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

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LONG-TERM GOAL

The long-term goal of this collaborative research effort is to enhance understanding of how variability in physical, biological and acoustic signals impact marine mammal habitat use. In particular, what are the effects of manmade underwater sound on marine mammal health and physiology, and what are the consequences of these effects at the marine mammal population level? A major component of this research is to use passive ambient sound to identify the physical environment present, and then to use this information to interpret the biological data collected. This report describes the passive component of this project.

OBJECTIVES

The objectives of the passive acoustic component of this collaborative research effort are to identify and make synoptic measurements of the physical environment that the marine mammals (whales and seals) are using. Attention to the physical environment is often absent from biological studies and yet is an important component of biological processes. Physical oceanographic processes, including wave breaking, rainfall and sea ice processes, all have distinctive acoustic signatures that can be used to detect, classify and quantify them. Learning to identify physical processes acoustically will be an important aid to more encompassing ecosystem studies. Furthermore, ambient noise levels in the Bering Sea are measured directly and provide a background baseline for future studies and human activities. 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 kinds of exposure that pose the greatest risk. The Bering Sea is an ecosystem that is presently experiencing rapid climate change, has relatively healthy populations of cetaceans and seals, and supports the largest fishery in the US EEZ.

One especially interesting component of the Bering Sea ecosystem is that it is ice-covered for part of the year. Understanding how marine mammals interact with sea ice is particularly difficult to study as the environment is extremely difficult to sample by more traditional means such as ship cruises or maintaining surface moorings. In fact, NOAA does not attempt to maintain surface moorings during most of the year because of the threat of sea ice, and other harsh conditions. Acoustic sampling of this environment offers the possibility to extend measurements of the environment throughout the year.

APPROACH

This project is a three-year field 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 (Figure 1) (Stabeno and Hunt, 2002). An acoustic monitoring system using both active and passive acoustic sensors has been developed and deployed. The passive component is used to assess the physical environment and to detect and identify cetaceans and ice seals present near the moorings. The active component is used to investigate zooplankton distribution and abundance. Ancillary measurements of water column characteristics (temperature, salinity, nutrients, ice cover, etc.) will be available from the standard NOAA instrumentation on the moorings.

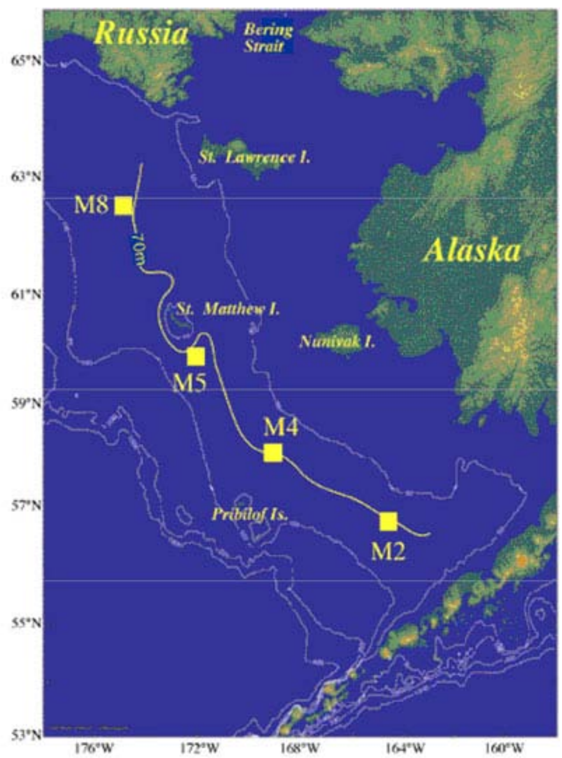

Figure 1. Map showing the location of the moorings (M2 and M5) maintained by NOAA that are being used for this project.

The component of the project that is associated with the passive acoustic monitoring of the environment is the specialty of Nystuen (APL/UW). The instrumentation used are Passive Aquatic Listeners (PALs), designed and developed at APL/UW. This report describes the use and interpretation of these instruments to support the objectives of this research project. This is the APL/UW component of this research effort.

PALs have been used for nearly a decade to quantitatively monitor the physical marine environment (Ma and Nystuen, 2005; Nystuen et al., 2010). They are not continuous recorders, but rather low duty cycle recorders that produce a time series of spectra, with an adaptive sampling strategy that allows different processes to be sampled differently when appropriate. One new feature is to record short temporal time series (4.5 seconds at 100,000 Hz sampling rate) that can be used to identify transient sounds such as calls and clicks from marine mammals. This feature has been used to detect and identify specific cetacean species, in particular, killer whales (Nystuen et al. 2007), and from the data collected as part of this project at the M5 mooring (Miksis-Olds et al., 2010).

