CRUISE REPORT: R/V SEA DIVER NAGL-98-01A JULY 9–16, 1998

Acknowledgements

We are grateful to the Captain Ralph van Hoek and the crew of the R/V Sea Diver for their help in making this a pleasant and extremely productive cruise. The cooperation and assistance of the ROV support group (Paul Donaldson, Nick Worobey and Matt Wetmore) from the National Undersea Research Center for the North Atlantic and Great Lakes (NURC/NAGL) was outstanding. We appreciate the research funding and ship time for this cruise that was provided by NURC/NAGL. Salary support came from the National Science Foundation and the Office of Naval Research. Live coverage of our cruise by ABC News via their science web site helped to convey the excitement and challenges that we experienced on this cruise to the general public.

This report was prepared by Mark Benfield, Peter Wiebe, Tim Stanton and Joe Warren with assistance from Malinda Sutor and Dezhang Chu. This cruise was sponsored by the National Undersea Research Program of the National Oceanic and Atmospheric Administration.

1.0 SUMMARY **3**

2.0 PERSONNEL **4**

2.1 Scientific Personnel 4

2.3 National Undersea Research Center for the North Atlantic & Great Lakes Personnel 5

2.2 R/V Sea Diver Officers and Crew 5

3.0 ACOUSTIC SYSTEMS **5**

3.1 ROV-Mounted Multi-Frequency Acoustic Array 5

3.1.1 Results 8

3.2 Towed Down-Looking Echo Sounder (Greene Bomber) 10

3.2.1 Results 11

4.0 CRUISE NARRATIVE **14**

Thursday, July 9, 1998 14

Friday, July 10, 1998 15

Saturday, July 11, 1998 17

Sunday July 12, 1998 17

Monday July 13, 1998 20

Tuesday July 14, 1998 21

Wednesday July 15, 1998 22

Thursday July 16, 1998 23

Friday July 17, 1998 23

APPENDIX A. EVENT LOG **25**

APPENDIX B. TOWED ACOUSTICS EVENT LOG **28**

APPENDIX C. CTD CAST RESULTS **33**

APPENDIX D. ABC NEWS WEB SITE CRUISE COVERAGE **34**

1.0 Summary

This was the first cruise of a National Undersea Research Center for the North Atlantic and Great Lakes project: "Estimating the in situ acoustic target strength distribution and abundance of diapausing *Calanus finmarchicus* and its invertebrate predators in the deep basins of the Gulf of Maine." The objective of this research was to collect *in situ* acoustic target strength measurements of the dominant invertebrate predators (the siphonophore *Nanomia cara* and the euphausiid *Meganyctiphanes norvegica*) and their prey (the calanoid copepods *Calanus finmarchicus*) in the Gulf of Maine.

The methodology involved a towed, dual-frequency, downward-looking echo sounder; and a multi-frequency acoustic transducer array mounted on the front of the MaxRover ROV. Acoustic patches were to be located with the towed system and then investigated with the ROV. In this way, we hoped to be able to collect target strength measurements from individual zooplanktors.

This research involved development of new technology and a new methodology. To our knowledge, no one had attempted to collect multi-frequency, *in situ* acoustic target strength data from an ROV. Given the complex nature of the research, we expected that much of the cruise would be spent addressing R&D and methodological issues.

The primary area of interest was Wilkinson Basin; however, the cruise was deliberately designed to be flexible with sampling conducted wherever suitable patches of plankton were located and sea states permitted ROV operations. Research was conducted in Wilkinson Basin, Stellwagen Bank in Massachusetts Bay and Cape Cod Bay (Fig. 1). In addition to ROV operations, nearly continuous, down-looking acoustic data were collected including two transects from Cape Cod to Massachusetts Bay.

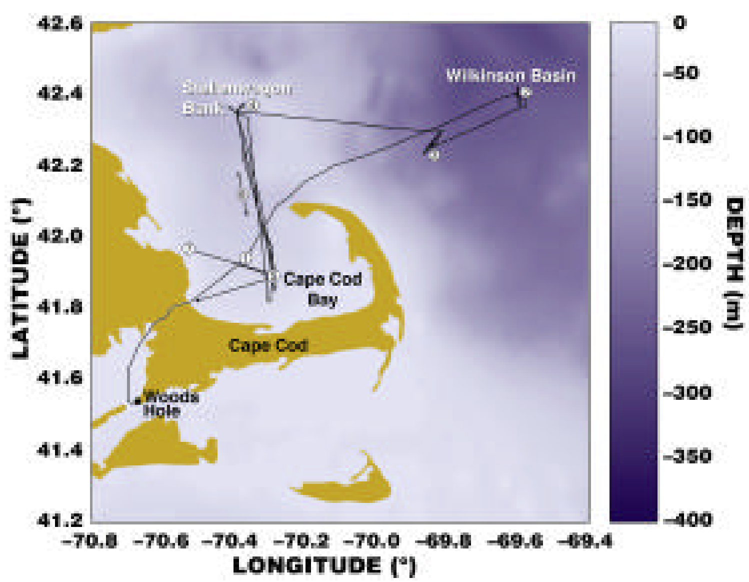

Figure 1. Cruise track for NAGL-98-01A. After leaving Woods Hole, ROV operations commenced in Cape Cod Bay ① and then shifted to Wilkinson Basin ② and ③. Increasing seas forced a move to Massachusetts Bay ④ and a subsequent return to the sheltered waters of Cape Cod Bay ⑤. Two 12 h duration, towed acoustic transects ⑥ were conducted between Cape Cod Bay and Stellwagen Bank on the nights of July 15 and 16. Final system calibrations on the ROV acoustics data ⑦ were performed near the coast on July 16. The R/V Sea Diver completed the final acoustic transect on the morning of July 17, recovered the Greene Bomber and steamed to Woods Hole for offloading.

The results of this cruise exceeded our expectations in all aspects and it can only be described as a great success. Heavy acoustic backscattering layers were located with the echo sounder. During 12 operational ROV deployments in Wilkinson Basin, Stellwagen Bank, Cape Cod Bay and Massachusetts Bay, we collected an extensive dataset of target strength measurements at three frequencies (24, 120 and 200 kHz). The majority of our data came from physonect siphonophores (*N. cara*) with some measurements from euphausiids (*M. norvegica*), medusae, and ctenophores. The quality of the data was comparable to laboratory estimates under optimal conditions. Video images of acoustic targets collected in conjunction with the acoustic data will provide estimates of the dimensions and orientations of each animal.

Our towed acoustic system provided valuable measurements of the distribution of target strengths from depth bins that were investigated with the ROV. In addition, the echo sounder was operating concurrently with the ROV during most dives. We completed two duplicate acoustic survey transects from Cape Cod Bay to Stellwagen Bank that were conducted during comparable time-frames and over the same bathymetric features. They suggest that there are persistent patches of acoustic backscatter at certain times and locations.

This cruise produced the following major results: (1) high-quality, *in situ*, multi-frequency acoustic target strength measurements coupled with video images of animal orientation from siphonophores, euphausiids and other scatterers (medusae, ctenophores and marine snow); (2) estimates of the volume scattering strength of dense concentrations of siphonophores; (3) video estimates of the concentrations of siphonophores and other gelatinous plankton; (4) confirmation of the absence of detectable scattering from marine snow and ctenophores; and (5) data for improved multi-frequency scattering models of zooplankton with gas inclusions.

