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The long range goal of this project has been to develop acoustical techniques and instruments for the measurement and analysis of the spatial and temporal structure of oceanic and neritic zooplankton and micronekton populations. In this particular effort, we refined, tested, and evaluated an existing prototype autonomous active acoustic system (the BIOacoustic Sensing Platform And Relay - BIOSPAR) for observation of high frequency (120 and 420 kHz) acoustic backscattering. The system was reconfigured so that it could command and control a newly developed digital echo sounder now produced by BioSonics, Inc. The system has been field tested on two cruises to Georges Bank and the Gulf of Maine.

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Final Report for ONR Grant N00014-93-1-0771.
Title.

Development of advanced volume scattering instrumentation: A bottom moored and drifting bioacoustic sensing platform and relay.

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Abstract.

The long range goal of this project has been to develop acoustical techniques and instruments for the measurement and analysis of the spatial and temporal structure of oceanic and neritic zooplankton and micronekton populations. In this particular effort, we refined, tested, and evaluated an existing prototype autonomous active acoustic system (the BIOacoustic Sensing Platform And Relay - BIOSPAR) for observation of high frequency (120 and 420 kHz) acoustic backscattering. The system was reconfigured so that it could command and control a newly developed digital echo sounder now produced by BioSonics, Inc. The system has been field tested on two cruises to Georges Bank and the Gulf of Maine.

Introduction.

The specific goal of this project was to continue the development and testing of acoustical instrumentation which will enable field studies of oceanic and neritic zooplankton and micronekton populations. The platform under development, BIOSPAR, is unique, technologically advanced system capable of deployment in a variety of autonomous modalities. During the period of this project, significant changes to the hardware and software of the system were made to make the system more energy efficient, more easily duplicateable, and less expensive. Testing of the newly configured system was performed both dockside and at sea. A recently published paper describes most of the work conducted under this project (Wiebe, et. al. 1995). A brief summary of results follows.

Hardware developments.

The refinements to BIOSPAR included:

1) The replacement of the original controller computer with a PC/104 which is a low-power DOS PC compatible microprocessor based system. PC/104 is a new

standard for industrial and embedded PC systems (Lehrbaum, 1993). It provides commercial products ideally suited for use in oceanographic data collection systems.

2) The development (in collaboration with engineers at BioSonics, Inc) of a new digital echo sounder system for integration into BIOSPAR.
3) The replacement of the original VHF and ARGOS telemetry systems with more advanced low power systems.
4) The mass storage recording system was changed to use large, SCSI interfaced, hard disks (1 gb - expandable to seven drives). These are now a reliable and cost effective media for large volume data storage in oceanographic instruments.
5) Power supply and control circuits were improved to gain greater operating efficiency and longer operational deployments. These modifications included the use of solar panels, gel-cel lead-acid batteries, and improved voltage regulators.

Software Developments.

New operational and test software was created:

1) To interface and communicate with the BioSonics intelligent transducers which use high-speed serial links for control and data communications.
2) To adapt to the new PC/104 based data collection system which provides improved PC-DOS system capabilities, extended speed specifications, advanced interface resources, and better peripheral support.
3) To support the large volume hard-disk storage media which provides a simplified interface along with substantially improved reliability and lower power consumption.
4) To improve the telemetry methods and formats in order to transmit more information through the local VHF link and the satellite link.

Field testing

Dock trials were conducted:

The dock tests were used to test the transducers, to verify the operation of the software and to determine the accuracy of returned signals based on the use of the standard ping-pong ball target. Also verified was the reliability of the software (and hardware) to cycle at the specified rate for long period of time. Telemetry was tested using VHF and satellite up-link receivers.

Two test cruises have taken place:

September/October 1993 - During the first field trial on a cruise last September/October, the system was outfitted with a newly developed BioSonics digital echo sounder which our project engineers had a hand in specifying and designing. Since we were working with a prototype piece of gear, it was a stripped down version that only was able to do echo integration. With this version we were able to show that the time series of acoustic profiles from BIOSPAR (420 kHz) matched almost exactly the time series of profiles we obtained from a down looking 420 kHz sounder in the towed body. A description of BIOSPAR as it was configured for this cruise was published in Sea Technology in 1995 - copy attached.

