PASSIVE ACOUSTIC DETECTION AND MONITORING OF ENDANGERED WHALES IN THE ARCTIC (BEAUFORT, CHUKCHI)

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ECOSYSTEM OBSERVATIONS IN THE CHUKCHI SEA: BIOPHYSICAL MOORINGS AND CLIMATE MODELING

QUARTERLY REPORT

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Executive Summary

Through an Inter-Agency agreement (IA) between the National Marine Mammal Laboratory (NMML) and the Bureau of Ocean Energy Management (BOEM), NMML is conducting a dedicated multi-year study of the distribution and relative abundance of endangered whales in the Chukchi Sea Planning Area and relate variation in those parameters to oceanographic conditions, indices of potential prey density, and anthropogenic activities. This quarterly report covers the period between April 16th and July 15th 2013.

The major activities during this period consisted of data analysis and synthesis. In addition, although the CHAOZ field work portion of the study has concluded, we will continue to deploy instruments and collect data to maintain the extensive dataset established during CHAOZ. These instruments will be deployed under the Arctic Whale Ecology Study (ARCWEST). This cruise will take place from 12 August through 17 September 2013 on a TBD chartered vessel. Analyses are currently ongoing, and some preliminary results are detailed below.

Introduction and objectives

The western Arctic physical climate is rapidly changing. The summer Arctic minimum sea ice extent in September 2012 reached a new record of 3.61 million square kilometers, a further 16% reduction from a record set in 2007 (4.30 million square kilometers). This area was more than 50% less than that of two decades ago. The speed of these changes was unexpected, as the consensus of the climate research community just a few years ago was that such changes would not be seen for another thirty years. As sea temperature, oceanographic currents, and prey availability are altered by climate change, changes in baleen whale species composition, abundance, and distribution are expected (and evidenced already by local knowledge and opportunistic sightings). In addition, the observed northward retreat of the minimum extent of summer sea ice has the potential to create opportunities for the expansion of oil and gas-related exploration and development into previously closed seasons and localities in the Alaskan Arctic. It may also open maritime transportation lanes across the Arctic adding to the ambient noise in the environment. This combination of increasing anthropogenic impacts coupled with the steadily increasing abundance and related seasonal range expansion by the bowhead, gray, humpback, and fin whales, indicates that more complete information on the year-round presence of large whales is needed in the Chukchi Sea planning area. Timing and location of whale migrations may play an important role in assessing where, when, or how exploration or access to petroleum reserves may be conducted to mitigate or minimize the impact on protected species.

This study has four component projects: oceanography, passive acoustics, zooplankton, and climate modeling. Each component project is a technical discipline and is coordinated by a Project Leader with extensive experience in that discipline. Passive acoustic moorings, deployed concurrently with bio-physical moorings will provide previously unattainable year-round assessments of the seasonal occurrence of bowhead, humpback, right, fin, gray, and other whales in this planning area and their response to environmental changes (including oceanographic conditions, climate, indices of potential prey density, and anthropogenic activities). Moorings permit observations during long periods when ice covers the region, especially during the critical spring and early summer periods when spring phytoplankton blooms occur. Such measurements are virtually impossible to obtain from ships, because of the relatively short duration of cruises and severe limitations in the availability of ships able to work in ice-covered seas.

The overall goal of this multi-year IA study is to document the distribution and relative abundance of bowhead, humpback, right, fin, gray, and other whales in areas of potential seismic surveying, drilling, construction, and production activities and relate changes in those variables to oceanographic conditions, indices of potential prey density, and anthropogenic activities.

The specific objectives are:

1. Assess the year-round seasonal occurrence of bowhead, gray, and other whale calls in the Chukchi Sea.
2. Estimate relative abundance of these whales.
3. Obtain two full years of biophysical measurements on the shallow Chukchi shelf utilizing moorings at three sites, and collect hydrographic and lower trophic level data during deployment/recovery of the moorings.
4. Evaluate the extent to which variability in environmental conditions such as sea ice, oceanic currents, water temperature and salinity, and prey abundance influence whale distribution and relative abundance.
5. Run the National Center for Atmospheric Research (NCAR) climate model (Community Earth System Model: CESM1.0) for future projections using the sea ice extents from 2007/2008 as initial conditions.
6. Analyze multiple ensemble members CESM as well as the group of CMIP5 models to assess the future variability of sea ice cover and extended sea ice free seasons during fall for the Chukchi Sea.
7. Evaluate whether changes in seasonal sea ice extent are resulting in a northward shift of Bering Sea cetacean species such as fin, humpback, and North Pacific right whales.
8. Provide long-term estimates of habitat use for large whale species and compare this with predictions about annual ice coverage to establish predictive variables that describe large whale occurrence.

ACOUSTICS COMPONENT

Preliminary results

The last deployments of the long-term passive acoustic recorders for CHAOZ were retrieved on the 2012 vessel survey (Fig. 1) and analyses are ongoing. The middle Icy Cape mooring from 2011-2012 has been fully analyzed for mid-frequency (0-800 Hz) sounds. Results from this mooring are shown in Figure 2. A comparison of bowhead whale call detections between the 2010-2011 and 2011-2012 deployments on this mooring can be seen in Figure 3. The fall migration pulse has a smaller peak and is more compressed in time in 2011 than in 2010. In addition, the pulse in call detections for the 2012 spring migration occurred much earlier than that for the 2011 spring migration.

2013 analysis plans

Data analysis of the other two 2011-2012 long-term moorings has begun. We have been running a new version of our Matlab-based SoundChecker program to allow for simultaneous multi-species analysis.

We will also be implementing the Baumgartner (WHOI) low-frequency detection and classification system (LFDCS). Dr. Baumgartner presented his LFDCS at a workshop at NMML on April 15-16, 2013. We hope to begin use of this system in the fall. If successful, this system will reduce the amount of effort expended on each recording. It will also allow us to fine-tune any auto-detection devices installed on gliders we may send out into our study areas in the future.

Most effort in 2013 will be spent analyzing the recordings and integrating our results with those from the oceanography and zooplankton components.

