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ANALYZING DISTRIBUTIONS OF ZOOPLANKTON AND MICRONEKTON USING HIGH-FREQUENCY, DUAL-BEAM ACOUSTICS

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INTRODUCTION

Recent progress in the development of high-frequency, dual-beam acoustics has opened up new research opportunities for the study of zooplankton and micronekton [1, 2, 3]. In combination with echo-integration, the dual-beam technique can be used to estimate the size structure, numerical abundance, and biomass of pelagic animal assemblages [2]. The ability to make these estimates with high spatial resolution and in near-real time [3] will enable investigators to study in situ processes over a much wider range of spatial and temporal scales than was previously possible.

Dual-beam acoustical equipment developed for deployment on research submersibles and remotely operated vehicles (ROV's) has provided unique data sets on the vertical distributions and small-scale horizontal patchiness of zooplankton and micronekton [2, 3, 4, 5]. These data sets have allowed us (1) to make inferences concerning diel vertical migration behavior and (2) to generate hypotheses on the physical and biological processes underlying zooplankton and micronekton distributional patterns [2, 4]. Future deployments of dual-beam equipment on multiple opening/closing net systems and free-drifting as well as moored buoy systems will enable investigators to survey larger areas and collect longer time series data sets.

APPLICATION OF THE DUAL-BEAM TECHNIQUE TO ZOOPLANKTON AND MICRONEKTON

The dual-beam technique has been used quite successfully in determining size-specific information on fish distributions [6, 7]. The basic principles of the technique are the same whether the targets are zooplankton, micronekton, or nekton. Due to their smaller sizes, different sound-scattering properties, and higher abundances relative to fish, crustacean zooplankton and micronekton must be studied with equipment specifically designed to enhance target detectability and resolution. These properties can be enhanced by using higher frequency sound, shorter pulse widths, and narrower beamwidths [2]. Presently, we are using 420 kHz or 1 MHz sound, 0.3 ms pulse widths, and 3- and 10-degree beamwidths.

The key to using the dual-beam technique effectively on small organisms is to deploy the transducer in a manner that gets it sufficiently close to resolve individual targets. We typically work in the range from 1.5 m in front of the transducer to about 10 to 15 m away. The former limit is set by the near-field effects of the transducer; the latter is determined by the technique's effective working range. Although absorption of high-frequency sound sets the theoretical upper limit to the working range, the effective upper limit is set by resolution considerations. The dual-beam technique relies on the acoustical system's ability to resolve individual targets. At a given numerical abundance of targets, this ability diminishes as sampling volume increases. Since sampling volume increases with distance from the transducer, the system's effective range is determined in part by ambient target abundance and in part by the beamwidths of the transducer. With its present configuration, our system operates effectively in reasonably rich (numerical abundances less than or approaching 1000 animals per cubic meter) continental shelf and slope environments to about 10 to 15 m away. In more dilute environments such as the open ocean, the effective upper limit of the range may approach the theoretical limit. Of course, in extremely rich coastal environments (numerical abundances greatly exceeding 1000 animals per cubic meter), the technique may give strongly biased results or prove impractical.

