Acoustic Resonance Classification of Swimbladder-Bearing Fish

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LONG-TERM GOALS

To understand and exploit the resonance scattering by swimbladder-bearing fish (typically in the 1-10 kHz frequency region). Exploitation of the resonances can significantly reduce ambiguities in interpreting acoustic scattering in terms of meaningful biological parameters compared with traditional higher frequency approaches.

OBJECTIVES

To conduct a new class of quantitative acoustic studies of scattering by swimbladder-bearing fish utilizing new commercial broadband-acoustic technology that is optimized for use in the resonance scattering region of fish.

APPROACH

This research is taking advantage of a commercial system that was originally designed for marine geological and gas/oil exploration. It is especially attractive for use in studying swimbladder-bearing fish because this seismic system was optimized for use in the frequency band in which swimbladders typically resonate. Using ONR DURIP funding, this system has been purchased for use in this research grant. The off-the-shelf sensors on the system (in particular, the transmitters and receivers) have been selected and configured in a manner best suited for the fish application. Since the scattering by fish is not well understood in the resonance region, the system is being used for making direct measurements (off a dock and at sea) of target strengths of fish, as well as for surveying fish in their natural habitat. The survey was part of a NOAA/NMFS fisheries study and included trawling for ground truthing and used traditional high frequency echo sounders for comparison. Data will be interpreted in terms of existing physics-based scattering models whose parameters may be determined empirically as a result of the target strength measurements. Tim Stanton oversees the entire program and is involved in every aspect. Dezhang Chu is playing a key role by having participated in finalizing

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14. ABSTRACT
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15. SUBJECT TERMS

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system specifications, conducting the system calibration, making measurements of target strength, participating in the at-sea study, and processing the data. Jim Irish participated in finalizing system specifications and overseeing logistics of the calibrations and field measurements.

WORK COMPLETED

A significant range of work was completed including completion of the specification of the DURIP system, ordering the system, testing it at three facilities and at sea, and the actual use of it at sea in collaboration with NOAA.

1. Finalizing specification of the DURIP system. There were two major specification issues which were mostly addressed in the previous year: position of the hydrophone elements and diameter of the tow cable. The position of the elements dictated the beampatterns, which are also strongly dependent upon frequency. The cable diameter strongly influences drag, which needs to be minimized. Last year, it was determined that the elements need to make up two arrays- an inner and outer array. The combination of the two could be used for the lower frequencies and the inner one could be used for the higher frequencies. This year, the specification was finalized for the order of the system. Regarding the cable, last year, it was determined that a 0.32-in.-diameter cable would suffice over a 0.68-in.-diameter cable. The drag and cost would be lowered. This year, the specification was finalized for the order of the system.

2. Ordering the DURIP system. In addition to finalizing the specifications to the number and location of the hydrophone elements and diameter of the tow cable, the choice of other sensors was finalized. The sensor package includes the hydrophones, two acoustic transmitters, one acoustic transceiver, depth sensor, and an acoustic transponder. The towbody was also selected. The system was then ordered through Edgetech.

3. Testing unit in Boca Raton, Florida. Prior to delivery of the system, we traveled to Edgetech in Boca Raton, Florida, which was the site of assembly of the acoustic unit. There, along with the engineers who built the system, we performed two days of tests in a local lake. With the unit configured upside down in a frame on the bottom of the lake, echoes were measured from a calibration sphere and from the surface of the lake. During this period, a failure in one of the boards was identified, which was replaced before shipment.

4. Testing the unit at the well in the WHOI pier. After the unit was delivered to WHOI, we tested the system over about a 10-week period in the 60-ft.-deep well. The tests consisted of making measurements with calibration spheres of various sizes. These tests served several purposes-- providing calibration information, allowing us to "practice" using the system under ideal conditions (versus at sea), and providing a rapid means for us to test application software that we were writing for postprocessing of acoustic data.