2.0 Personnel

2.1 Scientific Personnel

Dr. Mark C. Benfield (Chief Scientist)
LSU Coastal Fisheries Institute
218 Wetland Resources
Baton Rouge, LA 70803
(504) 388–6372 mbenfie@lsu.edu

Dr. Peter H. Wiebe (Scientist)
Woods Hole Oceanographic Institution
Department of Biology, MS-33
Woods Hole, MA 02543
(508) 289–2313 pwiebe@whoi.edu

Dr. Timothy K. Stanton (Scientist)
Woods Hole Oceanographic Institution
Applied Ocean Physics & Engineering, MS-11
Woods Hole, MA 02543
(508) 289–2757 tstanton@whoi.edu

Dr. Dezhang Chu (Scientist)
Woods Hole Oceanographic Institution
Applied Ocean Physics & Engineering
Woods Hole, MA 02543
dchu@whoi.edu

Joe Warren, MIT/WHOI (Graduate Student)
Woods Hole Oceanographic Institution
Applied Ocean Physics and Engineering, MS-9
Woods Hole, MA 02543
(508) 289–2471 schmoe@mit.edu

Malinda Sutor (Graduate Student)
Louisiana State University
Department of Zoology
Baton Rouge, LA 70803
(504) 388–1745 msutor@unix1.sncc.lsu.edu

2.3 National Undersea Research Center for the North Atlantic & Great Lakes Personnel

Paul Donaldson (ROV Pilot)
NURC/NAGL
1084 Shennecossett Road
Groton, CT 06340–6097
(860) 405-9144 donalds@uconnvm.uconn.edu

Nick Worobey (ROV Engineer)
NURC/NAGL
1084 Shennecossett Road
Groton, CT 06340–6097(860) 405-9144

Matt Wetmore (ROV Technician)
NURC/NAGL
1084 Shennecossett Road
Groton, CT 06340–6097

2.2 R/V Sea Diver Officers and Crew

Ralph van Hoek (Master) Michael Clark (Chief Mate) Mike Schoeiller (Mate)

Peter Knight (Chief Engineer) Joe Welch (Asst. Engineer) Craig Robertson (Seaman).

3.0 Acoustic Systems

3.1 ROV-Mounted Multi-Frequency Acoustic Array

We originally proposed to mount a 5 frequency (38, 120, 200, 420, 1000 kHz) array on the MaxRover. There are a limited number of sources for broad-band, narrow beam transducers capable of operating at depth and we were unable to locate a supplier for the two highest frequencies (420 and1000 kHz). A 500 kHz transducer was obtained; however, this custom built product failed to provide adequate source levels and could not be used. Although 38 kHz is a standard fish-finding frequency, we substituted a 24 kHz system because of its operational relevance to U.S. Naval tactical torpedo systems. Thus, the array that we used consisted of three frequencies: 24, 120 and 200 kHz.

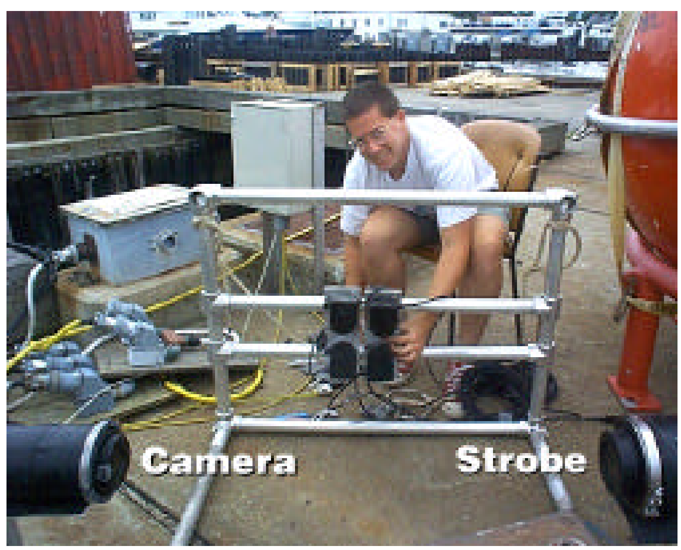

Figure 2. Proposed orientation of the video system in relation to the acoustic transducer array. Two of the three transducer pairs (120 and 200 kHz) are visible in this image. The assembly on which the transducers are mounted was to be mated to the front of the MaxRover ROV.

The transducer array was to be mated to the surface signal processing hardware via a 304 m cable. This cable proved to be inadequate because of excessive resistance and capacitance which caused it to behave as a low-pass filter. The solution to this problem was to either obtain a new cable or use a shorter section of the existing one. Due to budget and time constraints we opted for the latter option. We determined that a 45 m length would not compromise system sensitivity. While this shorter length constrained our ability to operate at depth, it was sufficient to address the broader goal of the project – integration of the array with an ROV for collection of target strength measurements.

We planned to place the transducers on a speed-rail mated to the front of the MaxRover so that the acoustic beam was aimed at a focal point located approximately 1 m in front of the transducer pairs (Fig. 2).

In addition to target strength measurements, we also needed video images of each animal. Video would provide critical information about the identity, size and orientation of each target. A Video Plankton Recorder system consisting of a camera and strobe in pressure housings was to be mounted on the same speed-rail as the transducers so that its image plane was orthogonal to the acoustic beam and centered on the acoustical focal point (Fig. 2). In this configuration, video could be triggered by each acoustic ping to obtain an image of each target.

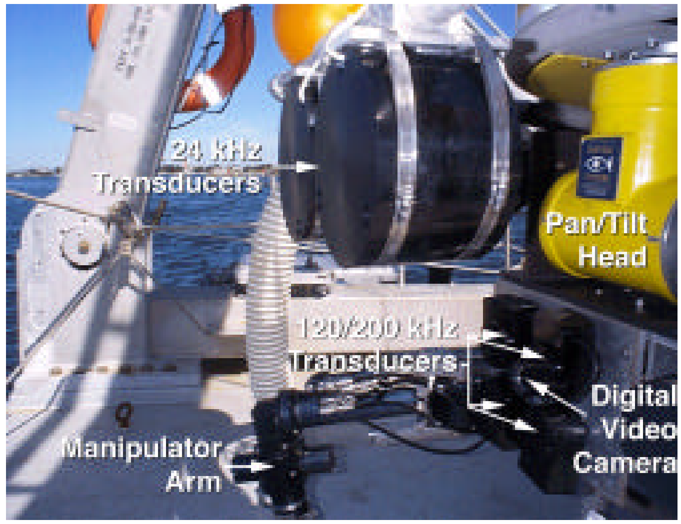

Figure 3. Initial configuration of the acoustic array and video camera on the front of the MaxRover. The camera is aimed in parallel with the transducer pairs and the center of the video image intercepts the focal point of the 120/200 kHz transducers.

With the arrival of the MaxRover, it became evident that the weight of the video/strobe system coupled with its distance forward of the front of the ROV would create ballasting problems during deployment and recovery. Although we did not know it at the time, later experience proved that such a configuration would also have resulted in problematic acoustic returns from the side-lobes of the transducers.

The ROV was equipped with two video cameras. We decided to utilize one of these – a color digital video camera – as a substitute for our VPR. We modified our configuration so that transducers and camera both faced forward with focal points of the 120 and 200 kHz transducers coincident with the center of the video field of view (Fig. 3). Both the 120/200 kHz transducers and the video camera were attached to the pan/tilt head of the ROV. The 24 kHz transducers were mounted above the 120/200 kHz pairs on a fixed frame (Fig. 3). Their broader beams had a focal point slightly above and forward of the 120/200 kHz pairs.

This configuration was tested in the Woods Hole Harbor using standard targets and appeared to function properly. Side-lobes from the 120 kHz transducer were producing returns from the remote manipulator arm on the ROV; however, since this was fixed in place, the returns were constant and could theoretically be subtracted from the data. When the system was tested operationally in Cape Cod Bay, it became evident that the turbulence in the water was changing the side-lobe returns. Each echo was slightly different and therefore, could not be subtracted as a constant. For this reason, the system underwent a third, and final modification. All three transducer pairs and the digital video camera were moved forward and the manipulator arm was stowed behind them. This configuration (Fig. 4) worked without further problems.