Synthesis

Berchok is working to provide Napp with text on our passive acoustics results for the submission of the note to Geophysical Research Letters which is described in the Zooplankton Component section below.

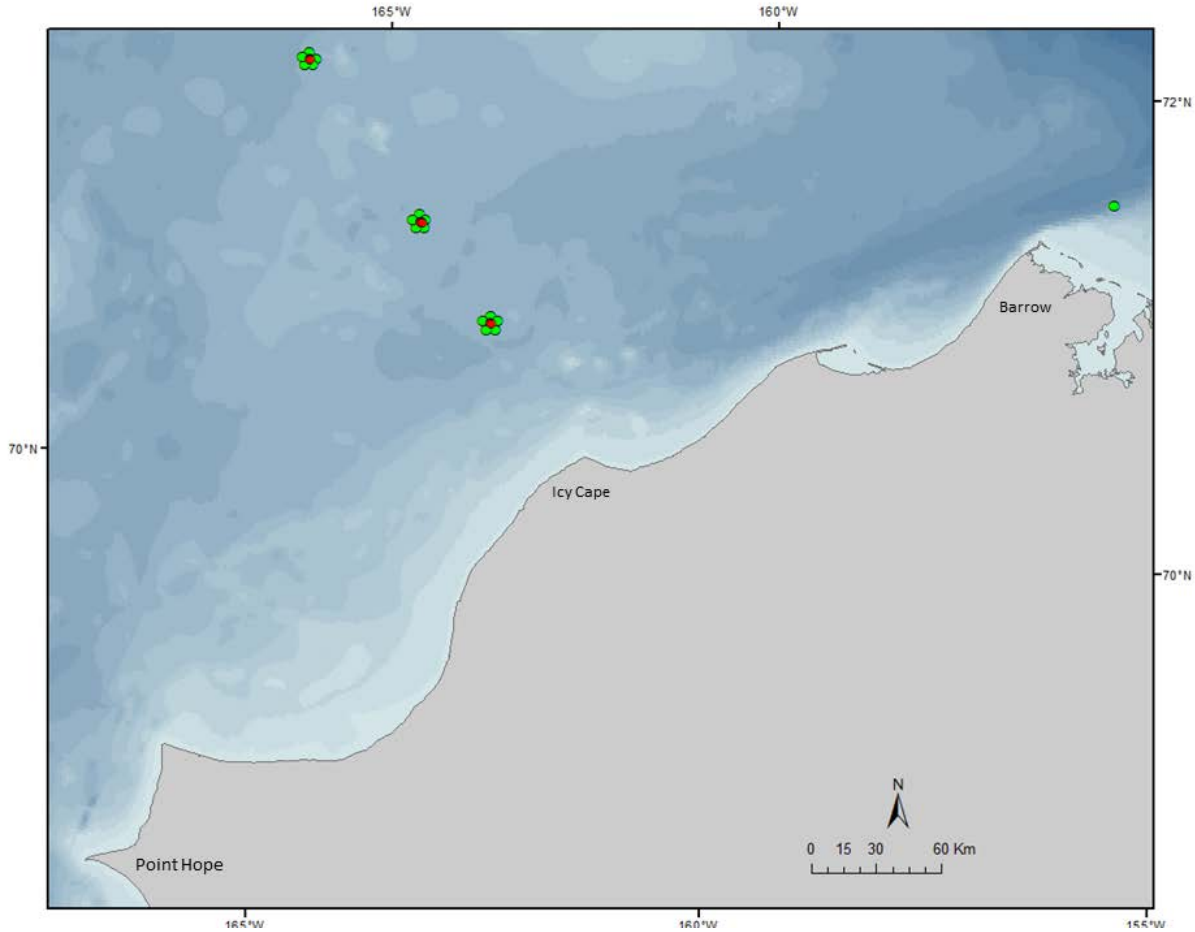

Figure 1. Map of CHAOZ moorings retrieved in 2012. Green dot – passive acoustic recorder mooring, red dot – biophysical mooring.

