommendation, adopted by the Environmental Research Laboratory (ERL), that the offshore dumping areas not be used.

Bahama Banks Research Program

The Bahama Banks research program has been centered around the Perry *HYDROLAB* habitat, an underwater manned facility located off the southern coast of Grand Bahama Island near Freeport.

NOAA/MUS&T has used the *HYDROLAB* to assess coral reef ecology, to establish the effects of pollutants on reef metabolism, to study the various species of extant fauna and flora, and to support marine scientist and diver training and verify the more rigorous diving excursion limits. From the *HYDROLAB,* underwater marine instrumentation and physiological instruments have been extensively tested and evaluated. Also, several interesting ex-

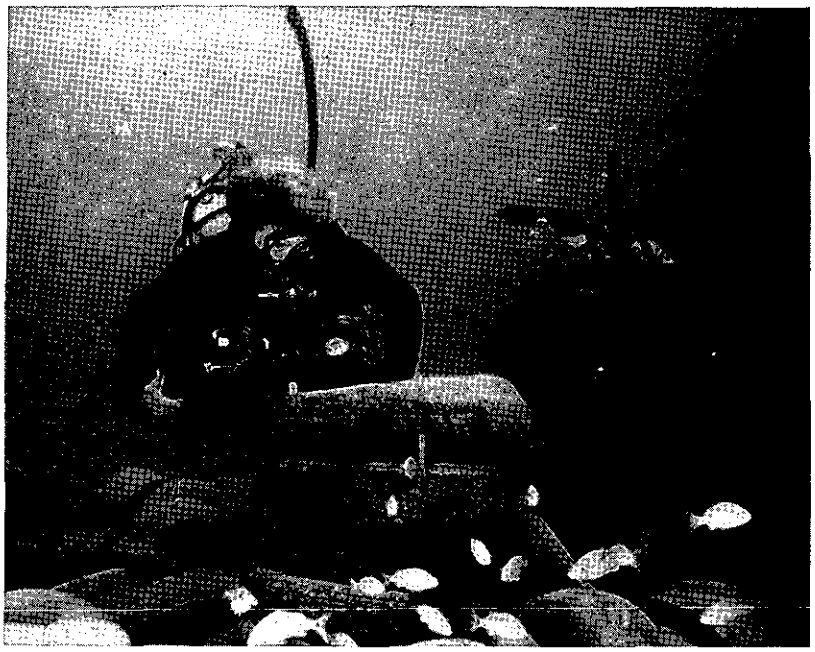


FIGURE 11.—A fish count on an artificial reef during FLARE.

periments on cosmic ray radiation intensity as a function of water depth have been conducted from and within the laboratory.

This underwater habitat, leased from the Perry Foundation, Riviera Beach, Fla., is unique in the Western Hemisphere if not the world as being in continuous operation since 1971. It has drawn international attention and participation and has enabled several hundred marine and other scientists from academia, industry, Federal and State governments, and various research institutions to gain useful experience and much new data while participating in the Bahama Banks research program.

Table 7 is a summary of *HYDROLAB* use in fiscal year 1975.

Mission 1

Principal investigator.—Sylvia A. Earle, Natural History Museum of Los Angeles County.

Associate investigators.—Thomas Hopkins and Deborah Reeck, University of West Florida; Ann Hurley, Scripps Institution of Oceanography.

Dates.—July 3–15, 1974.

Facilities used.—Habitat *HYDROLAB*.

Objectives:

—To obtain new information on flora composition at depths greater than 30 m (100 ft), including seasonal changes in abundance and diversity.

—To observe correlated activities of herbivorous fishes.

—To continue day-night tagging studies in order to measure the "fidelity" in the same animal.

—To test the strength of the homing drive by experimentally blocking crevices used by individual animals.

—To estimate "fidelity" by relocating day-night tags placed on *Asterophyton* sites during a *HYDROLAB* mission in January–February 1974.

—To confirm that the smaller mottled form is obligatory to the fronds of *Pterogorgia* and does not retreat to a crevice, but stays by day in the fronds wrapping them into a knot.

—To measure disc size and color in order to compare this population with a population from the Florida Middleground area where there are some strikingly different behaviorial patterns. Disc size may also relate to age.

—To observe crepuscular activity.

—To determine roost preference in large animals by taking inventory of selected sites.

—To first determine natural light levels correlated with activity, then to use artificial light to induce responses in situ.

Results:

Marine plants were collected from the intertidal zone to more than 15 m depth and from 15 to 62 m depth along a transect line from the *HYDROLAB* to the dropoff. At least 20 additional species of algae were obtained, and seasonal abundance of several species, especially *Microdictyon marinum,* noted.

Special collections were made of plants occurring in crevices and caves or other shaded areas in 15–25

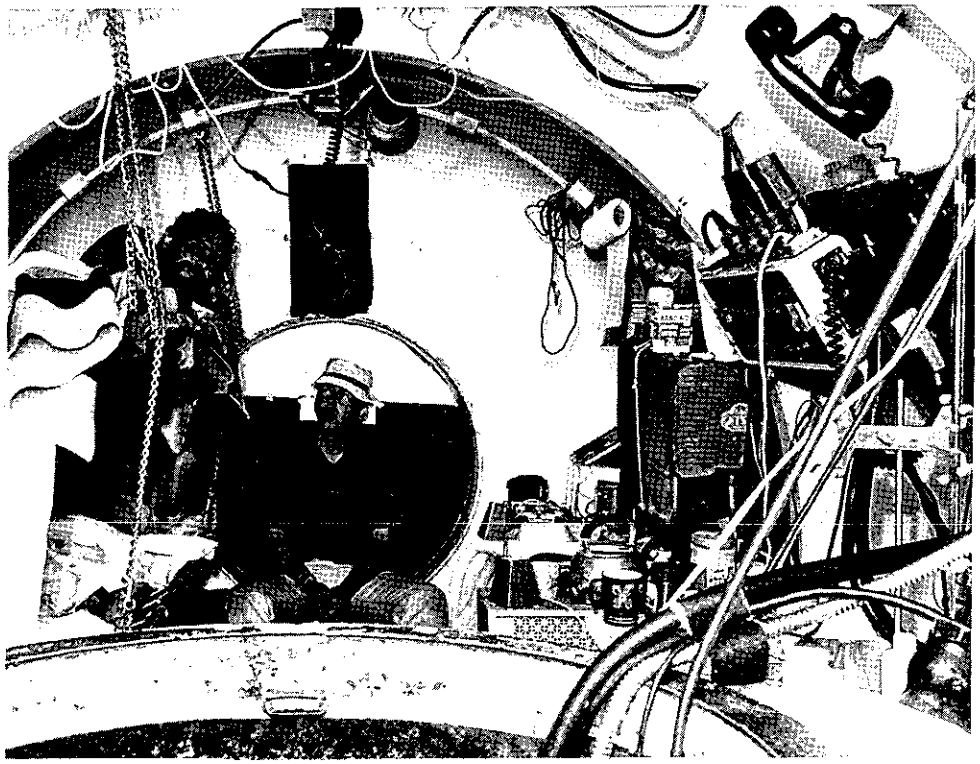


FIGURE 12.—Interior of *HYDROLAB* habitat. Entrance lock is in the foreground; viewing window in the rear.

m depth. Such plants are not common on the reef generally, but are so in deeper water, 40–60 m, in exposed areas. For some species, a distribution pattern appears correlated with low light intensity. The greatest diversity of plants appears to be on the reef itself, where grazers are common.

Of particular interest during this mission were collections from an open sand area in 30–60 m depth to a region of transition from a gradual slope to a steep escarpment. At least two species of algae that were conspicuous in previous collections from this area were not apparent during this mission. However, many of the new species found during the mission came from this area.

More than 20 herbivores were noted, and the habits of several prominent grazers were observed. Small schools of grazing parrotfishes and surgeonfishes were observed and photographed, and a list was made of plants that were being eaten. Day-night tagging information was obtained for over 75 individual animals and will permit a meaningful expression of distance traveled. Homing fidelity is now well established.

Three crevices that were occupied by basket starfishes by day were blocked. At all three the animals found their way over or through the blocking debris, showing a strong homing drive. Of 14 day-night crevices tagged during January and February 1974, 11 still were occupied. The three empty crevice stations had no *Asterophyton* within 1 m or more. Since these animals rarely move, it is likely that an outside force intervened.

There is no longer any doubt that the smaller mottled *Asterophyton* is obligatory (99%) to *Pterogorgia*. Questions remain concerning the identity of this form—whether it is the same species as the large *Asterophyton*. Previous assumptions about age and sex must now be examined in the laboratory.

Over 30 new disc measurements were recorded which, when added to previous data, should provide an adequate sample of each area.

Crepuscular activity was observed during one evening. The animals began to move at 2020 local time. All observed animals moved into place very quickly in a measured response. Animals at different locations (200 m apart) were moving virtually simultaneously. At 0612 local time the basket starfishes were in their crevices but still loose, and some still had an arm out. Again the uniformity of re-

TABLE 7.—*Utilization of HYDROLAB facility, fiscal year 1975*

Date	Mission	Subject	Depth	Duration	No. of divers	Man-days
			Ft	*Days*		
July 1974	1	Biology	45	8	4	32
August 1974	2	Training/physiology	45	3	4	12
Do	3	Training/biology	45	3	4	12
Do	4	do	45	3	4	12
Do	5	Training/fishery biology	45	3	4	12
Do	6	do	45	3	4	12
Do	7	Training/equipment test	45	3	4	12
Do	8	Training/oceanography/geology	45	3	4	12
Do	9	Oceanography	45	8	4	32
September 1974	10	Biology	45	8	4	32
Do	11	Physiology/biology	45	5	4	20
Do	12	do	45	5	4	20
Do	13	do	45	5	4	20
November 1974	14	Geology	45	7	3	21
Do	15	Cosmic radiation	45	2	3	6
Do	16	Biology	45	7	3	21
December 1974	17	do	45	4	4	16
Do	18	Fishery biology	45	7	3	21
January 1975	19	Instrument test and evaluation	45	7	3	21
Do	20	Fishery biology	45	7	2	14
April 1975	21	Oceanography/biology/geology/chemistry/training	60	[1] 20	[1] 16	[1] 80
Total				121	89	440

[1] Four missions, 5 days and four divers each mission.

sponse was striking. In contrast, the basket starfishes living on *Pterogorgia* definitely came out later and curled up earlier.

A significant amount of information on bathymetric zonation of scleractinian corals was obtained, including new information about coral growth zones of the escarpment from 33 to 62 m. The following species were obtained at the depths stated:

Agaricia lamarcki Milne Edwards & Haime, 1851. 62 m.

Agaricia undata (Ellis and Solander, 1786). 62 m.

Dichocoenia stokesi Milne Edwards & Haime, 1849. Uncommon. 40–46 m.

Helioseris cucullata (Ellis and Solander, 1786). Most common coral obtained from 40–46 m.

Madracis decactis (Lyman, 1857). Common in all depths sampled, 20–62 m.

Madracis formosa Wells, 1973. 40–46 m.

Meandrina meandrites f. *danai* Milne Edwards & Haime, 1849. 40–62 m.

Meandrina meandrites forma *meandrites* (Linne, 1758). 40–46 m.

Montastrea cavernosa (Linne, 1767). Uncommon. One unusual colony obtained from 62 m, July 11.

Scolymia lacera (Pallas, 1766). 20–62 m.

Scolymia cubensis (Milne Edwards and Haime, 1849). 20–62 m.

Stephanocoenia michelinii Milne Edwards and Haime, 1849. 40–46 m.

Several tentative generalizations can be made about the collections:

—*Helioseris cucullata* is the most common scleractinian at 40–46 m and the most frequently collected.

—*Agaricia lamarcki* appears to be the dominant species at 61–62 m.

—*Madracis decactis* is common in all depths sampled.

—At least two growth forms of *Meandrina meandrites* forma *meandrites* seem common. One resembles *Dendrogyra cylindricas* in depths shallower than 27 m, whereas in the escarpment region is a small stalked form.

In the shallow littoral area in the vicinity of the *HYDROLAB* few scleractinians were noted: *Side-*

rastrea radians, Porites astreoides, P. porites, P. divaricata, Favia fragum, and *Dichocoenia stokesi.* Octocorals were far more abundant in this area.

The behavior of the fairy basslet, *Gramma loreto,* was studied:

—This fish swims with its ventral aspect toward the substrate. When no substrate is present, it assumes a dorsal-up position. The purpose of observations was to determine the nature of the visual cue causing the animals to swim upside down, their characteristic position when close to coral heads. Experiments were performed underwater and in the shore-based laboratory to test whether a dorsal light response is sufficient to explain this position, and preliminary results suggest that it is. Further experiments will be performed along these lines at Scripps Institution of Oceanography.

—This fish lives in holes usually on the undersides of overhanging rock ledges. Observations indicate that each fish has a home territory that includes a few holes. When threatened, they quickly retreat to the nearest available hole. *Gramma* that enter another's territory are driven away. When a fish is moved from its home territory to a new location, it appears confused and agitated. It will often not use available holes when threatened. This makes the fish highly vulnerable, and several so moved were quickly eaten, usually by small groupers, soon after they were released. This occurred even though numerous resident *Gramma* quickly retreated when the grouper approached.

Squid behavior.—Catching squid at night was proved feasible in the vicinity of the external light of the *HYDROLAB*. The light must be left off until well after dark (2200). When it is then turned on, many small swimming invertebrates, fish larvae, and squid (*Loligo pealii* and *Sepiateutis* sp.) appear. The *Loligo* are usually in schools of 5–15 individuals. If the light is turned on too early, certain fish, predominantly bar jacks, appear, and the squid are either absent or perhaps eaten. Squid that were attracted to the light after dark were captured with a small hand-held dip net and placed in net-covered cages for transfer to the surface. On the support boat, the live squid were placed in large garbage cans filled with seawater and taken to the laboratory on shore for further observations.