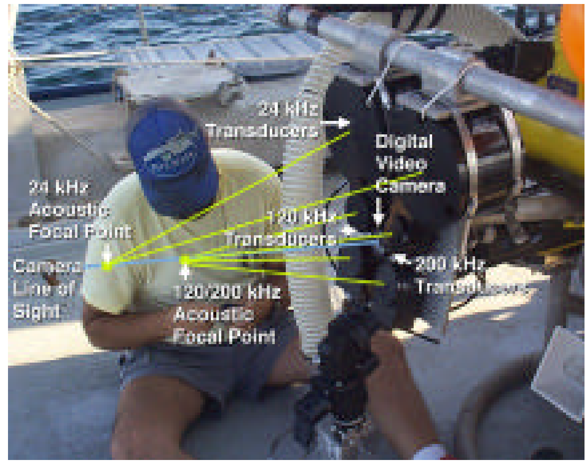

Figure 4. Modifications to the transducer mounting pattern on July 12 resulted in this forward looking arrangement. The acoustic focal points of all three frequencies coincided with the optical line of sight of the digital video camera.

The field of view from the digital video camera was determined by mounting a calibration reference in front of the camera at the distance of the acoustic focal point. Video was collected of this target while the system was submerged and calibrations were collected from frame-grabbed still images (Fig. 5). The field of view of the camera was 736 mm wide x 552 mm high. The depth of field could not be accurately determined underwater, but appeared to be fairly deep.

The data acquisition system used on this cruise consisted of two independent acoustic and video acquisition systems that were run concurrently and linked with a true test logic (TTL) sync signal. This sync signal is controlled by the PC and is linked via BNC cables to all systems.

The acoustic system was controlled by a custom Visual Basic computer program (written by Bob Eastwood and Dezhang Chu). This program controls a Analogic Polynomial Waveform Generator (WG), which produces our waveform signal, and a LeCroy Digitizing Oscilloscope, which records our received echo signal.

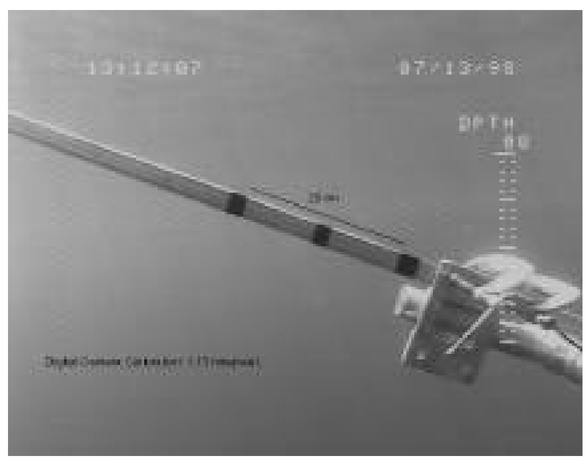

Figure 5. The reference target viewed through the digital video camera that was located between the 120 and 200 kHz transducers. This image has a scale of 1.15 mm·pixel^{-1}.

All waveform parameters (pulse duration, frequency, chirp rate) were set in the Visual Basic program. They were transferred via a General Purpose Information Bus (GPIB) interface to the WG, which produced an electrical voltage signal. This signal was amplified by a ENI power amplifier, and then run through a simple switching box to determine which "transmit" transducer it will power. The signal was then scattered in the water column and was subsequently detected by the "receiving" transducer. The electrical signal was run to a battery powered Panametrics amplifier, next to a KleinHeist high pass filter, and then through a RiTec combination filter/amplifier. Finally, that processed signal was received by the oscilloscope.

An average of the background noise was taken for each acoustic data acquisition setup. That background noise was then subtracted from the received echo "on-the-fly" within the oscilloscope. The oscilloscope displayed the processed echo on the screen, and the Visual Basic program also displayed a copy of the echo on the PC screen (as well as storing it on the hard drive of the PC).

The timing of all this was controlled by the waveform generator's sync signal which was also run (via a BNC T-connector) to the sync input of the video acquisition program. The MuTech MV-1000 was the frame grabbing board used, and the MvSeq program for Windows was the interface to control it. Parameters within the program can be set to select the camera used, internal or external sync, and number of frames to be grabbed. The "grabbed images" were stored on the hard drive in a user-selected format. Once the frame grabbing program was set up and started, the Visual Basic program was run concurrently. This allowed us to capture video images at the same time as the acoustic echo was acquired.

3.1.1 Results

We mounted 24 kHz acoustic transducers, as well as 120 kHz, and 200 kHz transducers and a digital video camera on the ROV. This integrated acoustics/optics configuration allowed us to identify the animals as they passed through the acoustic beam. Thus, we had co-registration of target strength data and species. This type of measurement is important as it was done *in situ* and provided a critical connection between controlled laboratory measurements and field surveys.

The measurements were quite revealing, especially for the gas-bearing zooplankton (siphonophores). As we have indicated in prior publications, target strengths of siphonophores as measured in the laboratory (1 m depth) were quite high. However, we did not have much evidence as to the gas content of the animals when they were at their natural depths. At deeper depths, do they shrink or do they generate gas so as to maintain a constant diameter of gas inclusion? While this question remains a topic for active research, our *in situ* target strength measurements show significant echoes from these animals at all of our depths (5–25 m) confirming the prediction that these animals can be significant sources of reverberation in the ocean.

Reverberation is a source of noise in torpedo systems. If there is a highlight in the echoes above a certain threshold, then that highlight could be interpreted by the system as the target of interest. For torpedoes, that threshold is at about -70 dB (volume scattering strength). For one animal per cubic meter with a target strength of -70 dB, then the echo from that animal would be at the threshold. The numerical density of siphonophores in the areas we studied was frequently at one per cubic meter. Our *in situ* measurements revealed target strengths at 24 kHz to be in the range -60 dB to -55 dB, putting the animals well above the torpedo threshold. A several-hundred-meter-long patch of these animals (which is common) could cause a significant false alarm in a Navy system.

This prediction of false alarm is consistent with observation of highlights in the data from torpedo runs in this general area. The data had unusually high levels that could not be explained by her reverberation model that included only the bottom and surface reverberation. The spike in the data occurred in a region where there was a very strong thermal gradient (a condition conducive to the presence of siphonophores and other zooplankton). Given the general absence of fish in that area, the false target could very well have been a layer of siphonophores.

It is well known that gelatinous animals such as siphonophores are under-sampled by conventional sampling techniques (nets). Nets typically destroy these animals and a net tow will generally not yield a representative number of animals. This was certainly true in our region. Using the ROV camera, we consistently observed roughly one siphonophore per cubic meter in these scattering layers. However, our net tows (vertical, horizontal, and oblique tows) yielded few, if any, siphonophores! There are two important facts that need to be pointed out: (1): at these lower acoustic frequencies, the scattering by the gas inclusion tends to increase due to the resonance of the bubble ("in spite" of the fact that the wavelength is much longer than the dimensions of the bubble); and (2) at these lower acoustic frequencies, the scattering by animals "not" containing gas tends to reduce to insignificant levels "because" of the fact that the wavelength is much longer than the dimensions of the animals. Combining these two facts — at the lower frequencies — the only discrete targets that are detectable are the ones containing gas such as siphonophores. Thus, the lower end of high frequency acoustics can be used to detect animals that are otherwise grossly undersampled by conventional methods!

Thus, the importance of sound scattering by siphonophores appears to have been underestimated by the oceanographic community. When large scattering patches are observed and the scattering levels are high, the patch is quite often dismissed as a fish school. That tends to propagate a general misunderstanding about the various sources of reverberation in the ocean. When correlation between net tows and acoustic surveys is attempted, the siphonophores that may be present, and contributing to the echoes, may not actually be caught due to their fragility. The echoes will then be attributed to whatever else is caught in the net or be attributed to fish that avoided the net.

