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Cumulative and Synergistic Effects of Physical, Biological, and Acoustic Signals on Marine Mammal Habitat Use

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LONG-TERM GOALS

The long-term goal of this collaborative research effort is to enhance the understanding of how variability in physical, biological, and acoustic signals impact marine mammal habitat use. This is especially critical in areas like the Bering Sea where global climate change can lead to rapid changes of the entire ecosystem. Progressive climate change has the potential to expose areas of the Arctic and sub-Arctic that have been previously unavailable for civilian and military use. Baseline measurements will play an important role in mitigation efforts and environmental assessments as commercial and military activity increases in the region.

OBJECTIVES

The main objective of this work is to relate synoptic measurements of prey distribution, physical oceanographic process, and sound levels to marine mammal habitat use on the eastern Bering Sea shelf. Integrated data such as these will be vital in understanding the relationship between marine mammals and their environment both in the presence and absence of specific noise sources. Long-term measurements will play an important role in determining the point at which cumulative effects of the environment and human activities impact animal populations, and in identifying the conditions that pose the greatest risk.

Effort in Year 3 of this project was focused on data analysis and integration. Year 1 was devoted to instrument acquisition and mooring deployment. Work done in Year 2 was geared towards data processing and classification of sound sources from passive acoustic recordings acquired from two sub-surface NOAA moorings in the Bering Sea. This involved the detection and classification of marine mammal vocalizations, human activities, and geophysical signals from passive acoustic datasets. A time series of volume backscatter was also generated from different regions of the water column in Year 2. During the past year, datasets from the different acoustic sensors have begun to be integrated to provide insight on potential prey patterns corresponding to marine mammal presence and vocal behavior. Acoustic measurements have also been integrated with synoptic measurements of ice and hydrographic parameters to identify the combination of factors most strongly associated with marine mammal presence and habitat use in this area.

APPROACH

This project is a three-year study involving long-term monitoring of the physical and biological environment at two established NOAA mooring sites (known as M2 and M5) in the Bering Sea (Stabeno and Hunt, 2002). An acoustic monitoring system using both active and passive acoustic sensors was developed and deployed at the end of Year 1 on NOAA FOCI moorings maintained by the Pacific Marine Environmental Laboratory (PMEL). Data downloads and mooring maintenance has occurred at 6-12 month intervals. Final data retrieval is scheduled in September/October 2010. The passive acoustic dataset is being used to assess the physical environment and to detect and identify vocalizations from marine mammals and sounds generated by human activity present near the moorings. Passive recorders on each mooring include a Passive Aquatic Listener (PAL) and AURAL recorder from the National Marine Mammal Laboratory. The PALs are adaptive sub-sampling instruments that store spectra and short 4.5 sec soundbites, where as the AURAL recorders produce a continuous time series on a set sampling schedule of 8 minutes every half hour. Comparison of the two datasets will determine how effective an adaptive sub-sampling technique is for detecting species diversity, what proportion of vocalizations is missed with the sub-sampling protocol, and whether appropriate parameters can be estimated to calculate the probability of detection for specific species. The active acoustics component is used to investigate zooplankton and fish distribution, patterns, and abundance. The active system includes a three frequency suite of scientific echosounders [Acoustic Water Column Profilers (AWCPs)] that are deployed on each mooring (125 kHz, 200 kHz, and 460 kHz). Ancillary measurements of water column characteristics (current, temperature, salinity, nutrients, chlorophyll, etc.) will be available from the standard NOAA instrumentation on the moorings.

Application of the data to the study of ecosystem dynamics is a multi-step process. Patterns and interactions of measured variables are first being examined within each region according to the following sequence. 1) Datasets generated from the active and passive acoustic sensors are analyzed separately to identify characteristics and patterns specific to the mooring location. 2) Time series of individual parameters are overlaid to identify potential interactions or covariance. 3) A mixed-model analysis will be performed to quantify relationships between marine mammal presence and environmental sound parameters, characteristics of physical processes, and prey abundance. Following the separate analyses in each of the two study regions, observed patterns and factors relating to habitat use will be compared between regions.

WORK COMPLETED

Mooring cruises took place in Sept/Oct 2009 and Apr/May 2010. During the NOAA FOCI mooring cruise in Sept/Oct 2009, data was returned from May 2009-Sept/Oct 2009 at both moorings. It was discovered that the PAL at M2 had a power malfunction which prevented data collection over the full duration of the deployment. All other instruments operated the full duration of the deployment. All M2 and M5 instruments were repaired/refurbished and re-deployed in Sept/Oct 2009. Only M2 was retrieved for data download and re-deployment in Apr/May 2010 because the ice sheet extended south past the M5 mooring location preventing access to this mooring. One of the M2 AWCP instruments collected a full deployment of data, but it then malfunctioned prior to re-deployment at M2. Only 2 AWCP frequencies were deployed on M2 for the summer season while the third instrument was repaired. Final data retrieval from instruments at M2 and M5 is scheduled for Oct 2010.