Missions 2-8

Principal investigator.—R. E. Smith, State University System of Florida, Institute of Oceanography.

Dates.—July 30–August 20, 1974.

Facilities used.—Habitat *HYDROLAB*.

Objectives:

The training and guidance of graduate students in (a) the use of a saturation habitat and its support facilities and instrumentation, and (b) in-situ observing and measuring underwater in human physiology, invertebrate ecology, vertebrate ecology, ocean engineering, and physical oceanography. Six programs were conducted by seven teams.

Mission objectives and team composition were as follows:

Mission 2.—Objectives: Set up housekeeping and study the effect of hyperbaric air on the hematocrits of saturation divers. Team members: R. K. O'Bryan, MC, U.S. Navy; C. J. Russell, Slippery Rock State University, Pa.; J. McDonald, Scientists-in-the-Sea (SITS) staff; R. Clarke, Perry Foundation, Inc.

Mission 3.—Objectives: Characterize the commensal complex associated with the alga-like anemone *Lebrunia danae* and compare this characterization with the ringed anemone *Bartholomea annulata.* Team members: W. F. Herrnkind, G. Stanton, E. Conklin, Florida State University; S. Cooley, University of West Florida.

Mission 4.—Objectives: same as 3. Team members: W. F. Herrnkind, F. Walton, Florida State University; B. Carr and C. Bernier, University of West Florida.

Mission 5.—Objective: To study crepuscular activities of three species of Bahamian parrotfish. Team members: S. Earle, Los Angeles County Museum; L. Bullock, C. Smith, and I. Workman, University of West Florida.

Mission 6.—Objective: To test and evaluate an underwater hydraulic tool. Team members: A. J. Llewellyn, University of South Florida; M. Sheehan, Naval Coastal Systems Laboratory, Panama City, Fla.; A. Stollar and M. Muirhead, University of West Florida.

Mission 7.—Objective: To investigate behavioral reactions of vertebrates and invertebrates to a low-power laser beam. Team members: A. J. Llewellyn, University of South Florida; A. LaBonte, Miami-Dade Junior College; D. Rau and D. Vidal, U.S. Naval Academy.

Mission 8.—Objectives: To make circulation and hydrographic observations and a general geomorphological survey around the habitat, and to experiment with underwater survey techniques. Team members: W. W. Schroeder, Dauphin Island Sea Laboratory, University of Alabama; J. N. Brooks, U.S. Naval

Academy; J. W. Hicks, University of Florida; D. K. Hubbard, University of South Carolina.

Mission 2

Introduction.—Saturation diving in shallow underwater habitats has been shown to be useful in a variety of ocean-related projects. Although physiological studies in shallow habitats have not revealed any immediate life-threatening stresses on the human body, they have shown definite changes in a number of body systems. Of interest is the effect of hyperbaric air on the hematocrits of saturation divers.

During the *TEKTITE* underwater laboratory missions [4] no change in the hematocrit was noted during a 3-week exposure to pressure at 50 ft. In previous *HYDROLAB* studies, however, the blood hematocrits consistently fell significantly, with the lowest value recorded 6 hr after decompression. The most likely explanation for this discrepancy is that the breathing medium in *TEKTITE* was a nitrogen-oxygen mixture that provided a PO_2 similar to surface air (150 mm Hg), whereas that in *HYDROLAB* was compressed air resulting in a PO_2 of approximately 363 mm Hg. The intention in this study was to compare the effect on the hematocrit of compressed air and a mixture of 91% nitrogen-9% oxygen at a depth of 42 ft of seawater. Because of last minute difficulty in obtaining the necessary equipment, the mixed gas was not available; and thus the following report describes the effect of compressed air on the hematocrit of saturation divers.

Methods.—Control blood samples were drawn on the morning of the saturation dive. Additional samples were drawn at 6 hr before decompression, at predecompression, and 6 hr after decompression. All samples were placed in "vacutainer" tubes. The samples drawn in the habitat were vented with needles to allow expanding air to escape during the transport of the specimens to the surface. All samples were delivered to a local hospital for centrifugation and hematocrit determination.

Results.—The hematocrits for each diver were:

Diver	Predive	6 hr before decompression	Predecompression	6 hr after decompression
R.C.	41	39	41	45
J.R.	40	40	37	42
J.M.	46	44	42	50
R.O.	43	43	39	44

Three of the divers revealed a significantly decreased hematocrit during exposure to an atmosphere with a high partial pressure of oxygen. The average predive hematocrit was 42.5%, which dropped to 39.7% at predecompression. The 6-7 hr postdecompression average showed a significant increase to 45.2%.

Discussion.—The results support previous findings at *HYDROLAB* and with the paucity of data thus far are significant. The only finding at variance with earlier reports is the significant elevation of the hematocrit 6 hr after decompression. Dehydration of the divers during the long decompresion and 6 hr rest before the final sampling may lead to hemoconcentration, resulting in a falsely elevated hematocrit, but since fluid intake and urine output were not monitored, this couldn't be proved.

There may be something about a compressed air environment that produces a decrease in hematocrit. Perhaps the high partial pressure of oxygen decreases the need for red blood cells, and therefore some of them are taken out of the circulation. The mechanism for this is unknown, and only sophisticated experimentation, probably through the use of radioactive-labeled red blood cells, will lead to an answer.

Summary.—Exposure to a compressed air environment leads to a drop in the hematocrit of saturation divers. The high partial pressure of oxygen may be responsible, but has not been proved. A postdive elevation in hematocrit was probably the result of dehydration and hemoconcentration.

Missions 3–4

Introduction.—The only commonly recognized anemone-symbiont assemblage in the tropical western Atlantic shallow waters is the *Bartholomea annulata* complex. This includes primarily the cleaner shrimps *Periclimenes pedersoni* and *P. yucatanicus,* an alpheid *Alpheus armatus,* the red mysid *Heteromysis actinae,* and occasionally a spider crab *Mithrax commensalis,* the arrow crab *Stenorynchus seticornis,* the shrimp *Thor amboinensis,* and at least two other species of *Periclimenes, P. rathbunae* and *P. americanus.*

Such complexes were commonly observed in the *HYDROLAB* area. Also, the alga-like anemone, *Lebrunia danae,* frequently hosted some of the same symbionts, particularly two species of *Periclimenes, Thor amboinensis, Mithrax commensalis,* and *Stenorynchus seticornis,* as well as a blenny and an ophiuroid. A cursory examination of other anemones showed either no associated assemblages or infrequent presence of those anemones, as in the case of

[4] Off St. John's, Virgin Islands, 1968–69.

Condylactis sp. known to occasionally host some commensals.

The *Lebrunia danae* assemblage was characterized both by being previously undescribed and by the implications of possible competition between the two sympatric anemones and their respective roles in the local fish cleaning relationships.

Methods.—Aquanauts visually searched the substrate from depths of 10 m, just north of the *HYDROLAB,* southward along and adjacent to the transect line to a depth of approximately 40 m. Unsaturated divers also examined the inner reefs at 3–5 m depth. At each anemone site were recorded the depth, position relative to substrate topography (e.g., atop the reef, on the side of the ledge), the approximate size of the anemone, and the number and type of faunal associates. Each site was marked by a numbered, 5-cm diameter, styrofoam disc secured 1–2 m above the reef top by monofilament line. Anemones with particularly interesting characteristics were later photographed (both 35 mm still and 16 mm cine), collected, observed behaviorally, or all three.

The area of highest density was further examined by measuring the intersite distances with tape and compass in order to reconstruct the distribution pattern and estimate density. To compare the relative abundance of *Bartholomea annulata* and *Lebrunia danae,* their most populous areas were thoroughly searched, counting the occurrences of both species, their substrate positions, and number and type of commensals.

Lebrunia danae: Commensals and Distribution

The anemone *Lebrunia danae* was observed by McClendon (1911) in the Tortugas and described by Hargitt (1911) as *Credactis variablis.* McClendon called attention to the alga-like appearance of the bifurcated fronds and the anemone's diurnal nature. Eighteen of 21 individuals withdrew noticeably into their crevices as the sun set; 3 could not be located.

At Grand Bahama, the *Lebrunia danae* were on hard substrate throughout the depth range examined by the aquanauts; i.e., 10–40 m. This range included six reasonably distinct regions that intergrade from the *HYDROLAB* seaward: isolated rock clumps on sand plain (10–12 m), landward reef edge with concentrated clumps (12–15 m), reef center with the greatest surface area of rock clumps (15–20 m), seaward edge of the main reef (25 m), isolated clumps (25–30 m), and isolated small clumps on the sharp slope leading to the deep ledge (30–40 m). Commensals were observed with some *L. danae* in all regions except at 40 m, where the excursion range was limited and only two anemones were sighted.

Each commensal species maintained a distinct positional relationship with its anemone.

If the St. John back reef and canyon areas are considered most ecologically equivalent to the reef center at Grand Bahama, *Lebrunia danae* appears to occupy approximately the same "niche" as *Bartholomea annulata,* at least in respect to *Periclimenes* sp. This applies to number of shrimp per occupied anemone, density, and proportion of occupancy. *L. danae* occurs in the Virgin Islands, but apparently is not particularly common or the commensals are less inclined to it for habitation. Further study is needed to explain the comparative occurrence of each complex. Nevertheless, the *L. danae* complex is a prominent feature of the area and warrants attention as a second recognized western Atlantic anemone-commensal association.

Mission 5

Introduction.—Parrotfishes are common and conspicuous members of coral reef communities throughout the world. During earlier missions of the SITS project in 1974, habits of eight species were observed, and collections made of the plants the parrotfish feed upon in the vicinity of *HYDROLAB.*

Other observations indicated unusual crepuscular behavior for three parrotfish species—*Scarus coeruleus* (blue parrotfish), *S. coelestenus* (midnight parrotfish), and *S. guacamaia* (rainbow parrotfish). More than 100 large males of these three species have commonly been observed at all seasons, gathered at a site 200–300 m seaward of *HYDROLAB.* Many gathered at cleaning stations, sometimes lining up before cleaner shrimp or cleaner gobies. Most of them, when not being cleaned, swam rapidly in large circles around the area where they later retired. All emitted clouds of excreta, and many swam rapidly with mouths widely extended, sometimes as if challenging or charging.

The following objectives were outlined during the SITS mission 4:

—To observe crepuscular behavior of male parrotfish *Scarus coeruleus, S. guacamaia,* and *S. coelestinus.*

—To tag night dens and record incidence of "cocoons."

—To tag parrotfishes in their dens and on the following nights to see if they return to the same dens.

—To observe day activities, especially of tagged individuals; to monitor range, associates, and food habits.

—To gather plants on the reef, especially those obviously favored by parrotfish.

Methods.—Evening-night excursions were made from *HYDROLAB* on August 8 and 9. Daytime activity was recorded on August 8, 9, and 10, including two excursions to a depth of 130 ft on August 8 and 9. Fish tags were made with small hooks and numbered plastic ribbons.

Results.—A few parrotfishes were observed on the evening of August 8, and only three were found in their dens. The dens were marked.

At 0620 on August 9, six *Scarus coeruleus,* three *S. coelestinus,* and two *S. guacamaia* were observed, including two *S. coeruleus* being cleaned by cleaner gobies and one *S. coeruleus* being cleaned by cleaner shrimp. At 1845 only three *S. coeruleus* were observed, one being cleaned by cleaner gobies.

At 0620 on August 10, six *Scarus coeruleus,* seven *S. guacamaia,* and five *S. coelestinus* were observed, including one *S. coelestinus* being cleaned by cleaner shrimp.

Food Habits

Scarus coeruleus feed together or singly, but rarely mix with other parrotfish or other species. A group of five to seven stayed by day in the vicinity of the habitat and often moved onto the open sand, took mouthfuls of it, passed it through their gill covers, then moved on. *S. guacamaia* and *S. coelestinus* were seen by day feeding singly on the reef proper, concentrating on filamentous algae that grow on dead coral and other hard surfaces and on *microdictyon marinus,* a green alga especially abundant at this season.

Mission 6

Introduction.—A red beam neon laser with a 5-mW output was used in a preliminary study to determine the relative sensitivity of reef fish to the coherent light of a laser beam. All observations were taken from within the main window of *HYDROLAB*. Maximum range was 15–20 ft, depending on amount of planktonic matter in the sea column.

Method.—The laser box was held in both hands to play the beam back and forth across the eyes of individual fish. The beam was also held stationary to get the reaction of slower moving fish.

Discussion.—The intention in this preliminary study was not to establish definite conclusions but to show a trend in animal behavior. The data indicate that sensitivity varies greatly with ambient light intensity. Small reef dwelling fish were the most sensitive group, but their sensitivity decreased during daylight hours. Although few large fish were observed, the Nassau grouper was found to be highly sensitive to each irradiation during the evening hours. The only other large fish observed was the southern stingray. As with the smaller, fast-moving species (blue runners and yellowtail snappers), the results were indeterminate. Although the subject may have reacted, it was difficult to expose the individual to radiation for an extended period because of its normally erratic movement and speed.

Mission 7

Introduction.—Hydraulic tools are widely used by military divers for salvage and by divers in industry for oil platform and general underwater construction. The *HYDROLAB* operation presented a unique opportunity to evaluate underwater tools during a saturation mission. The economic and logistic value of saturation diving was recently recognized by both industry and the military.

Results.—The divers were equipped with a variety of tools, including wire rope and cutter, diver-powered hydraulic pump, stud guns, hydraulic impact wrench, NAVSEA lift bag, and ancillary equipment, and performed various tapping, reaming, drilling, cutting, and studding tasks. Operations were directed from the habitat through its large window.

