WOODS HOLE OCEANOGRAPHIC INSTITUTION

Applied Ocean Physics and Engineering Department

November 14, 2017

Dr. Robert H. Headrick
Office of Naval Research, Code 322
875 N. Randolph Street, Suite 1425
Arlington, VA 22203-1995

Dear Dr. Headrick:

Enclosed is the Final Report for ONR Grant No. N00014-13-1-0315 entitled "TREX13: Mid-Frequency Measurements and Modeling of Scattering by Fish," Principal Investigator Dr. Timothy K. Stanton.

Sincerely,

Shirley Barkley
Administrative Associate II

Enclosures

cc: Administrative Grants Officer
Defense Technical Information Center
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TREX13: Mid-Frequency Measurements and Modeling of Scattering by Fish

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LONG-TERM GOALS

To quantify properties of mid-frequency acoustic reverberation in terms of the physical and biological properties of the environment. The results will improve the ability to predict sonar performance.

OBJECTIVES

This component of the TREX13 program concerns characterizing the contributions of acoustic scattering by fish to the reverberation. The clutter characteristics of the fish will also be quantified.

APPROACH

The research was based, in part, on a large multi-PI experiment that took place in April/May, 2013 off of Panama City, Florida. The program was led by APL:UW (Tang/Heffner) and details of the experiment are in their reports and publications. A key element of the fish component was the measurements of mid-frequency reverberation from a fixed source and receiver. The measurements were made nearly continuously, 24 hours per day. Another key element to the fish effort is the UW-led (Horne) high frequency surveys of fish in the area. The WHOI-led (Stanton) effort focussed on designing the fish component of the experiments and identifying echoes that were due to the fish that were presumed to be present. Although the original proposed approach also included analyzing and modeling the mid-frequency reverberation data in terms of the fish echoes, funding was stopped before that activity could begin. Stanton oversaw this fish component of the research and participated in all phases of the research. Jones conducted data analysis of the fish echoes. The analysis included characterizing the echoes in terms of their spatial distribution and how that distribution changed in time (day to night and within the night). These efforts were leveraged by those of other PIs in the TREX13 program through participation in regularly scheduled workshops.

WORK COMPLETED

The following tasks were completed:

1. **Design of fish-acoustics component of experiment.** This involved discussions with the Chief Scientists of the program, D.J. Tang and Todd Heffner, and the PI of the fish survey component, John Horne.

2. **Participating in the fish-acoustics component of the experiment.** This took place for one week in May, 2013 off of Panama City, Florida. Since the acoustic equipment was being run by APL:UW, Stanton's principal activity involved identifying fish in the video monitor mounted on the seafloor. Also, fish were viewed from the sea surface (near-surface fish only) and from a diver-held video camera. A secondary activity involved investigating a persistent source of narrowband noise near 5 kHz that was observed by John Preston and others to occur at night. Results are summarized as follows:

    a. *Mid-frequency reverberation data.* The reverberation time series showed episodes of elevated levels (Figs. 1, 2). The degree to which the echoes were elevated varied in time both within an hour, within the day, and from day to day. Specifically, it only became elevated at night and not every night. Furthermore, within the periods of elevated levels, the signals varied from ping to ping. This pattern of echoes is consistent with the patchiness and diurnal migration of fish. And, at these mid-frequencies, the echoes are most likely from fish with gas-filled swimbladders.

    b. *Presence of fish at experimental site.* There were three species of fish that dominated the numbers in the fixed camera system: 1) Round scad ("cigar minnow") (*Decapterus punctatus)*, 2) Tomtate (a type of "grunt" fish) (*Haemulon aurolineatum)*, and 3) Atlantic spadefish ("angelfish") (*Chaetodipterus faber)*. Each of these fish has a swimbladder. Images of these species, taken off the web, are given in Fig. 3. These fish appeared to be in the size range 6-12" long. At any given time, there were many fish in the view of the camera (10's to 100's). The presence of clouds of fish around the equipment was observed by divers. There were also observations through a diver-held video and from the surface of schools of fish that were not directly associated with the tower. The schools were swimming freely, constantly changing direction, shape, and size. The schools are estimated to be 10- 40' in length. In several schools, the fish were identified to be round scad and tomtate (same as two of the types of fish near the tower).

