Bio-Alpha off the West Coast

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LONG-TERM GOALS

Develop quantitative models of the effects of fish with swim bladders on attenuation (bio-alpha), transmission loss, and scintillation index in the ocean.

OBJECTIVES

Conduct an experiment off the west coast to determine the effects of hake and sardines, the dominant species of fish with swim bladders off the west coast of the USA, on attenuation (bio-alpha), transmission loss (TL) and scintillation index (SI). Determine the effects of gas production and removal from swim bladders of hake, a physoclist, on the temporal evolution of resonance frequencies. Isolate the effects of hake from the effects of sardines and anchovies, which may be present in large numbers during the experiment. Determine bubble cloud effects of schools of sardines and hake.

APPROACH

Bio-alpha measurements will be made along a track that traverses a mesoscale region, where the concentrations of the target species, hake and sardines are high. We will select the site of the bio-alpha measurements, based on biological scattering maps generated by Dr. Roger Gauss of NRL, and echo sounder and trawling measurements by Dr. Kelly Benoit-Bird of the Oregon State University (OSU) and Dr. Dezhang Chu of the Northwest Fisheries Science Center (NWFSC). The selected track will be relatively flat, approximately parallel to shore.

We will conduct measurements of TL vs. range (0-8 km) and frequency (0.2-5 kHz), about 6 times during night, and about 6 times during day for 2 days. The transit speed will be nominally 3 knots. The depth of the source will be alternated between a near surface depth (TBD), and a near bottom depth (TBD). To minimize the uncertainty of geoacoustic effects on TL we will repeat TL measurements along the same (or if necessary, a nearby track) when fish are absent.

We will make concurrent measurements of sound speed profiles with XBT's and depths of fish layers with an echo sounder from the source ship. The composition of the dominant species along this track will be provided by Dr. Kelly Benoit-Bird of the OSU and Dr. Dezhang Chu of the NWFSC.

We will also conduct measurements of SI with the ship at an *approximately* fixed range (to the extent possible without DP), at about 5 km, for 1 hour periods during night and day. We will not conduct long term TL and SI measurements between a fixed source and fixed receivers, as originally planned,

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because the assigned ship, the RV New Horizon, is not equipped with a Dynamic Positioning (DP) System.

We will employ sources, provided by Dr. Roger Gauss of the Naval Research Laboratory (NRL) to generate a series of CW signals between 200 Hz and 5 kHz at source levels below 180 dB, and EARS buoys, provided by Dr. Jeffrey Schindall of NRL, to receive the CW signals. The configuration of the bio-alpha experiment is illustrated in Figure 1. These sources will be programmed to transmit about sixty CW tones between 220 Hz and 5 kHz (220, 233, 247…Hz) ($f_{N+1} = 1.059\ f_N$) over about 10 minutes, every 10 minutes for several days. The duty cycle will be 10 %. Ideally we will be able to transmit 4 frequencies simultaneously, and reduce the cycle period to 2.5 minutes, reduce the cycle distance from 800 to 200 m, and increase the number of samples per measurement (at each frequency) from 10 to 40. The actual transmission sequence will be designed after engineering tests at Lake Seneca. The receiving array, which will consists of several EARS arrays, will be adapted to the depth of the selected site: 5 EARS arrays in water depths of about 200 m, 4 in water depths of about 160 m, etc.

