ARCTIC WHALE ECOLOGY STUDY (ARCWEST): USE OF THE CHUKCHI SEA BY ENDANGERED BALEEN AND OTHER WHALES (WESTWARD EXTENSION OF THE BOWFEST)

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Executive Summary

Through an Inter-Agency agreement (IAA) between the National Oceanic and Atmospheric Administration (NOAA), National Marine Fisheries Service (NMFS), Alaska Fisheries Science Center (AFSC), Marine Mammal Laboratory (MML) and the Bureau of Ocean Energy Management (BOEM), MML is conducting a dedicated multi-year study to determine relationships between dominant currents passing from the Bering Sea into and through the Chukchi Sea and prey resources delivered to the Barrow Arch area (an area of high bowhead whale and prey concentrations between Wainwright and Smith Bay), and to provide information about the dynamic nature of those relationships relative to whale distribution and habitat utilization in the eastern Chukchi and extreme western Beaufort Seas. This study will also provide important baseline data on the occurrence, distribution, and habitat use of large whales in an area that is subject to rapid change in climate and human industrial development. This quarterly report covers work conducted from July through September 2016.

The major activities during this quarter consisted of the processing and analysis of data collected during the 2013, 2014, and 2015 cruises, and continuing the analysis and synthesis work necessary for the final report. Although not part of the original ARCWEST plan, there was a 2016 cruise for the Arctic Long-Term Integrated Mooring Array (ALTIMA) project, supported by funding from NOAA's Office of Oceanic and Atmospheric Research (OAR, Stabeno) with supplemental funding from BOEM through ARCWEST. NOAA contracted with KB Fisheries, Inc. to charter the F/V *Aquila* for the survey, which left Nome, AK on 3 September and returned to Dutch Harbor, AK on 29 September. This survey allowed us to retrieve and redeploy the biophysical and acoustic moorings which were turned over in 2015, ensuring continuation of our long time series of data begun in 2010 (with some sites beginning in 2007). The passive acoustics and satellite tagging groups have also met Public Access of Research Results (PARR) requirement deadlines, and the oceanographic and zooplankton groups are working to meet these deadlines. Highlights of progress and results to date are listed below by objective, with additional details in the main body of the report.

1. Assess patterns of spatial and temporal use of the Chukchi Sea by endangered bowhead, fin and humpback whales, and beluga and gray whales.

    - For 2016, 35% (30 of 85) of sonobuoys had acoustic detections. This was double the 18% (14 of 78) seen last year, but was still slightly lower than that seen before 2015 (i.e., 46% (69 of 149) in 2014 and 51% (64/126) in 2013).

    - The passive acoustics team continues to process the long-term time series in the Chukchi Sea. Analyses are well under way and are on track for completion in time for the final report. Emphases have been made on data collected nearshore from Barrow Canyon to Icy Cape to be able to integrate with Carol Ladd's polynya work (Ladd *et al.*, 2016); off Icy Cape for continuation of the analysis started during the BOEM-funded Chukchi Acoustics, Oceanography, and Zooplankton Study (CHAOZ); off Wainwright and Point Hope for integration in Kennedy's developing paper on gray whale satellite telemetry, and off Point Hope for Berchok's multi-disciplinary, multi-institutional paper on the DBO 3 region for the DBO special issue.

    - The passive acoustics team continues to collaborate and work with colleagues on autodetectors to try and streamline our fin whale analyses. Whichever method works the best will be run on all datasets (including those from ARCWEST), with a randomized

subsample manually checked to ground-truth the detector data. This will greatly reduce the overall time to analyze each mooring for this subarctic species.

- As a continuation of her IFAW-funded work on eastern North Pacific Right Whales, Dana Wright, with funding from the Marine Mammal Commission, is now including additional moorings in the Northern Bering Sea and from Unimak Pass. To date, she has completed analysis for the majority of the moorings and is on track for completion of the final northern sites by the end of the year. She is analyzing the data for right whales among other mid‑frequency species (i.e., bowhead, humpback, minke, and gray whales; as well as walrus and other pinnipeds), which will provide essential information on movements on the wintering grounds and migratory timing of these important Chukchi species. Recent funding from the National Fish and Wildlife Foundation (NFWF) has allowed analyses to expand to the critical mid-latitudes of the Bering Sea shelf. All analysts are using data from recorders that have been funded by various BOEM projects.

- State-space models applied to telemetry data revealed potentially important foraging habitats.

2. Assess the population structure and origin of whales in the region.

    - Linda Vate Brattstrom has finished boxing the first set of beluga calls from the spring peak in the BF10_AU_03 mooring. Ellen Garland will use this information to compare vocal drift in beluga calls over time. She will combine this with her work on population differences in beluga calling repertoires for a manuscript projected to be completed by this spring.

    - Photographs of humpback, killer, and gray whales are being compared to existing catalogs.

3. Evaluate ecological relationships for the species, including physical and biological oceanography that affect critical habitat for these species.

    - The ARCWEST and CHAOZ-X studies have provided passive acoustic data that extends the time series started in 2010 (and 2007 in some locations), covers a broader spatial range, and comes from recorders that consistently lasted for their full twelve-month deployments. This complete data set will allow a more robust statistical treatment that will be used to validate many of the findings from the CHAOZ study (i.e., bowhead whale (negative correlation) and bearded seal (positive correlation) calling activity versus ice thickness and concentration, positive correlation of bowhead calling activity with wind speed, proxies for prey with gray whale, bearded seal, and walrus calling activity, beluga calling activity with polynyas, etc.), as well as to inform new findings.