    c. *Persistent narrowband noise at experimental site.* This peak was observed by John Preston and others to begin near dusk, persist throughout the night, and end near dawn. Also, it had directional characteristics in that it was observed to be coming from two sectors. This peak is consistent with the recent several years of observations by Carrie Wall and others near this site. The purpose of their work was to identify sounds due to various species of fish. While other sources of sound (100's Hz) in this region were identified by them as being definitively due to fish, this particular sound could only be hypothesized by Wall as being due to fish. It is strongly suspected to be of biological origin because of its diurnal nature. The sound was hypothesized by Wall as being due to the gas being released in association with the diurnal migration of the swimbladder-bearing Clupeid fish (e.g., herring) in the area.

3. **Displaying and inspecting beam-level echo data from selected days.** The goal of this task was to separate echoes from fixed sources of scattering (such as the seafloor) from echoes from moving sources (such as fish). This began with receiving and inspecting selected data from APL:UW which had candidate fish echoes in it. These data were from along the reverberation track. We turned the echoes from the beam-level series of pings into movies and inspected the data qualitatively for fixed and moving echoes.

4. **Identifying fish echoes in data.** From task#3, fish echoes were identified in many sets of data and are illustrated in Fig. 4. These echoes were coherent from ping-to-ping and moved slowly across the reverberation track. That quality, in addition to being patchy and varying in patch shape and dimension from ping-to-ping, is consistent with echoes from patches of fish. This is in contrast to echoes from other sources that remained relatively constant from ping to ping. These fish-like echoes were observed only at night. There were generally no fish-like echoes during the day, which is consistent with the diurnal migration of fish.

   Also, at these mid-frequencies, the echoes are most likely from fish with gas-filled swimbladders. As discussed above and illustrated in Fig. 3, the fish observed throughout the experiments on the seafloor-mounted camera were identified as being ones with swimbladders.

5. **Investigating existing models of scattering by bubbles (swimbladder-bearing fish) near boundary.** A question in this research has arisen regarding the degree to which the fish contribute to the scattering when they are near the seafloor. There is an abundance of literature on acoustic scattering of bubbles near a water/pressure-release interface (sea surface) and insight was obtained through a literature search. Since swimbladdering-bearing fish behave as monopole scatterers at mid-frequencies, calculations involving spherical bubbles apply.

   In a paper by Ye and Feuillade (J. Acoust. Soc. Am., vol. 102, pp. 798-805,1997), it was shown that when the bubbles approach the sea surface (i.e., a pressure release surface), the resonance frequency increases while the scattering amplitude at resonance decreases. Conversely, for a hard surface, it is expected that the resonance frequency would decrease and scattering amplitude at resonance to increase when the bubble approaches the hard surface (Feuillade, personal communication, 2014). In the context of the current problem (fish approaching the seafloor), the latter results would be more applicable. If the fish are resonating at depths away from the bottom, then it is possible that the resonance frequency would decrease as they approach the bottom and the scattering amplitude (now above resonance) would decrease. However, if the fish are below resonance at depths away from the bottom, then it is possible that, once near the bottom, they become resonant and the scattering amplitude increases.

After the above tasks were completed, no new funding was awarded. As a result, there was minimal progress throughout the remainder of the grant period, using funds carried over from the previous year. Tasks completed are:

6. **Workshop participation.** Stanton participated in the TREX13 workshop in Indianapolis in Nov. 2014 and did some followup work. The participation included 1) giving a presentation on progress in FY14 and 2) making plans, pending new funding, for analyzing fish-echo data being made available by APL:UW. According to APL:UW, approximately 50% of the long-range acoustic reverberation data collected in the TREX13 experiment contained echoes from fish significant enough to contaminate the reverberation data from the seafloor. Plans were made during the workshop and as part of followup tasks to analyze those data in terms of 1) the energy of the fish echoes relative to that from the seafloor, 2) echo statistics associated with the fish echoes and the degree to which those statistics are non-Rayleigh, and 3) the fraction of fish echoes being reverberation-like vs clutter-like.

7. **Special session at scientific conference.** Stanton co-organized and co-chaired a special session entitled "Acoustic scattering by aquatic organisms" that was held at the ASA/ASJ joint scientific meeting in Honolulu, Hawaii in Nov./Dec. 2016. TREX13 participants were encouraged to attend and/or present their results at this special session.