September 1994 - We took BIOSPAR to sea again for another test run in September 1994, but this time we had it outfitted with two frequencies (120 and 420 kHz) each capable of operating in the dual-beam mode. Multiplexing problems however limited data acquisition to echo integration. During this cruise, an experiment was conducted in the Gulf of Maine (Wilkinson Basin) in which BIOSPAR was deployed in drifting mode for a 4-day period and data were collected at 15 minute intervals. During the drift period, four grids were run using a newly constructed towed acoustic system, BIOMAPER, with respect to BIOSPAR which nominally were 1 nm on a side. In addition, MOCNESS net tows were made to ground truth the acoustic data and to provide a basis for applying the acoustic models being developed by Stanton, Wiebe, and co-workers (Stanton, el. al., 1994; Stanton, et. al., in press) to the acoustic data being acquired.

While the grant period has ended and the funds have been expended, we are still working on the analysis of the data collected during field experiments conducted in the Gulf of Maine to evaluate BIOSPAR's performance. This evaluation should prove valuable because the acoustic hardware used in BIOSPAR is interchangeable with the acoustic hardware in the towed vehicle - BIOMAPER

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New Tool for Bioacoustical Oceanography

Free-Drifting/Moored Autonomous Acoustic Platform for Long-Term Measurement of Biomass

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Zooplankton and micronekton are responsible for a significant fraction of acoustic volume backscattering at frequencies above 1 kHz (Anderson and Zahuranec, 1977). They exhibit pronounced variations in numbers and biomass in space and in time, which are due in part to behavioral activities (such as diel migration and social aggregations) and in part to larger mesoscale patterns related to variations in the physical environment. The result is substantial variations in the volume backscattering.

Changes in volume backscattering in any given biogeographic province or watermass vary on a variety of time scales ranging from daily to seasonal to yearly. While in some ocean areas the general levels of high frequency volume reverberation are predictable to some extent, for many areas—especially coastal regimes—the biological and physical factors that affect the levels are not well understood and as a result the levels are not sufficiently predictable.

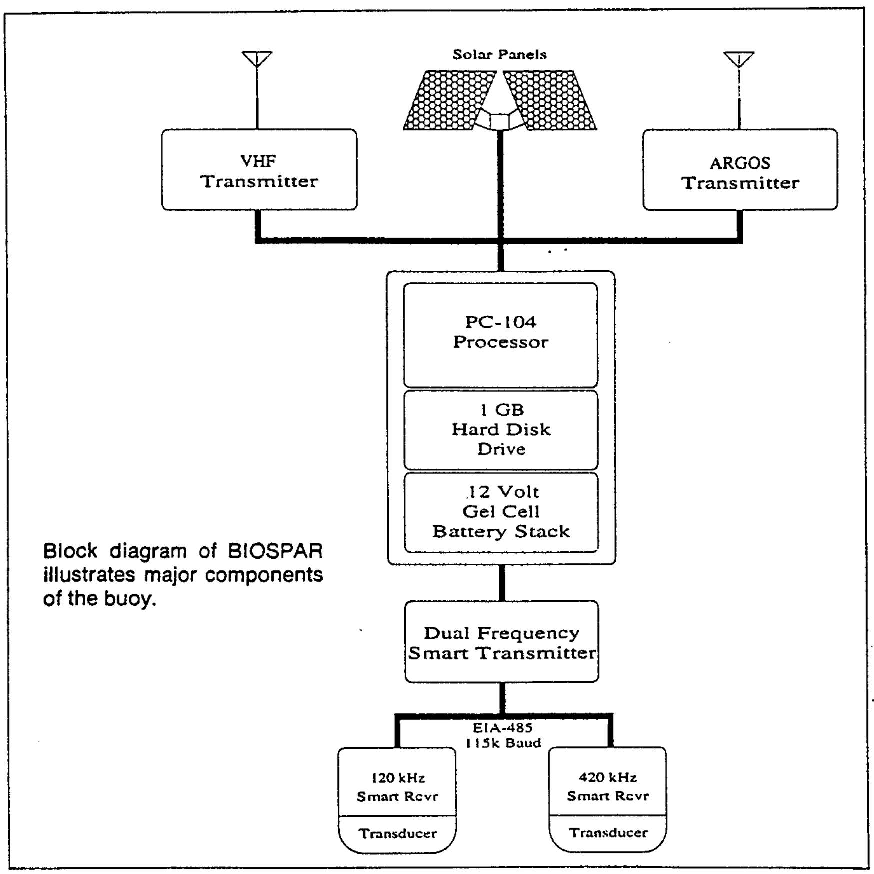
Complicating this situation is a basic problem in bioacoustics involving the degree to which volume reverberation is due to backscattering from organisms versus ocean microstructure.