WORK COMPLETED

Three active/passive acoustic instrumentation packages have been acquired by ARL/PSU (Miksis-Olds). Two existing PALs from APL/UW (Nystuen) were refurbished and deployed during the first year. Three years of data have been collected from both mooring sites, and an additional year of PAL data from previous deployments at M2 and M5 have been incorporated into the data analysis effort. In particular, two full years of PAL data from M5 (2007-2009) are available for this effort. The third year of data have just been recovered (Sept 2010). Three new PALs have been fabricated and are currently deployed at both mooring sites, and now at M8 (Fig 1).

Initial analysis has been performed on the PAL data from 2007-2009 at M5, and PAL data from summer 2004 and fall 2008 at M2 have been analyzed. The PAL data from 2004 has been published (Nystuen et al. 2010) under separate funding. New manuscripts are under preparation and several presentations at scientific conferences have occurred.

RESULTS

The 2008-2009 data from the M5 mooring demonstrated at least five different soundscapes associated with sea ice coverage. This includes physical ice sounds, and the sounds of marine mammals associated with sea ice, especially bowhead whales, bearded seals, ribbon seals and walrus. The ice pack was present at M5 from Day 5 – Day 137 (5 Jan to 17 May) (Fig 2.). The ice onset was characterized by a large increase in the number of sound samples containing transient sounds. The 2009 sea ice had an interesting interlude in late February/ early March when the ice pulled back to the north for about 20 days (24 Feb – Mar 16), and then returned until mid-May (Day 137 – May 17). This episode was detected acoustically, including the acoustic soundscape of open water soundscape on Days 57/58 and 69. The interlude ended rapidly on Day 75 when thick, continuous pack ice returned and persisted until May.

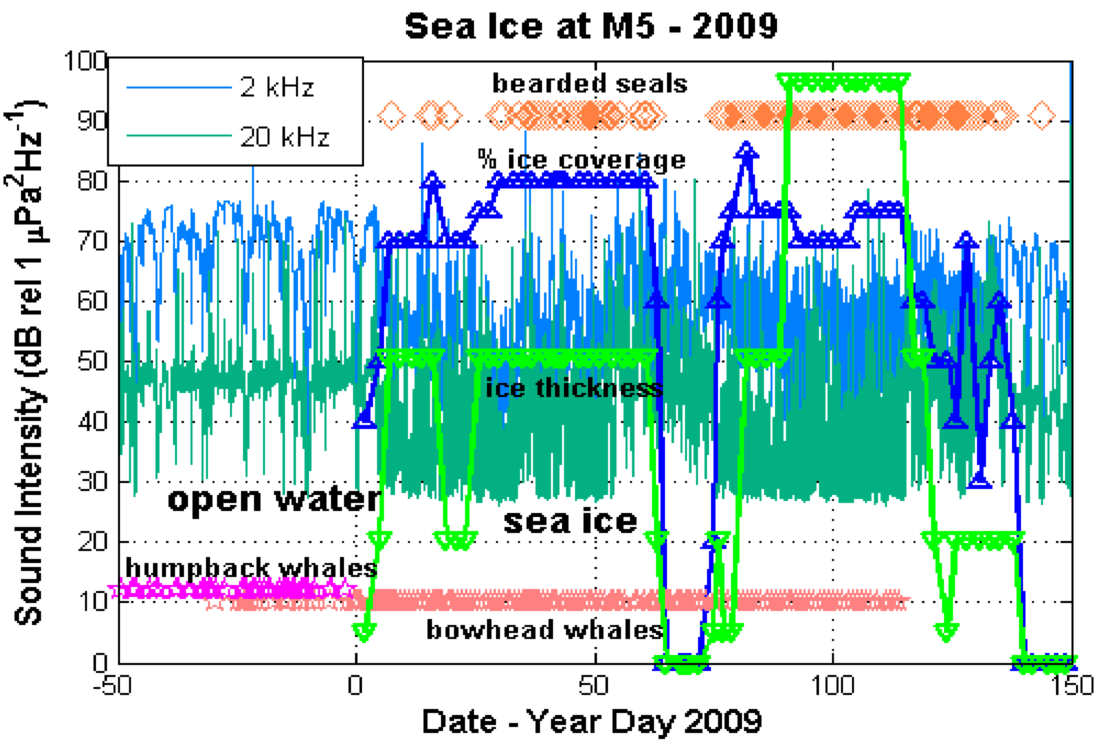

Figure 2. Overview of sea ice conditions during the winter of 2008-2009 at Mooring M5. Sound levels at 2 and 20 kHz are displayed, showing ice onset on Day 5 (Jan 5) and ending on Day 137 (May 17). Also shown are animal choruses, including humpback whale (an open water species), bowhead whale (associated with sea ice) and bearded seal (associated with thicker sea ice). Sea ice coverage (%) and ice thickness (in cm) are from satellite measurements. An interlude of relatively open water occurred from Day 55-74 (Feb 24 to Mar 15).