RESULTS

The TREX13 measurements illustrate the spatial and temporal variability of mid-frequency echoes due to the presence of fish. They also illustrate the importance of accounting for fish echoes, as these echoes dominated echoes from other sources (seafloor and sea surface) in spite of the fact that this was a shallow waveguide with many echoes from both boundaries. Specifically, as reported by APL:UW, approximately 50% of the long-range acoustic reverberation data contained echoes from fish significant enough to contaminate the seafloor-echo data.

The fish echoes occurred only at night, varied from night to night (and not being significant some nights), and varied within a night. Very importantly, the fish were shown to migrate horizontally at night. This observation, in combination with the fact that the scattering by fish near a boundary can change significantly (increase or decrease, depending on their resonance frequency), may help to explain why there are negligible fish echoes during the day. That is, during the day, the fish may have either moved out of the region or moved to the seafloor.

Also, on a related note, the diurnal pattern of noise observed in the mid-frequency band is also presumed to be related to the presence of fish, as they are not only scatterers of sound, but they are also producers of sound. It is probably a different type of fish that scattered sound vs produced the sound.

What makes all of these results special is the controlled nature of the reverberation experiments and associated characterization of the environment. Because of the control, the environmental properties can be accounted for in the modeling of the acoustic propagation and scattering and the fish-echo data can be studied with greater accuracy (fewer unknowns) than in other previous studies.

IMPACT/APPLICATIONS

With approximately 50% of the data containing echoes from fish, these results add to the growing body of evidence of the importance of fish in the performance of sonars—both active and passive sonars. The spatial and temporal variability of the fish will cause a correspondingly variable effect on the performance of sonars. Depending on the size and degree of heterogeneity of the fish distributions, the fish echoes will either be a source of "clutter" (i.e., target-like) or reverberation (i.e., background-like), each which affect the performance of ASW systems.

These data are consistent with the pattern of significant changes in reverberation and clutter as observed in Navy surface ship mid-frequency active systems.

RELATED PROJECTS

This research built on the methods that Stanton, Jones, and colleagues developed in two other former ONR programs: 1) ONR MMB/NOPP project (N00014-1-10-0127) in which mid-frequency fish-echo data were collected in a complex propagation environment (Gulf of Maine) and 2) HiFAST FNC program in which fish echoes were simulated for use in Navy sonar trainers (SAST-NAVSEA and CASE-NAVAIR). In each program, simulation tools were developed to describe various aspects of fish echoes (spectral and statistical) as a result of long-range propagation of a mid-frequency acoustic signal in a complex ocean waveguide. The HiFAST program has resulted in three transitions completed so far (SAST ACB13, SAST ACB15, and CASE).