With respect to the siphonophore targets, we are continuing the development of laboratory methods to study the resonance scattering of the siphonophores. The first version of a prototype source has already been constructed and tested this summer by graduate student Lieutenant Ben Reeder. This broadband source will help to provide basic information on the physics of the scattering near resonance (damping of the tissue is a major physics issue). Once the physics of the scattering near resonance is understood, then field versions of the system can be used for resonance classification. A manuscript describing the data collected during this cruise (In-situ target strengths of siphonophores) is currently in preparation for submission to the ICES Journal of Marine Research.

With respect to smaller targets, a higher frequency (420-500 kHz) source will be required for inclusion on the array. We are working to secure such a device so that *Calanus finmarchicus* and other similarly-sized organisms (e.g.pteropods) can be studied.

3.2 Towed Down-Looking Echo Sounder (Greene Bomber)

The down-looking acoustics system consisted of a chartreuse, five-foot V-fin towed body (the Greene Bomber), a Hydroacoustics Technology, Inc Digital Echo Sounder (HTI-DES), several computers for data acquisition, post processing, and logging of notes, plus some other gear. In the Greene Bomber (Fig. 6), there were two down-looking transducers (120 and 420 kHz each with 3 degree beams), a multiplexor pressure case for multiplexing the data from the two transducers, and an Environmental Sensing System (ESS). The ESS was mounted inside the V-fin with temperature, conductivity, and fluorescence sensors attached to a stainless steel framework outside of the fiberglass housing. A downwelling light sensor was attached to the tail. The fish was also carrying a transponder that would have proved useful in locating it if it had happened to break free of the towing cable. The tow-body was deployed from the port quarter of SEA DIVER and collected data both during and between stations. The general towing speed was about 4.5 kts.

In the lab, the data came in on a single 24 conductor cable with separate shielded groups of wires, one for each transducer and one for the ESS. The HTI-DES has its own computer (a PC104-80486 -100 MHz) and five digital Signal Processor boards (DSPs). It received the data from the transducers after passing through the (now infamous) MUX pressure case, did a series of complex processing steps, and then transferred the results to the Pentium PC over a local area network (LAN) where the data were logged to disk and displayed. Attached to the LAN were a HP Laser Jet 4 black and white printer and a Tektronix 220i color printer. Immense amounts of data were handled very quickly by this system.

Figure 6. The Greene Bomber is a V-fin towed body equipped with a dual frequency (120 and 420 kHz) down-looking echosounding system and suite of environmental sensors.

The environmental data came into a second PC and were processed, displayed, and logged to disk. Both systems required GPS navigation data and those data were being supplied by a Rockwell Jupiter GPS receiver which were logged as part of the ESS data stream. Periodically, the data were transferred to a third computer for post-processing. It was at this stage that we could visualize the acoustic records and begin to see the acoustic patterns which were characteristic of the Wilkinson Basin, Cape Cod Bay, and Massachusetts Bay.

To enable easy cross-correlation between the data files from the two computers recording the data, a log was kept of the start and end of the computer files along with comments about the files that are intended to assist in the post processing of the data (Appendix B).

3.2.1 Results

Conditions for conducting an echo sounder survey of the Wilkinson Basin, Massachusetts Bay, and Cape Cod Bay were ideal during a good portion of this cruise. There was very little wind and the seas were mostly 1 to 3 feet. We did however, have some electrical problems that degraded the quality of the data being collected. An intermittent problem developed shortly after we started echo sounding which involved frequent, but variable dropouts of the transmitted/received pings. The problem was more acute when we simultaneously used both frequencies. Considerable time was spent trying to identify the source of problem and the problem was finally isolated and fixed when, after by-passing the MUX bottle circuitry located in a pressure housing in the Greene Bomber, the signal was restored to design specifications. This occurred on day four of the cruise while anchored at the Cape Cod Bay station location.

Acoustic measurements with the HTI-DES consisted of along-track and time-series echo integration and on station target strength (TS) measurements. Prior to the MUX by-pass surgery, the quality of the data was significantly degraded; however, it was still possible to see the pattern of vertical layering in the upper 200 m of Wilkinson Basin and to gain some measure of the patchiness in distribution of the acoustic scatterers.

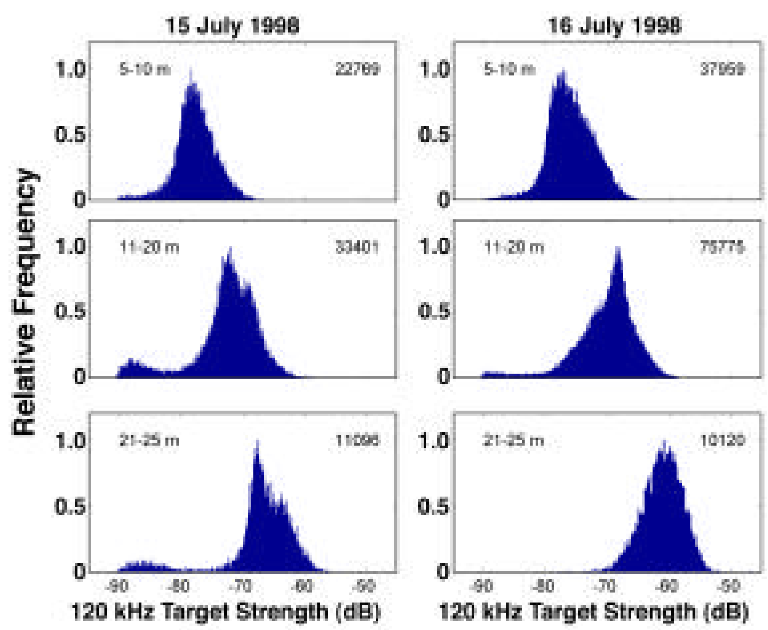

Figure 7. Target strength measurements made with the 120 kHz transducer at the Cape Cod Bay station on two consecutive days (YD 196 and YD 197).

During periods when

acoustic measurements were being made from the ROV, the HTI-DES was programmed to collect both echo integration and TS measurements (Fig. 7). These data will be used to make an inter-comparison between the TS distribution between the two acoustic systems. The pattern of target strength distribution was repeatable between days. Smaller TS were present in near surface waters and larger values were observed at depth. Some of the change in TS distribution towards larger sizes may have been due to the threshold noise levels increasing with depth, but most of the changes seem to be real with larger individuals being deeper in the water column. At each depth, several size modes were evident in the TS distribution. At each depth the TS distribution was shifted towards larger individuals on day 2 relative to the first day. Based on the acoustic and video observations made from the ROV, many of the TS values were made by the pneumatophores of siphonophores (*Nanomia cara*) that were very abundant throughout the region.

During the evening, after the ROV operations were completed, a survey of the region between Cape Cod Bay and Massachusetts Bay was done on two successive days (15 and 16 July 1998). The trackline was about 50 kilometers long and began in the very shallow waters of Cape Cod Bay. The first survey started before sunset and an upward migration of a scattering layer was observed along the first acoustic section (Fig. 8a). The scattering layer was most intense in a region just south of a large ledge of rock that separated the two bays. On the return leg of the first survey which took place between midnight and dawn, the scattering layer that had been at the surface was located at intermediate depths long before sunrise (Fig. 8a). This feature was repeated on the second survey that started about 2 hours later than the first. On the second survey (Fig. 8b), the scattering layer had already completed the upward migration and was already at the surface, and much of the deeper water column in Cape Cod Bay had relatively low volume backscattering levels. This region had begun to fill with heavier volume backscattering during the return leg on the second survey, again well before dawn (Fig. 8b).

In Massachusetts Bay, strong volume backscattering at the surface was patchy. The mid-water column had much lower levels of backscattering and there was a layer of strong backscatterers remained at depth just above the bottom on both nights.