All tools functioned well in the particular operation, but must be improved if they are to accommodate every possible underwater task. Drilling and wire cutting were done in the horizontal plane, but drill and pump design should be modified for drilling and cutting in the vertical plane. The problem is obvious in inner space—an apparent gravity-free environment. To drill and cut in a downward orientation, the diver needs to be heavily overweighted and able to transmit this weight to the tool (by a shoulder stock on diver and contour-shaped tool housing, for example). For drilling with a vertically oriented suspended test plate, some force opposite to the drill bit's direction of movement is needed. Overweighting the diver is not the solution. Perhaps a small hydraulically powered water jet can effectively provide the needed back pressure on the system by exerting a reacting force.

The self-contained hydraulic power source was found to be a great advantage, enabling the working diver to be independent of surface support.

Mission 8

Introduction.—The objectives of the mission were partly educational and reflected the engineering, geological, and oceanographic backgrounds of the students. They were to:

—Make circulation and hydrographic observations.

—Make a general geomorphological survey of the area (habitat to "wall").

—Experiment with underwater surveying techniques.

Results.—Circulation and hydrographic data were obtained by remote instrumentation, in-situ reading instrumentation, and dye studies.

Geological observations were successful and will be incorporated in the planning of a future study.

Underwater surveying techniques were attempted, but equipment failure and poor underwater visibility resulted in limited productivity.

Water movement in and out of Dill's "springs" was observed. Maximum flows were "in" 35 cm/sec and "out" 30 cm/sec.

Mission 9

Principal investigator.—William W. Schroeder, Assistant Professor of Marine Science, University of Alabama at Dauphin Island.

Dates.—Aug. 23–30 and Oct. 31–Nov. 7, 1974.

Facilities used.—Habitat *HYDROLAB.*

Objectives.—To document the circulation and characterize in terms of the basic hydrographic parameters the waters at the *HYDROLAB* site, using a shallow-water current and hydrographic monitoring system.

Results:

Aug. 23–30: The observed currents were a combination of a sustained west-southwest current and highly variable nondescript currents. The temperature of the water column was 29.1°–29.5°C, average 29.3°C; no thermocline. Salinity (conductivity) of the water column was 38.8–39.7 o/oo; average 39.0 o/oo. These data are considered greater than the maximum values expected for this area, but are presented here because there was no apparent instrument malfunction. Dissolved oxygen in the water column was 4.0–5.8 ppm.

Oct. 31–Nov. 7: The observed currents were the same as during the August part of the mission. Temperature of the water column was 26.2°–26.7°C, average 26.4°C; no thermocline. Salinity (conductivity) of the water column was 35.2–35.5 o/oo, average 35.4 o/oo. Dissolved oxygen was 5.3–6.2 ppm.

Mission 10

Principal investigator.—Donald B. Macurda, Jr., Museum of Paleontology, University of Michigan at Ann Arbor.

Associate investigator.—Gordon McBride, Department of Botany; James Porter, School of Natural Resources; Lee Sommers, Department of Atmospheric and Oceanic Sciences, University of Michigan.

Dates.—*September* 5–12, 1974.

Facilities used.—Habitat *HYDROLAB.*

Objectives:

—To determine the distribution of the crinoids from the depths of 40–150 ft, working across the Continental Shelf and down its upper part on Grand Bahama Island.

—To determine the photosynthesis and respiration of the coral *Montastrea cavernosa* and its photosynthetic algae, and to determine the principal food resources of this coral and when it actively fed.

—To determine the oxygen production and uptake in the algae *Riphocephalus, Halimeda,* and *Penecillus.*

—To determine the behavior of the tube worm *Spirobranchus* and organisms that might prey upon it.

Results:

The shallow-water crinoids of the Bahamas are part of a fauna which extends from the Bahamas southward to Brazil and westward to the coast of Central America. It reaches its greatest abundance in the southwest Caribbean and declines in diversity away from this point. Its distribution has been almost unknown because of the difficulties of dredge sampling the reef environment. There also has been very little information on the living habits of these animals and the exact sites on the reef that they occupy. But work over the last 2 years has established this fauna's distribution throughout the Caribbean. Grand Bahama Island represents the northernmost extension of the shallow-water Caribbean crinoids.

During a previous mission in *HYDROLAB,*[5] four species of crinoids were located at depths of 40–90 ft and their ecology investigated. The presence of these crinoids at greater depths throughout the West Indies was suggested by dives of short duration to

[5] See *HYDRO-LAB Journal* 2 (1): 9–24. 1973.

depths of 100–150 ft. A prime purpose of the present mission was to determine whether the animals were different in distribution and behavior at depths below 100 ft. Established were two primary points in bathymetric profile where crinoids reach their greatest abundance. One is on the outer edge of the middle reef at a depth of 60 ft, and the other is on the upper slope of the dropoff into the New Providence Channel at depths of 120–150 ft.

Crinoids often tend to congregate at breaks in slope, but this mission clearly established two zones of abundance both related to breaks in slope. This "edge effect," as it has been called, is the preference of the crinoids for places where, because of changes in slope, food supplies are apparently maximum. Five species of crinoids were present at these breaks in slope, but their relative abundance varied with depth. They were *Nemaster rubiginosa, N. discoidea, Analcidometra armata, Comactinia echinoptera* var *valida,* and *Ctenantedon kinziei.* The two species of *Nemaster* are current-avoiding crinoids which place themselves within the infrastructure of the reef. *A. armata* by contrast is current seeking and arrays itself on the Alcyonarians to take advantage of currents. *C. echinoptera* var *valida* is a nocturnal crinoid and feeds only at night. *C. kinziei* is also a cryptic crinoid, hiding within passages of the reef to take advantage of the currents.

The most abundant crinoid at the 60-ft break in slope is *Nemaster rubiginosa,* several times more abundant than at depths 70–80 ft. Two or three might be found occupying the same coral head. This animal is one of the most abundant in the West Indies and in the southern Caribbean shows a pronounced color difference in the arms. Instead of being orange with a black stripe as they are on Grand Bahama Island, they are almost jet black. A transition to the orange-armed variety can be seen in some of the other islands of the Bahamas, but nowhere is the dominance of the orange-armed form as certain as on Grand Bahama Island. There it was found also to extend to a depth of 150 ft, unusually deep for this species.

During the mission the comensal shrimp, *Paraclymenis meyeri,* was found on *Nemaster rubiginosa.* This is the first record of this species of shrimp north of the Antilles.

Nemaster discoidea was found more in the deeper parts of the reef at 60 ft deep, and at the second break in slope at 120–150 ft it was the most common crinoid. It was much less cryptic than in the shallower water, and the individuals were unusually large. They were attaching to whatever substrate would keep them from being covered by the talus that was gradually sliding into the deeper channel. There were several color varieties, which indicated an extremely favorable environment for their development. Their abundance at this particular depth, 120–150 ft, exceeds any other seen in the West Indies during the last 2 years.

Analcidometra was found to be more abundant than previously thought and in about equal numbers at both breaks in slope, at about 60 ft and 120–150 ft. These areas are obviously favorable for currents which provide food for *Analcidometra.* They were, however, less abundant than off the island of Andros, where tidal reversals are even more favorable.

Comactinia echinoptera var *valida* is a rare crinoid throughout the West Indies. Usually only two or three individuals are found at any one station. It occurred at both points in the break in slope; 120–150 ft was the deepest point yet observed for it in the West Indies.

The discovery of *Ctenantedon kinziei* (fig. 13, top left) climaxes a 2-year investigation of the distribution of this animal in the West Indies. It was originally discovered in 1970 in Curaçao and Colombia. During 1973–74, its range was extended northward to Belize and eastward to Barbados and Martinique. In 1973 it was discovered in Turks and Caicos. Its discovery on Grand Bahama Island represents a northward extension of its range of over 200 miles. It was found both at 60 ft and on the deeper profile at 130 ft where it was relatively abundant, clearly demonstrating that it is a common shallow-water West Indian crinoid. The difficulty in locating this animal is related to its deep position within the reef and its peak presence at depths of 100–150 ft.

The mechanism by which the crinoid's tube feet capture food has been in doubt. This mission established that each tube foot extends individually into the surrounding water mass. Without a mucus net between the tube feet, each is responsible for capture of the material immediately surrounding it—effected by the direct impingement of the food upon the tube feet and not upon a mucus web between. The feeding of the crinoids was apparently continuous on the slope break at 60 ft, as their guts contained food at whatever time they were sampled. In contrast, the deeper crinoids at 120–150 ft did not evince recent feeding during the period from 10:00 a.m. to 4:00 p.m. Their maximum food gathering must be at night.

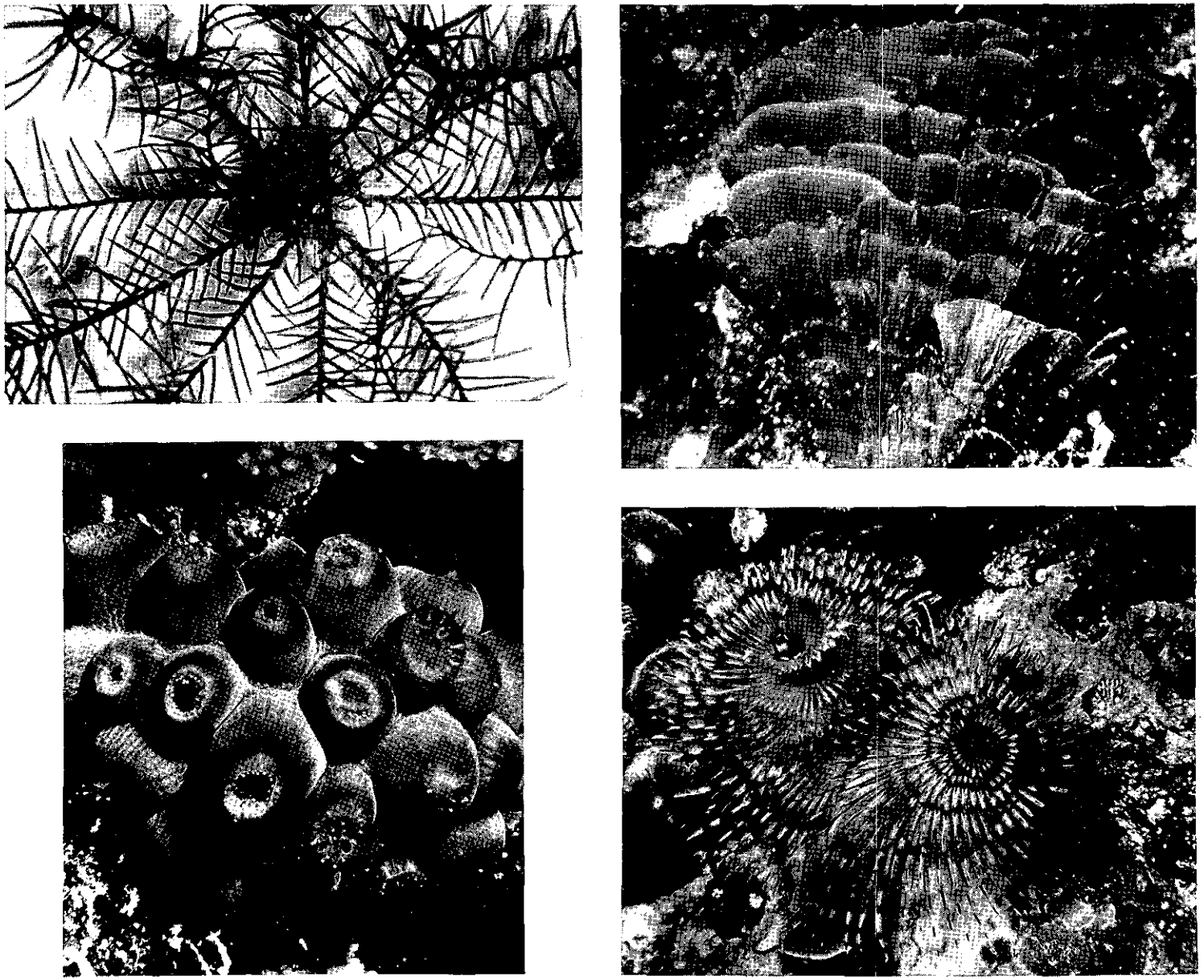


FIGURE 13.—(Top left) Crinoid *Ctenantedon kinziei;* (top right) alga *Riphocephalus phoenix;* (bottom left) coral *Montastrea cavernosa;* (bottom right) tube worm *Spirobranchus* sp.

During the saturation dive polarographic measurements were made of the photosynthetic oxygen uptake of three species of marine algae: *Penecillus capitatus, Halimeda tuna,* and *Riphocephalus phoenix* (fig. 13, top right). Each set of measurements was in triplicate and made over a 24-hr period in closed lucite chambers. A YSI BP54 oxygen meter with a probe attached to a 100-ft cord was used to measure oxygen concentration (fig. 14). All samples of algae used in the experiment were tagged, preserved, and returned to Ann Arbor for protein determinations.

Also, the productivity and metabolism of reef corals, particularly *Montastrea cavernosa* (fig. 13, lower left), and their plankton feeding capabilities were investigated. These studies were accompanied by quantitative plankton tows and quantitative samples of coral stomach contents. It may be possible to construct a total energy budget for populations of at least several Caribbean reef corals on the basis of this *HYDROLAB* mission. Reefs have been a center of controversy over how their intense local productivity is maintained in nutrient-poor tropical waters. Productivity is especially enigmatic with the apparent preponderance of animal rather than plant cover on the bottom. Based on this and previous *HYDROLAB* missions, the associated symbiotic algae in corals offers a partial explanation of the superficial dominance of animal coverage. Furthermore, the gut samples show a very tight recycling of nutrients and biomass on the reef in that over 85% by number and weight and over 90% by caloric value of the zooplankton captured by corals at night are resident on the reef. Thus, nutrient does not come from the open water, but grows and is consumed on the reef itself. Furthermore, most of the important (as food for coral) zooplankton are adults. The mobile pelagic stages are not so energetically significant as their resident adult. Peak feeding was indicated to occur at dusk and dawn during the vertical migratory period of the resident zooplankton off and back onto the reef.