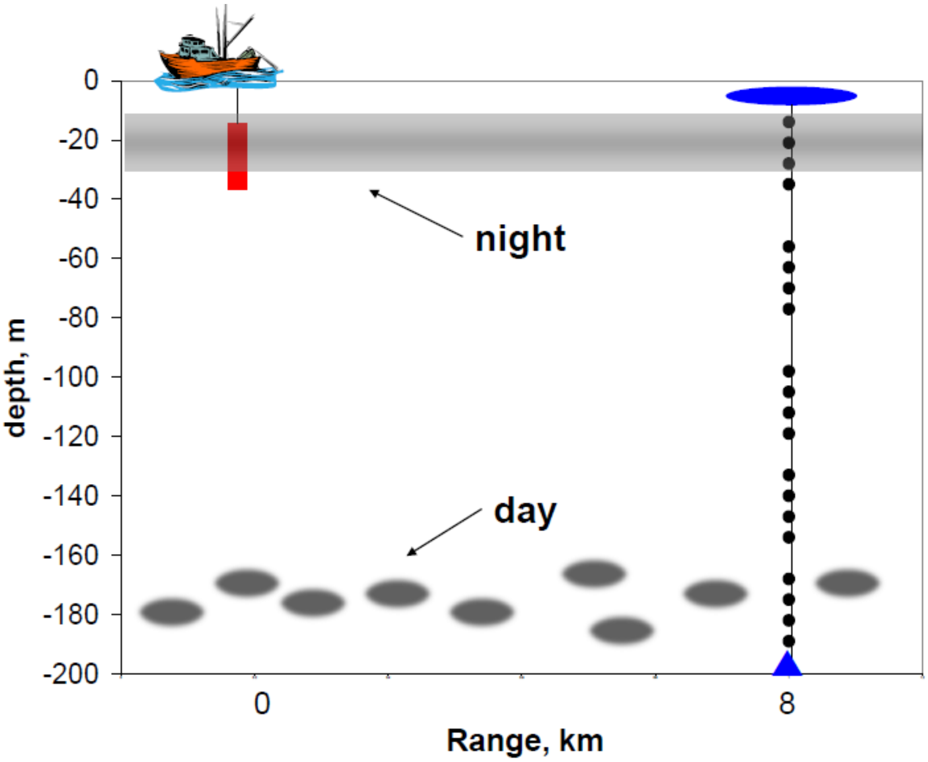

Figure 1. Nominal spatial configuration of the source and vertical receiving array deployed between a float and an anchor in 200 m of water, and idealized depths of hake and sardines in dispersed mode near the surface at night, and in school mode near the bottom during the day. The ship will traverse a track where fish concentrations are high.

We will deploy 3 thermistor strings along the measurement track, and one thermistor satring normal to the measurement track. The spatial configuration of the thermistor strings is designed to permit measurement of the temporal evolution of average sound speed profiles along the propagation path, and the magnitudes and directions of solitons, which propagate through the acoustic field. Each thermistor string will consist of at least 10 compact temperature sensors / recorders.

WORK COMPLETED

We conducted simulations of the effects of the target species, hake and sardines, on bio-alpha and TL, and designed an experiment to conduct concurrent measurements of bio-alpha, TL, SI, and fish composition and depths in the context of the ONR Fish Experiment during the summer of 2012.

RESULTS

We reviewed the behavior, bioacoustic properties and bio-geography of the target species, hake and sardines, which are expected to be present in significant numbers during this experiment. We simulated the effects of these species on bio-alpha. Effects of adult hake on attenuation are expected to be significant at frequencies below 1 kHz. Recent measurements suggest that Humbolt squid, which were present in large numbers when the ONR program was formulated, will probably not be present in large numbers and will probably not have a significant effect on bio-alpha during the experiment.

We adapted the PE model to include bio-alpha to permit calculation of TL in range dependent environments. This model is expected to be used during analysis of bio-alpha measurements at the ONR Fish Acoustics site. Previously reported bio-alpha experiments were conducted at sites where the bottom was flat, and range independent TL models were adequate.

To gain insights that may influence the design of the ONR Fish Acoustics experiment, we examined bio-alpha measurements, which were recorded during BAS II in the Santa Barbara Channel (SBC) (Diachok, 2005a), particularly at low frequencies. To isolate the effects of the bottom on TL at low frequencies, we developed a geo-acoustic model of the BAS II site, based on unpublished measurements of sound speed vs. depth, which were made during oil exploration surveys in the Santa Barbara Channel (Kamerling, personal communication). Figure 2 shows calculated values of the excess attenuation coefficient, A, due to bio-alpha, which were derived from BAS II measurements at frequencies between 300 and 1800 Hz. Values of A, were calculated from the equation,

$$A\ (\text{dB/km}) = [\text{TL(measured)} - \text{TL(calculated)}] / R$$

where TL(measured) represents 2 hour averaged values of TL, TL(calculated) includes effects of geoacoustic parameters of the bottom, but does not include bio-alpha due to layers of fish, and R = 3.8 km, the range between the source and receiving array during the BAS II experiment.