5. Calibrating the unit at the University of New Hampshire test tank-- two two-day calibrations. With the unit mounted on the bottom of the tank and with the transducers aiming upward, echoes from the smooth air/water interface were measured for all channels. These measurements provided a more accurate means of calibration over the spheres. The unit is programmable, so several waveforms were used per channel. The waveforms varied in duration, span of frequency, and amplitude weighting.

6. Testing the unit at sea on the R/V Tioga-- two one-day cruises. A full range of tests were conducted on the two cruises. Very importantly, the tow cabilities of the unit were tested, with cable tension measured as a function of tow speed and depth of towbody. The measurements were compared with the models that were used to select this particular cable. Also, the system was calibrated with one calibration sphere at various depths and the transmission signals were measured with a hydrophone.

7. Acoustic and net surveys of Georges Bank and Gulf of Maine regions; September 7-17, 2005 on the NOAA vessel FR/V Delaware II. The Edgetech towbody was deployed in numerous transects over Georges Bank, as well as Stellwagen Bank and Cape Cod Bay (Fig. 1). The system was towed near the sea surface, as well as near the seafloor so that it could be towed just above, and sometimes through, schools of fish. The system was calibrated versus depth in 10 m increments down to 180 m depth through use of a calibration sphere. Nets were used to sample the fish as a means to "ground truth" the acoustic data (Figs. 2 and 3). The fish were identified and sized. The schools of fish were predominantly Atlantic Herring, although various other fish and zooplankton were also caught. In addition to our acoustic system, three conventional hull-mounted systems were used at the frequencies 18 kHz, 38 kHz, and 120 kHz. These systems were sometimes turned off during the use of the Edgetech system to avoid interference.

The acoustic data across all frequency bands were viewed in real time as a means to guide the sampling and altitude of the towbody over the schools. In addition, after a transect, data were transferred to a separate computer for post-processing. Frequency spectra of the echoes were calculated for different acoustic features, including for fish schools and patches of zooplankton. Peaks were observed in the echo spectra from the swimbladder-bearing fish at approximately 3.5 kHz. A steep rise in the spectra from zooplankton was observed with a leveling off at 60 kHz and higher. In addition to the spectral processing, matched filter processing was applied to all echoes in order to improve the range resolution.

RESULTS

Although processing of the data has just begun at the time of this writing, much was learned during our "quick look" of the 50 Gbytes of data collected at sea.

1) High resolution: This new system was selected for its bandwidth to measure echo spectra of the fish. A most visually impressive capability of the system is the improvement in resolution over conventional narrow band systems. This improvement is due to the matched filter processing performed on broadband echoes. With a range resolution inversely related to bandwidth, the resolution ranged from about 20 cm in the low frequencies (single digit kHz) down to about 2 cm at the higher frequencies (10's of kHz). The combination of this improved resolution and towing the system near the fish resulted in a dramatic improvement over the narrowband high-frequency (120 kHz) hull-mounted system (Figs. 4 and 5). Through this improvement, the structure and patchiness of the fish schools could be resolved to a much finer degree (Fig. 4). Also, in the case in which we towed the system through the school, the fish could be resolved on an individual basis (Fig. 5) from each other and from the seafloor. Certainly, such resolution could be achieved by towing a very high frequency system near the fish, but it would also be sensitive zooplankton which could blur the image. This new system, which operates in the low kHz region, is only sensitive to the fish because of the low frequencies.

2) Peak in fish spectral curve: We have observed a consistent peak in data dominated by swimbladder-bearing fish. The peak occurs at about 3.5 kHz, which is consistent with the swimbladder resonance of this size of fish (20-cm-long Atlantic Herring) at a 200 m depth.

3) Strong frequency dependence in zooplankton spectral curve: In data dominated by zooplankton, we have observed a steep rise in spectral curve followed by a leveling off at 60 kHz or higher. This pattern is consistent with the large shrimp caught in the nets in that area.