The tube worm *Spirobranchus* (fig. 13, lower right) is one of the most common polychaete worms in the shallow marine environment. The two tentacles are usually found extending upward in a spiral from coral heads. Their exposed tissue would appear to be a natural food source for many of the reef fish. However, from extended observations of a small number of individuals both day and night, no fish or other organisms attempted to attack the tentacles. Various damselfish, brown chromis, wrasses, parrotfish, and groupers swam within a few centimetres of but with no effect on the worm. On several occasions the bicolored damselfish brushed the tentacles, yet never caused the worm to retract. This is in strong contrast to their behavior when approached by a diver, who will often cause their quick retraction. This may be partly relatable to the pressure wave created by the diver. When a worm was removed from its tube, its flesh was found highly attractive to the reef fish and would be consumed almost immediately. Only the body portion was attacked, however; the tentacles would not be eaten. Possibly there is some chemical toxin within the tentacles of the worm, and its brightly colored pattern of form might deter the reef fish.

Missions 11-13

Principal investigator.—Richard B. Philp, Professor, Department of Pharmacology, the University of Western Ontario, London, Ontario.

Associate investigators.—David Freeman, Iona Francey, and Brian Bishop, technologists, of the above department.

Date.—Sept. 13–Oct. 5, 1974.

Facilities used.—*HYDROLAB* underwater habitat and shore laboratory facilities, Freeport, Commonwealth of the Bahamas.

Objectives.—To determine whether a platelet-suppressive experimental drug identified as VK77-4CL2 (chemical name: 2-[(2-aminoethyl)amino]-4-morpholinothieno [3,2-d]phrimidine dihydrochloride) can prevent the postdecompression thrombocytopenia which has been observed following simulated diving in a dry, hyperbaric chamber and open-sea saturation diving; to determine whether such a drug can be taken safely in the hyperbaric environment; and to study hematological and blood chemical changes associated with the saturation diving milieu.

Procedure.—Twelve male divers, all in their early twenties, were saturated in groups of four for 5 days (including decompression time) in the *HYDROLAB* at approximate depth of 48 ft of seawater. Two members of each group took 300 mg of VK774 three times daily for 2 days before the dive, during the dive, and for 3 days thereafter. The other two took a placebo capsule identical in appearance to the active drug. Double-blind procedure was observed throughout the experiment. Blood samples (25 ml) were collected from each diver 48 hr, 24 hr, immediately predive, and once during the dive.

FIGURE 14.—Emplacing an oxygen probe in experimental chamber for coral production study.

Eight parameters were studied: red cell count, hemoglobin concentration, packed-cell volume, platelet counts, platelet aggregation, platelet adhesiveness, plasma levels of cholesterol and triglycerides, and plasma enzymes including glutamic oxaloacetic transaminase (GOT), creatine phosphokinase (CPK), lactic dehydrogenase (LDH), and alkaline phosphatase (ALP).

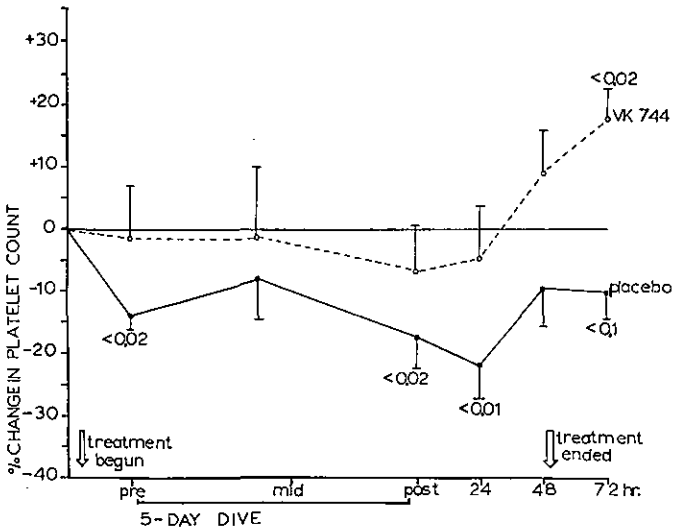
Results:

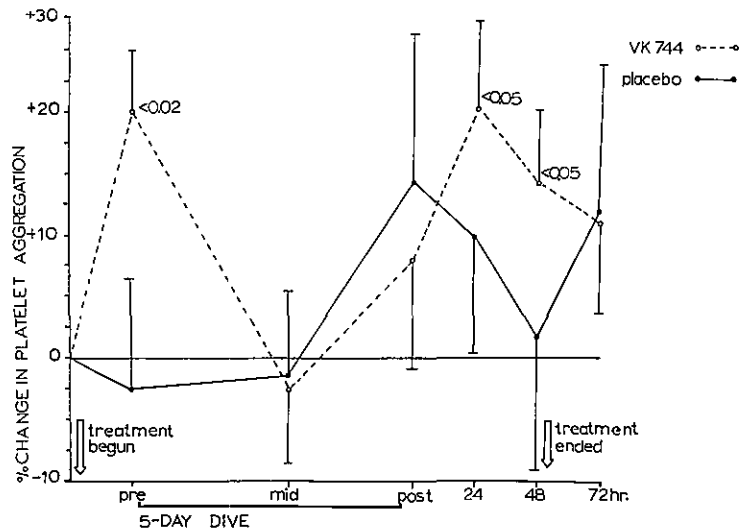
Except for several bouts of gastroenteritis and upper respiratory infections, no untoward effects of the medication were observed and no subject discontinued medication. Hematological parameters and blood chemistry values fell within normal ranges throughout the experiment, indicating no toxic manifestations of the drug treatment.

The control (placebo) group manifested a progressive fall in the circulating platelet count lasting for 48–72 hr postdecompression, with significant depressions immediately postdive and 24 hr postdive and statistically significant depression of platelet counts after decompression (fig. 15). In fact there was a statistically significant increase in circulating platelet counts 72 hr postdive. Neither group showed significant changes in the middive samples. Surprisingly, there was a statistically significant fall in circulating platelet count in the placebo group in the immediate, predive sample, but not in the treated group. No adequate explanation is available for this, but conceivably it could be related to increased catecholamine output from the adrenal glands resulting from understandable apprehension immediately before entering a foreign environment. The fact that the treated group did not demonstrate this platelet loss suggests that the drug may have protected their platelets from the catecholamines, which are known to aggregate platelets.

The platelet aggregation studies showed that the only statistically significant changes in aggregation were in the immediate predive sample (after 24 hr of drug treatment) and again at 24 and 48 hr postdive (fig. 15). Once again, this could indicate that the platelet population of the drug-treated group, while protected against removal from circulation of the drug, were more reactive because of increased catecholamine levels. The increased activity at 24 and 48 hr postdive is compatible with increased numbers of "young" platelets in the circulation as suggested by the significant increase in platelet count in this group. Young platelets are known to be more reactive to aggregation stimuli.

Tests showed that the treated group's platelet adhesiveness fell significantly in the predive samples, i.e., 24 hr after treatment (fig. 15). The placebo





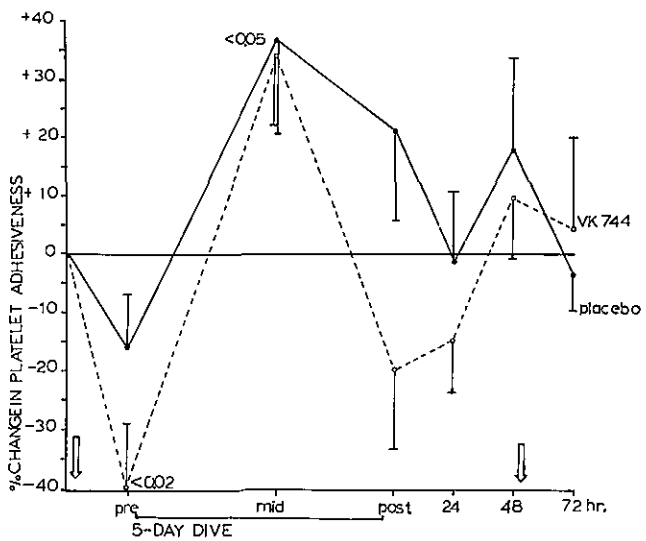


FIGURE 15.—Platelet variations in treated and control groups associated with saturation diving: Count, aggregation, and adhesiveness.

group showed a slight reduction at this point which was not statistically significant and which probably related to their concurrent loss of circulating platelets. Both groups showed statistically significant increases in adhesiveness in the middive samples. Whether this was an artifact related to the decompression of the blood samples (which occurred over 10–12 min) cannot be determined, but it seems unlikely that this factor would account for such a significant increase. Adhesiveness tended to be considerably lower in the treated group than in the placebo group in the immediate and 24-hr postdive samples, but the changes were not statistically significant.

Both groups displayed slight, progressive, postdive reductions in packed cell volume and hemoglobin concentration amounting to about a 5% loss toward the 48–72 hr samples, the difference being statistically significant ($p<0.05$). This may have been secondary to the removal of 200 ml of blood over a 10-day period. Cholesterol levels fell progressively in both groups of divers from the middive sample onward (fig. 16). The fall was greater in the treated group, achieving a 28% reduction by 72 hr postdive ($p<0.001$) compared with a 13% reduction in the placebo group ($p<0.005$). There were no noticeable dietary differences between the two groups, and the on-shore dietary habits of both groups were typical of North American eating patterns. It thus seems highly probable that this cholesterol loss was related to the saturation dive and the medication.

The above results generally confirm previous observations in an on-shore hyperbaric chamber and indicate that this platelet-suppressive drug can prevent postdecompression thrombocytopenia.[6]

Mission 14

Principal investigators.—Dennis K. Hubbard and Miles O. Hayes, University of South Carolina.

Associate investigators.—Duncan M. FitzGerald, Larry G. Ward, Albert C. Hine, Michael F. Stephen, and Jeffrey Yarus, University of South Carolina.

Dates.—Nov. 8–23, 1974.

Facility used.—*HYDROLAB* habitat.

Objectives:

—To construct a detailed bathymetric map of the bank margin off Bell Channel, Grand Bahama Island.

—To describe variations in morphologic parameters in the area (sediment character, changes in relic topography in the fore reef, delineation of environments, etc.).

—To investigate the subbottom character of the area.

—To determine the feasibility of the qualitative sediment tracer technique in carbonate areas and the amount of material being moved over the wall.

—To evaluate surveying techniques in an underwater environment.

These objectives were accomplished except for the last. Strong currents and low visibility prevented completion of this part of the study, and it will be discussed only briefly.

Results:

Bathymetry and Subbottom Studies

Data on the bottom and subbottom of the bank margin near *HYDROLAB* were collected using a Bludworth Model ES–130 recording fathometer and an EG&G Model 230 Uniboom subbottom profiling system. The Uniboom system and fathometer were operated simultaneously from a 42-ft boat. Separate fathometer profiles used to construct the bathymetric map near *HYDROLAB* were run from a smaller boat. The profiles were located using sextant fixes on landmarks surveyed by theodolite. From these data a bathymetric map of the sand surface was constructed, with variations in relic reef topography taken from the fathograms.

Variations in bank margin morphology were detected. This change in morphology is thought to be controlled by a large extant promontory. Apparently this promontory has been there throughout recent history and reflects itself in both the bottom and subbottom topography of the area.

Geomorphic Provinces

Variations in bottom character were determined using aerial photographs, fathometer profiles, and diver observations. Several specific geologic zones determined from this study included shoreface sands, a rock terrace, an inner rock ridge, a shallow reef, an inner sand flat, an outer sand flat, a deep fore reef, and a wall.

A thin carbonate sand cover 30–50 cm thick extends 20–50 m offshore from the beach. In some places where it is very thin, rock crops out on the beach face east of Bell Channel. In other places, it grades into thicker beach sands.

A shallow rock terrace extends approximately 1

[6] For a review of previous work in this area, see Philp, R. B.. 1974. A review of blood changes associated with compression-decompression: relationship to decompression sickness. *Undersea Biomedical Research* 1: 117–149.

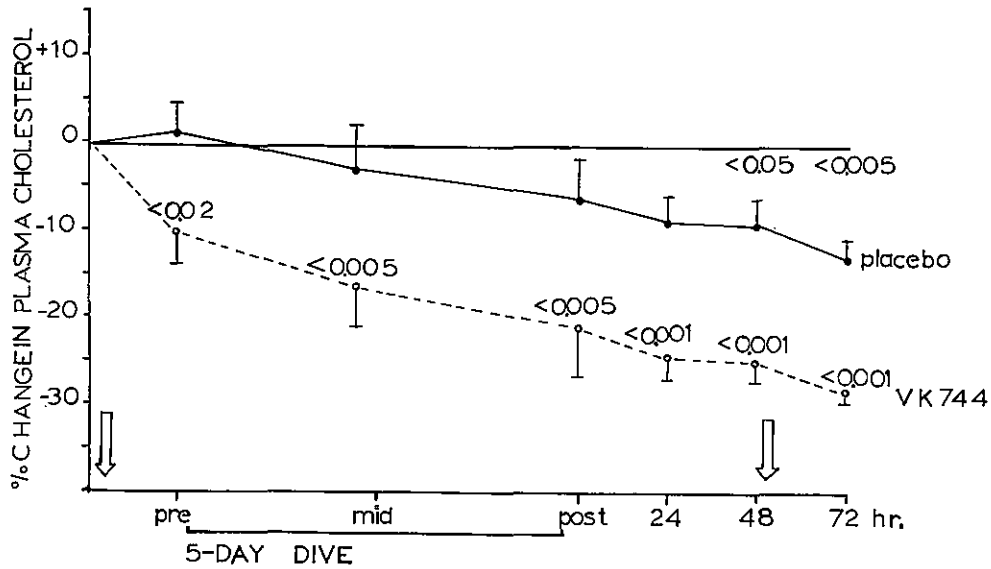


FIGURE 16.—Plasma cholesterol losses in treated and control groups during and following dive.

km offshore. In many places sediment cover is absent. Where sediment is present, it is bound up by thick algal mats.