The sea ice onset is clearly detected in the sound record (Fig.3). The PAL was programmed to detect and record transient sounds if they occurred. A transient sound was defined as a sound lasting less than 4.5 seconds, the sample time for a single PAL sample. During open water conditions relatively few transient sounds were detected, mostly from humpback, fin and killer whales. As the ice forms, bowhead whales, closely associated with sea ice, become the principal source of triggering, and then the sounds associated with sea ice forming, a bizarre squeaking sound, are also detected (Fig 4).

As the ice coverage increases and floes merge in to a sheet of ice, the sound levels at higher frequencies drop to very low levels (Fig. 5). The sounds associated with the whales continue, mostly below 5 kHz. From Days 15-25, variable relatively loud sound levels interspersed with the very quiet high frequency sound levels for under ice are detected. This is apparently unconsolidated ice. On Day 25 the ice pack becomes solid. The sounds of the ice seals, especially bearded, ribbon and walrus are being detected. In particular, the bearded seal chorus (Fig. 6) starts about Day 30. Their chorus appears to be a proxy for thicker sea ice. These animals are known to breed on the ice, and in the case of bearded seals, their calling is ubiquitous, and appears to be a proxy for thicker sea ice. In fact, triggering on the PAL by animals is so frequent that the daily quota of sound clips is met early in the day. However recall that the PAL is designed to record the spectra throughout the day, regardless of the number of sound clips saved. The spectral characteristic (soundscape) for the solid ice sheet continues until Day 35 (Feb 4).

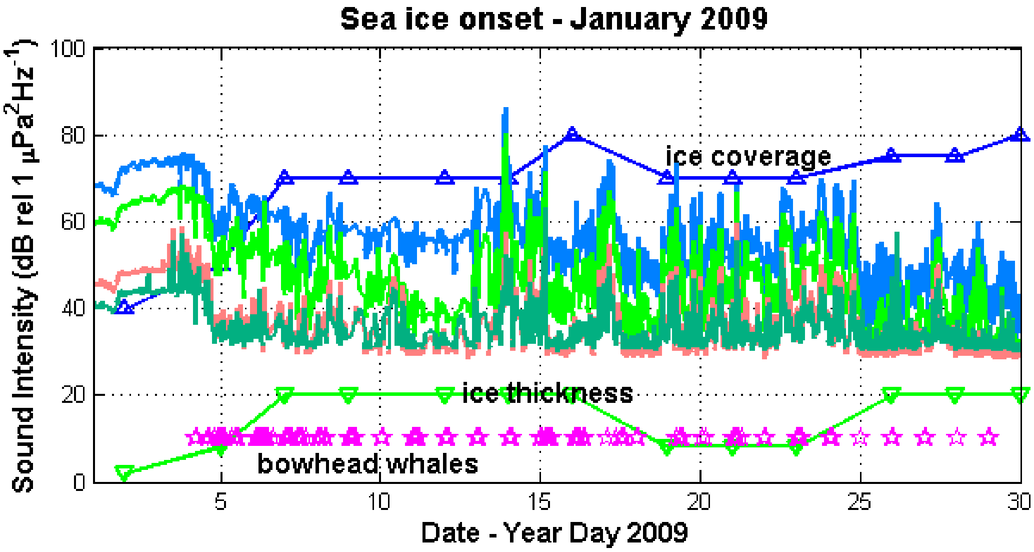

Figure 3. Onset of sea ice at M5. Sound levels at 1, 5, 20 and 40 kHz are shown with the bowhead whale chorus and satellite ice coverage data. The time period from Day 5-10 contained most of the recorded "alien squeaking" of ice floes rubbing. The period from Day 19-25 is apparently a mixture of floe bumping/solid ice and relatively open water. The ice sheet is consolidated on Day 25.