IMPACT/APPLICATIONS

The results have potential for two-fold impact: 1) Because of the large bandwidth of this system and the fact that two of the channels of the system operate in the low kHz region, the system not only has very high resolution to resolve fish and fish schools, but it can also select only the fish (versus zooplankton). Because of this combination of resolution and sensitivity to only fish, this approach can significantly improve studying the behavior of fish through improved accuracy in directly counting them and quantifying the patchiness of the schools. 2) The spectral characteristics of the fish and zooplankton echoes can be used for an accurate means of sizing the organisms. Traditionally, narrowband acoustic systems have been used to assess distributions of organisms, resulting in ambiguities in the analysis. Through use of this broadband system which provides nearly continuous portions of the echo spectra, important characteristics of the spectra can be determined accurately. For example, the resonance of the fish echo is directly related to the size of the swimbladder and the depth of the fish. Through knowledge of the depth and through use of scattering modeling, the size of the fish can be determined with fewer ambiguities than with traditional high frequency narrowband signals.

Since the above results were obtained with an off-the-shelf commercial system, it is possible that such valuable results can be obtained routinely by any investigator.

RELATED PROJECTS

This project is related to the ONR DURIP grant #N00014-04-1-0475 which was used to purchase the instrument that is being used in this project.

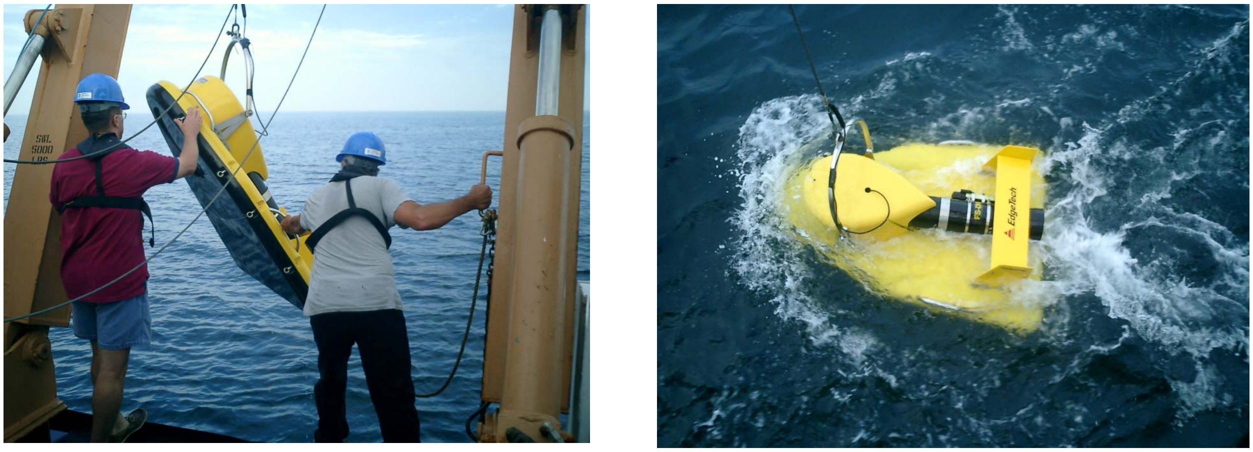

Figure 1. Edgetech towbody being deployed for use during the September 2005 cruise on the FR/V Delaware II. The system was towed near the surface, deep in the water over fish schools, and deep in the water through fish schools.

Figure 2. Pelagic trawl, provided by the National Marine Fisheries Service, streaming out behind the ship before being lowered down to depth.

Figure 3. Atlantic Herring sampled over Georges Bank. These were the dominant scatterers in the schools of fish. Euphausiids (two laid on top of middle fish, right panel) and other zooplankton and fish were also caught in the nets.

