Instantaneous Passive and Active Detection, Localization, Monitoring and Classification of Marine Mammals over Long Ranges with High-Resolution Towed Array Measurements

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LONG TERM GOALS

The objective of this proposal is to develop approaches to enable instantaneous passive and active acoustic detection, localization, continuous monitoring and classification of marine mammals over *wide areas* spanning hundreds of kilometers or more in range. This will be accomplished using high-resolution towed receiver array measurements of marine mammal vocalizations (passive) and potentially instantaneous wide-area ocean acoustic waveguide remote sensing (OAWRS) and imaging (active) of marine mammals.

OBJECTIVES

The specific objectives of this proposal are:
(A) Develop approaches for instantaneous passive marine mammal detection and localization with towed receiver array measurements of their vocalizations.
(B) Estimate source level of marine mammal vocalizations.
(C) Develop database of marine mammal vocalizations measured using a high-resolution towed receiver array for rapid access and processing.
(D) Develop approaches for automatic real-time classification of marine mammals from their received vocalizations.
(E) Develop approaches for potential co-registration and continuous tracking of marine mammals from their scattered signals received on an active OAWRS system.
(F) Quantify the temporal-spatial behavioral dynamics of whales in the Gulf of Maine from measurements of their vocalizations and scattering during a NOPP-funded experiment in Fall 2006 (GOME'06) (Refs. 1-3).

APPROACH AND WORK COMPLETED

I) Correlating passive OAWRS sensing of humpback whale distribution with active OAWRS imaging of Atlantic herring populations in the Gulf of Maine during GOME06.

Vocalizing humpback whales and spawning herring populations were simultaneously localized and imaged over thousands of square kilometers during the peak annual spawning period of Atlantic herring in the Gulf of Maine by instantaneous passive and active OAWRS techniques respectively in the Fall of 2006 (Refs. 10, 1-3). Whale bearings were determined by beamforming their vocalizations receive on the OAWRS high-resolution towed receiver array. Whale ranges were determined by applying the instantaneous array invariant method (Ref. 5) and the moving array triangulation technique (Ref. 9) we introduced to the whale sensing problem, leading to the spatial distribution of humpback whale call rate density shown in Fig. 1. The farthest whale localized extended roughly 100 km in range from the receiver array. This distance is roughly 10 times larger than the typical localization range of conventional passive marine mammal survey technique based on triangulation with single hydrophone measurements.

Furthermore, the humpback whale vocalization sequences were examined by time-frequency analysis (Refs. 4, 8) and classified into songs and various non-song call types (Ref. 10).

(II) Development of a Database Management System for organization and rapid access of received whale vocalization signals on the high-resolution towed horizontal OAWRS receiver array.

We have developed a database management system for the marine mammal vocalizations measured by the OAWRS high-resolution towed receiver array in the Gulf of Maine 2006 Experiment. We implemented the MySQL relational database management system (RDBMS) that uses the Java Hibernate libraries to integrate seamlessly with the MATLAB environment creating an extremely efficient workflow for algorithm development and data analysis by many concurrent users. The MySQL RDBMS also provides a central structure which new information regarding the research may be easily added as additional tables or fields without disturbing the underlying structure. This MySQL to MATLAB interface (M2MI) is a robust and flexible solution for the retrieval of specific data via complex queries which greatly aid in the rapid development of algorithms and data analysis. M2MI was capable of organizing and centralizing the over 4TB of data collected over 15 days of measurements containing over 10,000 unique humpback vocalizations into 60 features across 7 relational databases, significantly improving the workflow required for novel processing of the many recorded vocalizations. The search features in this data base include duration and complex frequency characteristics of the marine mammal vocalization signals, the changing environmental and experimental conditions such as water temperature, sound speed profile, sea state, receiver position, orientation and motion, date and time of recording, and derived parameters such as relative bearing, true bearing, and subsequently whale localization estimates.

(III) Humpback whale vocalization source level estimation.