There is evidence that the physical structure of the water itself may be a reverberatory source (Goodman, 1990). This is obviously a serious problem from the biological point of view since any contribution to the backscattering that is not biological in origin constitutes a source of error. It also is a problem for physical oceanographers using acoustics to visualize strong gradients and flow fields.

Inaccuracies in the visualization will occur if the backscattering sources are variable in time and space. This is especially true in regions of strong gradients where organisms tend to aggregate and important bio/physical interactions are believed to take place. Reliable bioacoustical tools and techniques must be developed to study them (Wiebe and Greene, 1994).

At the present time, however, there does not exist the instrumentation to conduct high resolution, time-series measurements of the vertical distribution of zooplankton biomass and size distribution and, to follow in three dimensions, the motion of individual biological and microstructure targets in a large ocean volume.

We have begun to address the lack



Block diagram of BIOSPAR illustrates major components of the buoy.

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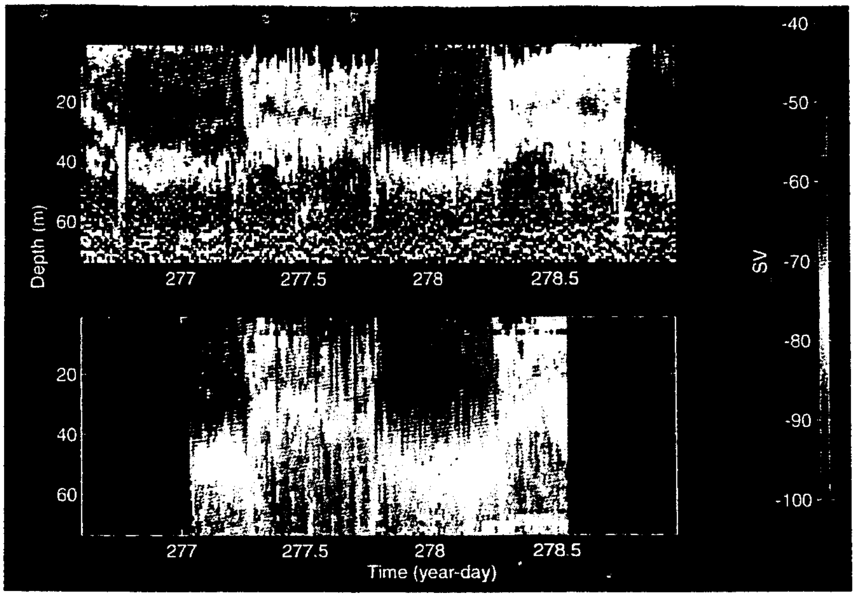


of instrumentation by constructing an autonomous free-drifting active acoustic system—the bioacoustic sensing platform and relay (BIOSPAR). The modular design consists of a two-frequency, dual-beam echosounder; a digital signal processor; mass storage; and a satellite and VHF radio communication system mounted in a spar buoy. It is capable of periodically and frequently collecting high frequency backscattering information (120 and 420 kHz) from remote locations and relaying the information to a ship or shore location in real time.

Above is time-series data collected during a 60-hour deployment of BIOSPAR in the Gulf of Maine (top). A towed fish ("Greene Bomber") equipped with a 420-kHz echosounder was operated nearby for 36.5 hours to obtain comparison data (bottom). Lower diagram shows possible deployment modalities for BIOSPAR instrumentation.

BIOSPAR Design Parameters

BIOSPAR carries two down-looking, dual-beam transducers—one operating at 420 kHz and the other operating at 120 kHz. Design parameters call for acoustically profiling the upper 50-100 meters of water column and providing estimates of backscattering volume and the target strength of individual targets down to a size less than -90 dB targets (≈3-millimeter-long plankton). From this acoustic information, estimates can be made of zooplankton biomass, density (numbers per volume of water), and acoustic size of individuals.