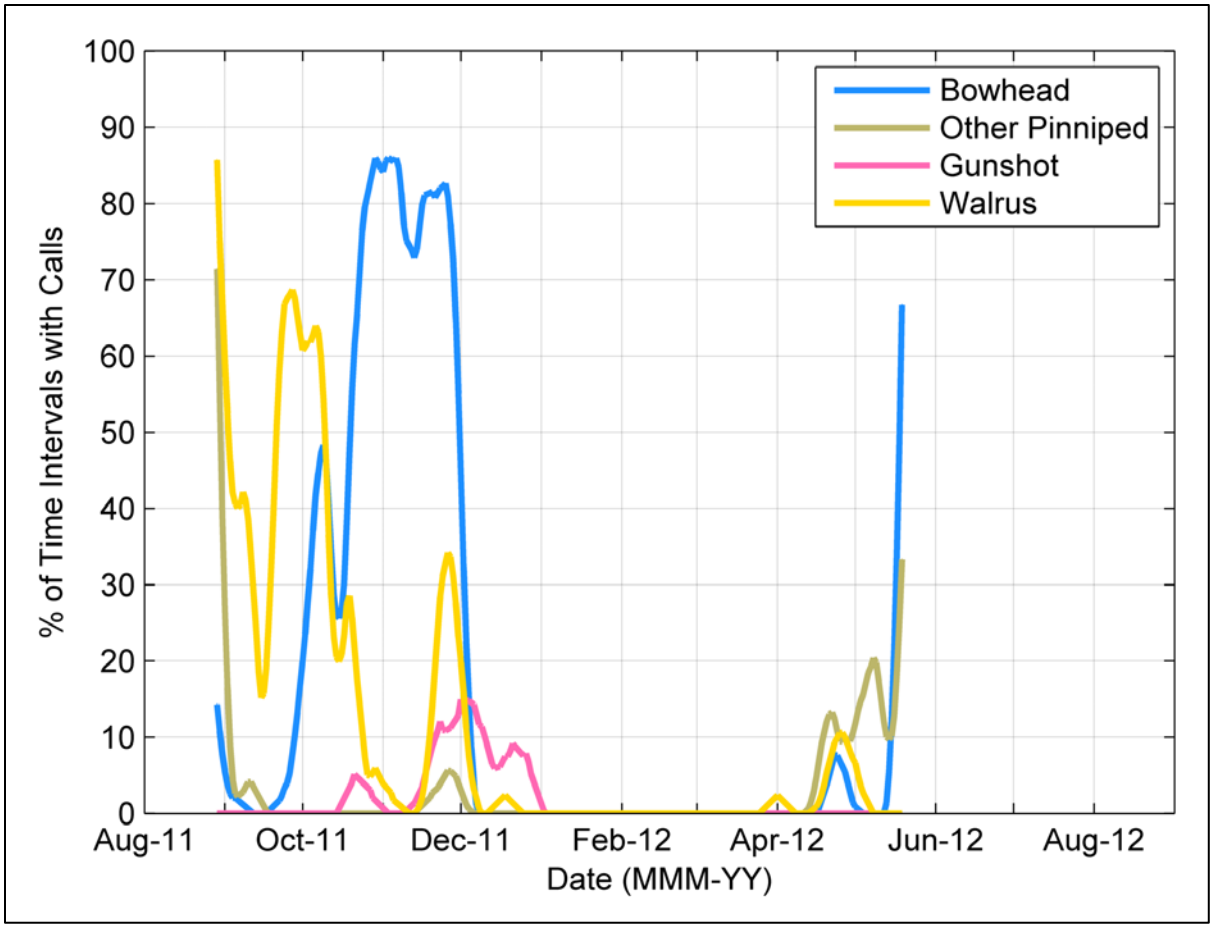

Figure 2. Seasonal acoustic detections of bowhead whales, walrus, other pinniped, and gunshot calls on one of the recorders in the middle mooring cluster off Icy Cape, AK (August 29, 2011 – May 19, 2012). Results are presented as a 7 day moving average of the number of 4 minute time intervals per day with calls detected.

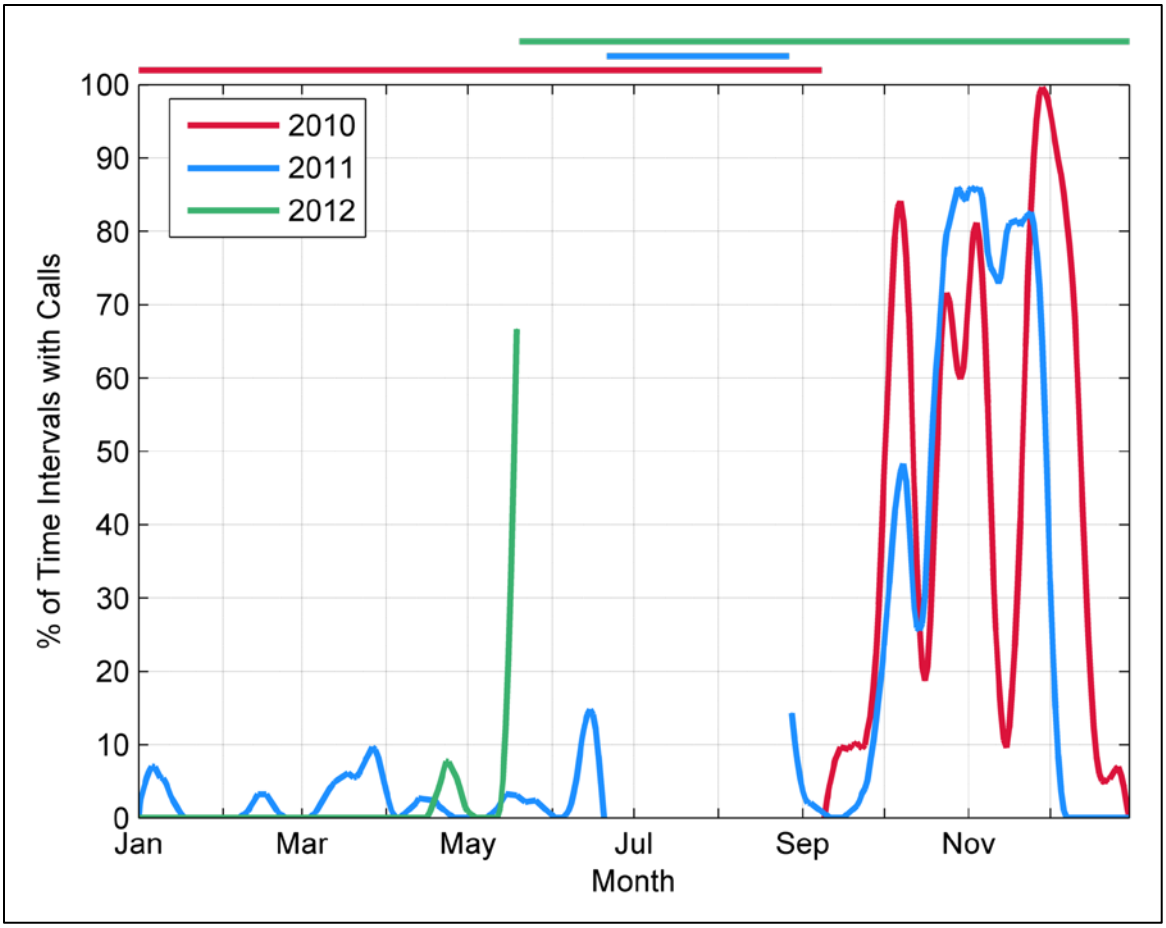

Figure 3. Interannual comparison (2010-2012) of bowhead whale acoustic detections on the middle mooring cluster off Icy Cape, AK. Results are presented as a 7 day moving average of the number of 3 hour time intervals per day with calls detected. Bars above the plot correspond with periods of no data for those years; lack of this bar with no visible curve below indicates the curve for those data is behind another color.

OCEANOGRAPHIC COMPONENT

Preliminary results

Long-term moorings:

All data from moorings have been processed and analysis has begun. The ice thickness at A3 was greater in 2011-12 than in 2010-11. Maximum keel depth at A3 in 2012 was 28.7 m, and occured on April 16, while in 2011 the maximum keel depth was 20.2 which occurred on April 19. This deep keel was comparable to the keel observed in 2011 at A1 and could be related to the very large, old floes that were advected westward into the Hanna Shoal region. These large, deep floes persisted all summer in 2012.