A project planning meeting focused on passive acoustic data analysis was held in State College, PA and attended by J. Miksis-Olds, J. Nystuen, S. Denes, and S. Parks in October 2009. A second project meeting attended by J Miksis-Olds, D. Mellinger, S. Denes, and J. Warren was held in State College, PA in June 2010. This meeting focused on the analysis of acoustic backscatter from the AWCP instruments and the comparison of PAL and AURAL data.

Data Processing

Detection and categorization of sounds from the PAL soundbites and AURAL recordings at M5 over the 2008-2009 time period was completed. Two different energy detectors were run on the AURAL data: 1) 0.1-1 kHz, and 2) 0.9-4 kHz. Species classification of vocalizations within the PAL soundbites and those outputted from the detector was done by three trained human listeners.

During the winter season at M5, the PAL often exceeded its pre-programmed limit for storing soundbites within the first or second hour of the day because of the high vocal activity of ice breeding pinnipeds. However, spectra were generated and stored every 10 minutes throughout the day by default. During period of high vocal activity, spectra were generated and stored every 2 minutes. To identify stereotyped vocalizations from spectra saved by the PAL when soundbites are not available, spectral templates are being developed for bearded seals, ribbon seals and Pacific walrus. These templates are based on spectra calculated from soundbites identified as containing a stereotyped vocalization of one of these species. The soundbites with detections for these species were reviewed to select files with high signal to noise ratios. The set of SNR detections has been divided into training and testing sets. The vocalizations of interest were extracted from the training group and spectra were created from 20 millisecond clips, as in the automated spectra collection for the PAL during deployment. The resulting spectra were grouped with similar spectra. An average spectrum for each group was then computed, these average spectra are now the templates for the vocalization. The templates will then be compared with a set of spectra from randomly selected sound clips and the test group to determine their effectiveness in identifying spectral signatures of these vocalizations. Ultimately, the templates will be used as a filter to identify species specific vocalizations from spectra when there is no soundbite for comparison. By combining PAL spectra and soundbite detections, a time series of daily species presence will generated for comparison to AURAL detections.

Time series of volume backscatter at different depth layers (surface, mid-water column, deep water column, and bottom) were generated from the AWCP data at M2 and M5. Acoustic backscatter was integrated over a 24 hour period in each of the 2 m thick depth layers (Figure 1). The acoustic signature of salient aggregations and layers detected in echograms were generated from the

simultaneous measurements at three frequencies using a dB differencing technique (Figure 2) (DeRobertis et al., 2010). We are currently working with Alexei Pinchuk (University of Alaska, Fairbanks) and Joe Warren (Stony Brook University) to match acoustic signatures to species composition determined by net tows and to run DWBA models for estimating target strength distributions of Bering zooplankton species. This information will then be used in inverse processing techniques for estimating biomass and density.

Data Analysis

Analysis of the proportion of time sound is generated during a calling bout for select species was completed using PAL soundbite data. This information was then used to estimate the probability of detection by the PAL for specific species (Table 1) (Miksis-Olds et al., 2010).

The first phase of comparing detections of the PAL (adaptive-sub-sampling) to those of the AURAL (scheduled sub-sampling) was completed, and the second phase is underway. During the first phase of analysis, daily species detections from PAL soundbites and AURAL detections were compared for four days each month (days 1, 8, 15, and 23). During the second phase of comparison, daily species detections from the PAL spectra will be added to the overall evaluation.

Dataset integration is ongoing. Initial integration of the passive acoustics, active acoustics, ice characteristics, and hydrography has focused on a specific ice-related event at the M5 mooring location. During the winter of 2009, there was a rapid treat and subsequent re-extension of the ice over the mooring in March 2009 (Figure 3). This occurred over a two week period and perturbations in all the data sets were identified over this time period. A spectrographic analysis of volume backscatter has identified period of intense and absent vertical migration of zooplankton in relation to ice characteristics (Figure 4). Relationships between marine mammal detections, environmental sound levels, ice characteristics, and relative zooplankton biomass have also been identified.

The analysis and corresponding results of the ambient sound measurements related to this project is described in the collaborative Annual Report by Jeffrey Nystuen (Award Number N000140810394).

RESULTS

Results stemming from this year's efforts highlight 1) the comparison between the sampling strategies of the adaptive sub-sampling PAL and scheduled sampling of the AURAL for 8 continuous minutes every half hour, and 2) the ecosystem response to a rapid ice retreat event at the M5 mooring location.

A comparison of the daily species detections between the PAL soundbites and AURAL detections revealed that recorder performance was highly species and vocalization related (Figure 5). The PAL outperformed the AURAL in detecting both high (dominant frequency > 10 kHz) and low frequency (domiant frequency < 4 kHz) clicks of echolocating cetaceans. The detection of bowhead whales was simialr for both instruments, and the detection of humpback whales from the PAL soundbites and AURAL detections was equal overall but with detections on different days. The detection of ice assocaited pinnipeds was generally higher by the AURAL when compared to the PAL soundbite detections, with a high degree of overlap between the 2 instruments for these species. The restriction of the number of PAL soundbites stored each day greatly restricted how much of the day was represented in the soundbites. Often the soundbite quota was exceeded within the first 2 hours of the day. PAL spectral data consistenly sampled and stored data all day throughout the deployment period.