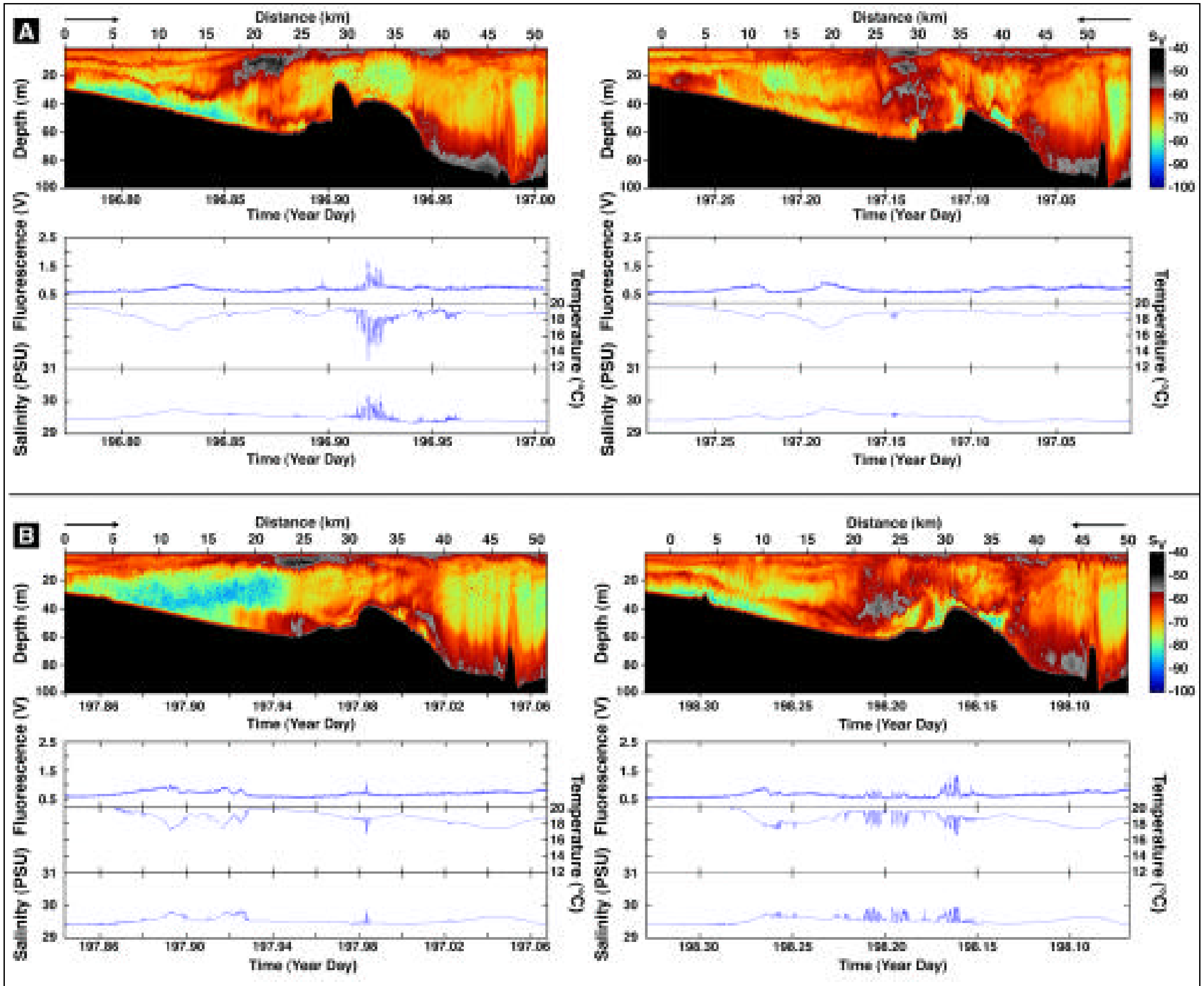

Figure 8. Volume backscattering patterns along transects made from Cape Cod Bay to Massachusetts Bay west of Stellwagen Bank during the evening hours of YD 196/197 and 197/198. Top Panel A illustrates the Cape Cod Bay to Massachusetts Bay transect on July 15/16. The left panel is the outbound transect (arrow indicates the direction of travel). The right panel is the return trip and it has been flipped horizontally for comparison of bathymetric and scattering features. The lower panels B illustrate the second transect on July 16/17.

4.0 Cruise Narrative

<u>Thursday, July 9, 1998</u>

The R/V Sea Diver arrived at Woods Hole at 0800. Peter and I inspected the lab space and found that there was tight, but adequate room for all our hardware. The deck of the Sea Diver was very crowded by the MaxRover and its umbilical cable plus the ROV control van. We arranged for the NOMAD davit system (used for launch and recovery of the Greene Bomber) to be brought down from storage for mounting on the Sea Diver. Inspections of available space suggested that the available space on the starboard side (forward of the ship's articulating crane and aft of the science van) could be a problem given the dimensions of the davit.

During the previous afternoon, Peter, Malinda and I had connected the transducers and associated electronics to the Greene Bomber and completed a dip test. That test confirmed that (1) the noise levels were improved relative to the last cruise, but not as much as Peter would have liked; and (2) that the transducers could see the bottom of the well at about 16m. In the morning, the environmental sensing system (ESS) was initialized and operational. Next, Peter and Malinda suspended three reference targets beneath Greene Bomber so that the two transducers could be calibrated. The results were not encouraging. Although the targets were visible at the correct depths on both transducers, the target strengths did not match theoretical values (Table I).

Table 1. Measured and predicted target strengths of three reference targets beneath the Greene Bomber on July 9, 1998.

Reference Target	Depth Below Transducer (m)	Expected Target Strength (dB) 120 kHz	Expected Target Strength (dB) 420 kHz	Measured Target Strength (dB) 120 kHz	Measured Target Strength (dB) 420 kHz
21.2 mm Tungsten Carbide Sphere	5		-43.7		-46.8±1.6
Ping-Pong Ball	6		-42.0		-40.9±3.2
38.1 mm Tungsten Carbide Sphere	7	-39.5		-44.3±0.4	

While the Greene Bomber was being calibrated, I arranged to have plywood cut to cover the countertops in the lab so that our tie-downs would not damage the benches on the ship. I also started writing some of the introductory text for the first ABCNEWS.com article. Tim, Chu and Joe began to attach the speed-rail frame for the array to the front of the MaxRover. The weight of the VPR and its distance from the front of the ROV proved to be problematic. The heavy pressure casings of the VPR and strobe would have caused the ROV to lean forward at an acute angle during launch and recovery. The VPR also created another problem. Slight shifts in its orientation would have required re-aiming in a water tank. The distance between the strobe and camera (7 feet) meant that we needed to place a large tank on the ship for re-calibration. There simply wasn't room for the tank so I planned to contact ESL to see if they had a trough that would work.

Meanwhile, the NOMAD davit arrived and it became clear that it wouldn't fit in the space available. Its weight would also create ballasting problems for the ship. It turned out that the ship's articulating crane was sufficient to handle the Greene Bomber which obviated the need for our davit. Several other fortunate events followed.

We decided that the cameras on the ROV might substitute for the VPR. If we could use the high-magnification camera then there would not be any need for the VPR which would eliminate both the trim problem and the need for a calibration tank. I reviewed some tapes from the previous mission and it appeared that the high-magnification camera might work. We'd need to know the width, height and depth of field of the camera, in order for animals to be measured. The use of the ROV camera meant that we'd need to send an additional video feed to our lab so that Tim's group could communicate with the pilot. It turned out that the best solution was to co-locate Tim's acoustic group with the ROV team in the ROV van. Paul had space and Chu and Joe started moving in. This freed up some room in the science van that it turned out, was in short supply.

Another fortunate break was the decision by Paul Donaldson that the ROV could be deployed at night. This may have been due to the short cable that we were going to use and consequent shallow depth. Night operations were considered very desirable because the siphonophores might only be accessible at night due to their vertical migration behavior. We might also be able to attract other targets to the array with the ROV lights.