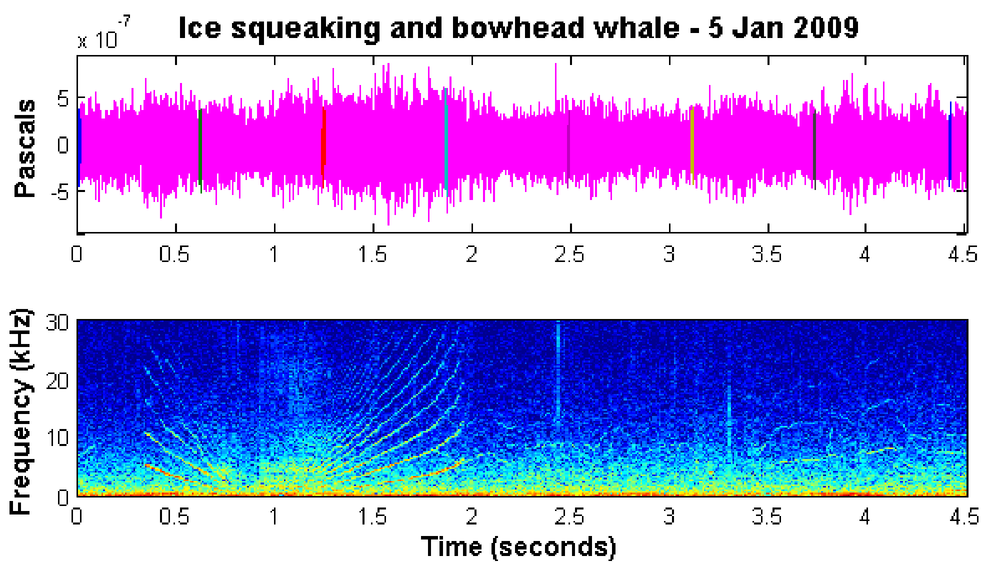

Figure 4. The bizarre sound of ice floe rubbing as the sea ice forms. These squeaks are detected only during the periods of ice formation (early January). The bowhead whale chorus has begun, with whale calls mostly below 5 kHz in frequency.

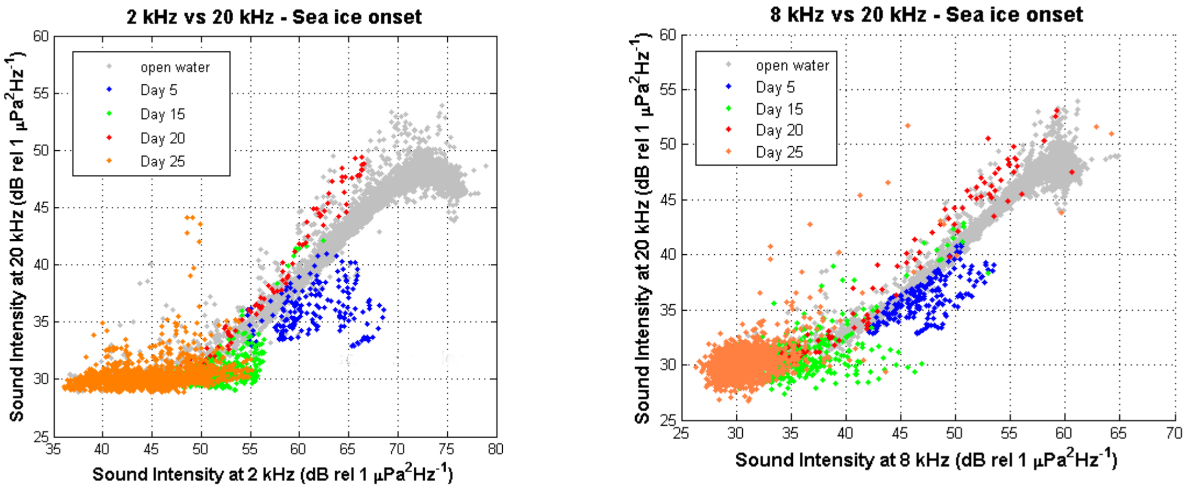

Figure 5. Soundscapes at M5 during sea ice onset, presented as the ratio of frequency pairs. The gray background points are the soundscape of open water, recorded in Dec 2008. Ice floe squeaking (Day 5-10) are shown in blue and have relatively louder lower frequency content. Frozen conditions (Day 25) are very quiet above 5 kHz, but still contain bowhead whale calling centered at about 2 kHz.