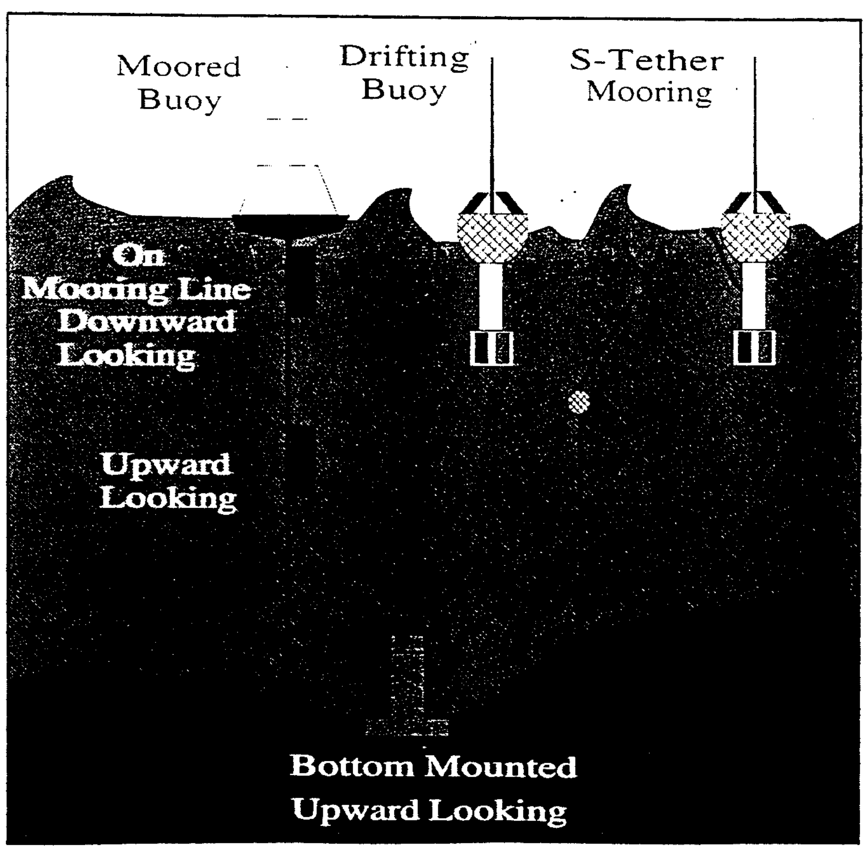
The instrument is currently programmed to collect data for 1 minute every 15 minutes; for each frequency, the data consist of individual target strengths as a function of range and average backscattering strength for each 1-meter range interval. All data are stored on mass storage units in the buoy for post-processing. Reduced data in the form of a target strength histogram and integrated intensity for 10 depth intervals at each frequency are averaged over a specified time interval —nominally 2 hours—for daily transmission to shore. Real-time VHF one-way radio telemetry is also available.

Digital Transceiver/Processing. The digital architecture in the echosounder design (produced by BioSonics) contrasts strongly with traditional analog architectures. This design allows the acoustic signal to be digitized inside the transducer unit and sent—in digital form—up the signal cable, in effect removing the effect of long cables. For certain applications using very long cable runs, the transducer signal cable should be electro-optical for less attenuation.

The acoustic signal is processed by a digital signal processor, sampling quadrature pairs at a 52-kHz rate. A broad range of frequencies is available. A unique proprietary sampling technique provides 120 dB of instantaneous dynamic range. This wide range allows simultaneous measurements of large signals from shallow fish schools that might accumulate under the buoy and small signals from individual plankton that are at some distance. The wide dynamic range also allows the system to be designed with no gain adjustments, simplifying the operation.

The time varied gain (TVG) of the system is completely digital and implemented in the analysis algorithms rather than the actual stored acoustic data. Receiver bandwidth is automatically matched to the transmit pulse length in order to achieve the optimal signal-to-noise ratio.

The programmable transmitters are mounted in a separate pressure housing and addressed individually by the PC104 system controller. The transmit pulse length is selectable and single-frequency tone burst or FM slide



("chirp") pulses can be transmitted.