The remainder of the day was spent moving the Greene Bomber acoustics hardware and various other computers into the science van. By about 23h00 we had the acoustics acquisition gear on board and secured. The mounting hardware for Tim's acoustics system was nearly completed and we planned to conduct a dip test in the morning. Our sailing time was revised to 12h00 on Friday.

<u>Friday, July 10, 1998</u>

In the morning we finished mounting the three pairs of transducers on the ROV. The 120 and 200 kHz pairs were mounted on the ROV pan/tilt head. A speed-rail on the front of the ROV supported a pair of 24 kHz transducers that were aimed forward. The focal points of the 120/200 kHz transducers were adjusted so that they were coincident and centered on the screen of the digital video camera. Targets were in the horizontal/vertical plane of the transducers when they were centered on the screen with the pan/tilt set to 0° elevation and 0° azimuth. The 24 kHz transducer pair produced a fairly wide beam so that they did not have a well defined focal point. Instead, we opted for a point 1 m in front of the mid-point of the two transducers. The pan/tilt head still had to be moved so that it was aimed at that point.

The ROV was deployed for a test dive off the fantail of the ship after lunch. The launch went smoothly and the video images were clear. Unfortunately, the system was overloaded with noise. Whenever the thrusters were activated, a strong spike with a signal of 500 kHz was generated. This was particularly problematic for the 200 kHz system. Overall levels of noise were unacceptably high. Relative the Tim's laboratory tests, deployment in a tank on the WHOI dock resulted in an increase of noise and loss of sensitivity. Once the system had been integrated with the ROV, this degradation was so severe that it was not considered likely that the system could be used operationally. In addition to the broad-band noise, there was also strong spiking with a frequency of 120 Hz. The latter suggested that the noise was associated with some power rectification source — perhaps the UPS system.

We made a reference target by gluing some rulers to plexiglass and mounted this target on the frame so that it was centered on the camera. The frame-grabber captures a 640 wide x 480 pixel high image. This image was calibrated by measuring the dimensions of the horizontal ruler (222 mm) and the height of the plexiglas bracket (175 mm). The results indicated that the scale was 1.14 mm per pixel.

In an attempt to eliminate the noise, Tim's group installed some hardware filtering systems. This was only partially successful. When they isolated their system using a line from shore power, the noise level dropped substantially. That suggested that the source of the noise was the ship. Whenever the video feed from the ROV control van was connected to Tim's system, the level of broadband noise increased substantially. Further, by selectively shutting down various breakers in the ROV van, the noise level could be reduced. Unfortunately, these breakers were associated with critical systems.

Paul noted that a ground fault interrupt breaker was tripping whenever he powered on his system and that this problem began after Tim's electronics had been installed. A ground fault would explain much of the problem. The problem was that it was after hours at WHOI on a Friday. We really had a stroke of luck when Tim discovered that Ned Forester (a Senior Engineer at WHOI) was working late on a problem with an AUV. Ned has a wealth of expertise diagnosing hardware problems and we couldn't have found a better troubleshooter.

Ned spent several hours isolating the problem and his findings suggested that the metal ROV van was an extremely "dirty" environment from an electronic perspective. Peter and I had another look at the space in our science van and decided we could accommodate Tim's group if we used our space more efficiently. The move would have been useless, unless the science van was substantially less contaminated by noise. Chu and Joe brought in an oscilloscope and discovered that the science van was as bad as the ROV van. We started looking for the sources of electrical noise by shutting down various breakers and systems. The culprit turned out to be the ship's UPS and an adjacent power supply. These were non-essential systems and once they had been shut down, the lab power was fairly clean. There was still some spiking with a frequency of 120 Hz but that was better than the current situation in the ROV van. The last information we gained before Ned left was that the ship had a spare transformer in storage that could be rigged up to supply us with clean, isolated ac power.

By about 21h00 we began to move Tim's equipment into the science lab. That move took most of the evening and by 01h30. All of their systems were tied down and ready for use. We scheduled a departure for 08h00 and planned to install the isolated ac line from the transformer in the morning. Everyone went to sleep between 01h30 and 02h00.

Saturday, July 11, 1998

Our 08h00 departure was delayed by the resignation of our cook. He left the ship on short notice for personal reasons leaving us stranded on a weekend with little hope of finding a replacement. We checked the possibility of replacements with personnel at WHOI and I walked over to the R/V Albatross at NMFS. Tim took the opportunity to look for a video isolation transformer. Meanwhile, Jay Dufur from WHOI was kind enough to come to the ship on a Saturday morning to install a new power line from an isolation transformer. That system effectively isolated the power to the acoustic acquisition systems from all other power consumption on board. It became clear that we were not going to find a replacement cook and the Captain decided that we would not starve. At 10h30 when the power supply was installed, we departed from Woods Hole for the Gulf of Maine/Cape Cod Bay via the Cape Cod Canal.

A safety briefing was completed after lunch at 12h30 and we decided that we would seek sheltered water for our first deployment. After that, we planned to place the Greene Bomber in the water and look for target patches. By 15h00 we were on station in Cape Cod Bay (41° 54.657 70° 23.304) where the water was flat calm and there was sufficient depth for us to check out the acoustic systems in situ.

The ROV was deployed in a short time and by 15h20 we had video of the surface waters of Cape Cod Bay. There were lots of bubbles from the ship's wake but no visible animals. Tim/Chu/Joe started looking at system noise levels while the transducers were passive and the levels were comparable to those measured in the lab. This was excellent news. Once they switched their systems to active mode, noise levels remained very low.

We deployed the Greene Bomber in water at 41° 56.02N –70° 22.25W at 18h45. It appeared to tow very well from the ship's articulating crane that was located on the starboard side, just aft of the science van. Initial noise levels looked higher than Peter expected. We began a slow 4.5 knot steam towards station 1. After some time, it was apparent that the system was missing certain pings. The oscilloscope trace showed the bottom return on some pings, but others were flat. The net result was that the echogram, which shows averages of 30 pings, contained drop-out areas where many missed pings contributed to greatly reduced scattering. This drop-out problem continued through the evening and during that time, Peter worked to try and diagnose/document the malfunction.

Shortly before 20h00 I established a cellular modem connection to the Internet and transferred 7 images and a report to ABC News. The signal strength was good; however, the connection was slow (4800 baud) and it required approximately 15 minute to transmit all the data. Tim, Chu and Joe examined some of the data collected during the check-out dive and we all turned in before midnight.

Sunday July 12, 1998

We woke up at 06h00 and arrived on station 1 (42.40, 70.37) at about 07h00. We jogged on station until each group was ready for the days operations. Peter's system was still operating intermittently, but provided us with a picture of the pattern of scattering. During the night, the Greene Bomber revealed a long patch of elevated scattering at 120 kHz located between 3-30m depth (Fig. 9). At the dive site there was a moderate layer of scattering at about 3-5m, and a strong layer at about 135m that may have been siphonophores. The shallow layer looked promising because it allowed us to operate the ROV with some horizontal slack in the tether, thus permitting more (but limited) horizontal maneuverability.

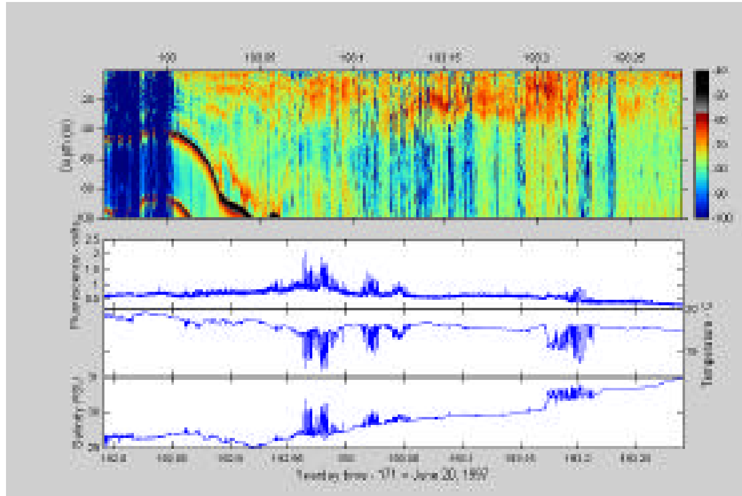

Figure 9. Volume backscattering at 120kHz along a transect from Cape Cod Bay (left) to mid-Wilkinson Basin (right). The elevated scattering between 3-30m was probably due in part, to siphonophores. The vertical lineations with low volume backscattering are drop out due to a system malfunction.