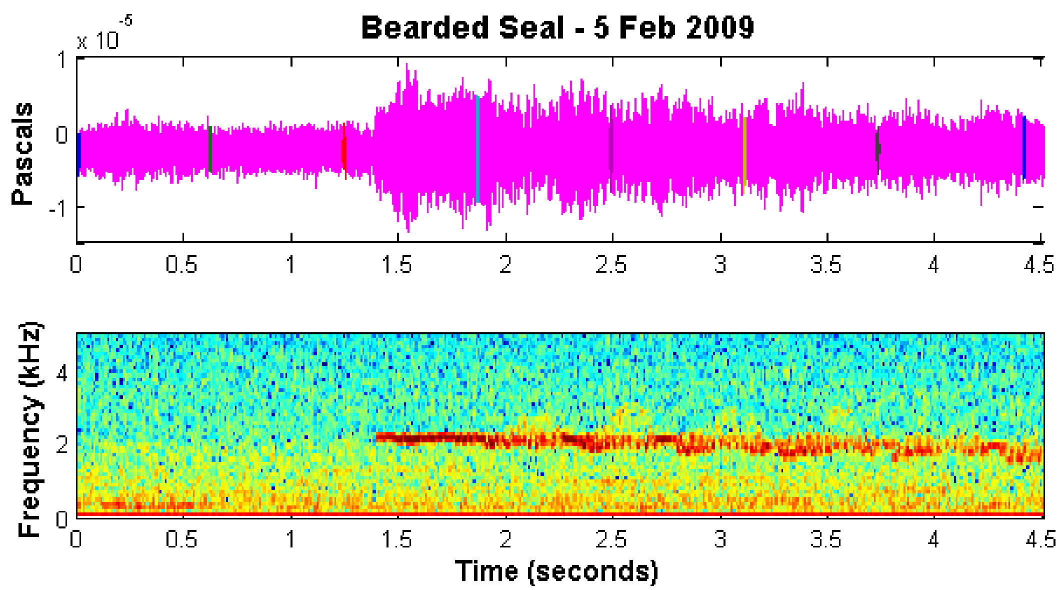

Figure 6. The acoustic signature of a bearded seal. The time series is shown above and the sonogram below. The characteristic call is a long descending warbler lasting many seconds.

On Day 36, a huge cracking sound is recorded (Fig 7). This sound clip is the ice sheet breaking, and an open water lead forming. Floe banging is subsequently detected, confirming the soundscape for floe banging. This is relatively loud at all frequencies. The ice seals and bowhead whale calls continue.

Another interesting soundscape of sea ice is a "fizzing" sound with relatively high levels of high frequency sound content. This is apparently the sound of melting ice in water, perhaps small bits of ice melting. It is speculated that the sound is coming from bubbles popping into the water as the ice melts. It is relatively loud at the higher frequencies (over 20 kHz), suggesting that the bubbles being injected into the water are relatively small (less than 150 μm radius).

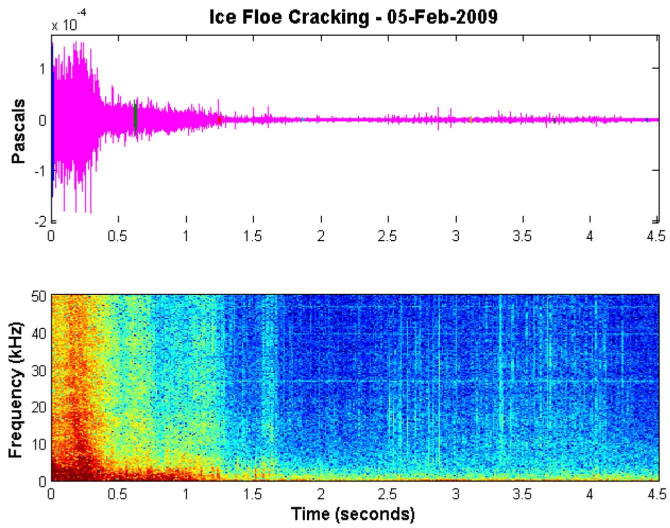

Figure 7. The sound of the ice sheet breaking (ice lead forming).