The source level (SL) of several thousand humpback whale vocalization signals (identified as humpback whale song units which constitute hundreds of humpback whale song themes) were estimated from the measured sound pressure level (SPL) of received humpback whale vocalizations by the highly sampled, large-aperture OAWRS towed horizontal receiver array after correcting for the expected one-way transmission loss (TL) from estimated whale locations to the GPS-measured receiver array centers. The TL was calculated using a calibrated stochastic range-dependent ocean acoustic propagation model RAM based on the parabolic equation. Typical singing depths of humpback whale, known to be in the range 2 to 23 m, were used as inputs to calculate the expected one-way TL from singing whale locations to the GPS-measured receiver array locations by Monte-Carlo simulation and using the experimentally measured range and depth dependent sound speed profiles acquired during GOME06 as the input.

(IV) Other areas.

The other areas of active research in the group include algorithm development for automatic detection and classification of whales in measured data, whale TS estimation from their scattered levels in active OAWRS data, development of full-field model for scattering from combined whale lung, flesh and blubber in a random range-dependent ocean waveguide valid at low frequencies of several hundred Hz to a few kHz, detailed tracking of whale individuals and correlation to bathymetry, oceanography, fish and larvae distribution from GOME'06 data, potential response or lack of to certain types of anthropogenic sound in the ocean such as sonar transmissions and shipping noise.

RESULTS

IA) Correlating passive OAWRS sensing of humpback whale distribution with active OAWRS imaging of Atlantic herring populations in the Gulf of Maine during GOME06.

We find that the vast majority of vocalizing humpback whales were spatially distributed in regions coinciding with the primary aggregations of spawning herring during the peak annual herring spawning period in the Gulf of Maine (Figure 1). During daylight hours, herring were found to be dispersed on the seafloor in deeper waters over wide areas of Georges Bank’s northern flank (Makris et. al., Science 2009; Gong et. al., JASA 2011). At sunset, they would rise and converge to form dense and massive evening shoals, which migrated to the shallow waters of Georges Bank for spawning, following a regular diurnal pattern (Makris et. al., Science 2009; Gong et. al., JASA 2011). We find the humpback whale vocalization behavior followed a similarly strong diurnal pattern, temporally and spatially synchronous with the herring shoal formation process, with vocalization rates roughly ten times higher at night than during daylight hours (Ref. 10). At night, most humpback whale vocalizations originated from concentrated regions with dense evening herring shoals, while during daytime, their origins were more widely distributed over areas with significant but diffuse pre-shoal herring populations (compare Fig. 1(A) with Fig. 1(B)). These findings are consistent with a feeding-behavior cause for the elevated humpback whale nocturnal vocalization rates and spatial focusing on dense shoals.

IB) Classifying humpback whale vocalizations during their feeding season in the Gulf of Maine

Detailed time-frequency analysis of humpback whale vocalizations measured during their Fall feeding season show the vocalizations are comprised of: (i) non-song calls, dominated by repetitive downsweep “meows” occurring roughly every 30 seconds on average during night-time hours which apparently have not been previously observed, bow-shaped calls and feeding cries (see Ref. 10); and (ii) songs. The repetitive non-song calls were highly diurnal and synchronous with the herring shoal formation process, consistent with hunting and feeding behavior. In contrast, songs occurred at a constant rate with no diurnal variation, and are apparently unrelated to feeding and the highly diurnal herring spawning activities. We also showed with this dataset the active OAWRS survey transmissions had no effect on humpback whale song since we measured constant humpback whale song occurrence and production rates over our entire survey area roughly 400-km in diameter covering most of the Gulf of Maine, including Stellwagen Bank, both before and during the active OAWRS survey.

(III) Humpback whale vocalization source level estimation.

The estimated SLs of humpback whale song unit were found to roughly follow a Gaussian distribution with a mean and a median SL of 179.8 and 179.1 dB re 1mPa and 1 m, respectively, and a standard deviation of 7.7 dB (Ref. 10). Vast majority of the estimated humpback whale song unit SLs were found to be in the range 170 to 190 dB re 1mPa and 1 m, which are consistent with previously reported humpback whale song SLs. These humpback whale song units were recorded with the high-resolution OAWRS towed horizontal receiver array over a period of 10 days during GOME06.