We anticipate a much higher degree of overlap between the detections from the AURAL and PAL once the information from the PAL spectra is incorporated into the analysis.

The integration of acoustic time series with other environmental data reveal that upper and lower trophic level dynamics are tightly coupled to sea ice in the Bering Sea (Figures 1, 3, 4, 6, and 7). The volume backscatter, indicative of zooplankton abundance, was at a minimum during ice covered periods and rapidly increased to the yearly maximum in the deep water layer during the temporary ice retreat in March 2009 (Figure 1). Spectral analysis of the volume backscatter also reveal a strong vertical migration during periods of seasonal open water and during the temporary ice retreat (Figures 2, 3, and 4). The ratio of volume backscatter at the different frequencies suggests that species composition of the vertical migration differs from that of the zooplankton layer tracking the pycnocline during the daylight hours (Figure 2).

The presence of ice breeding pinnipeds and foraging bowhead whales coincided with the arrival of ice over the M5 mooring (Figure 6). During the ice retreat, bowhead whales and walrus vocalizations continued to be detected, while bearded and ribbon seal detections were absent. It is not known if the ice seals left the area in conjunction with the ice, or whether they remained in the area and did not engage in vocal mating displays. Biomass of zooplankton did increase in the area during the temporary retreat, and the cessation of ice breeding pinniped vocalizations may reflect a shift in activity from breeding to feeding during this time. When the ice returned after the rapid retreat, bearded seals were detected almost immediately, whereas ribbon seal vocalizations were not regularly detected again until the ice was thicker than 20 inches (Figure 7). This suggests that ice utilization by ice seals is species dependent and related to specific characteristics of the ice.

IMPACT/APPLICATIONS

The acoustic measurement system used in this project has the advantage of being deployed for long periods of time on subsurface moorings, affording the opportunity to collect valuable data during the harshest conditions of the winter season when traditional sampling techniques are not possible. The combination of acoustic and environmental datasets revealed that there is a rapid ecosystem response to relatively short-term change in ice cover, which has a profound effect on zooplankton abundance in the deeper water column. Identifying relationships between physical forcing mechanisms, biological activity, and marine mammal habitat use will not only be critical in understanding and ultimately predicting how marine mammals respond to noise, but also to how ecosystems respond to variability on multiple time scales.

The system used in this study is appropriate for use in almost all marine environments. It provides an advantage over continuous recording instruments in that the initial real-time processing of environmental sound by the PALs detects and identifies sources of interest without an overwhelming amount of data needing post-processing. The PALs and active acoustic sensors can be programmed to sample at the same time scale to ensure synoptic data collection. The adaptive sub-sampling protocol of the PAL is flexible and can incorporate a wide range of detection algorithms. A modified soundbite protocol will insure more representative coverage of time series throughout the day compared to the current sampling strategy that did not partition the soundbite acquisition.

It is highly likely that the acoustic environment of the Bering Sea will be altered as the area experiences climate changes. The Bering Sea has already experienced significant warming (~3°C) over the last several decades which has been closely associated with a marked decrease in sea ice

concentration, duration, and maximum extent over the area (Stabeno et al. 2007; Wang and Overland 2009). Direct climate effects will be linked to ice coverage, and indirect acoustic effects will occur as humans begin to use areas previously inaccessible due to ice. How this will impact the diverse sub-Arctic marine mammal species is unknown, but extreme care should be taken in interpreting the effects of sound on animals in this area as their entire ecosystem will be in a state of flux.

TRANSITIONS

This project represents a transition from the acoustic (both passive and active) detection and characterization of specific sound sources and targets to the study of ecosystem acoustics and ecosystem response to environmental change.

RELATED PROJECTS

Soundbites recorded from the PAL have been shared with Brian Branstetter (National Marine Mammal Foundation) to be used as potential natural maskers in an auditory masking study for bottlenose dolphins (Award Number: N000141010500).

Acoustic backscatter measurements from the AWCP instruments will be integrated with ship measurements of phytoplankton species composition, size structure, and productivity to understand the potential consequences on zooplankton populations measured from moored acoustical observations in a NASA ROSES funded project.

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Nystuen, JA, Miksis-Olds, JL (2010). Soundscapes under sea ice:Can we listen for open water? Acoustical Society of America, Baltimore, MD. April 19-23.

Miksis-Olds, JL, Nystuen, JA (2010). Acoustic tracking of upper trophic level dynamics in the Bering Sea. 2101 Ocean Sciences Meeting. Portland, OR. February 22-26.