CALIBRATION EXPERIMENTS

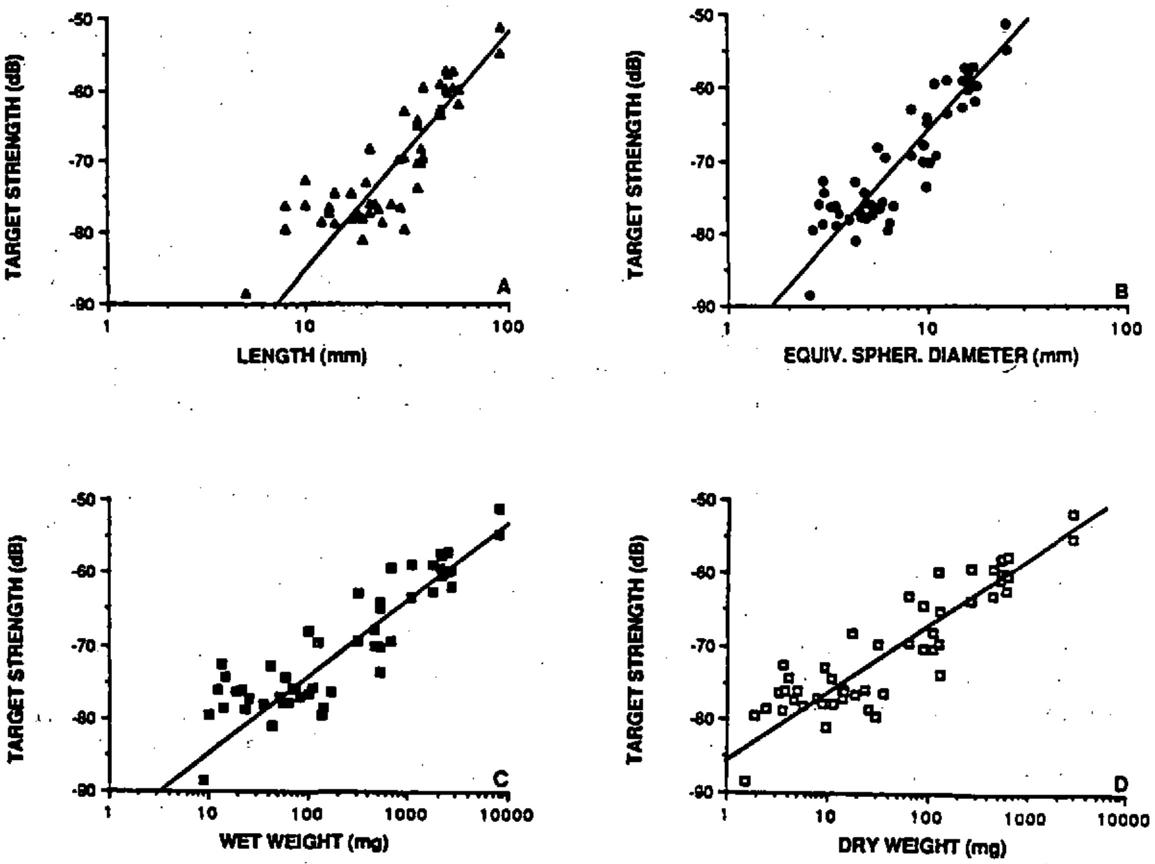
In summer 1987, calibration experiments were conducted at Friday Harbor Laboratories in Friday Harbor, Washington, USA, to establish the relationships between acoustical target strength and various measurements of zooplankton size (length, equivalent spherical diameter, wet weight, dry weight). All calibration experiments were conducted with 420 kHz sound. The details of the equipment and experimental protocol used are described by Greene et al. [2] and Wiebe et al. [8].

The results from these calibration experiments are summarized here (Table 1, Fig. 1); detailed discussions and interpretations of the results can be found elsewhere [2, 8]. As can be seen from Fig. 1, there is a highly significant, linear relationship between target strength and the logarithms of length, equivalent spherical diameter, wet weight, and dry weight. The slopes from these relationships imply that the backscattering cross sections of zooplankton and micronekton increase as the cubes of their lengths. This finding is important because it contrasts sharply with the empirical and theoretical relationships reported for fish [9, 10, 11] and confirms some of Stanton's theoretical predictions for zooplankton [12].

Table 1. Regression relationships between Target Strength (dB) and the logarithms of Length (mm), Equivalent Spherical Diameter (mm), Wet Weight (mg), and Dry Weight (mg). Table from Greene et al. [2].