Along most of the study area, a rock ridge with varying relief up to 2 m is located on the seaward edge of the rock terrace. The substrata is bedrock, which is highly bored and devoid of sediment.

The shallow or inner reef is located on a rock ridge like the one just described. The area is dominated by *Acropora palmata, A. cervicornis,* and a variety of "head" corals. This reef acts as a natural breakwater for the southerly exposed beaches during periods of wave attack.

Between the shallow reef and the fore reef, there is a gently seaward-sloping (slope = 1.65°) sand flat approximately 400 m wide. *HYDROLAB* is located on the seaward edge of this region. Mushroom-shaped rock outcrops dot the area. The interareas are covered by a thin sediment, in some places as little as 20 cm. The flat is crisscrossed by numerous joint systems along which fresh water once ran. At least one tidal spring has been observed along one of the joints.

An area 20 m landward of *HYDROLAB* was excavated with an airlift to expose and sample a contact between beach rock and old reef rock. The areas between adjacent mushroom-shaped outcrops were excavated to expose an apparent contact between two coral reef sequences. Both levels were sampled and are being dated to determine the age difference, if any, between the two levels.

A prototype tracing study attempted to qualitatively determine the amount of sediment moving through the area. The tracer was dyed and released at two sites.

Part of the dyed sand was placed 30 m west of *HYDROLAB* near the edge of the inner sand flat. This sand did not move significantly despite the high waves (2–3 m) throughout much of the mission. Bedforms were generated and sediment moved in an oscillatory motion, but net movement was small. The tracer patch remained almost intact during the period of observation. It appears, therefore, that except during severe storms, the sediment on the inner flat near the habitat is stable. Observations in shallower water did document the movement of sediment in shallower water. *HYDROLAB* is, therefore, very close to the effective depth of the waves.

The other tracer site was in one of the grooves incising the top of the wall. The dyed *Halimeda tuna* placed there immediately started a gradual downslope movement. After 3 days the entire dyed mass was displaced several inches downslope. Inspection of the site 3 weeks after the mission showed considerable dilution of the dye patch (over 50% of the dyed sand was gone), and the dye patch was completely spread between the injection point and the end of the groove (a distance of 4 m). This downslope movement of sediment through the groove appears to be the result of (1) gravity and (2) the return flow from storm waves piling up against the coast, which can move considerable volumes of sediment seaward. The second mechanism is further

hypothesized to move material from the fore reef to the outer sand flat and to the top of the wall.

In order to estimate the amount of material moving down these grooves, sediment traps were placed on the wall at a depth of 195 ft. The traps collected sediment over periods of 2 days (during the mission) and 30 days (after the mission). The amount of material collected verifies that much material is moving over the edge of the wall into deeper water.

Mission 15

Principal investigators.—Peter Kotzer, Western Washington State College; Jere J. Lord, University of Washington; Kurt Stehling, MUS&T office, NOAA.

Dates.—Nov. 25–29, 1974.

Facility used.—*HYDROLAB* and Bahamas Surface Laboratory.

Objectives.—To retrieve detector with data on the composition of radiation at 190 ft underwater.

Results.—For the first time, background-free photographic and nuclear-sensitive emulsions were exposed for 256 days, beginning on Mar. 15, 1974, at a depth of 190 ft and developed in an underwater facility. Fifty-two cm^3 Illford G5 emulsions had been emplaced at approximately 26°45′N and 78°30′W. Eight pellicles, each less than 1 mm thick and 2.5X4 in. in surface area, were processed under the protection of 10 nuclear mean free paths of water absorber in *HYDROLAB* at a depth of 45 ft.

Seven of the plates were completely scanned for radiation particles over the last half year. High-energy neutrons, mu mesons, and pi mesons were found among the many radioactive events recorded by the emulsions. The first scan of these events yielded the following distribution:

Plate	*Muons*	*Neutrons*	*Pions*
1	27	3	1
2	26	2	0
3	28	6	1
4	22	6	0
5	9	1	0
6	13	3	0
7	10	0	0
Total	135	21	2

These events are believed to be from photonuclear interaction of high-energy cosmic ray muons with water nuclei. Specifically,

$$\mu + (Z,A) \rightarrow \pi, K, N, p + \mu + (Z',A')$$

The electromagnetic field surrounding the muon is presumed to interact with the nucleus to create π and K mesons as well as breaking the nucleus into fragments including its constituent neutrons and protons. Based on this mechanism and by adding surviving surface muons to the measured number of stopping muons, we have developed a theoretical distribution that displays our data. Since ours are the only data on the undersea composition, we include measurements made under rock, taking into account differences in nuclear composition between rock and water.

The preliminary scan agrees well with theory—unlike our earlier data at 25 and 33 m underwater, which showed an anomalously low yield. On the other hand, the measured rates for stopping pions are low.

Clearly, longer exposures prepared in deeper habitats are required to see if the pion anomaly exists at greater depths and if the stopping muon rates remain consistent with theoretical calculations or at higher magnetic latitudes.

An abstract of the results of this experiment has been accepted for publication at the 14th International Conference on Cosmic Rays, Munich, Federal Republic of Germany.

Mission 16

Principal investigator.—Dennis L. Taylor, University of Miami.

Associate investigators.—Patric Colin, University of Puerto Rico; Bruce Chalker, University of Miami.

Dates.—Nov. 11–21, 1974.

Facility used.—*HYDROLAB* habitat.

Objectives:

—To determine calcification rates of corals in the light and dark and in the presence of photosynthetic inhibitors DCMU and methyl viologen for hermatypic species, and to determine kinetics of calcium and carbonate uptake for all species. Using *Dendrophyllia* sp., to determine rates of Ca^{45} uptake for a range of sizes (newly settled to "mature").

—To continue long-term experiments to determine the direction, rate, and extent of intracolonial transport in hermatypic corals.

—To continue earlier surveys and document coral growth form and corresponding habitat.

—To analyze burrowing fish communities on a sand flat and deep reef slope, and to determine community structure and interactions in these environments and the extent and effects of burrowing.

Results:

The following species were studied: *Montastrea annularis, M. Cavernosa, Acropora cervicornis, Porites porites,* and *Dendrophyllia* sp. Surface divers processed samples for tissue and skeletal fractions, and counting and data analysis were done in Miami. C^{14} amino acids, protein hydrolysate, sugars, and Ca^{45} were utilized.

Kinetic analysis of data derived from studies of Ca^{45} uptake shows the existence of a system for mediated transport. Such a system demands an energy resource. Current information derived from light/dark experiments and inhibition studies indicates that the photosynthetic activity of algal endosymbionts found in the species can satisfy this demand. This single observation is highly significant. Previously, transport of Ca^{++} was postulated as a diffusional process. Geologists interpret their data on strontium/calcium ratios on this assumption, which this study has shown to be incorrect. Hence, reinterpretation of geochemical data will be required.

Data on Ca^{++} uptake by size classes of *Dendrophyllia* sp. indicate that the rate of calcification is not constant throughout the life of this ahermatype. Growth and calcification rate is most rapid in immature specimens and declines logarithmically as the animal approaches its maximum size. These data serve to clarify earlier laboratory studies comparing hermatypic and ahermatypic calcification. It should now be possible to study calcification in ahermatypes during their maximal growth identified in these experiments and to obtain meaningful comparative data.

Trauma to deep-dwelling ahermatypes during collection was a problem in shore-based studies. The work reported here was made possible by excursions to depths below 120 ft, which couldn't have been done without saturation technology.

The studies on the intracolonial transport of organic compounds and Ca^{++} in *Montastrea annularis* and *Acropora cervicornis* demonstrated that transport is a rapid phenomenon with a strong unidirectional character. In both species, materials were observed to move preferentially toward the areas of maximum growth and calcification in the colony. In *A. cervicornis* this is toward the branch tip. In *M. annularis* taken from 100-ft depths, transport is toward the edge of the growing plate.

Mission 17

Principal investigators.—M. P. Lynch, Virginia Institute of Marine Science (VIMS); J. Morgan Wells, MUS&T, NOAA; Michael Castagna, VIMS; Robert J. Orth, VIMS and University of Maryland, and Barry H. Gump and Harry S. Hertz, National Bureau of Standards (NBS).

Associate investigators.—James Lewis and Steve Snyder, VIMS.

Dates.—Dec. 2–12, 1974.

Facilities used.—*HYDROLAB* habitat.

Objectives:

—Determine the impact of various doses of chlorine on community metabolism.

—Assess the colonization of macroinvertebrates on an artificial substrate (artificial seagrass).

—Compare colonization of artificial substrates in tropical and temperate systems.

—Assess partitioning of mercury between various components of the ecosystem.

—Compare behavior of different drogue designs.

—Develop methodologies for Chesapeake Bay underwater studies.

—Develop methodology for the sampling and analysis of petroleum hydrocarbons in seawater and sediments.

Results.—The mission was shortened by 3 saturation days because of flooding of the habitat between missions.

Chlorine Studies

Plexiglas domes, 132 cm (52 in.) in diameter, were treated with various concentrations of chlorine, and behavioral modification associated with dosing was observed (fig. 17). Doses of approximately 9.5 ppm caused rapid motion, then high mortality. Decrease of dose to approximately 1 ppm caused no visually observable disturbance. Oxygen consumption in treated domes in the second experiment was less than in control domes. The NBS prototype chlorine meter did not function properly within the habitat. Subsequent investigation indicated that the calomel electrode junction was sensitive to pressure, and venting would be necessary at other than sea level pressures. These initial experiments provided protocols for use in temperate waters. Temperate water experiments in Chesapeake Bay were scheduled for summer 1975.

Colonization Studies

Artificial sea grass substrates were placed near *HYDROLAB* to assess colonization of macroinvertebrates and vertebrates. No colonization was observed during the first 4 days of emplacement, com-

FIGURE 17.—Scientist withdraws water samples from under hemispheres treated with different amounts of chlorine in benthic metabolism study.

pared with the situation in temperate (Chesapeake Bay) waters where initial colonization occurs during the first 24–48 hr.

Mercury Studies

Samples of dissolved mercury were obtained from water within Plexiglas domes, both in contact with and isolated from sediment, over a 24-hr period after the domes were inoculated with various doses of mercuric chloride. These samples were collected for NBS, and the results of analysis should now be available.

Drogue Studies

Three different- design drogues—"window shade," cross vane, and "V"—were released at the same time in the same immediate vicinity. Dye tracers were placed on each drogue for visual determination of drogue path. Physically the drogue systems (buoyancy, tension, height, width, etc.) were alike except for design. Each drogue was suspended from its surface buoy in an upright (no canting) position.

Trails of dye indicated that the drogues moved in directions other than those of the water mass in which initially placed.

All drogues traveled in the same general direction as wind and swell. The cross vane and window shade drogue traveled at approximately the same rate. The V drogue traveled at a much slower speed.

The V drogue was observed underwater to aline with its open end toward the direction of travel. During swell passage it would tilt, with the open end of the V moving upward toward the vertical and then slowly moving downward to the vertical. Initially, the V drogue motion seems to more accurately indicate movement of the water mass in which initially placed. The tilting motion appears to counteract in some manner the pull by the surface buoy. Drogue direction was principally controlled by wind, indicating the need for extreme care in evaluating shallow drogue data in the presence of active winds.

More diver observations of drogue behavior are recommended and being planned at VIMS.

Methodology Development

Protocols for benthic respiration studies to evaluate pollution effects were developed. Although diving conditions are considered ideal at the *HYDROLAB* site compared with conditions in Chesapeake Bay, the protocols developed at *HYDROLAB* are expected to have greatly benefited the surface-serviced benthic metalolism studies in Chesapeake Bay during the summer of 1975.

Hydrocarbon Studies

Water samples at the surface and at 10 m and sediments from the bottom were taken in a control area near *HYDROLAB* and in an area of suspected hydrocarbon presence near a tanker transfer facility. A new sampler, developed at NBS, was used (fig. 18). The samples were frozen in dry ice and returned to NBS for analysis. Petroleum hydrocarbons were common in open ocean water, and some were found in the sediments beneath the oil tanker transfer facility.

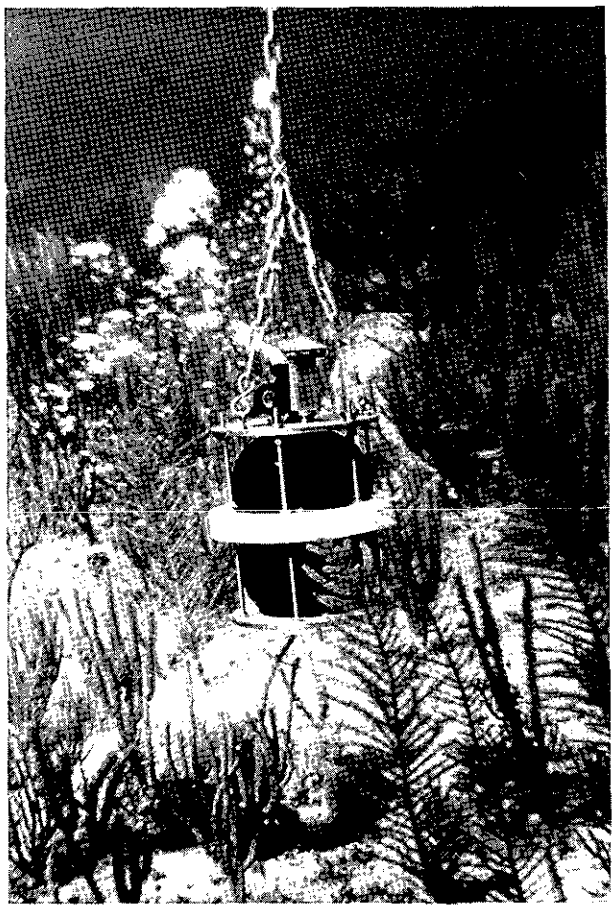


FIGURE 18.—National Bureau of Standards petroleum hydrocarbon sampler.