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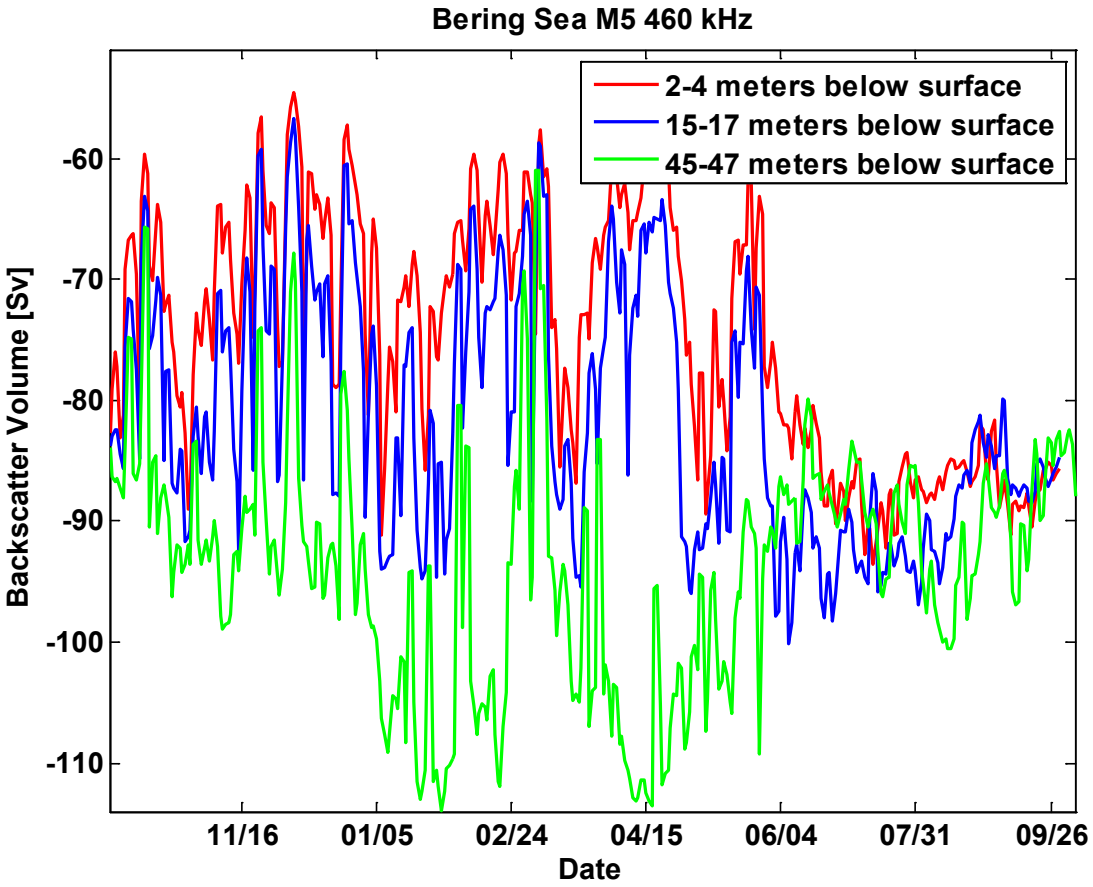
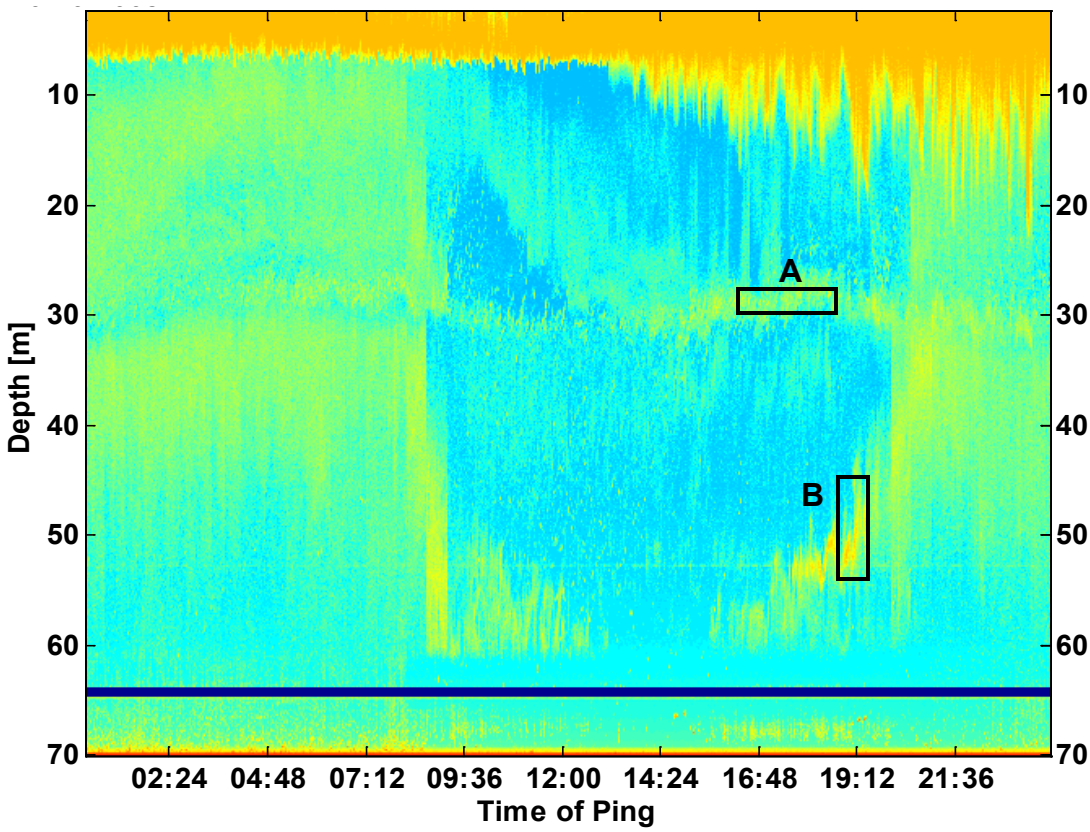
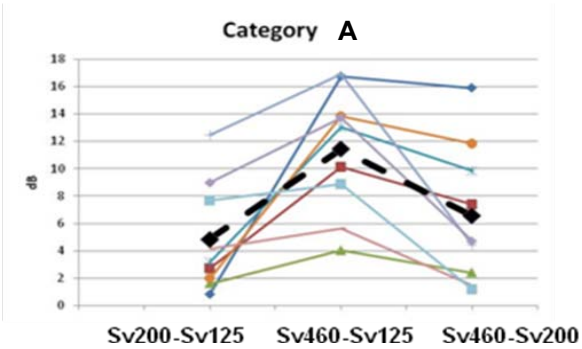