Differences in A between day and night are negligible at 300 Hz (< 1 dB/km), but become significant at higher frequencies. Strong absorption lines are evident at 1.1 kHz at 13 m at night and at 1.6 kHz at 41 m during the day. These lines are attributed to 15 cm sardines and schools of sardines respectively. Estimates of layer depths, which were derived by matching TL measurements with calculations that included an attenuating layer (Diachok and Wales, 2005b), are consistent with concurrent echo sounder measurements. Attribution of these lines to 15 cm sardines is based on concurrent trawls.

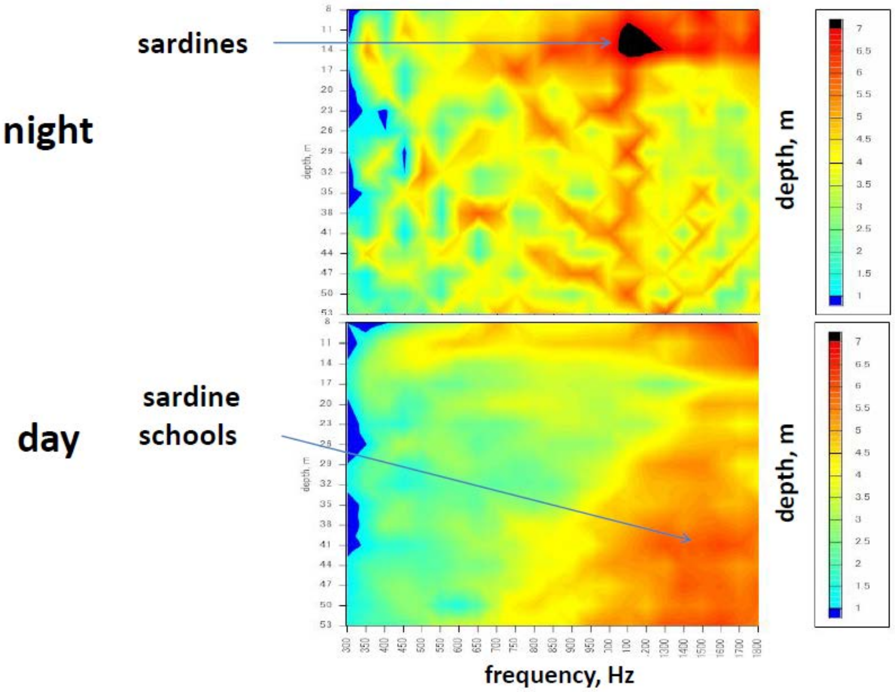

Figure 2. Calculated values of the attenuation coefficient due to bio-alpha derived from transmission loss measurements recorded during bio-alpha experiment in the Santa Barbara Channel during night (top) and day (bottom). The peaks at 1.1 kHz at 13 m at night and 1.6 kHz at 41 m during day are attributed to sardines in dispersed and school modes respectively.

Figure 3 (top) shows a comparison of theoretical calculations and measurements of the resonance frequency of 15 cm long sardines vs. depth at the BAS II site during night, when sardines were dispersed, and day, when sardines were in schools. The theoretical calculations are based on previously reported measurements of the effective radius, r, of the swim bladder of sardines. The discrepancy between calculated and measured values during the day is attributed to “bubble cloud” frequencies of sardine schools, F, which are theoretically lower than frequencies of dispersed sardines, f (Diachok, 1999). These results are similar to the measurements of resonance frequencies of sardines in dispersed and school modes, which were observed in the Gulf of Lion, as shown in Figure 3 (bottom) (Diachok, 1999). F = 0.63 f and F = 0.75 f in data recorded in the Gulf of Lion and Santa Barbara Channel respectively. Measured values of bubble cloud frequencies of schools are consistent with calculations of the fundamental resonance frequencies of bubble clouds, based on previously reported values of the average separation between and total numbers of fish in sardine schools (Hahn and Diachok, 2011).