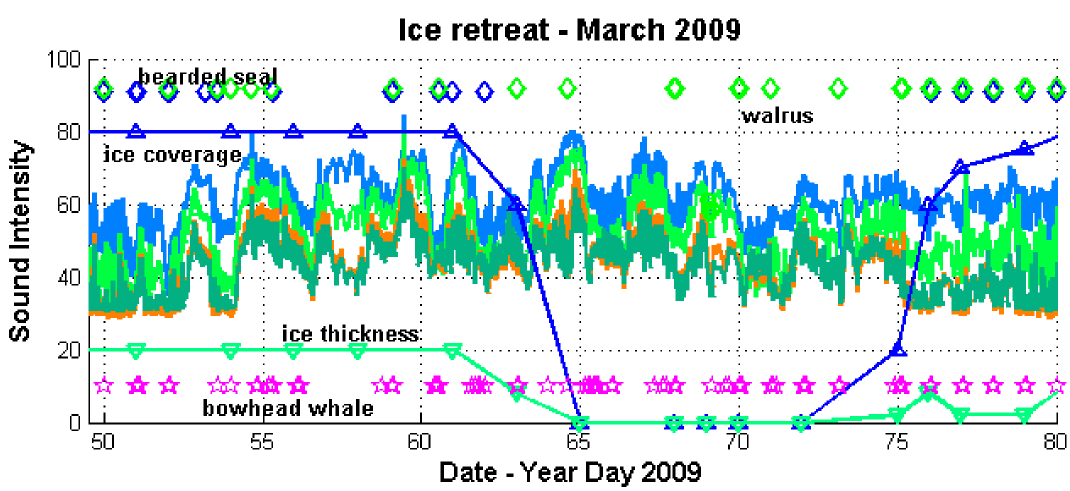

Figure 8. Sea ice retreat. From Days 55-74, the pack ice retreated to the north. Soundscapes for floe banging, fizzing and open water were detected acoustically. The bearded seal chorus was not detected during these conditions, and even the ubiquitous bowhead whale chorus was absent on Day 57/58. Thick ice conditions returned abruptly on Day 75. Sound levels at 1, 5, 20 and 40 kHz are shown, with bowhead whale and bearded seal choruses. Ice thickness (inches) and coverage (%) are from satellite measurements.

On Day 55, the ice pack breaks again. On Day 57, open water is detected acoustically. The bearded seal detections are suddenly absent, as are bowhead whales, suggesting that even the ice edge is distant from the M5 mooring, that is, open water is present. And active acoustic soundings record the start of an unexpected biological bloom (Miksis-Olds et al. 2010). Satellite coverage at the M5 mooring does not show a drop in ice coverage or thickness until Day 61 (Mar 2), several days later. The soundscapes of floe bumping and fizzing alternate for several days. On Day 69, open water soundscapes are again detected. No ice seals, except walrus, are detected from Days 56-59 and Days 63 - 75. However, most of the soundscapes are not open water, but rather the sounds of floe bumping and ice fizzing, suggesting icy water, but with only small floes (pieces of ice) present. The acoustic record suggests longer open water conditions than reported by the satellite data, starting sooner (Day 57) but ending on the same date (Day 75). During most of the interlude bowhead whales and walrus are still detected, suggesting that there is sea ice nearby. The other ice seals, in particular, ribbon and bearded seals, are not recorded during this period.

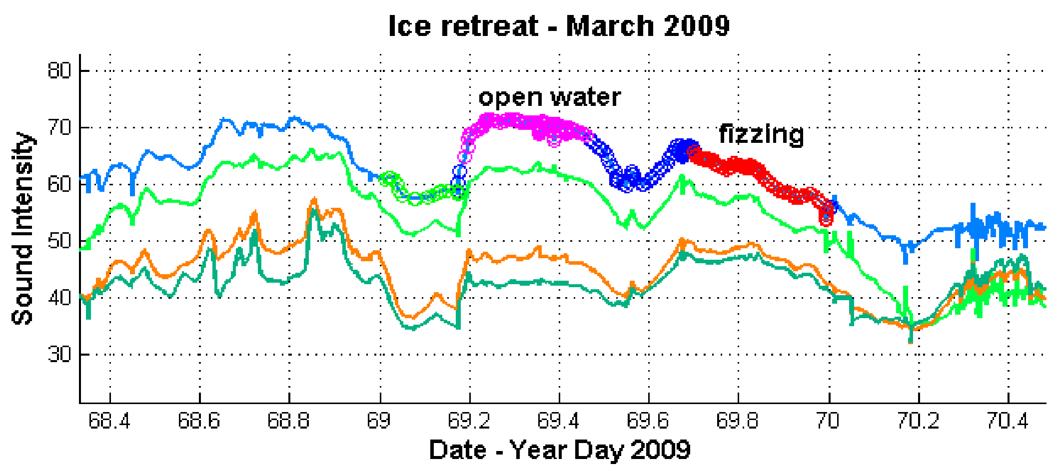

Figure 8. Details of the open water soundscape recorded on Day 69 (Mar 10), and subsequent fizzing, an ice soundscape. The sound levels at 1, 5, 20 and 40 kHz are shown.