Ice thickness and area coverage data from 2010-2011 were used in the interpretation of zooplankton ACDP backscatter data presented at the Alaska Marine Science Symposium (AMSS) meeting in January 2013. These data helped confirm when ice left the region and when ADCP backscatter was attributed to zooplankton and not ice.

Analysis of the ice thickness data shows daily standard deviation is comparable to the mean. Ice thickness is not correlated with percent ice cover (Fig. 4). The average daily ice thickness varies on variety of scales, but in both 2010-2011 and in 2011-2012 the thickness increased by ~3 cm day^{-1}.

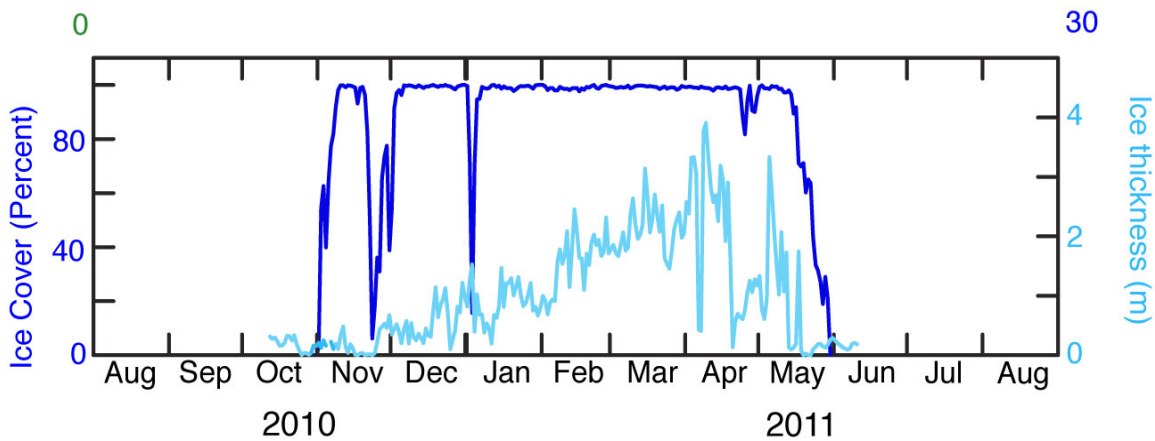

Figure 4. Percent ice cover from satellite data and the ice thickness from moored instrument.

Satellite-tracked drifters:

In August 2012, 12 satellite-tracked drifters were deployed. By January 2013, five were still transmitting. Each was trapped in the sea ice. Most of the drifters moved rapidly eastward when the large ice began to break up in the Beaufort Sea in the winter of 2012. The trajectories of three drifters are shown in Figure 5. They are still within the ice field and are heading westward. Last transmission was on July 14, 2013. An animation of the drifter trajectories can be found at http://www.pmel.noaa.gov/foci/visualizations/drifter/chuk2013.html

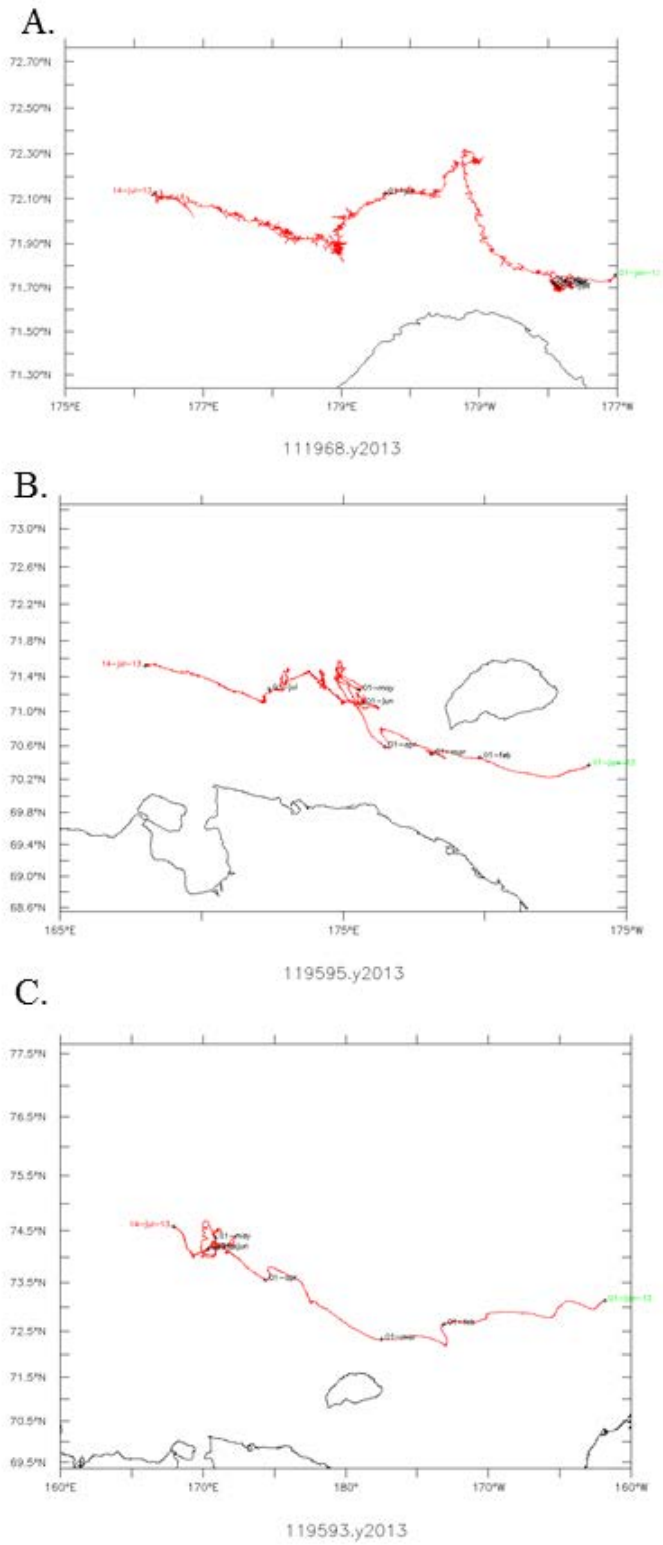

Figure 5. (A) Buoy 11968, (B) 119595 and (C) Buoy 119593 were all trapped in the ice and not transmitting regularly. The last transmission was on July 14, 2013. They are still within the ice field, ad moving westward at ~ 1 km per day. Dates are indicated on the plot (approximately every 10 days).