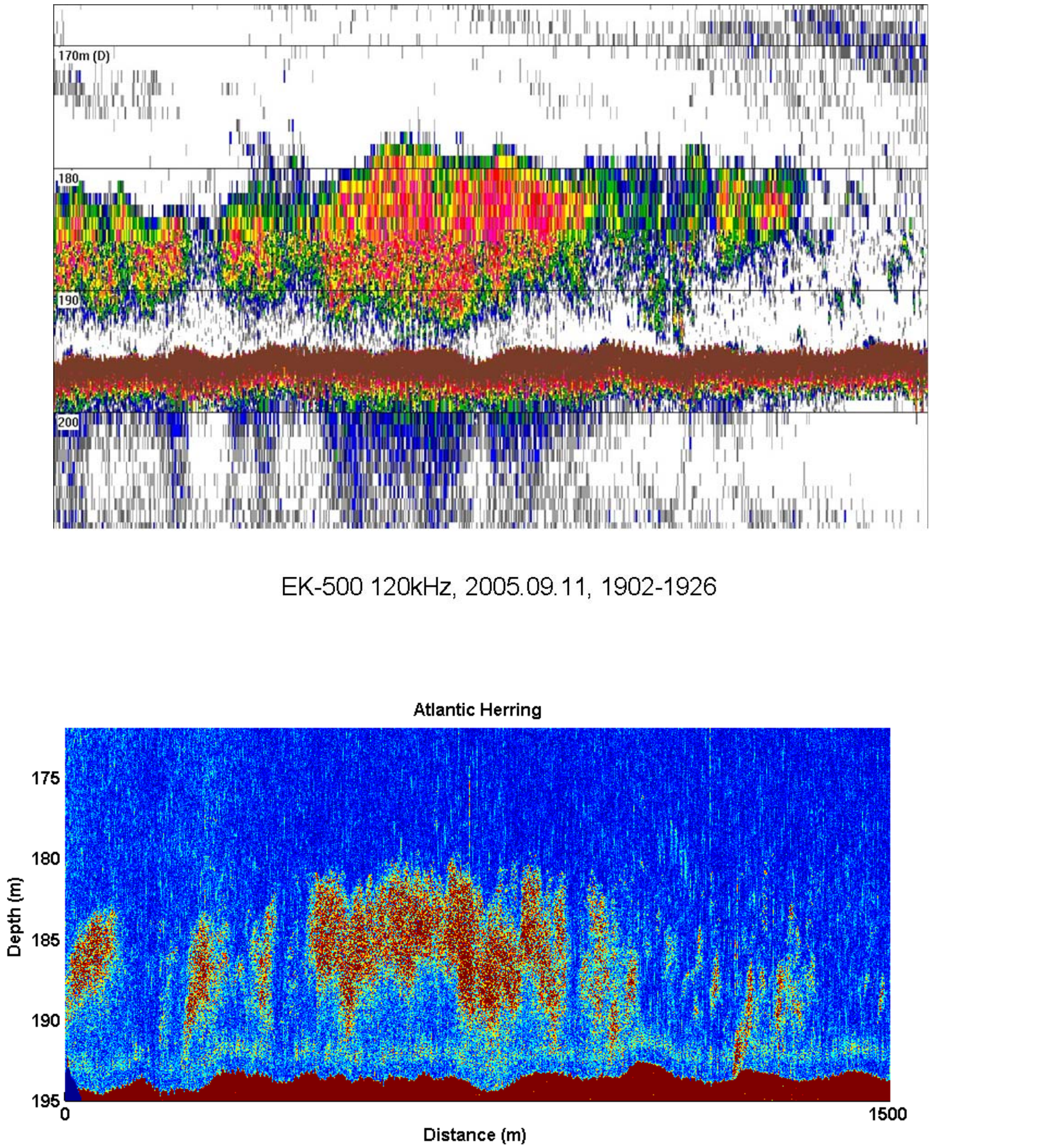

Figure 4. Top panel: Echogram of herring school from hull-mounted EK-500 120 kHz echosounder on September, 2005 cruise on FR/V Delaware II. Bottom panel: Echogram of same section of herring school using Edgetech system; 7-17 kHz band. Although the frequencies are much lower with the Edgetech system, the combination of matched filter processing (providing 10 cm range resolution) and towing deeply over the school, provides a significant improvement in resolution of the fish school over the traditional high frequency hull-mounted system.