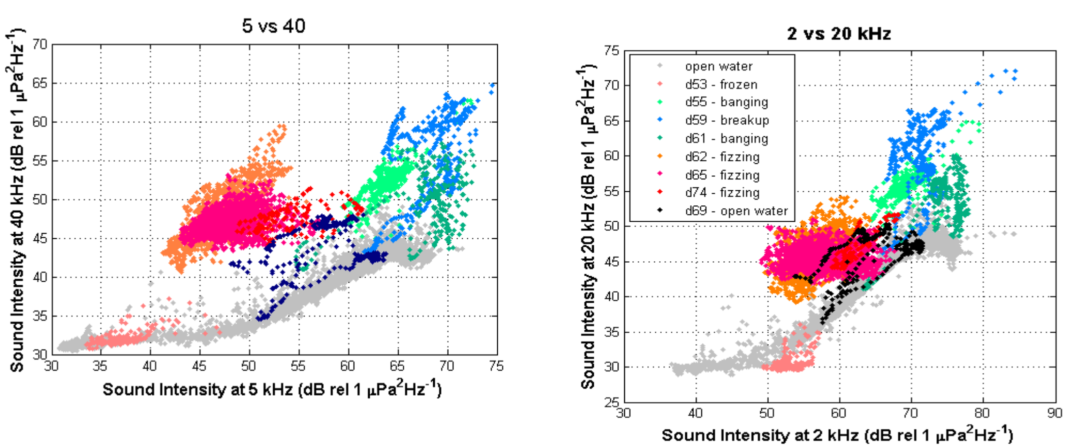

Figure 9. Sea ice soundscapes shown as the ratio between frequencies for the sea ice retreat period at M5 (Day 55-74). Ice floe banging (blue colors) and ice fizzing (red colors) are clearly separated from open water (gray). Day 69, showing a progression of ice conditions from open water to fizzing is shown in black.

On Day 75 (Mar 16), the solid sea ice conditions are acoustically detected. The bearded and ribbon seals are once again detected and the satellite observations show a return of the sea ice. The soundscape is the soundscape for sold ice coverage. This condition remains present until Day 115, when loud floe banging is once again detected. The solid ice sheet has apparently broken, and the seasonal breakup of the ice has begun. The bowhead whales detections finally disappear as this mammal begins its annual migration to the Arctic Ocean. The soundscape shows loud floe-banging conditions mixed with periods of fizzing. Ice seals continue to be detected until the ice disappears on Day 137. After Day 137, only open water soundscapes are recorded, including the resumed detection of open water animal species, including killer and beluga whales.

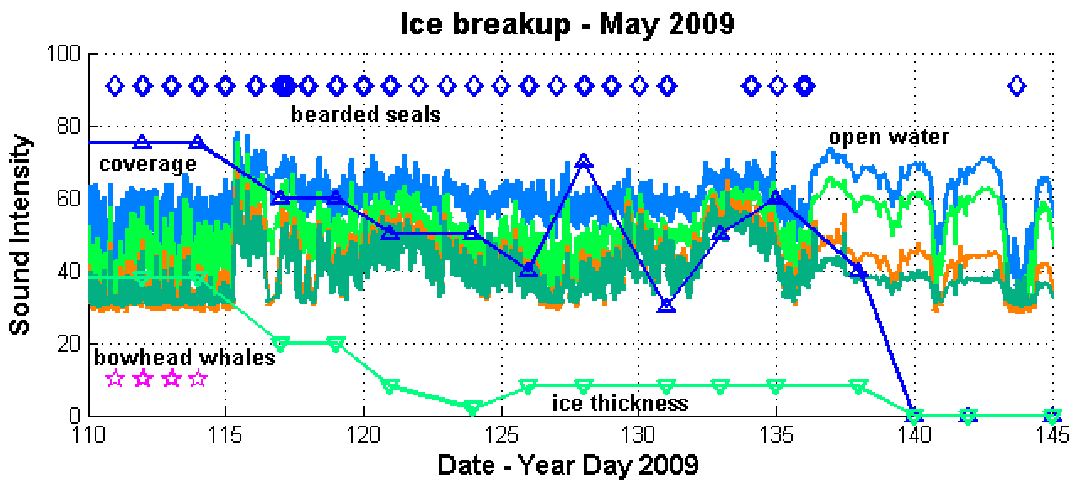

Figure 10. Seasonal sea ice breakup at Mooring M5. The solid ice sheet cracks on Day 115. Soundscapes of floe banging and ice fizzing alternate until Day 137 when open water soundscape returns for the season. The bowhead whales migrate north, with their chorus ending on Day 114. The bearded seal chorus persists until the ice cover ends on Day 137. Shown are the sound levels at 1, 5, 20 and 40 kHz, together with ice coverage (%) and thickness (inches).