2013 preparations and analysis plans

All moorings have been built for an August deployment and all equipment has been prepared. The drifters will be deployed during late July, on ship of opportunity, and in August, on our cruise. In the coming year our effort will be placed on completing analysis of all mooring, drifter, satellite, and hydrographic data and then synthesizing these data with the other components of the project (mammals, zooplankton, and climate). For example, examining oceanographic conditions during the times when marine mammal vocalizations are detected in each subregion; examining oceanographic conditions during the times when zooplankton volume backscatter is high; documenting cross-shelf and inter-annual variability in measured variables; examining oceanographic conditions and vocalizations in polynyas, and during the spring and fall transitions; and working to understand how loss of sea ice affects upper ocean processes.

ZOOPLANKTON COMPONENT

Zooplankton Acoustics
Analysis of ADCP and TAPS data continues. We have been examining zooplankton net data from the 2012 cruise to determine which scattering models are most appropriate to apply to TAPS data from the mooring. During 2012 thecate pteropods (small shelled pelagic molluscs) were prevalent in the study area. Target strengths for 1 mm pteropod can be > 7 db higher than that of a 5 mm copepod in the Rayleigh part of the scattering curve. Thus we are experimenting with multi-scattering model solutions to the inverse problem.

Preserved Zooplankton Samples
Data sheets for preserved zooplankton samples from the August 2012 cruise were returned from Poland during the last quarter, however the computer data entry program was not finished until this quarter. Data were entered by Poland at the end of the quarter.

Synthesis
Napp is taking the lead on a note for submission to Geophysical Research Letters synthesizing some of the initial results from the CHAOZ project. The note will attempt to identify and describe several "events" where we have physical, plankton, and marine mammal observations.

2013 analysis plans
We will continue to focus our analyses of TAPS, ADCP, and zooplankton net data. The 2012 net data must undergo QA/QC procedures during the next quarter before being ready for use. The multi-model inverse solution will be tested after the addition of a model for a hard elastic scatterer (pteropods). We hope to complete a draft of the synthesis note describing unique events during the CHAOZ field years.

OCEAN NOISE AND REAL-TIME PASSIVE ACOUSTIC MONITORING

Auto-Detection Buoy System (AB)

The NOAA-NW buoy, deployed from August 29 through November 09, 2012, was equipped with a new version of the on-board electronics, and software enabling simultaneous recording, spectral measurement and detection. The real-time detection software is based on a plug-in architecture, which enables new detection algorithms to be deployed with a minimum of software development time. This deployment was the first time we targeted species other than Northern Right Whales, and a new algorithm was used in an attempt to capture bowhead whale (BWHD) calls. What follows is a description of this novel AB detector.

Since the time-frequency shape of BWHD vocalizations is generally not consistent, Template-type approaches are not optimal. Instead, we used a bank of four line segment detection filters in the spectrogram domain, of which the output is a four-component vector spectrogram, with the components representing the relative strengths of short horizontal, vertical, upward-sloping, or downward-sloping lines. Selecting the maximum-valued component, we get a rudimentary estimate of line direction, and an amplitude estimate. We use this amplitude in much the same way as in another one of Bioacoustics Research Program's (BRP) detection algorithm (for right whale), joining frequency-domain peaks along the time axis to create tracks, which are the output of the first stage of the detector.

In order to positively identify tracks as whale calls, we assign a score to each track, using an HMM-based classifier (hidden Markov model), operating on the sequence of peak frequencies and line direction estimates. The software loads a set of trained models to compare against each candidate track, selecting the class assignment of the model with the highest score. The chief advantage of this approach is that as the number of examples increases, the models can be re-trained to increase performance. The number of models can also be increased if new classes of either true whale calls or noise/clutter are identified. For the NOAA-NW deployment, however, the models were only loosely trained on a data set of BWHD calls recorded in the Beaufort Sea in August of 2008, and since only a small number of positively-identified calls existed, the models were never re-trained on the Chukchi data. Although we intended to manually identify all of the BWHD whale calls present in the recorded data, much of the data from the deployment was corrupted by a still-unidentified source of impulsive noise, making it difficult to reliably identify whale calls.

During the next quarter (August-October, 2013) we will identify an appropriate protocol to analyze the performance of the detector, likely involving the manual review of a portion of the AB flash-card data and comparing it to the automated detections. We would also like to compare the performance of BRP's on-board AB detector to other existing BWHD call detectors in the literature, for example by Thode et. al., 2012[1].

Marine Autonomous Recording Unit (MARU)

Manual analysis of the 2010-2012 MARU data was started in March and completed in June, 2013. Following similar protocols from other parallel research projects in the Arctic (i.e. Synthesis of Arctic Research, SOAR), the manual extraction effort created a daily index (in 12-hour bins) of acoustic presence/no presence for two focal "species": bowhead whales (BWHD) and seismic activity.

Figure 6 illustrates a sample spectrogram (detected on November 30th, 2010) corresponding to a BWHD song extracted in the manual analysis stage.