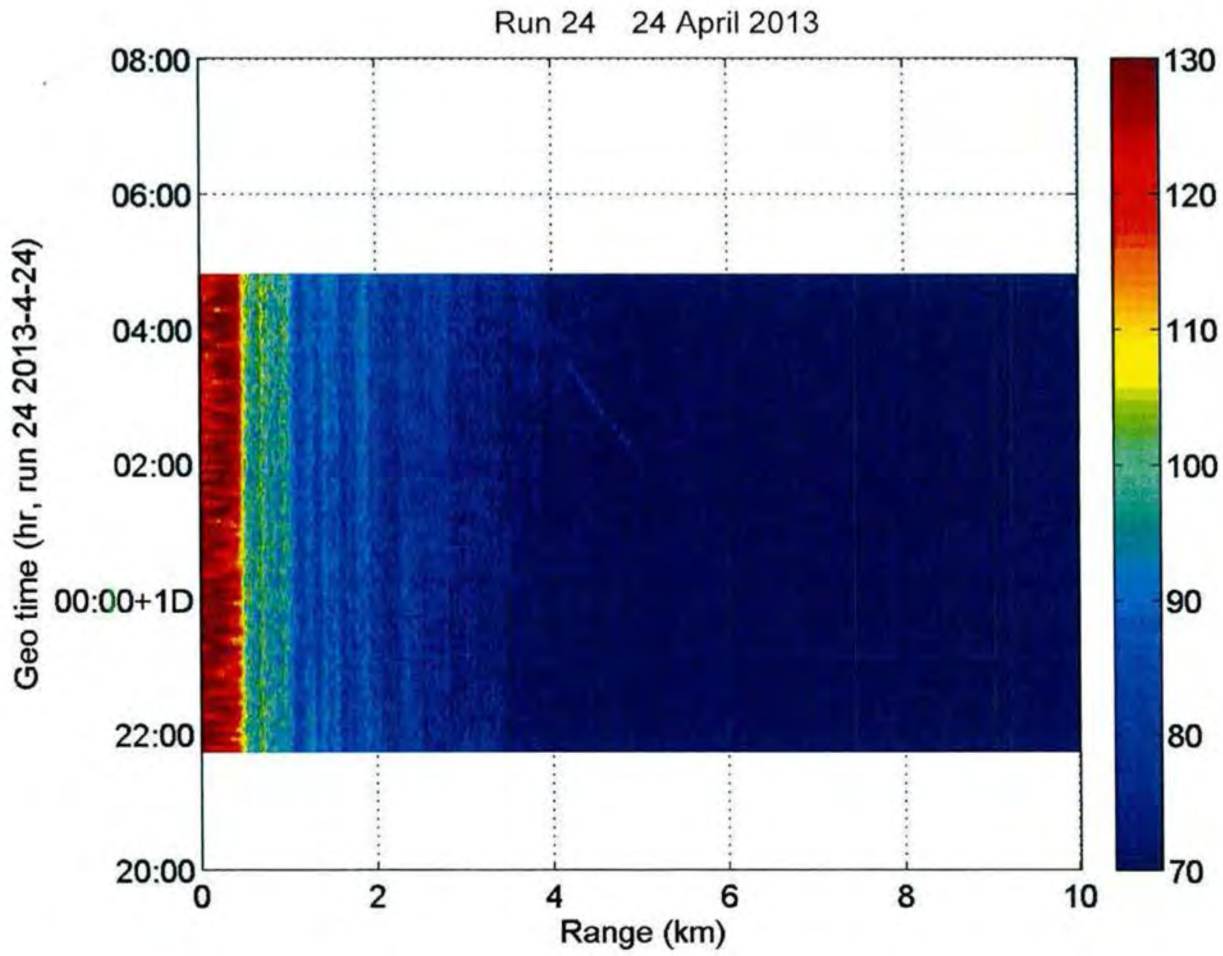

Figure 1. Night-time data from a single beam of mid-frequency reverberation system collected as part of TREX13 experiment. Times given on the vertical axis are local (Florida) time on a 24-hour clock. The data reveal negligible presence of fish.