Variables	Predictive Regression	Functional Regression	r^2
TS, Log(L)	TS = -107.7 + 26.6 Log(L)	TS = -114.2 + 31.1 Log(L)	0.73
TS, Log(ESD)	TS = -93.9 + 27.7 Log(ESD)	TS = -96.6 + 30.8 Log(ESD)	0.81
TS, Log(WW)	TS = -91.3 + 9.2 Log(WW)	TS = -93.7 + 10.3 Log(WW)	0.81
TS, Log(DW)	TS = -84.4 + 8.8 Log(DW)	TS = -85.9 + 9.7 Log(DW)	0.83

Figure 1. Functional regressions for Target Strength versus A. Length; B. Equivalent Spherical Diameter; C. Wet Weight; and D. Dry Weight. Figure from Greene et al. [2].



FIELD STUDIES WITH A SUBMERSIBLE

In autumn 1987, initial field studies with the dual-beam acoustical system were conducted at sites in the deep basins of the Gulf of Maine and the submarine canyons south of Georges Bank [2, 3, 4]. Deployed on the Johnson Sea Link (JSL) research submersible (Fig. 2), the system was used to collect dual-beam and echo-integration data on the vertical distributions of krill (Fig. 3).

Figure 2. The Johnson Sea Link submersible with dual-beam acoustical system deployed.

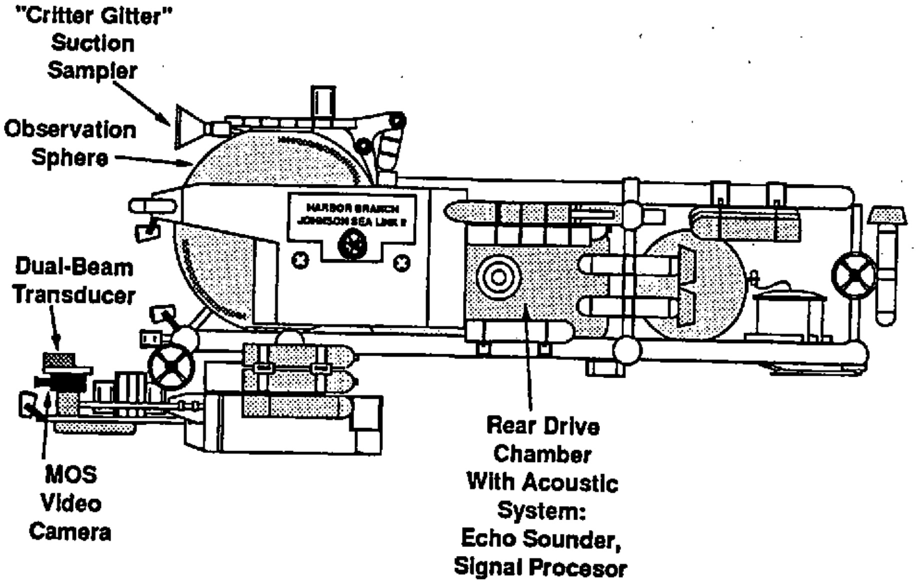
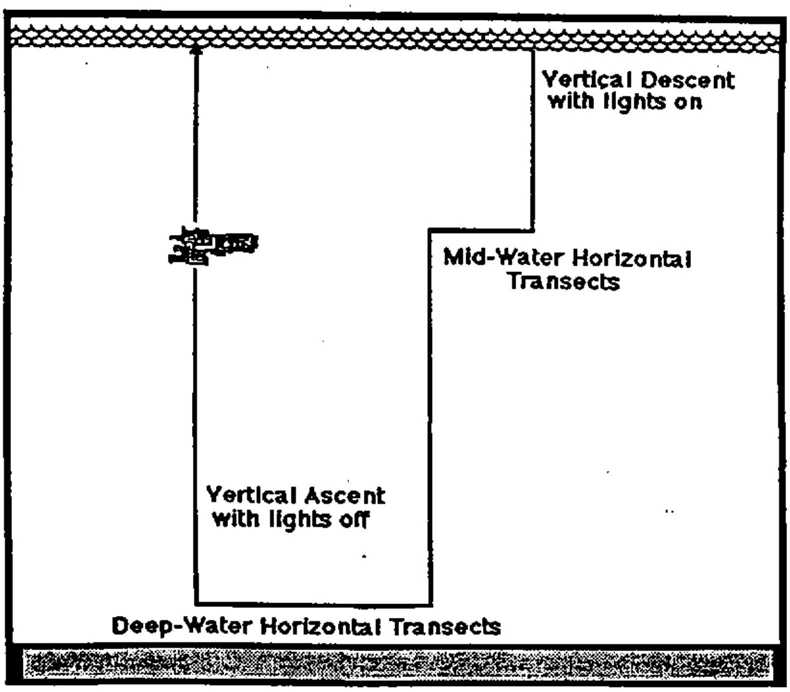
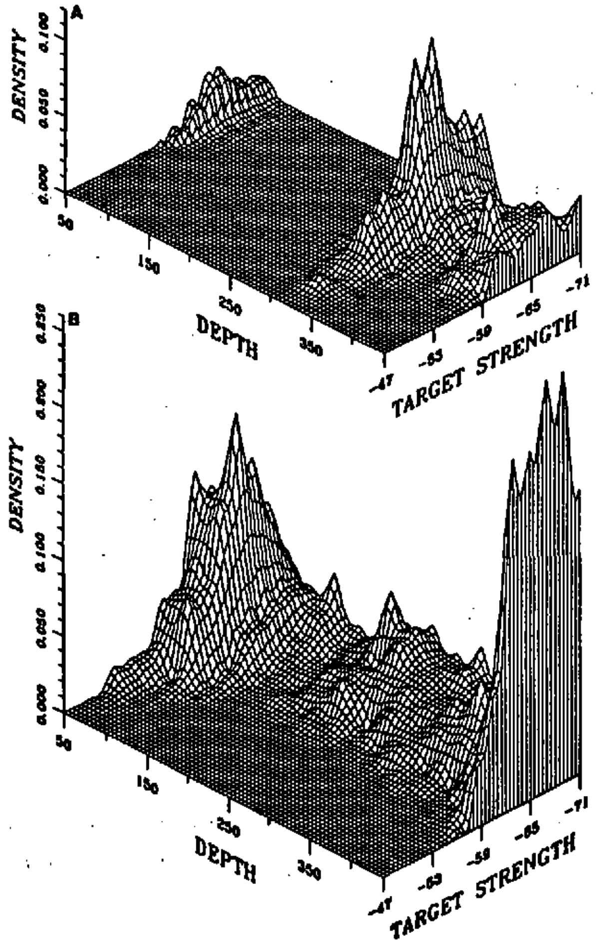