Mission 18

Principal investigator.—Robert Wicklund, Perry Foundation, Inc.

Associate investigators.—Richard Clarke, Rick Asprey, Robert Hensted, Perry Foundation, Inc.

Dates.—Dec. 12–19, 1974.

Facility used.—*HYDROLAB* habitat.

Objectives.—To study the following:

—Increased pressure effects on physoclistous reef fishes.

—Behavior patterns of some fish.

—Techniques for capturing live specimens under water.

—Water movements and significance.

Results:

Experiment I: Two specimens of *Haemulon plumieri* (white grunt) were captured at 60-ft depth and moved to 135 and 165 ft, respectively, at 1625 on Dec. 13. Both fishes were returned alive to the habitat on the morning of December 14. The fish returned from 135 ft showed positive buoyancy, indicating that its bladder was functioning. The fish from 165 ft remained negatively buoyant. It fell out of the canister on the way back to the habitat, but it appeared to be dying.

Experiment II: Moved *Haemulon plumieri* captured at 60 ft to 105, 135, 165, and 195 ft on the morning of December 14. The specimen at 165 ft was lost. Specimens from 105 and 135 ft were returned to *HYDROLAB* at 1425 positively buoyant and released after 2 days. The specimen from 195 ft was dead.

Experiment III. Two *Haemulon plumieri* captured at 60 ft were placed at 195 ft at 1405 on December 15 and returned to the habitat at 1015 next day. Both fish were negatively buoyant at 135 and 165 ft, but became positive at 50 ft.

Another specimen placed at 195 ft was lying on its side in arched position, but was returned to 50 ft neutrally buoyant. All were released the next day.

Experiment IV: *Haemulon plumieri* captured at 55–60 ft were placed in new arrays at 150, 160, 170, and 180 ft in the morning of December 16. All specimens were in poor condition 24 hr later. Specimens at 170 ft were dead. One at 180 ft was lying in arched position. These fish spent several days in a holding pen before being moved to deeper water. Apparently the trauma of capture and harrassment by large grouper and a large moray eel

weakened them, and they were not suitable for the experiment.

Experiment V: *Haemulon plumieri* were captured at 55–60 ft and placed at 150, 160, 170, and 195 ft in the morning of December 18. Table 8 describes the results.

Discussion.—The above results, although similar to those of previous experiments, have revealed additional information.

The total time at depth may be as important as the depth changes. The fish at 150 ft or deeper were usually dead after 2 days. If kept for 1 day at 150–175 ft, they usually survived. However, several specimens suffered either death or damage to the swim bladder at 195 ft. The relative health of the specimens may have been responsible for some of the results. The treatment they received, such as predator harrassment during experiment IV, weakened them so they could not endure the trauma of increased compression.

The general conclusion is that a healthy specimen of *Haemulon plumieri* that is subjected to an increase of pressure somewhere around 100% will suffer death or swim bladder damage sometime after 24 hr. Always, however, the fish becomes immediately distressed when subjected to rapid increases in pressure. Theoretically, this and similar species would not make excursions much deeper than the reef they inhabit.

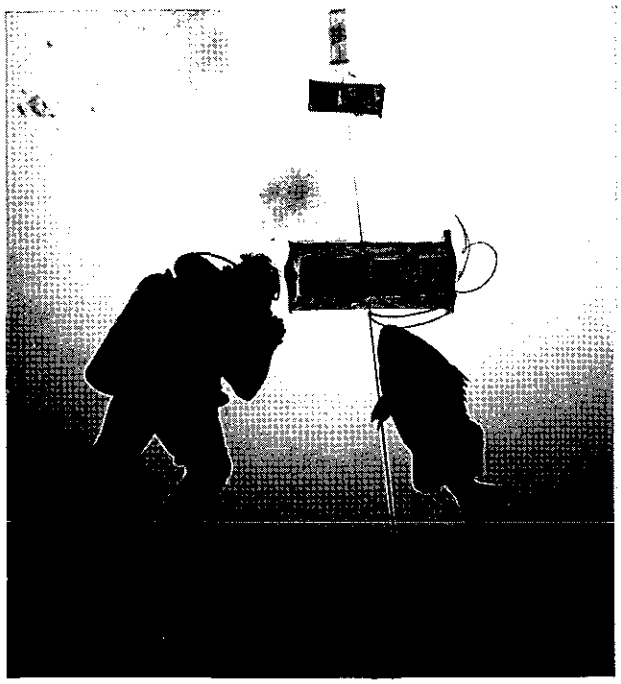


FIGURE 19.—A large grouper joins a scientist in observing a specimen in the holding chamber during buoyancy control experiment. (Photograph by Dick Clarke.)

TABLE 8.—*Pressure effects on reef fishes*

Depth	Time at depth	Condition
Ft	*Days*	
150	1	Dead.[1]
150	1	Alive, positively buoyant.
160	1	do.
160	2	Dead.
170	2	do.
180	2	do.
196	1	Alive, negatively buoyant.

[1] Fish sick prior to experiment.

Behavior Patterns

At evening twilight *Haemulon sciurus* migrate to their feeding grounds on the flats slightly deeper than their daytime habitat and about 0.3 miles westward. Most *H. plumieri* migrate westward along shallower trails and move inshore. *H. flavolineatum,* representing a small population on the offshore reef, move only into adjoining flats and generally not far from their daytime habitat. Both *H. plumieri* and *H. sciurus* do not venture more than 2 ft or so from the bottom. They follow the bottom contours while moving, even when in imminent danger. The knowledge of this behavior trait was used to capture live specimens underwater.

Haemulon sciurus does not trap during the day, whereas *H. plumieri* will readily swim into a baited trap. *H. plumieri* also has been observed feeding during the day.

During the cold months *Haemulon plumieri* apparently does not feed readily, for they could not be trapped with bait during December when the water temperature ranged at 23.5°–24.5°C. During October 1973, when the temperature was 26.1°–27.4°C, it was possible to trap *H. plumieri.*

During the day small groups of *Haemulon plumieri* remain in specific sites along their twilight migratory trails. The horse-eyed jack *Caranx latus* schools in tight groups continuously circling onto themselves. Apparently there are two separate groups in each school, one staying above the other. There is no mixing of the two groups except for a large jack occasionally moving from the top group to the back of the bottom group, appearing to heard the back

stragglers along.

The peacock flounder *Bothus lunatus* uses the reef heads for its initial escape from stress, although it has several other means of escaping a predator and usually is found out on the open sand.

Techniques for Capturing Live Specimens Underwater

During the studies of the white grunt, several techniques were developed for capturing specimens of bottom dwelling fish without physically harming them and transferring them through the water column. The first technique involved construction of a trap covered with nylon netting. The unique part is a nylon sock constructed on one end of the trap with a drawstring opening.

After the fish is captured, it is herded into the sock area. Here a diver can close the net around the fish and then, holding it firmly, transfer it to a holding cylinder through the drawstring opening.

A second technique for capturing bottom specimens unharmed involved a 15×3-ft net with floats on top and weights on the bottom. The net was stretched across the top of a coral head near a school of fish (grunt in this case). The fish were then herded toward the net. These fish do not swim off the bottom, and so one could be frightened into the net, after which a diver would wrap the net around the fish and transfer it into a holding cylinder.

Water Movements and Their Significance

During this mission and on several other dives, changes in water temperature and transparency were noted, indicating movements of water masses.

On December 17 a mass of cool, low-transparency water with a distinct leading edge moved into the *HYDROLAB* area. The visibility dropped from 50–60 ft at 0900 to 15–20 ft at 1300 EST. The tide was outgoing from 0900 to 1545. Strong northerly winds began at 1200.

Obviously this water mass moved from inshore on an outgoing tide. The shallows along the coast and in the waterways cool rapidly during the winter, becoming denser than the offshore water. The denser, low-visibility water moved under the offshore water, causing an inverted temperature structure.

The influx of cooled water on the outer reefs could have a detrimental effect over long periods of time on the inhabitants of the reef, especially the corals. Perhaps the large mass of cool water is made possible by the recent (past 15 yr) construction of waterways and bays on Grand Bahama Island. These bays, which are adjacent to the *HYDROLAB* site, have several inlets to flush water in and out. Cooling of the bays is quicker and more extensive than of offshore waters.

Possibly, therefore, an artificial environment has been created by the bays' construction, allowing detrimental amounts of cool, low-visibility water to attack the reefs.

Mission 19

Principal investigator.—Barbara Pijanowski, National Oceanographic Instrumentation Center, NOAA.

Associate investigators.—J. A. Llewellyn, University of South Florida; Robin Morehouse, Alan Smith, University of Florida.

Dates.—Jan. 5–11, 1975.

Facility used.—*HYDROLAB* habitat.

Objectives.—The water quality instrumentation project of the National Oceanographic Instrumentation Center is a continuing program of test and evaluation of water quality systems. These are systems designed to simultaneously measure temperature, conductivity, dissolved oxygen, and pH in either profiling or monitoring modes. In fiscal year 1973 evaluations were completed on four systems, and laboratory evaluations of two more systems, the InterOcean Model 513D and Whitney/Montedoro Mark II, were completed in fiscal year 1975. To realistically evaluate such systems, it is necessary to test in the field as well as in the laboratory. The primary objective of this mission was to obtain field performance data on the InterOcean and Whitney systems, specifically:

—Calibration stability and drift of sensors
—Reliability
—Ease of handling underwater and surface units
—Pressure effects on sensors.

To support laboratory evaluations of in-situ systems, it is necessary to develop and validate the standards against which the instruments are referred. Thus a laboratory salinometer (Beckman RS-7B) was to be evaluated for its measurement of in-situ and bottled samples to determine the effect on salinity measurement of removing water samples from the environment.

Results.—In order to observe the instruments in a monitoring mode, the sensor packages were placed in and around a hole in the ocean floor about 500 ft from the habitat. Previously a tidal water flow had been observed through the hole. A surface station

was set up over the hole, and for a 24-hr period temperature, conductivity, dissolved oxygen, pH, current, and pressure were monitored inside and outside the hole. Temperature was measured and water samples for reference analysis of salinity and pH were collected by divers at 2-hr intervals. All equipment operated satisfactorily for the duration of the monitoring period.

Profiling capability of the water quality instruments was examined by lowering the systems to 300 ft from a surface vessel while divers collected samples for analysis to a depth of 150 ft. The InterOcean system began to produce erratic data at 150 ft on its first drop to that depth. The cause was broken wires in its cable, probably from handling, and the system had to be dropped from further testing. The Whitney system operated satisfactorily at all depths, but displayed some error under pressure.

Tests with the laboratory salinometer could not be completed because of several problems. It was not operational when delivered to the habitat, but recovered from apparent pressure effects on its electronics after 24 hr. Samples were run successfully for 1 day, but then a fluctuating AC power supply from the habitat power generator caused the instrument, which requires a constant power input, to malfunction.

The Whitney system was monitored from the habitat for 48 hr. During this time, power fluctuations in the habitat limited the amount of information that could be collected. Specific error and failure data on the InterOcean and Whitney systems will be published in field testing reports.

Mission 20

Principal investigator.—Robert Wicklund, Perry Foundation, Inc.

Associate investigators.—Dennison Breeze, Ocean Agents, Inc.; C. Lavett Smith, American Museum of Natural History.

Date.—Jan. 15–21, 1975.

Facility.—*HYDROLAB* habitat.

Objective.—To study behavior of bottom fishes related to specifically designed fish traps and continue studies of seasonalities and spatial relationships of fish communities on the coral reefs.

Experiment 1: Five traps were placed, respectively, on the sand plateau, seaward of the deep reef, on the deep reef, on the artificial kelp bed, and 50 ft outside the *HYDROLAB* window. All traps were bait free and fitted with snap-shut doors triggered by corrosion on a magnesium link made from welding wire. All links worked well and the trap doors shut on schedule. These traps were designed to fish for deepwater bottom species for given periods of time and then shut, thereby preventing them from continuously fishing in the event they are lost.

Experiment 2: This was designed to test the control separation of several magnesium link designs. The links were built into an S shape with small pieces of soft iron wire wrapped around the center. The number of iron wraps determined the time period for the links to separate. One wrap took approximately 4 hr; two wraps, 3 hr; three wraps, 2 hr; four wraps, 1 hr; five wraps, about ½ hr. The tightness of the iron wraps and tension of the doors also affected the time of link separation.

Experiment 3: Five traps were set in front of the *HYDROLAB* window, all baited. The trap designs were (1) triangle, (2) rectangle covered wtih black plastic strips, open entry, (3) rectangle, open entry, (4) rectangle with small entry in clear Lexan door, and (5) small cuban trap.

The results (table 9) of the fish trap experiments suggest that the shape of the trap is an important factor in its fish catching quality. For example, trap 1, the triangular tent-shaped trap, was entered only one-fifth as often as two of the rectangular traps, even though it was baited as heavily.

Trap 4 was rectangular and baited, but the clear Lexan door over the entry must have been a deterrent. Many fish approached the entry only to turn away, apparently detecting the door. Two groupers tried to enter the trap, but turned away as soon as they touched the Lexan door. The most successful traps were 2 and 3. Trap 3 was baited and had a large entry. Several black groupers made many entries into the trap to take the bait. Trap 2 was not baited, but the plastic strips attached to the sides offered a haven for the fish.