The DSP in the transducer, while providing digital or matched filtering, can also provide some signal processing functions. In addition to raw digital samples communicated up the signal cable, the DSP in the transducer may be programmed to provide volume reverberation measurements via echo integration in user-selected range and time cells. Echo envelope amplitudes and range for single echoes are also sent up the cable. Future developments include split-beam implementation of the digital transducer technology as well as a variety of post-processing software.

Acoustic calibration parameters are stored in ROM in the transducer, and an on-board cable loss measurement circuit makes the system self-calibrating. Transducers may be replaced or added without degrading the calibrated system.

Acoustic sensitivity of the transducers is quite high. The 420-kHz, 3° transducer has an on-axis sensitivity at 5 meters range equivalent to a target strength of -127 dB. An additional 10 dB of sensitivity can be achieved by narrowing the bandwidth slightly and transmitting a chirp pulse.

Digital echosounder architecture is ideally suited to unmanned platforms due to low self-noise, low power requirements, high acoustic sensitivity, versatility, internal processing capabilities, and low cost.

Computer Controller. The system is now controlled by a low-power DOS-PC compatible microcomputer (PC104) programmed to collect data from a BioSonics digital echosounder equipped with two dual-beam transducer units operating at different frequencies.

Implementing Sampling Strategies. The BIOSPAR power system consists of a parallel array of 12 volt "gell-cell" type sealed lead-acid batteries, which are connected through a charging controller circuit to a set of photovoltaic solar collectors. Power is then distributed to all components in the system through computer-controlled solid-state switches, allowing precise management of the power that is used. The batteries are located in the main electronics housing. There are enough batteries to power BIOSPAR for over a month with no sunlight at all.

Power consumption was a major concern during the development of BIOSPAR. It was important to ensure that the energy consumed was less than that which could be provided on average by the surface photovoltaic solar collector system. The accompanying table describes the power consumption of the various systems in the instrument, for a typical sampling strategy based on 15-minute intervals. The total energy usage is about 5,000 watt-seconds/hour, which requires less than 2 hours of sunlight per day on average to maintain full charge of the battery packs, keeping in mind that the solar panels will generate 20 watts typically in clear weather. Battery voltage is continuously monitored by the control computer and, if the battery charge begins to drop because of long periods without sunshine, the computer will automatically skip scheduled sampling intervals until the sun returns and the batteries recharge.

Power consumption is directly linked to the sampling strategy. If more frequent sampling is required, then the on-time at each sampling interval must be reduced. BIOSPAR allows the operator to program the type of data that is to be collected by the transducer, such as single beam raw data, dual beam raw data, or processed echo-integration data. The raw data modes require much more time between pings than the processed data modes because of the data transfer rate limitations of the system. The low power computer will only accept data at a maximum serial rate of 115 kilobits/second, which corresponds to approximately one ping/second in the single beam raw data mode. The onboard DSP chip in the digital transducer will allow the unit to collect and process up to 20 pings/second in the echo-integration mode, with a relatively small amount of data to be transferred at the end of the group of pings. By selecting the processed data mode, the operator can significantly reduce the overall power consumption as well as the mass storage requirements.

In many applications the desired solution may be a mix of the two basic modes, processed and raw, to compromise power availability versus the scientific data requirements.

Data Storage. On-board data storage is one SCSI-interfaced, 1-gigabyte hard disk drive expandable to multiple drives.

Results: First Field Deployment

BIOSPAR was deployed in an earlier hardware configuration at a site with approximately 80-meter water depth on the southern flank of Georges Bank between May 21-27, 1992. The instrument, tethered to an "S" mooring, provided 120-kHz volume backscattering and target strength information in 1-meter depth intervals down to the bottom over the entire time the mooring was in place. It collected data for 1 minute every 15 minutes. They were stored on an optical disk unit for post-processing. Reduced data in the form of minimum, maximum, and average target strength and integrated intensity for 10 depth intervals at each frequency were transmitted to shore daily over a four-day period via Argos satellite. When within 5-10 kilometers of the buoy, the ship received the full complement of data in real time by VHF radio telemetry. Comparison data were collected with a 420-kHz echosounder designed by BioSonics, deployed in an Endeco Inc. towed, 5-foot, V-fin fish to evaluate the buoy's acoustical performance with that of a known instrument.