Figure 1. Year time series of volume backscatter (Sv) at 460 kHz from mooring location M5 from 2008-2009. The temporary ice retreat occurred between 2/24/09 and 4/15/09





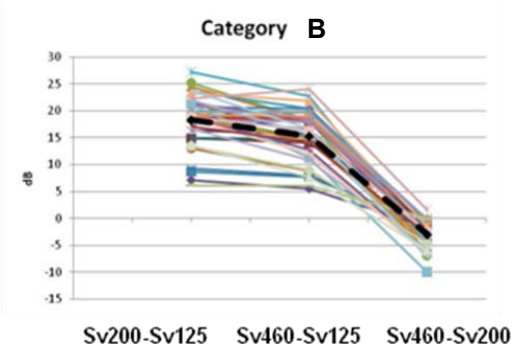


Figure 2. A 24 hour echogram from M2 on 09/30/2008 at 460 kHz. Note visible zooplankton layer concentrated at the pycnocline (A) and vertical migration event (B). The profiler operated in a vertical orientation, facing up towards the surface. Frequency ratio plot illustrate the differnece in speceis composition between the 2 regions

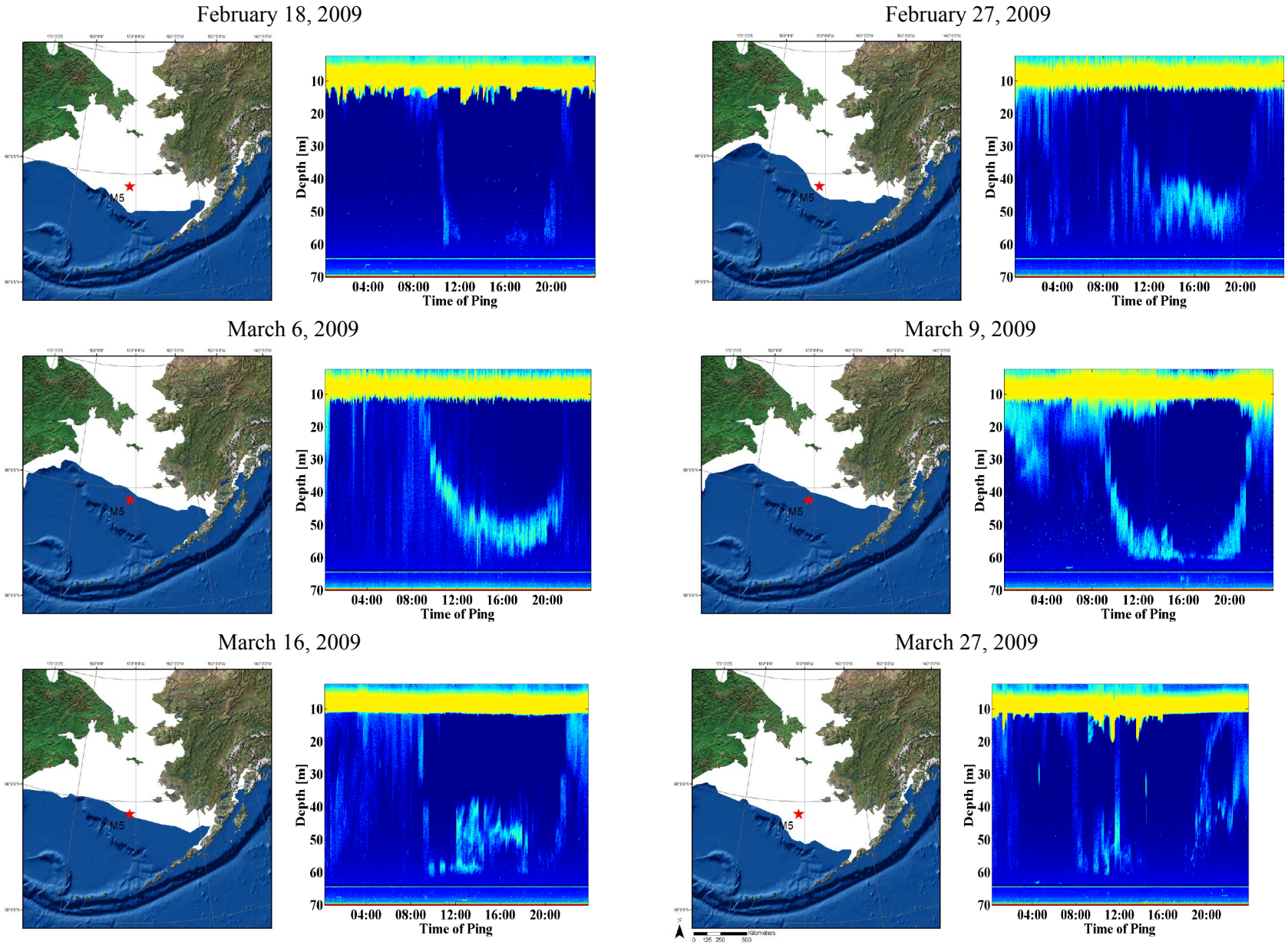


Figure 3. Ice extent and correspond 24-hour echogram (200 kHz) during the temporary retreat at mooring location M5

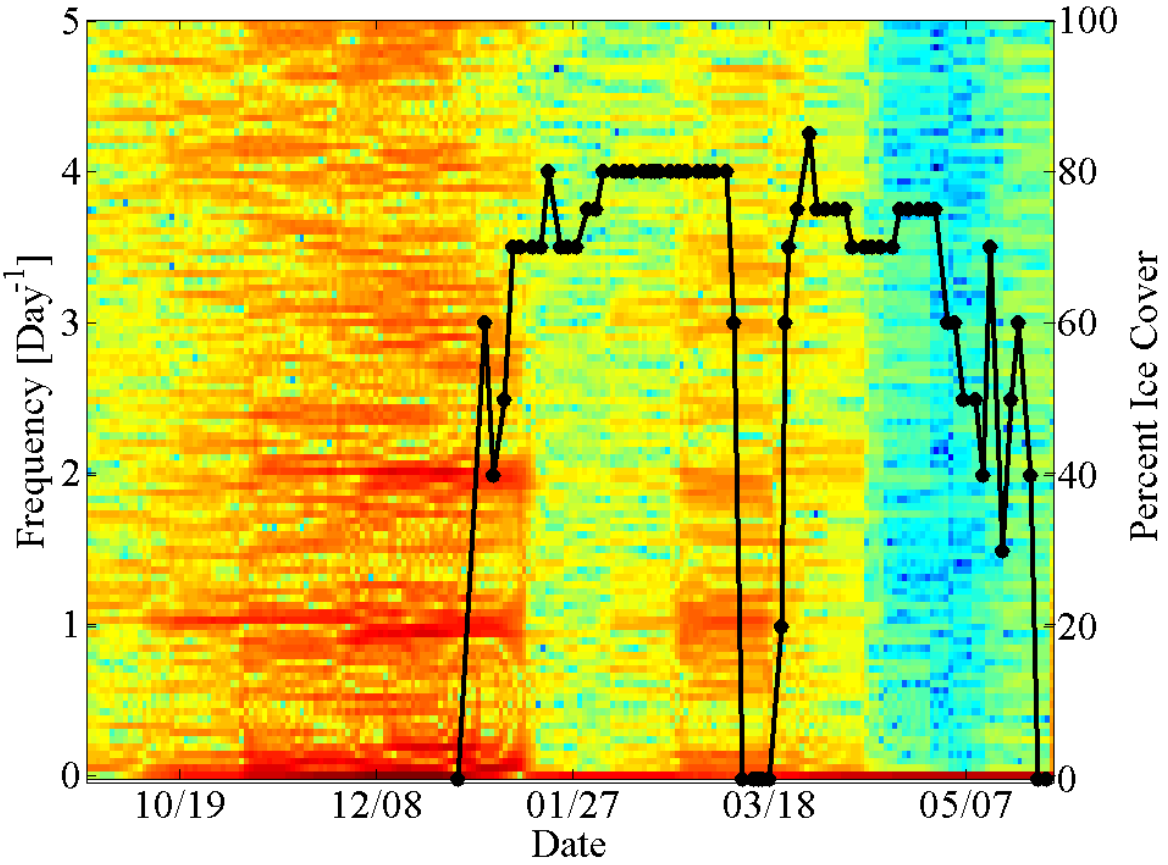


Figure 4. Spectrographic analysis of the Sv values from the 125 kHz unit at M5 45-47m below surface with a plot of Ice Coverage (black). Diurnal frequency components present in both ice free and temporary retreat periods