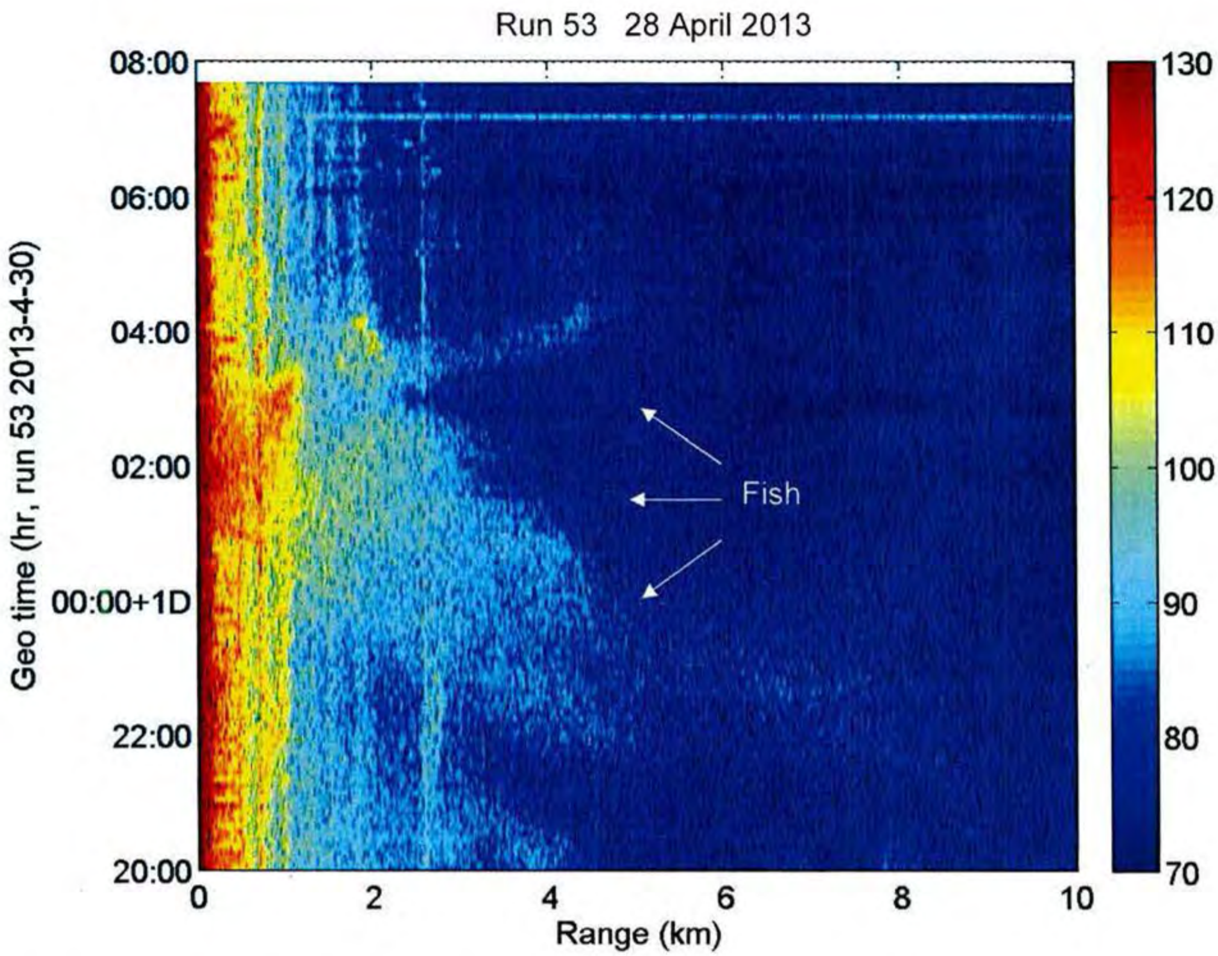

Figure 2. Same as Fig. 1, except that fish appeared in data during this night-time measurement.