Figure 3. Typical dive plan with Johnson Sea Link. Acoustical profiles collected during vertical ascent phase of dive.



Acoustical surveys from the JSL revealed the existence of extensive, high-density demersal layers of krill at all of our study sites [4]. In addition to their high abundance near the bottom, the krill were also observed to form deep scattering layers in the water column below 350 m during the day and to form more uniform distributions extending to the surface at night (Fig. 4). From these patterns, we were able to infer that many krill vertically migrate at least 350 to 400 m each way per day. Furthermore, the patterns were suggestive of two hypothetical interactions between bottom topography and the behavioral ecology of krill [2, 4]. Specifically, we hypothesized that the downward migrating layers of krill coalesce upon reaching bottom, thereby resulting in the high krill abundances observed there. Additionally, at the submarine canyon sites, the bottom topography may cause a funneling effect that would further concentrate the krill in high-density demersal layers. Future survey work both inside and outside of the submarine canyons is planned to test the validity of these hypotheses.

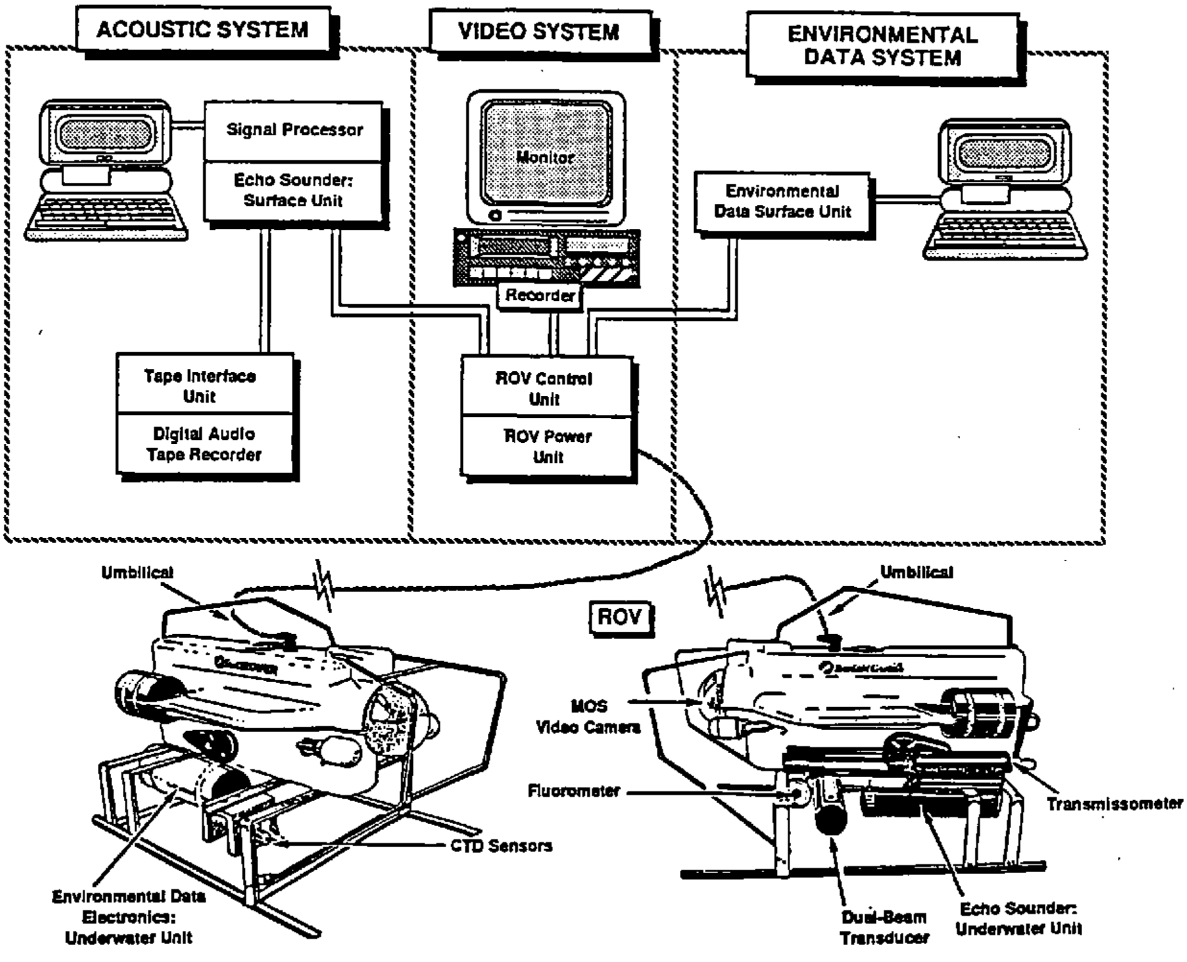
Figure 4. A. Daytime vertical profile of target densities from Hydrographer Canyon. Target densities (targets per cubic meter) for each depth interval (m) are apportioned to different target strength classes (dB). B. Nighttime vertical profile of target densities from Hydrographer Canyon. Figure from Greene et al. [2].



DEVELOPMENT OF A NEW REMOTE ECHO-SOUNDER AND ROV

In summer 1988, preliminary field tests with a new remote echo-sounder and ROV were conducted in Puget Sound, Washington, USA. The new echo-sounder was custom designed and built for our applications by BioSonics, Inc. It exhibits greatly enhanced sensitivity. One of the unique features of the new echo-sounder's design is its separation into two components, a surface unit and an underwater unit (Fig. 5). Amplification of the analogue signal produced by the underwater unit reduces cable losses in the signal to noise ratio, thereby ensuring the sensitivity required for zooplankton and micronekton studies.