TABLE 9.—*Summary of fish catches, by trap design*

Species	Trap design—				
	1	2	3	4	5
Black grouper	3	13	10	1	0
Yellowfin grouper	0	0	1	0	0
Cubera snapper	0	1	0	0	0
Others	0	1	1	2	5
Total	3	15	12	3	5

The success of the trap with the plastic was impressive, and it could save money by eliminating the need for bait, but there are problems. Because the plastic offers much resistence in the water, the trap is difficult to raise off the bottom at high speeds. Also, the plastic is very motile in currents and waves and probably would frighten some species of fish.

Mission 20a

Principal investigator.—C. Lavett Smith, Department of Ichthyology, The American Museum of Natural History, New York.

Associate investigators.—Robert Wicklund and Dennison K. Breese, Perry Foundation, Inc.

Dates.—Jan. 15–22, 1975.

Facility used.—*HYDROLAB* habitat.

Objectives.—The objective of this mission was to restudy the fishes of a small patch reef that was studied from *HYDROLAB* in March 1973. Needed were quantitative data on the numbers of species present on the reef and their relative abundance as a measure of the stability of the fish community. Patch reefs are ideal for this type of study because they are small enough to be studied by direct observation and complex enough to produce results that apply to other organism communities.

The techniques were simply repeated visual counts of the species and individual fishes present. Divers on open-circuit scuba swam over and around the reef at various times of the day and night locating individual fishes as well as aggregations within the reef fabric. In a previous study from the *TEKTITE* visual observations were combined with sampling, but the *HYDROLAB* reef was left undisturbed after a 1973 census, and the second census represents data from a reef that had not been artificially manipulated.

Results.—A total of 46 resident species were recorded during the two samples: 38 in 1973 and 39 in 1975, with 31 species present during both censuses. More individuals were present during 1975: 407 compared with 288 during 1973. The Shannon-Weaver diversity indexes were similar: 2.8 in 1973, 2.7 in 1975. The species present in only one census form only a minor part of the community—less than 4% of the individuals present belonged to such species.

The data are being used to prepare a summary of the life history information for each species present and external morphology, brain patterns, and gut structures, all offering clues as to how community balance is established and maintained. The analysis indicates that nearly every aspect of the fish community can be visualized as a gradient; for example, there is no sharp division between fishes that feed on plankton and piscivorous carnivores. Instead there is a complete spectrum of fishes that feed on small to large particles. In this way food resources are utilized effectively, and direct competition is minimized. Similar gradients in absolute body size, color patterns, defense and reproductive behavior, and microhabit preference have been established. Taken together, these observations provide a measure of the extreme precision with which the community is organized. This precision is, however, often masked by the degree of plasticity of each species that enables it to fit into different assemblages of competing species. Thus there is a pioneer effect in that similar reefs colonized in a different order will have different resident faunas. Though this makes the communities appear random, they are in fact precisely organized.

Project SCORE (Mission 21)

Introduction.—Project SCORE (Scientific Cooperative Operational Research Expedition) employed the *HYDROLAB*, a research submersible, a variety of underwater safety stations, and surface vessels and facilities for a month-long research project that began April 1, 1975, off Freeport, and was the last of the *HYDROLAB* projects in the fiscal year. The purpose was to enable concentrated studies of the vertical wall of a coral reef to depths as great as 250 ft (fig. 20).

SCORE used saturation diving, deep air excursions, and submersible lockout techniques for deep reef studies of fish, corals, algae, and geology of the reef environment. The project was carried out cooperatively by NOAA-MUS&T, the Harbor Branch Foundation, Inc., of Fort Pierce, Fla., and the Perry Foundation, Inc., of Riviera Beach, Fla., and with the participation of non-U.S. scientists.

The Perry *HYDROLAB* habitat provided diver teams with an underwater "home," and Harbor Branch's submersible Johnson *SEA LINK I* shuttled them from the laboratory to their research sites as far as a mile away and to depths 190 ft deeper than *HYDROLAB*.

Chief scientist.—James Miller, MUS&T, NOAA.

Program coordinator.—J. Morgan Wells, MUS&T,

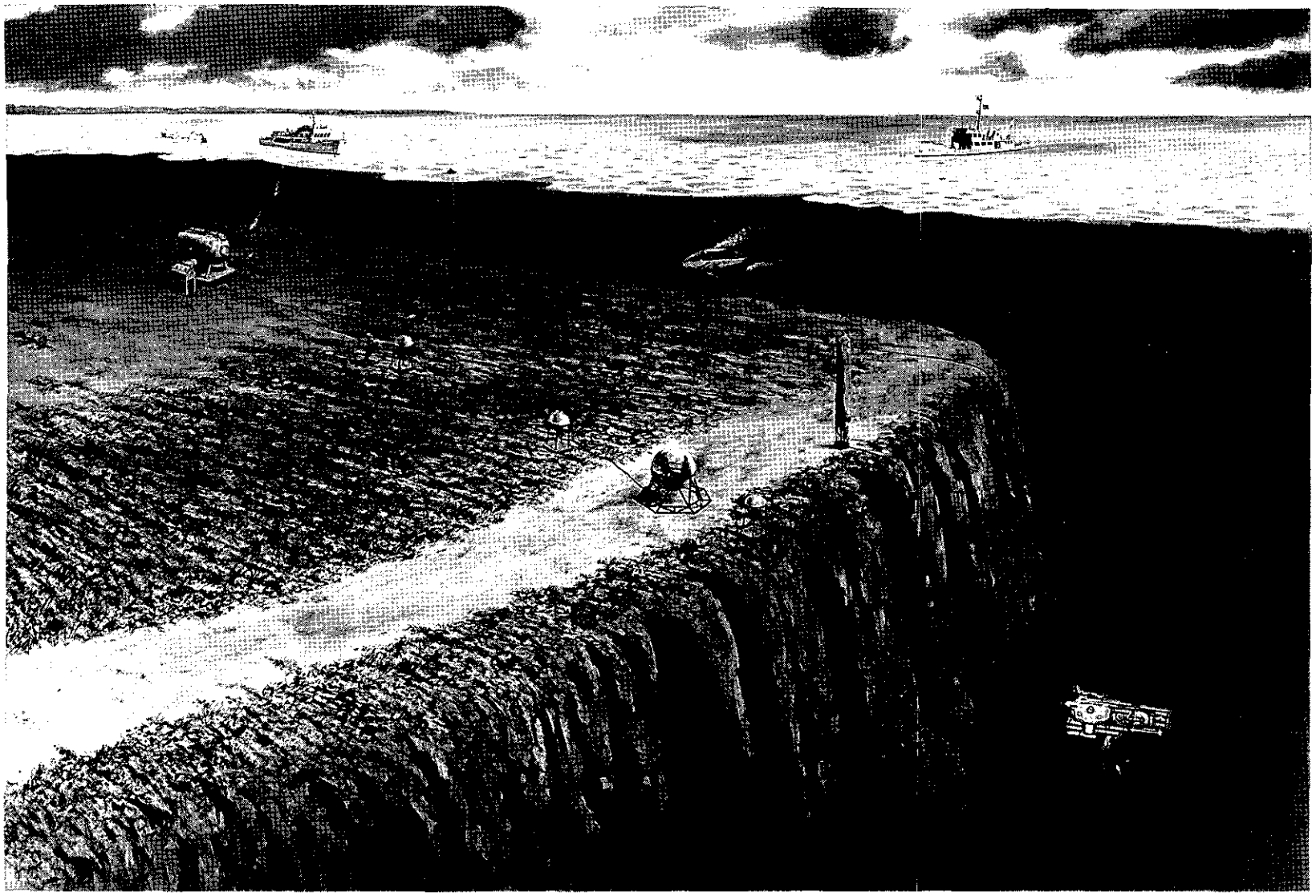


FIGURE 20.—Project SCORE (Scientific Cooperative Operational Research Expedition) concept. Johnson *SEA LINK* submersible is shown anchored to face of coral reef wall at depth of 200 ft with diver descending to 250 ft (lower right). Other team members are in Sub-Igloo (center) and *SHARK HUNTER* vehicle (center above), while support divers approach *HYDROLAB* (upper left). Tall cylinder on edge of coral reef is Undersea Instrumentation Chamber housing oceanographic instruments. Three underwater safety stations containing air supplies are along diver route for emergency use. Surface support vessels are the *UNDERSEA HUNTER* (left) and *R/V JOHNSON*.

NOAA. Other key personnel are listed at the end of this section.

Major facilities used:

—*HYDROLAB* at 60-ft depth.

—Sub-igloo, a small bottom "stopover" station.

—The Johnson *SEA LINK I* submersible.

Objectives.—The goals of project SCORE included:

—Developing safety procedures for prolonged deep air-saturation diving for use in coastal zone resource development.

—Extending the oceanographic, geological, chemical, and biological characterization of the reef environment.

—Extending studies of species composition, distribution, abundance, and dynamics to deeper reef areas.

—Obtaining environmental data on reaction of a coral reef community to natural and man-induced stresses.

—Demonstrating the technical aspects of joint-use ocean floor laboratories and lockout submersibles and deep air excursion tables.

—Evaluating safety and utility of support and operational equipment.

—Conducting hyperbaric chamber tests of new air excursion techniques.

—Studying adaptation to nitrogen narcosis during deep air-saturation excursion dives.

—Training scientists and technicians in the use of advanced technological diving systems for scientific investigation and support.

Procedures.—Although diving and scientific operations were essentially continuous, the missions were divided among several research teams including shore-based scientists. For each SCORE excursion, Johnson *SEA LINK I* transported one scientist and one Harbor Branch technician from the habitat to the edge of the cliff and over the wall and then anchored, with a special deep-sea anchor suspending the submersible over the cliff, at a depth of 229 ft. The scientist would then swim from the rear compartment and make his observations while the support diver watched over him and tended the combination air hose and communications line from inside the submarine. Had there been problems (there were none), the support diver could have left the submersible to assist the scientist.

After 35 min (the longest time actually spent in the water) at a maximum depth of 250 ft, the scientist reentered the rear compartment and the submersible returned to the habitat.

Results.—This long project produced a variety of data and new information, much of which is still being analyzed. The following, however, is a summary of those findings available to date:

—The diving experience with increased depth and time and the evolution of new diving tables enabled extended excursions to deeper areas.

—An unknown tiny, mushroomlike green alga (seaweed) was discovered.

—Four fish species, not yet identified and possibly new, were collected.

—A much greater understanding of the remote but important ecological community of a deep reef and the interactions of the organisms making up that community was gained.

—A detailed atlas of the reef is being prepared with the zones delineated, life forms mapped and described, and such characteristics as light quantity and reef metabolic rates included.

—Five distinct life zones between shore and dropoff have been identified.

—A very sharp break between the kinds and abundance of fish species that occur on the face of the wall and those on the top was located.

—A very large population of black snapper was discovered at 200 ft just over the dropoff.

—About 12 species of coral were discovered at 20 ft, increasing to a peak of about 18 species at 50–60-ft depth, and then decreasing to 10–12 species at 120 ft. From 150 ft on down, there were only about six species to be found. But all of the deepwater species also grow in shallower water.

—Better measurements of coral's sensitivity and reaction to light were made.

—Unlike shallower water corals, none of the few species of coral found near 250–ft-depth dominated the site.

—Photographed and directly observed a little-known process whereby one coral competes with another for space. When two species are sufficiently close together, one may send out slimy filaments that cover the other, inhibiting its growth and sometimes inflicting fatal injury.

—Collected red algae for laboratory study, seeking to better understand how red accessory pigments absorb light at depths where green cannot. The red pigments then pass the energy along to chlorophyll to facilitate photosynthesis.

—Analyzed zonation of soft corals, known as sea whips and sea fans, that are used by basket stars as perches from which to feed.

—Studied the reef-building process with the sub-

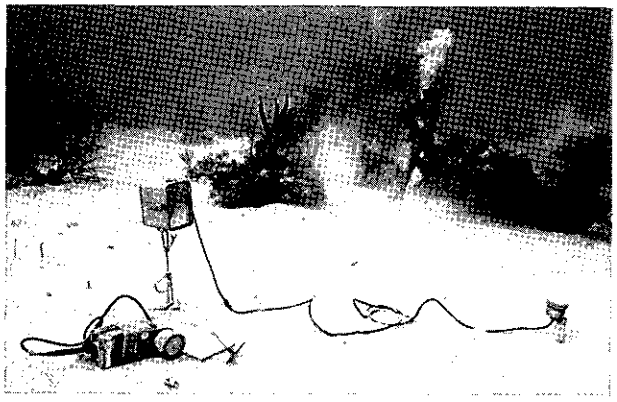


FIGURE 21.—Underwater photometers recording light levels.

mersible and with deep excursions from the habitat. Laboratory analysis of the stony skeletons of calcareous algae, corals, and other plants and animals whose skeletons make up the reef gave a new insight on reef building.

—Found evidence that the reef wall is still alive and growing, with more sediment going over the wall from the top of the reef than can be found at the bottom of the talus slope at the base of the wall.

—Discovered many platy coral skeletons stacked one on another along the reef walls—strong evidence of an outbuilding or "live" area rather than an eroding dead reef.

—Obtained new information on the hematology and blood chemistry from blood samples taken from the aquanauts before, during, and after their dives.