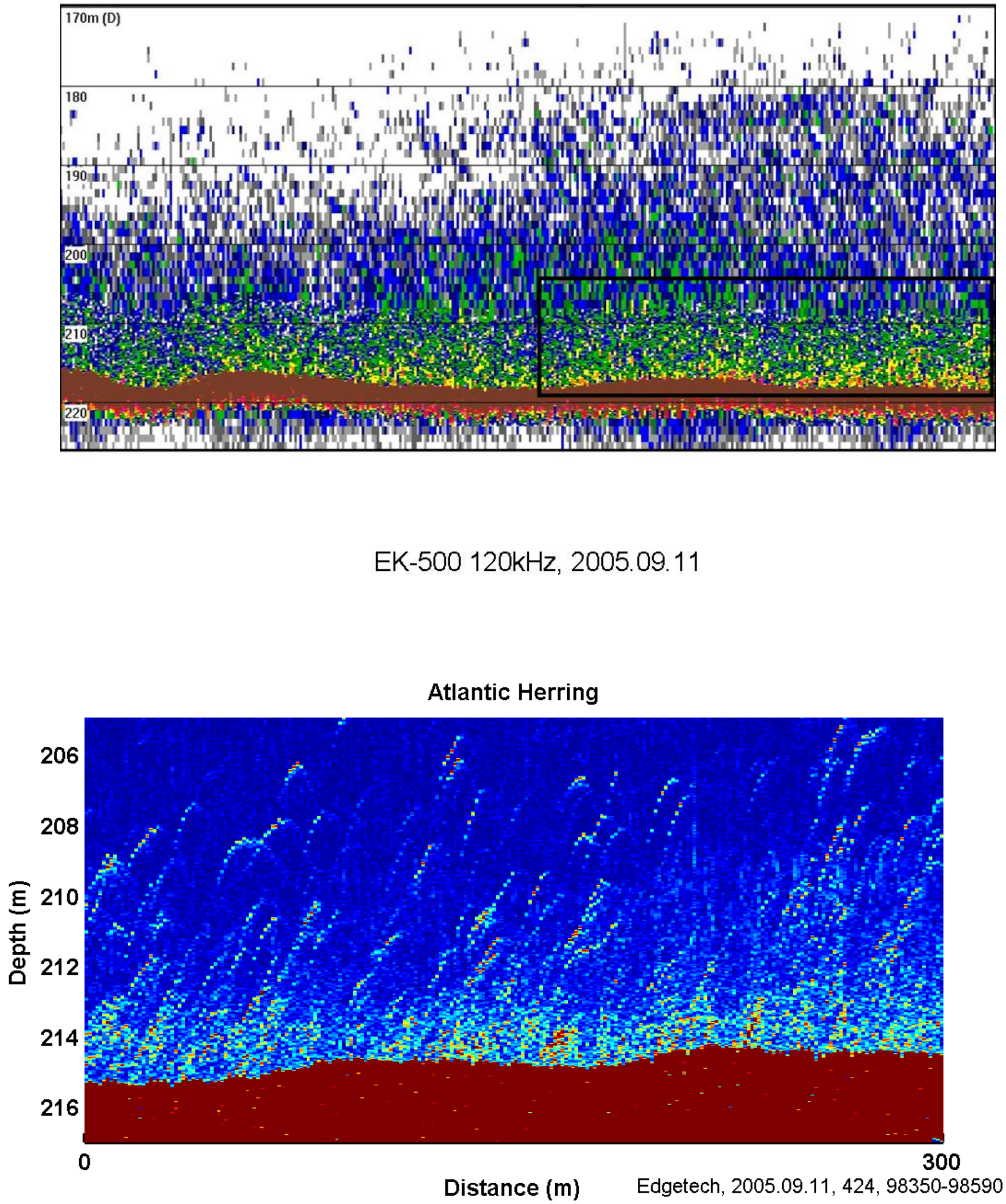

Figure 5. Top panel: Echogram of herring school from hull-mounted EK-500 120 kHz echosounder on September, 2005 cruise on FR/V Delaware II. Bottom panel: Echogram from <u>within box</u> in top panel using Edgetech system; 7-17 kHz band. In this case, the Edgetech towbody passed <u>through</u> the fish school, resulting in resolved echoes.