Figure 5. The Benthos SeaRover ROV with dual-beam acoustical system deployed.



The underwater unit of the echo-sounder is mounted on a modified Benthos SeaRover ROV, and the signal is transmitted up to the ROV's tether cable, through the ROV control unit, and into the echo-sounder's surface unit. From the surface unit, the signal is passed in two directions: first, to a BioSonics echo signal processor for near-real-time data processing, and second, to a BioSonics tape recorder interface and Sony digital audio tape recorder for digital storage of the raw data.

The final analyses of the data from our preliminary field tests are presently underway [5]. Some of the findings we can report at present include the following:

1. The new echo-sounder, operating at a frequency of 420 kHz, was sensitive enough to detect in situ individual zooplankters with target strengths as weak as -92 dB.

2. With the dual-beam transducer oriented to face horizontally, we were able to conduct vertical profiles with the ROV and examine the small-scale horizontal patchiness of zooplankton and micronekton biomass as a function of depth.

3. Synoptic "snapshots" of horizontal biomass distributions with a resolution of less than a meter are relatively straightforward; quasi-synoptic, two-dimensional biomass distributions can be mapped with high resolution if advective processes are negligible over the duration of a vertical profile.

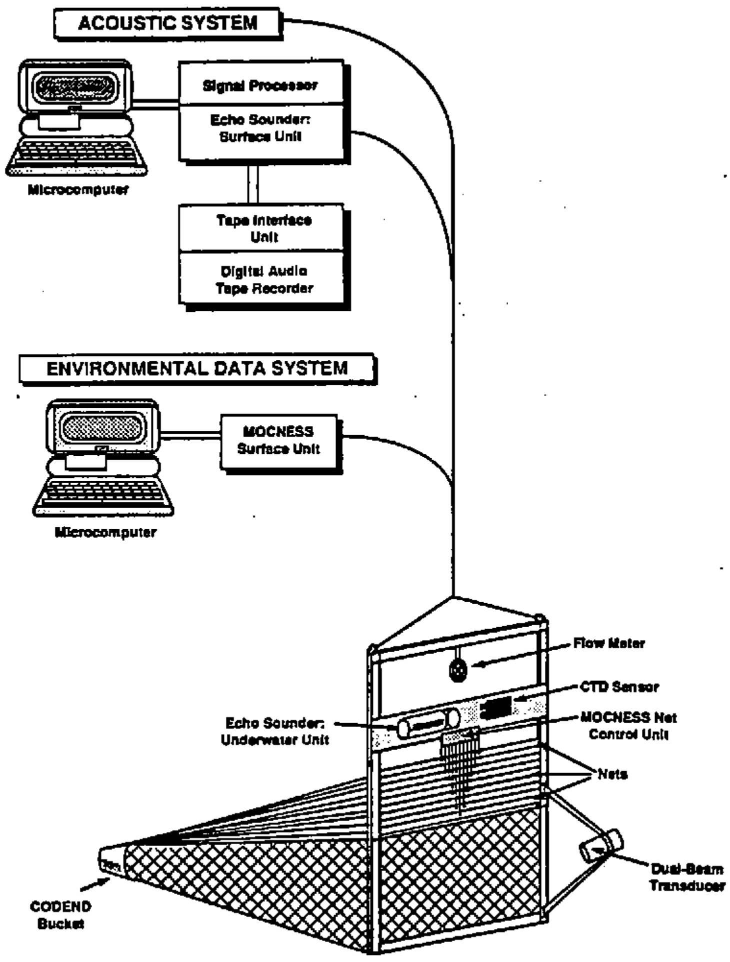
The above findings are very encouraging, and future field studies with the new remote echo-sounder and ROV are planned for spring 1989 on the pack ice of the East Greenland Sea and in the fjords near Trømso, Norway.