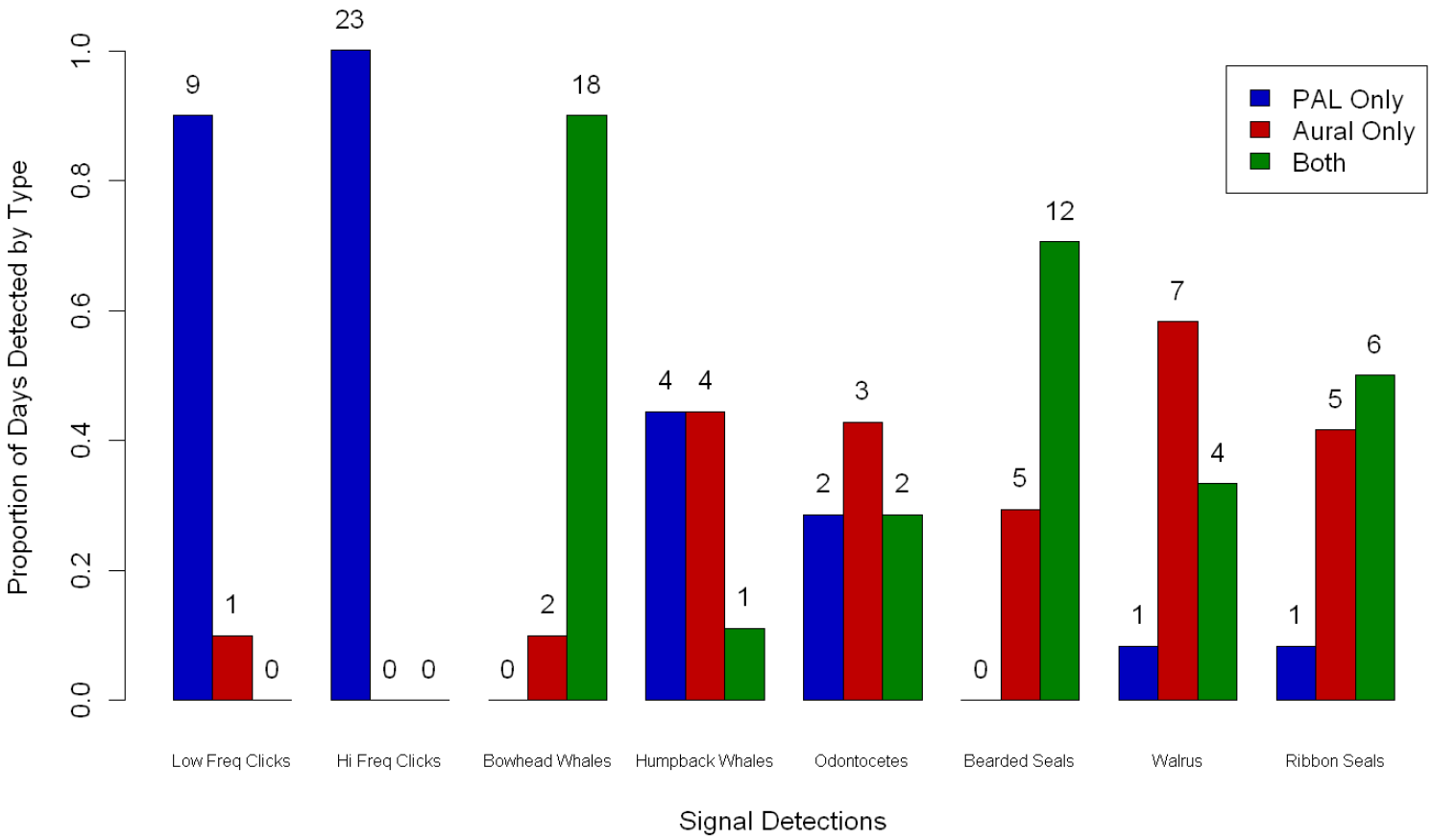


Figure 5. Comparison of PAL soundbite and AURAL detections sampled on days 1, 8, 15, and 23 of each month from Oct 2008 to June 2009. The numerical values above each bar indicate the number of days each species or signal was detected by the indicated recorder(s). Total number of days analyzed equaled 32 days