The buoy was observed in both calm and fairly rough sea conditions. The balance and stability of BIOSPAR appeared quite satisfactory. Most motion was vertical (heave) with minor tipping even in the rough seas. On most occasions, an angular offset of about 5° was observed due to the strong rotary tidal currents in the area (>1 knot). Neither the wind- and sea-induced motion nor the tidal action appeared to significantly affect the data acquisition.

The data acquired through the VHF telemetry link was converted into volume backscattering and plotted as vertical profiles versus time. A significant diel cycle was observed, which consisted of a layer of high volume backscattering residing at mid-depths (≈40 meters) during the day and moving up into the surface layer at dusk. Large transient targets appeared from time to time at mid-depth to just above the bottom, which may have been schools of herring or other larger fish.

After this first deployment, BIOSPAR was substantially modified to correct deficiencies and to improve performance. It was during this period that the BioSonics digital echosounder was integrated into BIOSPAR. The buoy was deployed in the Gulf of Maine as a free drifter for two and a half days (October 1993) with a 420-kHz smart transducer. Only echo integration data were collected. Comparison acoustic data were collected with the towed 420-kHz echosounder. The BIOSPAR data acquired through the VHF telemetry link were converted into volume backscattering and plot-

BIOSPAR Power				
System	Current (milliamps)	@ Voltage (volts)	On time Sec/hr	Energy use watt-sec/hr
BioSonics echosounder	600	12	120	864
Transmitter charge pump	300	12	40	144
Argos telemetry	450	12	42	227
VHF telemetry (optional)	327	12	160	628
Low power computer system	175	12	900	1890
1-Gbyte disk drive and SCSI	1083	12	60	780
Total Energy Use				**4532**

ted as vertical profiles versus time to provide near-real-time information, which were used to evaluate the performance of the system. Post-processing the nearly 160 megabytes of data revealed dramatic shifts in the layers associated with physical and biological processes. A diel cycle was observed that consisted of a layer of high volume backscattering residing near the surface at night and migrating to below 80 meters during the day.

Internal wave structure was also evident. The comparison towed body data, when decimated to match the exact timing of the BIOSPAR data, displayed a nearly identical pattern and agreed to within 2 dB of the overall average of the values between 10 and 40 meters depth over the 36-hour period when both sounders were operating. In spite of gale force winds and seas for much of the period, these data demonstrate that BIOSPAR operated without difficulty.

Conclusions

BIOSPAR represents the vanguard of new, technologically advanced instruments being developed in laboratories around the country and abroad for studying life in deep and shallow seas. It has the capability to be reconfigured for use in a variety of autonomous modalities. In order to take advantage of the capability to provide high-resolution, long time series or comprehensive space series, there are substantial hurdles to be overcome in areas of telemetry, processing, and storage of the massive amounts of data that instruments such as BIOSPAR are capable of producing.

There are also significant improvements needed in visualization tools and techniques in order to reconstruct images of the organism's spatial and temporal patterns. These developments, when complete, will enable researchers and managers alike to more effectively interpret complex data sets, thus leading to an enhanced understanding of the dynamics of ocean ecosystems. /st/

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Dr. Peter H. Wiebe is currently a senior scientist in the Biology Department at Woods Hole Oceanographic Institution where he has been in residence the past 25 years. He serves as chair of the U.S. GLOBEC Georges Bank Program and his principal research activities are focused on applications of acoustics to the study of the Georges Bank biological structure.

James J. Dawson has been extensively involved the past 13 years at BioSonics in the determination of market requirements and the definition of acoustic systems designs for the scientific community.

Kenneth E. Prada is a principal engineer in the Department of Applied Ocean Physics & Engineering at WHOI, where he has been since 1966. He specializes in design and implementation of computers and instrumentation systems for at-sea data acquisition and analysis.

Thomas C. Austin is a senior engineer in WHOI's Oceanographic Systems Lab specializing in underwater acoustics, signal processing, and unmanned underwater vehicles.

Dr. Timothy K. Stanton is a senior scientist at WHOI's Applied Ocean Physics & Engineering Department since 1988. His present work involves acoustic scattering processes of marine biota and the seafloor, using theoretical, laboratory, and field studies.