At 08h30 Malinda and Paul conducted a CTD cast with the SeaBird SBE19 profiler. The system was set for internal logging and was deployed from the fantail. The results indicated that this area was well stratified with a lens of warm water in the upper 50m over colder and saltier Maine Deep Water.

The ROV was deployed at approximately 09h45. A patch of scattering was centered around 3-5m depth; however, internal waves resulted in a vertical shift of ±5 m. Paul put the ROV down and we immediately started to see siphonophores. Prior to ground-truthing the patch, we had speculated that the patch was comprised of pteropods while the deep layer was siphonophores. This really helped to emphasize the importance of ground-truthing acoustic data and the risk of over-interpreting returns based on prior experiences.

Initially, Tim felt that the density of animals was too low for his team to start recording echoes; however, as he started to see echoes, they began recording data. Some kind of ghost echo was present on the 120 kHz system and he needed to look at the frame to see what might be causing it. This may have been due to the side-lobes of the transducer striking something on the frame. After almost 2 h, they completed data collection and requested recovery of the system. This dive was useful because it indicated that the 24 kHz system was performing very well with extremely low noise levels. No echoes appeared to have been collected at 24 kHz. The side-lobe issue needed to be addressed. The ROV was recovered at 14h00.

Once the ROV was recovered, we steamed towards a point NE of Provincetown that was inside of the 100 fathom isobath and outside of the shipping lanes. Tim worked to re-configure the transducers so that the 120/200 kHz pairs were just below the 24 kHz pair. The required construction of a new bracket. This configuration was far superior to the previous modification, and ironically, was very similar to what we proposed to construct! The three pairs of transducers sat facing forward with the acoustic focal points of the 120/200 kHz pair coincident. The line of sight of the digital camera was centered on the focal points of the 120/200 kHz transducers. The 24 kHz transducers were also oriented so that their beams coincided with the digital camera line-of-sight at a distance of 100 cm from the front of the transducers.

At 1820 Malinda conducted a CTD cast to 210 m. The results indicated that the area was well stratified with conditions that were similar to the previous cast. The ROV was deployed at 19h08 into waters that were teaming with siphonophores, medusae, ctenophores, gymnosome pteropods and marine snow. The acoustic systems were collecting echoes from almost every ping. Data indicated that the new transducer configuration had eliminated the side-lobe problem. It was an outstanding opportunity to collect data; however, all was not perfect.

Prior to the dive, the video lights had been re-configured to try and maximize the illumination. During the dive, the illumination levels were not sufficient for Joe to effectively see the siphonophores that the transducers were targeting. After examining several of the frame grabs that corresponded to apparently good echoes, it was clear that the level of illumination was inadequate. Tim finished tests to confirm that the side-lobe problem had indeed disappeared and then the ROV was recovered so that the lights could be re-aimed (Fig. 10). After 30 min the ROV was back in the water and the illumination was improved, but still not as bright as we had hoped. Nonetheless, it was workable and the dive proceeded.

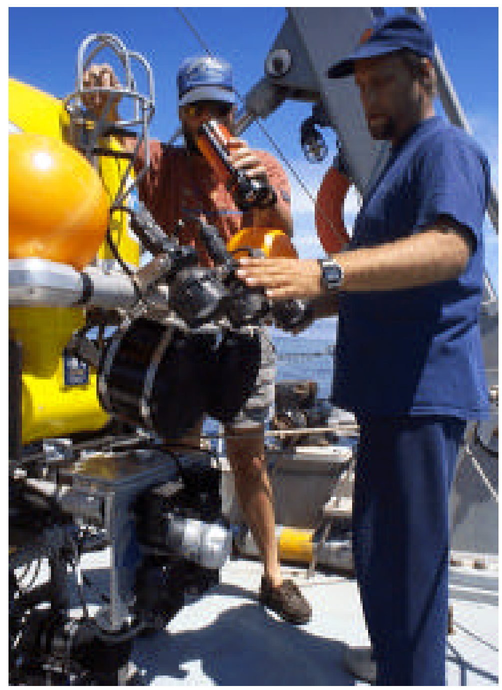

Figure 10. Acoustic and video configuration used for night dive on July 12, 1998. The only difference between this configuration and the schematic on Fig. 4, is the orientation of the lights above the 24 kHz transducers.

During the next 3 hours, Tim, Chu and Joe collected a large volume of acoustic and video data. The initial approach was to collect both video and acoustic data simultaneously. This limited the rate at which pings could be transmitted to 0.2 Hz. After Tim had judged that a sufficient quantity of data had been collected, an alternative strategy was initiated. A sequence of 10 video frames and acoustic pings were acquired. This allowed the timecode on the acoustic computer to be synchronized to the time-code on the video. Thereafter, the acoustic system operated without grabbing video frames with the understanding that the video data could be post-processed from tape to collect the images that corresponded to each ping. In this acoustic-only mode, data could be collected at 1 Hz. At 23h24, the ROV was recovered.

The data collected on the 120 kHz frequency appeared to be excellent. The 200 kHz transducer was still plagued by a noise problem; however, it may be possible to eliminate that interference via post-processing. Tim planned to try and collect 200 kHz data at a later point. The 24 kHz transducers were not indicating any targets even when the water was full of bubbles. This suggested a failure in the 24 kHz system. We stowed the gear and went to bed.

Monday July 13, 1998

Most of us slept in a bit later than usual. Once again, the weather and sea state were optimal. Joe spent the morning diagnosing the 24 kHz system fault. He identified a faulty cable connection that was replaced. Tests made by tapping on the transducer produced a signal. The next dive was to be used to test the system. Joe and I also installed an optical calibration target in front of the digital video camera. We mounted a ruler in front of the lens at a distance that corresponded to the focal point of the 120/200 kHz transducers.

After lunch, a whale was sighted near the ship and it swam directly beneath the Greene Bomber. Coincidentally, we saw a single high backscatter bin at depth of about 15m on the echogram.

The day's dive operations began at 12h45 with a CTD cast to a depth of 210 m. The profiles indicated that the water conditions have not changed substantially. A layer of fresher and warmer water extended to a depth of approximately m and overlay a layer of cold salty water. What was interesting was that temperature appeared to change as a series of steps in the upper layer. We have observed a distinct banding pattern in the scattering that may coincide with this thermal stepping.

The ROV was deployed at 13h12 for a short dive designed to estimate the scale of the video field and to test the slurp gun. The scale had not changed much (1.15 mm/pixel) from the previous measurement (1.14 mm/pixel).

Following the calibration dive, we redeployed the ROV for data collection. Siphonophores were abundant in the water column and the 24 kHz transducers detected intense volume reverberation. In addition, many echoes were detected for individual siphonophores. Once again the dive was highly successful with large numbers of measurements collected for both the 120 kHz and 24 kHz frequencies. The ROV was recovered after 17h00 and we conducted a net tow with the Reeve net. The haul was a vertical tow from 20 m to the surface. No intact siphonophores were collected, however a number of pteropods (*Limacina retroversa*) were present in the sample along with a ptomopterid polychaete and some small medusae. We planned to make an extended net tow after the evening ROV dive.

The CTD cast at 19h47-19h56 was taken to 208m. During the cast several internal waves were detected in the acoustics and environmental plots from the Greene Bomber. The influence of the internal waves on the temperature profile was obvious with a substantial difference in the temperature within the upper 50m between the upcast and downcast.