SCORE participants:

Brawley, Susan; University of California
Clarke, Richard; Perry Foundation, Inc.
Earle, Sylvia; Los Angeles County Museum [7]
Francy, Jill; University of Western Ontario
Ginsburg, Robert; University of Miami
Grimm, Diane; University of West Florida
Halas, John; Harbor Branch Foundation
Haxo, Francis; Scripps Institution of Oceanography
Hopkins, Thomas; University of West Florida [7]
Hubbard, Dennis; University of South Carolina [7]
Japp, Walter C.; Florida Department of Natural Resources [7]
Jaubert, Jean M.; Laboratory of General Biology, France [7]
Jones, Robert; Harbor Branch Foundation [7]
Meinert, William; Harbor Branch Foundation [7]
Nelson, Steven B.; Harbor Branch Foundation [7]
Olsen, David; Bureau of Fisheries and Wildlife, Virgin Islands [7]
Pamatmat, Mario; Auburn University
Philp, Richard; University of Western Ontario
Prentice, Jeffrey R.; Harbor Branch Foundation [7]
Schriever, Gerd; University of Kiel, Federal Republic of Germany [7]
Slater, Richard; University of Northern Colorado [7]
Smith, C. Lavett; American Museum of Natural History [7]
Wicklund, Robert; Perry Foundation, Inc.
Youngblood, David; Harbor Branch Foundation

Interagency

The second Interagency Committee on Marine Science and Engineering (ICMSE) report was prepared by the MUS&T office. It reviews and summarizes the manned undersea activities of the Federal agencies and the utilization of manned undersea research submersibles and habitats. The report compares the trends in availability and use of undersea platforms (submersibles and habitats) between 1972 and 1974, the status and availability of these facilities, and projected agency use for such platforms. The basis for much of the report is a survey of Federal agency requirements conducted during 1974 and a report prepared for the Atlantic International Search and Rescue Seminar of the U.S. Coast Guard in April 1975.

The report is based on a survey of the 11 ICMSE agencies to identify their operating, proposed, and planned programs for using manned undersea platforms.

[7] Aquanaut.

International Project FAMOUS

Introduction.—Project FAMOUS (French-American Mid-Ocean Undersea Study) was a cooperative program between France and the United States to study the geological features known as the Mid-Atlantic Ridge (fig. 22).

FAMOUS was established by the governments of France and the United States as a part of the U.S.-French Program for Cooperation in Oceanography. The lead agencies under this agreement are the Centre National pour l'Exploitation des Oceans (CNEXO) for France and NOAA for the United States. FAMOUS project activities of the French are being coordinated at the Centre Oceanologique de Bretagne (COB) at Brest, and U.S. activities at the Woods Hole Oceanographic Institution. Primary Federal agency participation and support for FAMOUS are by the National Science Foundation, NOAA, and the Navy. Others participating include the U.S. Geological Survey, Scripps Institution of Oceanography, Oregon State University, Dalhousie University (Canada), the Institute of Oceanographic Sciences (England), and the Institute of Geological Sciences (England).

Operations during the summer of 1974 utilized three submersibles (two French, one American) and a number of surface vessels and were the culmination of a 3-year study of the Mid-Atlantic Ridge. Scientists gathered information on plate tectonics, sea floor spreading, underwater volcanoes and earthquakes, sea floor mineral deposition, and other data that will aid in describing the processes of the dynamic earth.

The area investigated was approximately 400 nautical miles southeast of Ponta Delgada in the Azores. This site was chosen for its favorable weather and closeness to a logistic port.

Three submersibles were used with surface ships to gather data in the fracture zone and rift valley. They were the *ALVIN* and two French submersibles, *CYANA* and *ARCHIMEDE*. The *ARCHIMEDE* is the largest with a length of 69 ft and a depth capability of 36,000 ft. The *ALVIN* has a depth capability of 12,000 ft and a length of 23 ft; *CYANA*'s depth capability and length are 9,800 ft and 19 ft, respectively. Each carried a crew of three. All together the submersibles made 42 dives in water depths from 7,200 to 9,600 ft and traveled a distance of more than 50 km (31 miles) on the ocean bottom. Of these the *ALVIN* made 13 dives, spending 62 hr while traveling 19 km (11.6 miles), and took more than 12,000 photographs and collected 647 lb of rock samples. The MUS&T office of NOAA provided the financial support for *ALVIN* during the FAMOUS program.

Results.—A preliminary result of FAMOUS is the interesting indication that the lithospheric plates are being pulled apart rather than pushed by volcanism. This suggests that volcanic intrusion at the plate boundary is a consequence of sea floor spreading, not a cause of it. Most land formations studied were less than 100,000 years old, which in geologic time is fairly recent. Scientists were amazed at the amount of bottom dwelling organisms and fish in the fracture zone.

The French team discovered a number of deposits rich in iron and manganese. Such deposits may be caused by geothermal "hot springs" which heat the seawater, thereby allowing for increased concentrations of dissolved minerals. However, temperature gradients in the seawater may be very small (less than 0.1°C) because of the large heat sink of the surrounding seawater, making the mapping of these hot springs very difficult.

FIGURE 22.—The Mid-Atlantic Ridge and the continents.

The submersibles made detailed observations of lava flow morphology, fracture systems, and vent structures and established the stratigraphic sequence of intrusive and extrusive rocks of two layers in the rift valley walls and on the walls of a fracture zone. Data were obtained that indicate deformation on the rift valley walls. A set of rock samples was carefully documented with respect to structural features, flow boundaries, stratigraphic position, and geological orientation. The scientists identified the active intrusion zone, charted the zone using its magnetic, bathymetric, and geothermal characteristics, and related these to the broader tectonic framework inferred from the local seismicity. The terrain was photographed from the submersibles, and data on the features was logged. A magnetic petrology and water sediment laboratory for processing and analyzing recovered samples, libraries of all data, and facilities for followup studies were available on the *KNORR*, a research ship operated by WHOI.

On board the *KNORR*, several ancillary experiments were conducted to complement the diving program. A heat flow program and complementary gravity coring for the northern fracture zone provided data used in support of *ARCHIMEDE* operations. The heat flow measurements also complemented studies of submarine hydrothermal activity. Sonobuoys revealed microearthquakes in the fracture zone. Bottom seismographic studies, current meter deployment, and additional bottom photography were done from the *KNORR*. Acoustic frequencies for communication, navigation, and depth sounding were set to avoid interference among the many vehicles in the area.

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Multinational Mission in the Baltic Sea

Introduction.—An American scientist-diver team from NOAA joined with teams from the Federal Republic of Germany, France, and the United Kingdom in a 3-week undersea research project in the Baltic Sea during August 1974.

The project aimed to (1) develop techniques for monitoring metabolic responses and characteristics of bottom communities and their environment for use in assessing and forecasting environmetal health; to (2) evaluate the performance of the underwater laboratory *HELGOLAND* in supporting scientific research; and to (3) evaluate the performance of scientific instrumentation in the cold environment.

Program coordinator.—Joseph R. Vadus, MUS&T, NOAA.

Science coordinator.—J. Morgan Wells, MUS&T, NOAA.

Mission participants:

United States: J. Morgan Wells, MUS&T, NOAA; William Phoel, NMFS, NOAA; Maurice Lynch and Michael Castagna, Virginia Institute of Marine Science.

Federal Republic of Germany: Gerd Schriever, University of Kiel; Hans Belau and Nikolaus Neukirch, GKSS, Geesthacht.

France: R. Vassierre and Claude Falconetti, University of Nice.

United Kingdom: Mike Kettle, Admiralty Experimental Diving Unit (visiting for system familiarization).

The underwater laboratory *HELGOLAND* was located about 2.5 km (1.5 miles) offshore from the town of Niendorf at a depth of about 15 m (50 ft). It consists of two cylindrical sections, each with a diameter of 8 ft and length of 40 ft, providing 1,200 ft^3 of living and working space. The system is transportable and is towed to the operating site for deployment on the seabed.

HELGOLAND is connected by umbilical cables to a rugged surface buoy anchored nearby, which provided the power, life support, and communica-

tions facilities. Built in 1969, the system has been demonstrated in the North Sea to provide an all-weather, cold water operations capability.

In the summer 1974, U.S. scientists and engineers participated with the Germans in a 1-week mission in *HELGOLAND* near the island of Helgoland in the North Sea. Sponsored by NOAA's MUS&T office, the mission provided familiarization with cold water technology and diving physiology. During March 1974 a team of German scientists from the University of Kiel, University of Bochum, and GKSS participated in a 1-week mission in the NOAA-leased facility *HYDROLAB* in the Bahamas to become familiar with U.S. habitat technology and operations and to conduct surveys of marine life in tropical waters.

Results.—Three 1-week saturation diving missions were conducted from the *HELGOLAND.* During these missions, data were collected to establish the following:

—Biochemical, biological, and chemical oxygen demand of representative benthic communities.

—The effectiveness of different concentrations of formaldehyde in eliminating biological oxygen demand.

—The effects of different concentrations and combinations of antibiotics (streptomycin and penicillin) on the metabolism of the bacterial components of benthic communities.

—Continuous sea floor light levels during the 3-week period.

—Diurnal cycles of photosynthesis and respiration of benthic communities.

—Compensation light intensities and times of day for benthic communities.

—Photosynthetic rates of artificially high levels of illumination.

—Periodicity of respiration via dark enclosures.

—Ambient concentrations of nitrate and nitrite.

—Rate of uptake of nitrate by benthic communities.

—Ambient salinity.

—Vertical distribution patterns of oxygen and temperature from the bottom and upward for 7 m.

—Behavior, vertical movements, and abundance of benthic and pelagic organisms in response to oxygen and temperature levels and gradients.

—Lethal oxygen concentrations for selected benthic and pelagic species.

—Qualitative and quantitative sampling of benthic biota.

—Comparisons of chemical and electrochemical methods of oxygen determination.

Preliminary data analysis shows the following:

—Nitrate is rapidly utilized by benthic communities confined under plastic domes.

FIGURE 23.—A diver from *HELGOLAND* carrying underwater oxygen meter and formaldehyde containers to the experiment site in the Baltic Sea.

—Ambient levels of nitrate ranged from 28.6 to 6.0 microgram atoms per liter. Nitrite was below the level of detection of the method used (0.05 microgram atoms per liter). (Higher nitrate levels were associated with colder, oxygen-poor water.)

—Salinity was relatively constant (20.6–20.9 parts per thousand).

—Photosynthesis by benthic communities is light limited, as demonstrated by a severalfold increase under artificial illumination.

—Temperatures were from 6.0° to 14.9°C. Thermal stratification was often very pronounced, with gradients of up to 5°C between the bottom and 2 m above the bottom.

—During one mission a cold (6°C), low-oxygen (below 1 ppm) water mass passed through the area of the underwater laboratory. During this period of time the following observations were made:

Nudibranchs and starfish which were normally found among the algae and rocks moved to the highest points available (in numbers far greater than were suspected to be present) and extended their appendages.

Pelagic fish moved out of the area or to shallower water.

Jellyfish (*Aurelia* and *Cyanea*), which were often present in numbers up to 1 per m^3, were completely absent or represented by a few partially decomposed individuals.

Numerous dead fish were on the bottom.

Many benthic animals that normally burrow in the bottom were moving across the surface of the sediments.

—The presence of this low-oxygen water mass stimulated studies to determine the lethal oxygen levels for several benthic species. Domes were placed over portions of the bottom, and the organisms observed while their oxygen levels were recorded. The following observations were made:

Starfish, nudibranchs, and worms could often be revived after being rendered inactive by low oxygen for several hours, suggesting that a time factor is involved in death from hypoxia.

The oxygen consumption by benthic communities is strongly dependent on the oxygen concentration.

Starfish and nudibranchs will move to their normal positions among the algae if oxygen levels are increased.

Amphipods which normally remained in the sediments during the day move out and die at oxygen levels of approximately 0.5 ppm.

Project FISSHH

Following the summer 1974 mission in the Baltic Sea, plans were begun for a major autumn 1975 program: the First International Saturation Study of Herring and Hydroacoustics (FISSHH) to be conducted 9 miles off Rockport, Mass. The objectives of this project will be to (1) define the ecological factors affecting survival of North Atlantic herring egg beds, (2) conduct hydroacoustic experiments on target strength of pelagic fishes referring to species type, orientation, and fish biomass in the natural environment, (3) conduct fish behavior and trapping experiements, and (4) develop deep diving capabilities. Participants will include scientists from the United States, Germany, Poland, and Russia. The German underwater laboratory *HELGOLAND* will be used to further the studies conducted by the Northeast Fisheries Center (NEFC; see "Observations of Herring Egg Beds on Jeffreys Ledge").

During the second half of fiscal year 1975, major efforts were made by the MUS&T program office and the NMFS/NEFC Manned Undersea Research and Technology group to develop detailed plans for project FISSHH. Two visits were made to GKSS and the Sea Fisheries Institute in Poland to complete arrangements for the transport of the *HELGOLAND,* the GKSS operation staff, and Polish scientists aboard a Polish Fisheries Central Board vessel.

Japanese Program—JAMSTEC

Background.—A diving research program was continued in Yokosuka, Japan, under the auspices of the Japan Marine Science and Technology Center (JAMSTEC). According to the arrangement between the University of Hawaii and JAMSTEC, four scientists from the University joined Japanese scientists to jointly carry out the physiological portion of the research. Some MUS&T funding was provided.

Purpose:

—To study the effect of prolonged stay in a hyperbaric helium-oxygen environment on certain physiological systems such as body temperature regulation, energy exchange, and body fluid volume regulation.

—To study the effects of rapid increase in pressure during compression, paying particular attention to body fluid balance, the development of bradycardia, and changes in the thoracic impedance.

—To study the effects of immersion in water of 15°C (with dry suit) on thermal balance, thoracic impedance, and body fluid balance.

Results.—A variety of physiological parameters, such as body temperature, blood pressure, oxygen consumption, were studied and measured in a several-days stay in a dry heliox hyperbaric environment. The result has been new information for supporting and treating saturated divers in field operations. Details and data will be presented at Undersea Medical Society meetings.

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