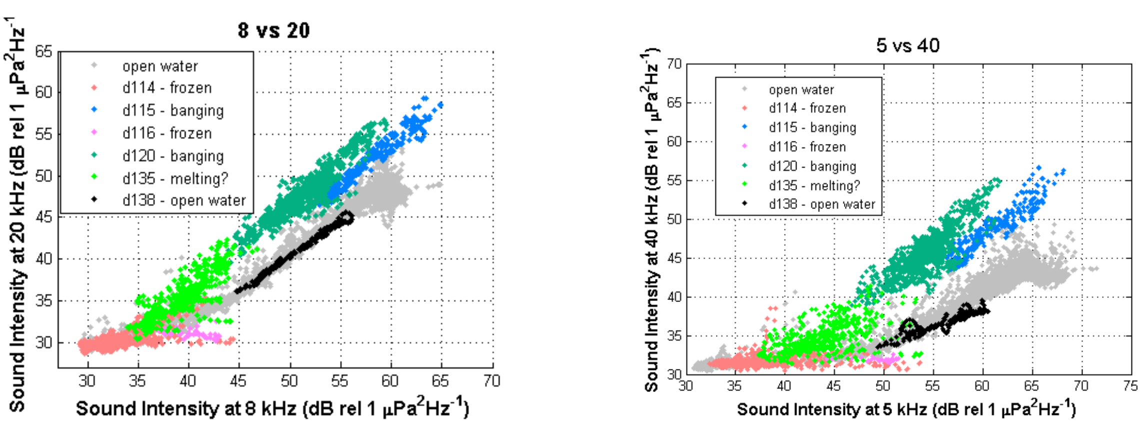

Figure 11. Sea ice soundscapes during the seasonal ice breakup (Days 115-136). Relatively quieter ice floe banging (blue) and fizzing (greens) characterize these soundscapes. Open water (gray from Dec 2008) and open water from Day 137 (black) are shown for comparison.

At least five distinctive sea ice soundscapes have been detected in the M5 mooring data. These soundscapes are distinctive and are indicative of different sea ice conditions at the ocean surface. The distinctive open water soundscape was detected during the apparent sea ice retreat in March, and indicates an earlier onset and longer duration than the satellite data. The sound of fizzing during melting suggests that the sea surface was covered by small bits of ice. Validation of the exact sea ice conditions during the sea ice retreat and the ultimate sea breakup may confirm this speculation.

It is clear from these data, that the sound of open water can be used to find open water surface conditions. The soundscape of solid ice and floe banging, potentially destructive for ocean instrumentation, can be used to predict when these instruments should be allowed to surface and report data to shore. It is not known if the sound of fizzing is also an ocean surface condition that allows instrumentation to surface safely or not.

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 harsh conditions of the winter season when traditional sampling techniques are not possible. The combination of year-round acoustic data collected with the active-passive acoustic system, hydrographic data collected by NOAA mooring sensors, and biological samples collected during each research cruise afford the opportunity to apply the acoustics to a large spectrum of scientific questions.

The passive identification of ice types present has significant applications outside of the marine mammal community. In particular, by identifying the presence or absence of surface ice, remote oceanographic instrumentation platforms, including drifters, sea gliders and sub-surface moorings can be allowed to surface in safe conditions (no ice) and report data back to users. This will allow potential data collection in remote ice-covered regions where data collection is sparse, and thus greatly expand knowledge of these environments.

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 detect and identify sources of interest without an overwhelming amount of data needing post-processing.

TRANSITIONS

Underwater ambient sound contains quantifiable information about the marine environment, especially sea surface conditions including wind speed, rainfall rate and type, and sea state conditions (bubbles), and now, the presence or absence of sea ice. Mostly this information is unused by oceanographers and the Navy. This project represents a transition from the study of ambient sounds themselves into the application of the physical environment inferred from the ambient sound as an aid for the interpretation of other types of data collected in the same environment. This is a fundamental advance for practical use of passive acoustic monitoring of the underwater marine environment.

RELATED PROJECTS

The ONR-supported project "Monitoring sea surface processes using high frequency ambient sound", N00014-04-1-099, has as its principal goal to make passive acoustic monitoring of the marine environment an accepted quantitative tool for measuring sea surface conditions (wind speed, rainfall and sea state), monitoring for the presence and identity of marine wildlife (especially whales), and monitoring anthropogenic activities including shipping, sonar and other industrial activities. The new effort described here builds on the research of this project.

Several NOAA-supported projects, including Passive Acoustic monitoring of killer and beluga whales at the Barren Islands, Alaska, the Bering Sea Acoustic Report (Nystuen et al, 2010), Marine Mammal Monitoring for NW Fisheries (Nystuen et al. 2007), and Monitoring killer whale predation at Stellar Sea Lion rookeries in the Aleutian Islands, use PALs as the principal monitoring instrument for the description of the environment and for the detection an identification of marine cetaceans and other marine animals. This project benefits directly from the data collection strategies and interpretation developed for these projects.

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