The evening dive was conducted with water that had high concentrations of siphonophores. High-quality data were collected with the 24 kHz and 120 kHz transducers. At approximately 21h30 we noted the presence of euphausiids. They appeared to increase in abundance, possibly due to their arrival at the surface from depths and perhaps due to attraction to the ROV lights.

Limited data were collected at the end of the dive with the 200 kHz transducers, but without video. Tim was not sure whether echoes were collected because there were large spikes marching through the data. The seas were building to 3 feet through the dive. Such sea states are calm for most oceanographic operations, but they complicated the ROV recovery. It was clear that we could not continue to conduct ROV ops with the forecast calling for 4–6' seas and I opted to sail towards Stellwagen Bank where the fetch was much shorter and seas were likely to be calm. Before leaving the dive area, Malinda, Joe and I conducted a double oblique cast with the Reeve net from the surface to 20m and back. The payout was very slow ($<30 m \cdot min^{-1}$), and the catch did not include any intact siphonophores. There was one large (1.5-2mm) pteropod, a ptomopterid polychaete, and several ctenophores and medusae. The catch was preserved in 5% formalin.

<u>Tuesday July 14, 1998</u>
We awoke with the ship on location in Stellwagen Bank. Seas were calm and dive operations were scheduled to begin at noon. The acoustics systems on Greene Bomber had completely shut down and we were unable to determine the extent of scattering in the region.

After breakfast, Tim, Peter and I discussed the options for the remainder of the cruise. I wanted to take advantage of the depth capabilities of the MaxRover to survey the deep acoustic layers in Wilkinson Basin. This would not have been possible until acoustic target strength measurements were concluded. Before Tim could remove the transducers, he needed to make some calibration checks by pointing the transducers inward so that transmitters were facing receivers. Our ultimate limitation on operations was a requirement that the ship get to Woods Hole by around noon on Friday.

With these constraints in mind, I scheduled the next two dives for data collection. The dive commencing at noon and the evening dive were for target strength measurements. Following these dives, Tim planned to reconfigure the transducers for a calibration check that will be conducted in the late-morning or early afternoon of Wednesday, July 15. After the calibration, we planned to steam to the middle of Wilkinson Basin for an acoustic survey and two deep dives to conduct video surveys of the deep scattering layers. Once those surveys were completed, we would steam for Woods Hole.

Malinda did a CTD cast at 11h51. The results showed that we were in fresher water with a strong thermocline from10-30m and a continual halocline from the surface to 30 m. Dive operations commenced at 12h15. There were few siphonophores or other macrozooplankton visible on the video; however, the water was full of marine snow –

primarily long diatom chains. This turned out to be a valuable exercise since during the previous night, the water contained high concentrations of marine snow with many siphonophores. Today's dive served as a control since only the marine snow was present. Few echoes were recorded.

The seas picked up slightly during the course of the dive and recovery required two additional people to handle the tether. Paul indicated that he could not dive there again unless the sea-state diminished. I decided to remain there until 18h30 to see whether the seas calmed down. There was a strong layer of scattering near the bottom and if it started to migrate up, Tim would have had some interesting targets. In the event that the seas did not calm down or the scattering layer did not rise, we would recover the Greene Bomber and steam to Cape Cod Bay (2 h). The waters there would have been calm enough for dive operations and we knew that siphonophores were abundant in the Bay.

The winds failed to diminish and by 18h30 it was clear that we could not deploy the ROV at our location in Massachusetts Bay. After a barbecue on the aft deck, we recovered the Greene Bomber and started steaming for Cape Cod Bay.

We arrived Cape Cod Bay at 21h00 and found that the waves were still too high for ROV operations. Given that searching for calmer water would have taken about an hour and by that time, it would be too late for a dive, I opted to suspend dive operations for the night. In the morning we planned to have a dive at 09h00. We redeployed the Greene Bomber and unfortunately, it was still malfunctioning. For the rest of the evening, Tim, Chu and Joe analyzed some of the day's target strength data while Peter tried to debug the Greene Bomber acoustics.

<u>Wednesday July 15, 1998</u>

The wind had dropped and the water in the Bay was quite calm. Dive operations were planned for 09h00. The Greene Bomber was recovered shortly after 07h00 so that Peter could examine the MUX bottle for faults. A CTD cast was taken at 08h35 and it showed that the water was stratified with a pycnocline from 12-20m depth. The ship dropped anchor after the CTD cast and the ROV was deployed at 09h00. The water contained siphonophores in moderate concentrations and conditions were ideal for target strength estimations. Once the ROV reached 20-23m depth, the data were of outstanding quality. At that point the ROV was moving up to the ship and then drifting back with the plankton. Paul was able to control the ROV so that individual animals remained in the acoustic focal point for periods of up to 5-10 sec and on several occasions, up to 30 sec (20-30 pings).

I managed to get a cellular connection to the web; however, it was so unstable that I was unable to completely access the ABC News website. I was able to determine that they were covering our cruise and we had a leader on their main page. In fact, we were the second headline, preceded only by Ken Starr's investigation. Trying to access their site any further was an exercise in extreme frustration and after draining my laptop and cell phone batteries, I gave up.

Peter and Chu worked on isolating and bypassing the hardware problem with the Greene Bomber MUX bottle. They managed to bypass the board in the MUX bottle with the objective of making a direct connection between the transducer and the DES box without utilizing the multiplexor in the underwater bottle. The Greene Bomber was once again operational and we redeployed it at 11h20.

The ROV was recovered just before lunch. After lunch, Malinda did another CTD cast and the ROV was deployed for an afternoon dive. Once the MaxRover had been recovered at 16h22, we did a net cast to try and collect siphonophores for taxonomic analysis. The results were disappointing. Even though we streamed the net for 30 min, only two small siphonophores were collected. We knew from the ROV camera data, that siphonophores were abundant in the water. We also knew that they were quite mobile organisms. The failure to collect many in the net suggested that they were actively avoiding the net.

After the net tow, we began the first of two planned acoustic transects between Cape Cod Bay and Massachusetts Bay. We had observed substantial variation in the scattering patterns during previous work between the two Bays and two duplicate transects conducted along the same trackline would help us to assess the stability and reproducibility of that structure. We timed the first transect so that we began prior to dusk. In that way, we hoped to capture any vertical migration events.

The one-way (Cape Cod Bay to Stellwagen Bank) transit time of the transect was approximately 6 h. The ship started the transect at 18h23, arrived at the end point (Stellwagen Bank) at midnight, and returned to Cape Cod Bay along the same track by 07h00.

<u>Thursday July 16, 1998</u>

On arrival in Cape Cod Bay, the ship anchored and we prepared for the ROV calibration dive. Following a CTD cast, there was a brief (30 min) ROV dive. It was obvious that the water was too shallow for Tim to effectively check his calibration at depth (30m) and we decided to raise the anchor and move to a deeper site. Although we found deeper water in the Bay, the sea state had increased and after about 2 h. I opted to move to sheltered water off Manomet Point. Final ROV acoustic system calibrations were completed by 18h28 and we weighed anchor and steamed to the start point of the previous night's transect.

The Greene Bomber was deployed at 20h05 and we began the transect. We started the second transect approximately 2h later than the first one and were therefore too late to observe the vertical migration. We also had to deviate slightly from our prior track to avoid fishing vessels and gear that were concentrated around a pinnacle in Massachusetts Bay. The ship arrived at Stellwagen Bank by 01h36 and returned to Cape Cod Bay by 07h30.

<u>Friday July 17, 1998</u>

The recovery of the Greene Bomber at 07h52 marked the conclusion of our scientific operations. The ship then steamed towards Woods Hole via the Cape Cod Canal while we dismantled and packed up our equipment. The return was uneventful until we arrived in Buzzards Bay. At that point, one of the ships' transmissions failed and we had to limp home on one engine. We arrived at the Woods Hole dock at 12h00 and offloaded.