[1] Thode, A.M., K.H. Kim, S.B. Blackwell, C.R. Greene Jr, C.S. Nations, T.L. McDonald, and A.M. Macrander. 2012. Automated detection and localization of bowhead whale sounds in the presence of seismic airgun surveys. The Journal of the Acoustical Society of America 131: 3726

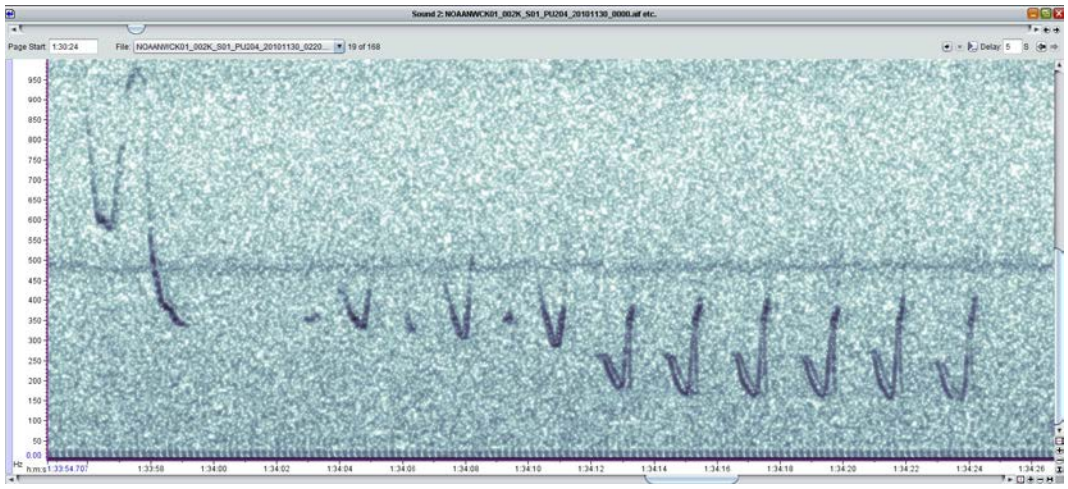

Figure 6. Sample BWHD song detected on November 30th, 2010 as recorded by a MARU off Icy Cape, AK.

Protocol: Manual analysts visually reviewed spectrograms (in 5-minute-page format) using the software RAVEN. Given that the 2010-2011 acoustic data was 50% duty cycled but 2011-2012 recorded continuously, for this second year dataset, out of each 12- hour period, only 30 minutes of every hour are inspected. Once the first occurrences of BWHD and seismic are marked in each 12-hour bin, the entire 12-hour period is characterized as having that particular species present. An index of 1 means presence was detected in the corresponding bin, thus a 2 means that both indices of the day had the species present. A 0 means that even after reviewing the entire 12-hour period, no signature of that species was detected. (Figs. 7 and 8).

While evaluating the manual analysis protocol, some of the concerns reported by the team related to:

- Difficulty in recognizing distant seismic impulses that have lost some of the original impulse characteristics (spreading over time, loss of high frequencies, etc.).
- Questions whether those distant, “smudged” seismic impulses should be reported in the same category as clear, distinct seismic activity (probably occurring closer to the receiver).
- Cases of stand-alone explosive sounds that resemble a seismic impulse, but are not part of a repetitive train. Possible sources: array misfire, seal bomb, whaling shot?
- Unknown biological sounds, potentially belonging to gray whales or humpbacks?

From Figure 7, it can be noticed that, as it is well known, local seismic presence tends to concentrate in the open water months of September and October. This matches a decline in bowhead whale detections during those weeks, although their daily presence was consistent right before the onset of seismics (June-August) and continues solidly after the seismic surveys are gone (October to December). In 2011-2012 (Fig. 8) there seems to be less seismic activity in the early portions of the open water season, thus the Arctic ice melt patters for that year will be investigated to find out if a weather factor prevented the normal start of seismic surveys. However, even once it begins, the BWHD activity index seems to detect higher levels of daily presence than the previous years. Using these indicators of presence, the next step will be to apply generalized linear models (GLM) or generalized additive models (GAM) to better understand the statistical correlation between the two presence patterns.

Moving forward, the next step will be to use the protocol of Guerra et. al.[2] (2011) to estimate what the background ambient levels would have been in the absence of seismic surveys, in order to quantify the impact specifically due to that disturbance. For this, we will look at times before/after the seismic survey and model the contribution of other natural noise sources, like weather and wind. Furthermore, an automated seismic detector developed at BRP (Dugan et. al, in progress) will be applied to the data, with the purpose of extracting detailed metrics that characterize each seismic impulse in time and frequency, as well as the seconds that immediately follow each shot. These measurements will provide a better understanding of the local acoustic habitat.

Acknowledgements: The CHAOZ MARU manual analysis effort at BRP is led by Russ Charif and Ann M. Warde and performed by research analysts: Kristin Hodge, Kaitlin Palmer, Elizabeth McDonald, Emily T. Griffiths, Clara and Maureen E. Loman. We thank them all for the work required in generating all Figures.

[2] Guerra M, Thode A.M, Blackwell SB, and Macrander A.M. 2011. Quantifying seismic survey reverberation off the Alaskan North Slope. The Journal of the Acoustical Society of America. 130 (5): 3046-58.