FUTURE DIRECTIONS

The development of remote dual-beam acoustical systems opens up many new directions for future research. Innovative methods of deployment will enable biological oceanographers to address issues considered intractable only a few years ago.

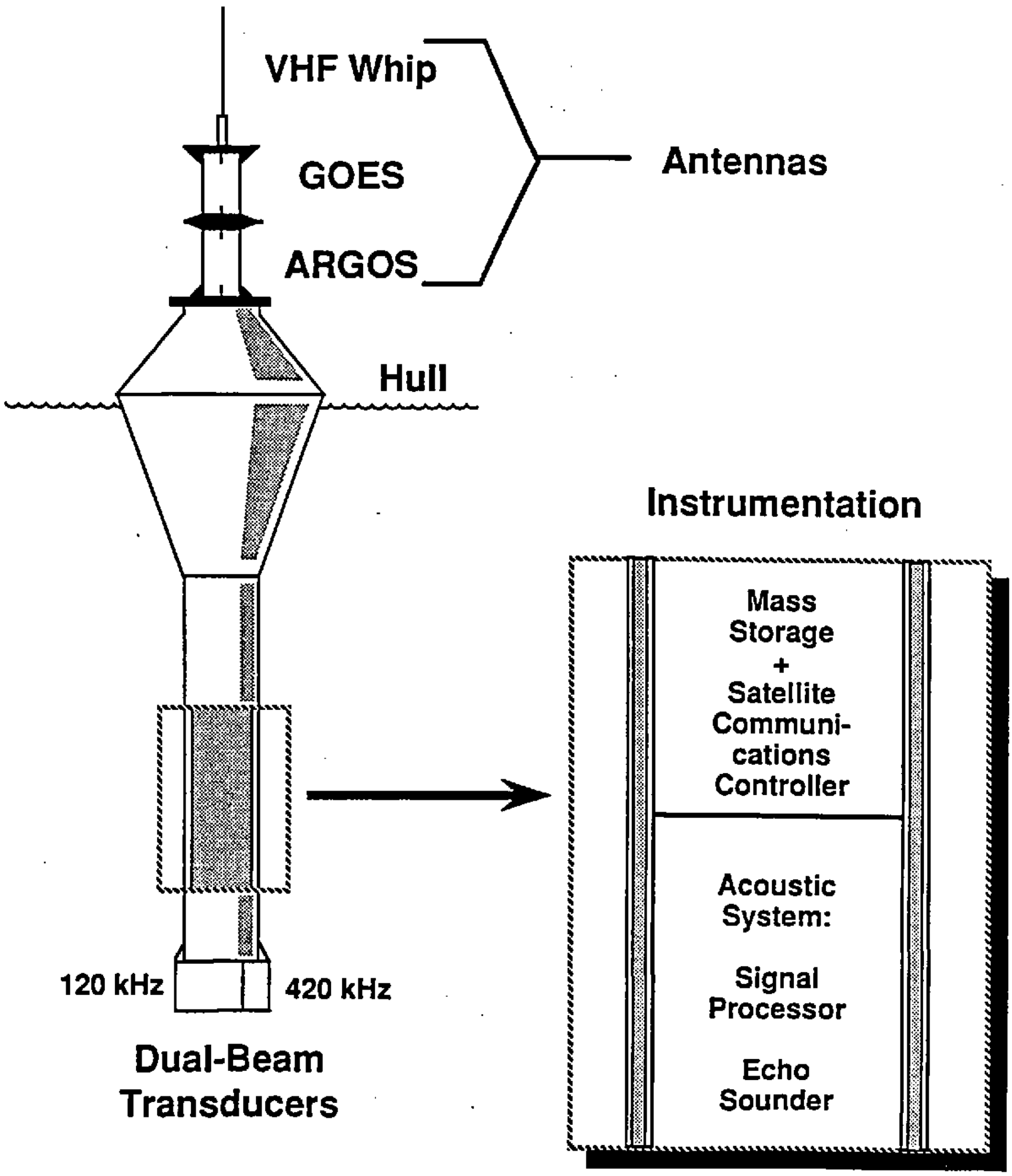
At present, we are developing methods for deploying the underwater unit of our new remote echo-sounder on a Multiple Opening/Closing Net and Environmental Sensing System, MOCNESS (Fig. 6) [12]. The MOCNESS deployment of the acoustical system introduces important new capabilities for surveying fine- to meso-scale distributional patterns. In addition, it provides a means for approaching the critical and previously unaddressed issue of quantitatively groundtruthing the acoustic data with simultaneously collected net samples. Initial field studies with this equipment are planned for summer 1990.