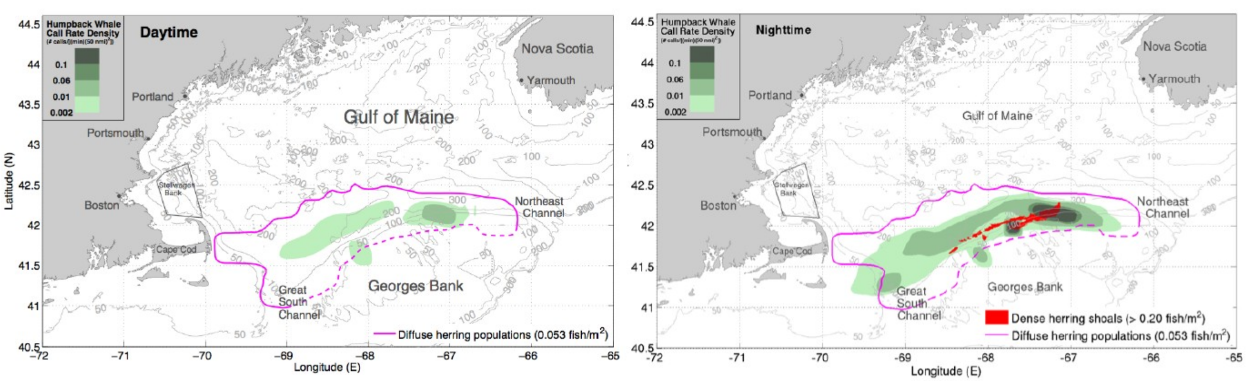

Figure 1: (A) Spatial distribution of vocalizing humpback whales coincides with the locations of diffuse herring populations during daytime hours. In daylight, the vast majority of the humpback whale vocalizations originate within areas containing diffuse herring populations (0.053 fish/m², bounded by magenta line). The green shaded areas indicate the daytime humpback whale call rate densities (number of calls/[(min) (50 nmi)²]) measured with the large aperture array. All data represent daytime means between September 22 and October 6, 2006. The dashed magenta line represents the southern bound of the Northeast Fisheries Science Center (NEFSC) survey tracks. The daytime hours are between sunrise and sunset (06:00:01 to 18:00:00 EDT) (B) Spatial distribution of vocalizing humpback whales coincides with the locations of dense evening herring shoals during nighttime hours. At night, vocalizing humpback whales become concentrated at and near dense evening herring shoals (> 0.2 fish/m², red shaded areas) that form along the northern flank of Georges Bank and call rates increase dramatically. The green

shaded areas indicate the nighttime humpback whale call rate densities (number of calls/[(min) (50 nmi)^2]) measured with the large aperture array. All data represent nighttime means between September 22 and October 6, 2006. The magenta line bounds the areas with diffused herring populations (0.053 fish/m^2). The dashed magenta line represents the southern bound of the NEFSC survey tracks. The data shown are for nighttime hours between sunset and sunrise the next day (18:00:01 to 06:00:00 EDT) (Figure from Ref. 10).

IMPACT AND APPLICATIONS

The combined passive and active acoustic sensing approach with towed arrays developed here provides an efficient approach for detecting, localizing and classifying marine mammals rapidly over wide areas for many important operations such as geophysical surveys, naval exercises and population assessment surveys that already deploy towed arrays. Acoustic sensing is the only approach that is effective during night-time operations, and in the daytime during poor weather conditions not conducive to visual surveys. The combined active and passive acoustic sensing approach allows continuous monitoring of marine mammals over ranges spanning 50 km or more, far greater than that possible with visual observations, typically limited to 10 km range or less. The methods proposed here do not require tagging and can be physically noninvasive for the marine mammals, since the sensing is carried out from very long ranges.

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