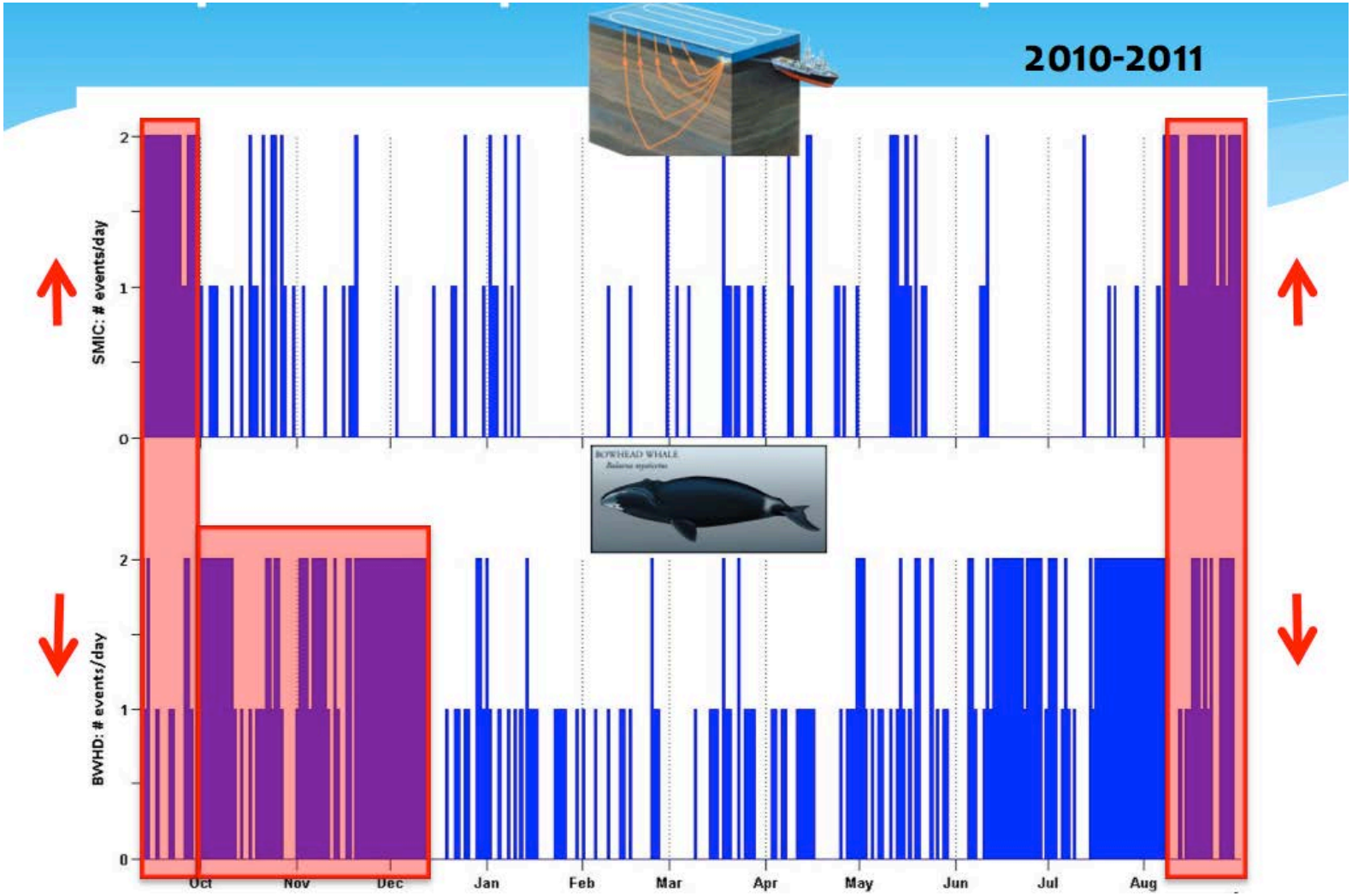

Figure 7. Daily presence of seismic signatures and bowhead whale calls off Icy Cape in the 2010-2011 data. An index of 2 means that the species was detected in both 12-hour bins of each day. A1 represents detection of the species in only one 12-hour bin of the day.

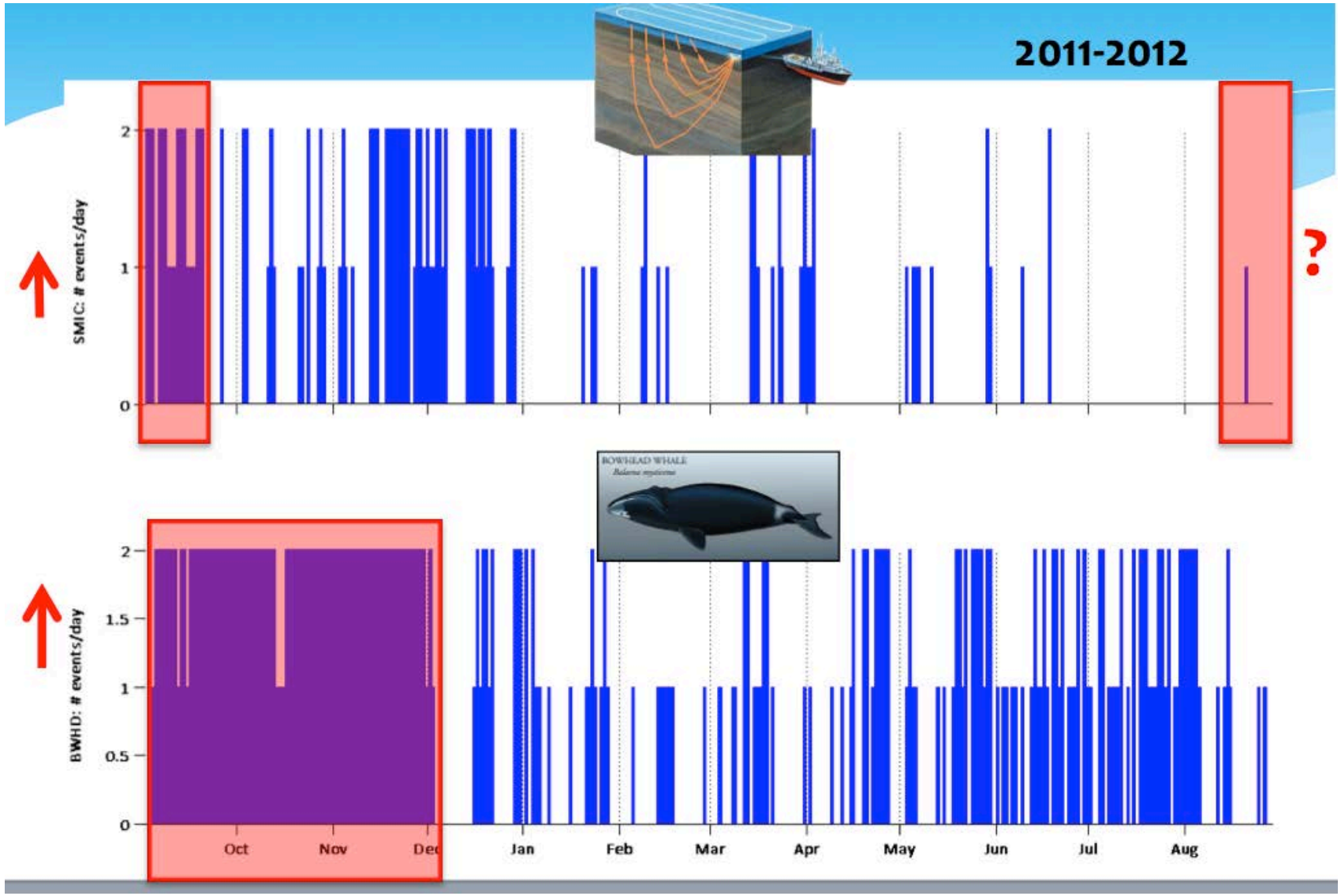

Figure 8. Daily acoustic presence of seismic signatures and bowhead whale calls off Icy Cape in the 2011-2012 data. An index of 2 means that the species was detected in both 12-hour bins of each day. A1 represents detection of the species in only one 12-hour bin of the day.