Figure 6. The MOCNESS with dual-beam acoustical system deployed.



Also underway at present is the development of a remote dual-beam acoustical and satellite communications system deployed on a spar buoy (Fig. 7). Referred to as the BIOSPAR (BIOacoustic Sensing Platform And Relay system) project, this effort is drawing together the talents of engineers and scientists from the Applied Physics Laboratory (Seattle, Washington, USA), BioSonics, Inc., the Boeing High Technology Center (Seattle, Washington, USA), and the Woods Hole Oceanographic Institution. The goal of this project is to construct an autonomous dual-beam acoustic profiler which will measure and telemeter volume-backscattering and target-strength data from remote oceanic locations via satellite to shore-based laboratories. Although surface-based, and thereby sacrificing some of the resolution capabilities found in the previously discussed deployment strategies, BIOSPAR will provide a unique free-drifting or moored platform from which to collect long time series acoustical data sets. Preliminary field tests with BIOSPAR are planned for autumn 1989.

Figure 7. The bioacoustical sensing platform and relay system, BIOSPAR.



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REFERENCES

[1] Richter, K.E. 1985. Acoustic scattering at 1.2 MHz from individual zooplankters and copepod populations. Deep-Sea Res. 32: 149-161.

[2] Greene, C.H., P.H. Wiebe and J. Burczynski. 1989. Analyzing zooplankton size distributions using high-frequency sound. Limnol. Oceanogr. In press.

[3] Greene, C.H., and P.H. Wiebe. 1988. New developments in bioacoustical oceanography. Sea Technol. 29: 27-29.

[4] Greene, C.H., P.H. Wiebe, J. Burczynski and M.J. Youngbluth. 1988. Acoustical detection of high-density demersal krill layers in the submarine canyons off Georges Bank. Science 241: 359-361.

[5] Greene, C.H., P.H. Wiebe, R.T. Miyamoto and J. Burczynski. In preparation. Probing the fine structure of ocean sound-scattering layers.

[6] Traynor, J.J., and J.E. Ehrenberg. 1979. Evaluation of the dual-beam acoustic fish target strength measurement method. J. Fish. Res. Bd. Canada 36: 1065-1071.

[7] Ehrenberg, J.E. 1983. A review of in situ target strength estimation techniques. FAO Fish. Rep. 300: 85-90.

[8] Wiebe, P.H., C.H. Greene and J. Burczynski. In preparation. Sound scattering by live zooplankton and micronekton: empirical studies with a dual-beam acoustical system.

[9] Love, R.H. 1971. Dorsal-aspect target strength of an individual fish. J. Acoust. Soc. Am. 49: 816-823.

[10] Love, R.H. 1977. Target strength of an individual fish at any aspect. J. Acoust. Soc. Am. 62: 1397-1403.

[11] Holliday, D.V. 1980. Use of acoustic frequency diversity for marine biological measurements, pp. 423-460. In F.P. Diemer et al. (eds.), Advanced Concepts in Ocean Measurements for Marine Biology. Univ. South Carolina Press.

[12] Wiebe, P.H., A.W. Morton, A.M. Bradley, R.H. Backus, J.E. Craddock, T.J. Cowles, V.A. Barber, and G.R. Flierl. 1985. New developments in the MOCNESS, an apparatus for sampling zooplankton and micronekton. Mar. Biol. 87: 313-323.