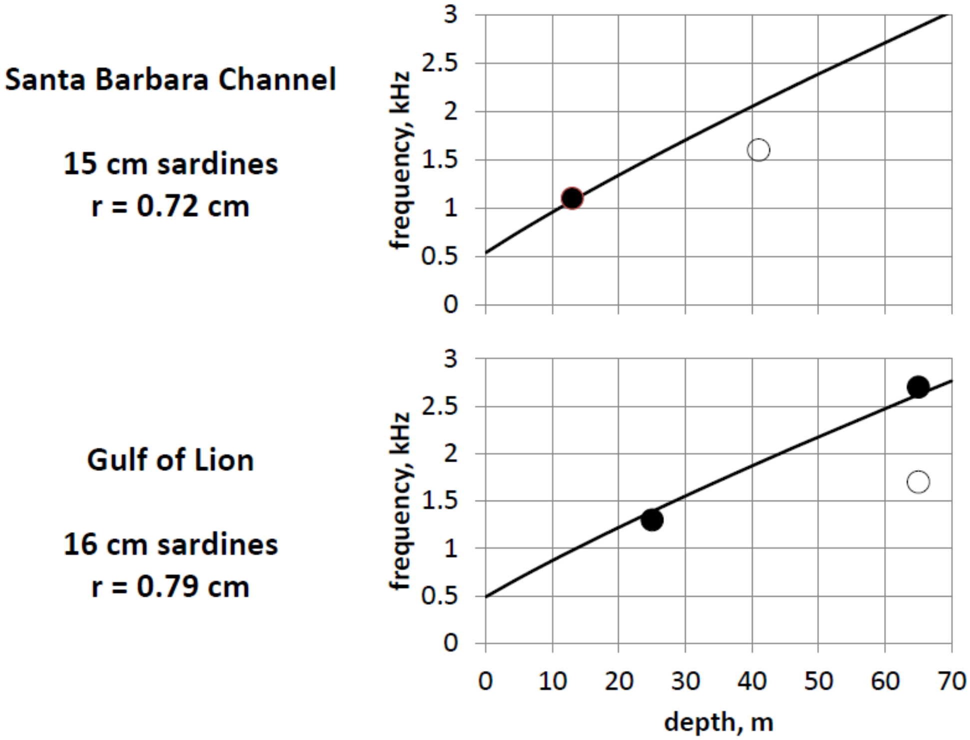

Figure 3. Theoretical calculations and measurements of resonance frequencies of dispersed sardines during night (●) and day (o) in the Santa Barbara Channel (top) and Gulf of Lion (bottom). The uncertainties in frequency, f, and depth, d: $\triangle f = \pm 100$ ***Hz,*** $\triangle d = \pm 3$ ***m. Measured frequencies of schools during day are consistent with theoretical calculations of the fundamental resonance frequencies of "bubble clouds".***

The peak at 750 Hz at 17 m and the speckle at frequencies below 750 Hz at night may possibly be due to schools of 15 cm long sardines. A significant percentage of sardines are known to generally remain in schools at shallow depths at night (Diachok, 1999). The percentage of sardines in schools at night in the SBC may be anomalously high due to the lights of nearby oil rigs.

The peak at 750 Hz at 17 m at night may also be due to juvenile (~ 26 cm) hake. Trawls during BAS II were not directed at hake, and no hake were caught, but they may have been present in large numbers in the SBC during this experiment.

We expect to measure bubble cloud resonances of sardine and possibly hake schools during the ONR Fish Acoustics experiment. Lack of measurements of the average separation between hake in schools, however precludes meaningful theoretical prediction of the resonance frequency of hake schools.

IMPACT/APPLICATIONS

The performance of Navy sonars is strongly affected by attenuation and reverberation due to scattering by marine organisms, specifically fish with swim bladders, in biologically intense environments, such as the Yellow and East China Seas. Existing Navy sonar performance models do not account for the effects of bio-alpha on transmission loss (TL) or reverberation. The proposed research is expected to provide the experimental basis for including bio-alpha in the Navy's performance prediction models.

Bioacoustic Absorption Spectroscopy (BAS) has the potential to permit classification of fish by size and depth in the context of ocean observatories (Diachok, 2011), and during routine fisheries surveys conducted by NOAA Fisheries Science Service laboratories.

RELATED PROJECTS

The results of this project are expected to transition to the planned Spawar AEMBERS Project, which is designed to assess and exploit marine bioacoustic effects on the Navy's sonar systems.

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