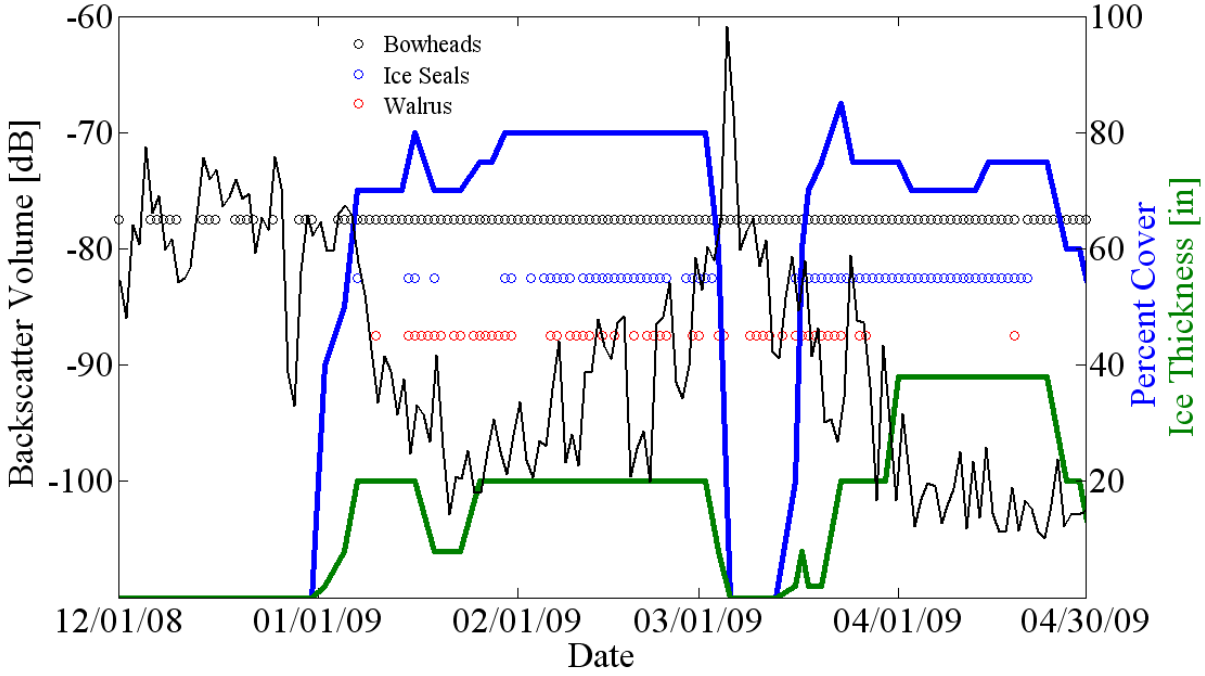


Figure 6. There is a strong relationship between the presence of several types of marine mammals and sea ice. Symbols associated with marine mammals indicate days when the species was detected and does not correlate with either of the y axes. The ice seals (bearded and ribbon seals) are present and vocalizing only when the ice pack is present. During the temporary retreat, the volume backscatter measured at 460 kHz in the lower water column (45-47 m below surface) reached an annual maximum

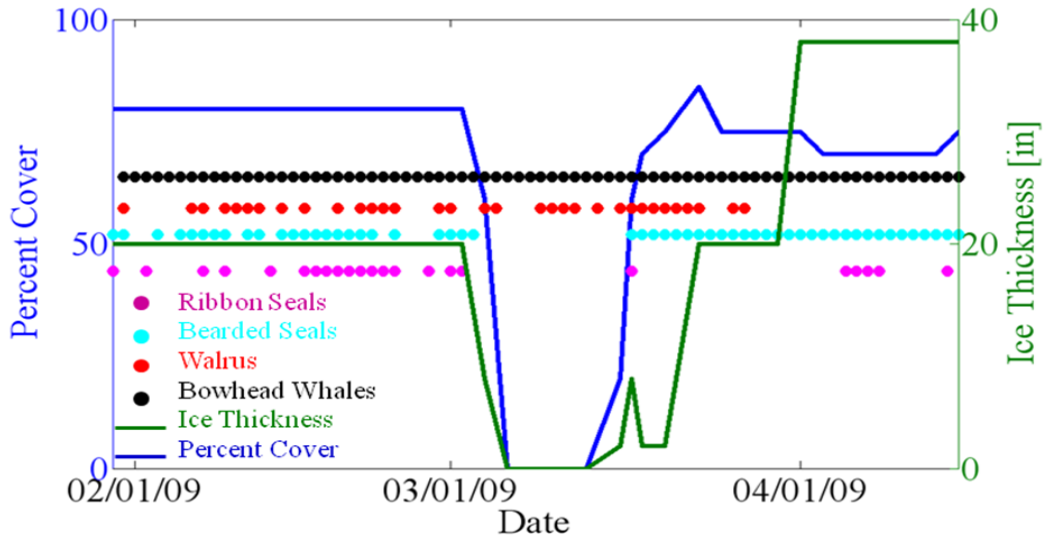


Figure 7. Detections of marine mammals before, during, and after the temporary ice retreat. Ribbon seals are not regularly detected after the retreat until the ice is thicker than 20 inches