CLIMATE MODELING COMPONENT

We have downloaded more than 3 TB of data from CMIP5 model simulations. The model simulated sea ice condition over the Arctic wide was assessed by Wang and Overland. The findings were published in 2012. Recently the two authors updated their 2012 study, with another paper published in Geophysical Research Letters, 2013. Among 36 models they evaluated, only 11 of them simulated the sea ice extent in reasonable agreement with observations. The outputs from our CESM1.0 models runs which were initialized with low sea ice coverage under RCP6.0 emissions scenario, were compared with the original CCSM4 runs. We found large internal variability among these models runs. We also compared model results (currents, temperature, salinity, and sea ice thickness) at the Chukchi Sea Icy Cape mooring sites (IC3, IC6, and IC11) with observations. The CESM simulated seasonal cycle of ocean temperature is in agreement with observations, although during ice free months the simulated ocean temperature at 40m depth is higher than that observed at the moorings. Another manuscript based on the same model runs were submitted to the Deep-Sea Research Part II recently with emphasize on the Eastern Bering Sea.

Significant meetings held or other contacts made

15-16 April 2013: Berchok, Crance, Stephanie Grassia, Ellen Garland, and Eliza Ives participated in a workshop at NMML presented by Mark Baumgartner (WHOI) on the use of his low-frequency detection and classification system (LFDCS).

April 29- May 1, 2013, Wang participated the AMS 12th Conference on Polar Meteorology and Oceanography held in Seattle, WA, and gave an oral presentation on "The recent shift of the Arctic Atmospheric Circulation and the Reduction of Sea Ice".

May 2013: Napp co-organized a Synthesis Of Arctic Research (SOAR) workshop with Elizabeth Logerwell. The workshop, in Seattle, laid the groundwork to begin a synthesis article on fishes of the Chukchi and Beaufort Seas.

June 17-20, 2013: Cheng participated the annual CESM workshop held at Breckenridge, CO

Presentations and Publications

Cheng, W., E. Curchitser, C. Ladd, and P. Stabeno. Ice-Ocean Interactions in the Eastern Bering Sea: NCAR CESM Simulations and Comparison with Observations. Submitted to Deep Sea Research, 2013.

Clark, C. W., C.L. Berchok, S. Blackwell, J. Citta, D. Hannay, J. Jones, L. Quakenbush, and K.M. Stafford. A year in the acoustic world of Western Arctic bowhead whales. In prep.

Crance, J.L. and C.L. Berchok. Farthest northeast acoustic detection of a fin whale (*Balaenoptera physalus*) in the Alaskan Chukchi Sea. In prep.

Guerra, M., A. N. Rice, and C. W. Clark. 2013. Acoustic environment as context to understand patterns in Arctic marine biodiversity. Invited talk at the Zoological Society of London. 17 May 2013. Abstract and audio available below.

Overland, J.E. and M. Wang. 2013 When will the summer Arctic be nearly sea ice free? Geophysical Research Letters *40*, DOI: 10.1002/grl.50316.

Wang, M. and J.E Overland. 2012. A sea ice free summer Arctic within 30 years-an update from CMIP5 models. Geophysical Research Letters 39, DOI: 10.1029/2012GL052868.

Abstract

Guerra, M., A. N. Rice, and C. W. Clark. 2013. Acoustic environment as context to understand patterns in Arctic marine biodiversity. Invited talk at the Zoological Society of London. 17 May 2013. Audio of the talk may be accessed at: http://www.zsl.org/science/events/new-technologies-for-monitoring-biodiversity,631,EV.html

Abstract: A critical component to understanding biodiversity is examining the environment in which organisms live. A marine acoustic environment (sometimes called soundscape) includes all the sounds from natural and anthropogenic sources. Natural sounds incorporate biological sources such as invertebrates, fishes and marine mammals, and abiotic sources, for example, wind-driven surface waves, earthquakes, rainfall and icebreaking. A contemporary marine acoustic environment inescapably incorporates the footprints of anthropogenic activities, most prevalently: commercial shipping, oil and gas (O&G) exploration, development and extraction, industrial construction and dredging and military defense exercises. In order for passive acoustic monitoring (PAM) tools to yield ecosystem-relevant information about biodiversity, this busy and complex sound field is the background against which target biological signals must be detected and the ecological context in which they must be interpreted. Here, we examine a case study in the Chukchi Sea (US Alaskan Arctic), which collected passive acoustic data over two consecutive years (2010-2012), with the goal of investigating the potential impacts of a rapidly changing acoustic environment on marine mammals. The bottom-mounted recorder was deployed 65 miles northwest off Icy Cape, AK in close proximity to O&G lease areas, where seismic survey impulsive sounds are used to map the composition of the continental shelf. This region is simultaneously an important breeding and feeding ground for the endangered bowhead whale (Balaena mysticetus) Bering-Chukchi- Beaufort population, possibly exposing them to ambient noise levels that could have chronic population level effects, while also confounding the application of PAM systems. The acoustic data were analyzed using a custom computational approach and resulting noise levels were correlated with local wind speed data, to understand the main contribution from natural sources. Visual inspection of spectrograms manually catalogued presence/no presence of bowhead whales and seismic surveys in 12-hr bins. Local seismic survey signatures largely correspond with ice-free months (mid-August through late October), but similar impulsive signals appear to be permeating from locations further away during other times of the year. Given the summer sea ice retreat in the region, future temporal and spatial expansions of energy and commercial shipping activities seem inevitable, altogether altering the Arctic's marine acoustic environment and biodiversity.