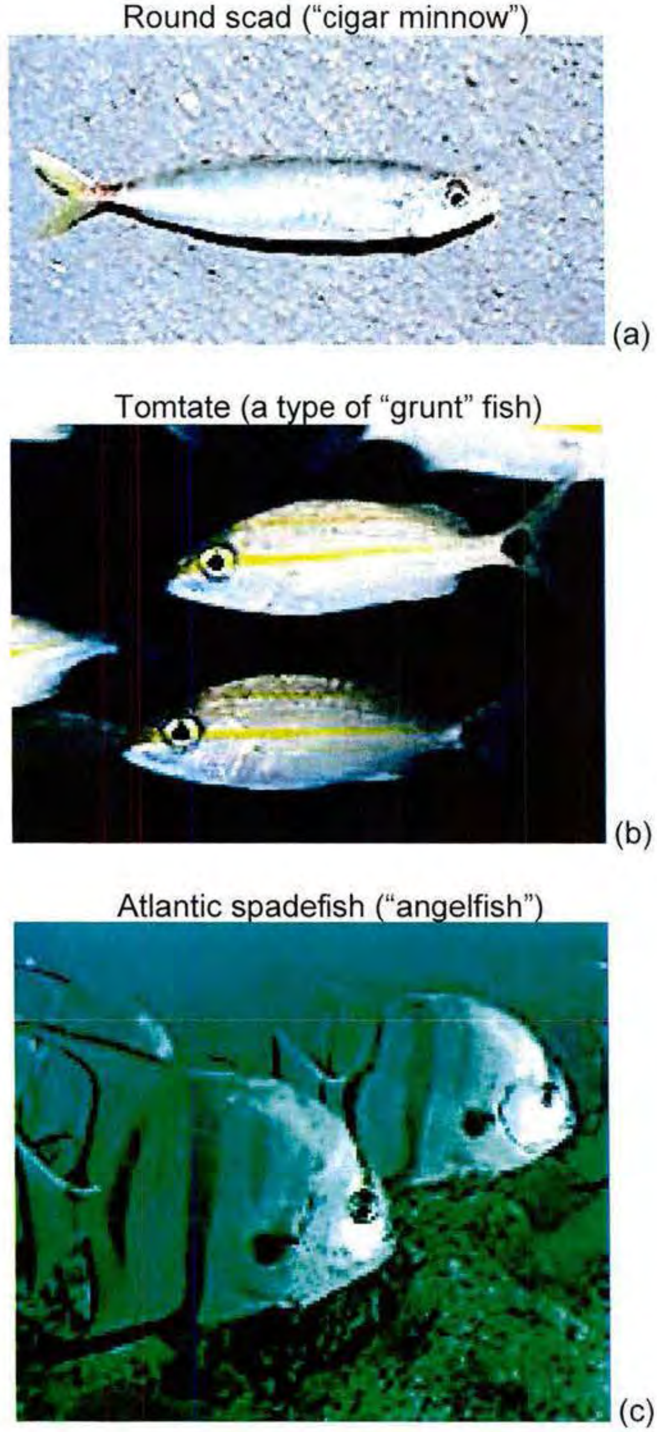

Figure 3. The dominant species of fish present at experimental site. All have swimbladders which can scatter sound at mid-frequencies. Photos taken off the web—various sources.

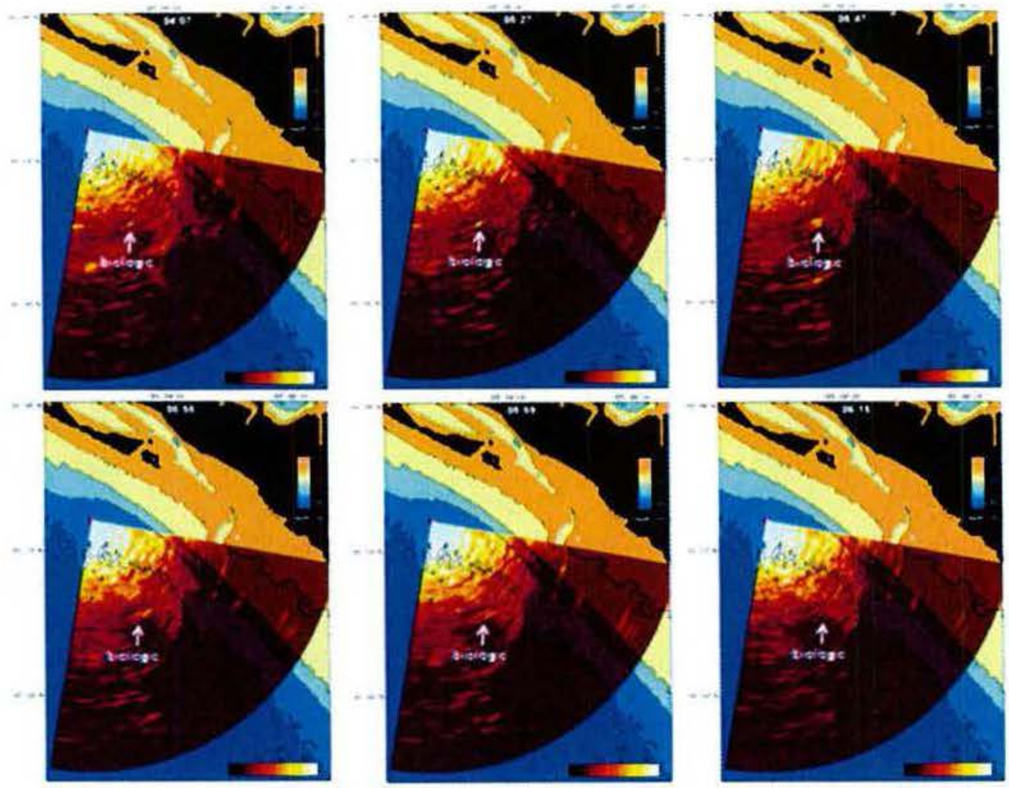

Figure 4. A patch of fish moving across the reverberation track in TREX13.

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