    - ADCP data from the 2011-2012 deployment showed intermittent diel vertical migration of zooplankton.

4. Conduct physical and biological oceanographic sampling to further understand the transport and advection of krill and nutrients from the northern Bering Sea through the Bering Strait and to the Barrow Arch area.

    - The monthly mean transport at Icy Cape has been explored using CHAOZ (2010–2011), ARCWEST (2012–2015), and CHAOZ-X (2012–2015) data. More than a third of the transport

entering the Arctic through Bering Strait remains on the shelf, heading toward the Barrow Arch area.

- The monthly mean transports during winter and fall were highly variable with large standard deviations each month. In addition, the year to year variability is also large. During April to August, year-to-year variability is much reduced.

- The August 2014 to August 2015 mooring and hydrographic data are available, except for the ice thickness data, which are taking longer to process and is now anticipated to be available in September.

- The 2015 plankton samples from the large mesh net have been processed by the Polish Plankton Sorting and Identification Center in Szczecin, Poland. The data will be QA/QC'd and uploaded in the database by late 2016. The 2013-2015 chlorophyll data were analyzed. Initial results show mean integrated chlorophyll-*a* was similar for all 3 years. The zooplankton data show that 2014 mean total abundance was more than double than in 2013.

Introduction and objectives

The western Arctic physical climate is rapidly changing. The Arctic sea ice extent reached a new low in maximum extend on March 24, 2016, breaking the record for the second year in a row (http://tinyurl.com/gw5xoo8). The maximum extend was 14.52 million square kilometers which is 1.12 million square kilometers below the 1981 to 2010 average of 15.64 million square kilometers. The speed of this ice loss was unexpected, as the consensus of the climate research community was that this level of ice reduction would not be seen for another thirty years (Wang and Overland, 2009). As sea temperature, oceanographic currents, and prey availability are altered by climate change, parallel 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 will also open maritime transportation lanes across the Arctic adding (to a potentially dramatic degree) 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 bowhead (*Balaena mysticetus*), gray (*Eschrichtius robustus*), humpback (*Megaptera novaeangliae*) and fin whales (*Balaenoptera physalus*) (e.g., see Clarke *et al*., 2013; Crance *et al*., 2015; Delarue *et al*., 2013; and Tsujii *et al*., 2016), mandates 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. Moreover, several species are used, or potentially used, for subsistence by native communities in both Russia and the US. Whales form an important part of the diet and cultural traditions of most people in villages along the coasts of the Chukchi Sea. Detailed knowledge of large whale migration and movement patterns is essential for effective population monitoring. Because all marine mammal species are subjected to changes in environmental variables such as oceanographic currents, sea temperature, sea ice cover, prey availability, and anthropogenic impacts, more complete information on

the year-round presence of these species in the Chukchi Sea, how presence relates to these variables, and the transport of nutrient and prey through the Chukchi Sea is needed.

The ARCWEST study has five component projects: visual observation, satellite tagging, passive acoustics, lower trophic level sampling, and physical oceanographic sampling. Visual surveys, along with sonobuoy deployments, will provide distributional data on baleen whales and other marine mammals. Satellite tagging will provide valuable information on both large- and fine-scale movements and habitat use of baleen whales. Passive acoustic moorings will provide year-round assessments of the seasonal occurrence of baleen whales. Concurrently deployed bio-physical moorings offer the potential of correlating whale distribution with biological and physical oceanographic conditions and indices of potential prey density. Satellite-tracked ocean current drifters will examine potential pathways to the areas of high biological importance. Our goal is to use these tools to understand the mechanisms responsible for the high biological activity so that we can predict, in a qualitative way, the effects of climate change on these preferred habitats.

The overall goal of this multi-year IAA is to use passive acoustic recorder deployments, visual and passive acoustic surveys, and satellite tagging to explore the distribution and movements of baleen whales in the Bering and Chukchi Seas, particularly in the Chukchi Sea lease areas. In addition, oceanographic and lower trophic level sampling and moorings will be used to explore the relationships between currents passing through the Bering Strait and resources delivered to the Barrow Arch area (an area of high bowhead whale and prey concentrations between Wainwright and Smith Bay), and the dynamic nature of those relationships relative to whale distribution and habitat utilization in the eastern Chukchi and extreme western Beaufort Seas.

The specific objectives are:

1. Assess patterns of spatial and temporal use of the Chukchi Sea by endangered bowhead, fin and humpback whales, and beluga and gray whales.

2. Assess the population structure and origin of whales in the region.

3. Evaluate ecological relationships for the species, including physical and biological oceanography that affect critical habitat for these species.

4. Conduct physical and biological oceanographic sampling to further understand the transport and advection of krill and nutrients from the northern Bering Sea through the Bering Strait and to the Barrow Arch area.

Cruise activities and summary

Although not part of the original ARCWEST planning, there was a 2016 cruise for the ALTIMA project, supported by funding from NOAA/OAR (Stabeno) with supplemental funding from BOEM through ARCWEST. NOAA contracted with KB Fisheries, Inc. to charter the F/V *Aquila* for the survey which left Nome, AK on 3 September and returned to Dutch Harbor, AK on 29 September. This survey allowed us to retrieve and redeploy the biophysical and acoustic moorings which were turned over in 2015, ensuring continuation of our long time series of data begun in 2010 (with some sites beginning in 2007). An underway visual survey and 24/7 passive acoustic monitoring were conducted as well as continuous biophysical sampling along the standard ARCWEST sampling lines (Figure 1).

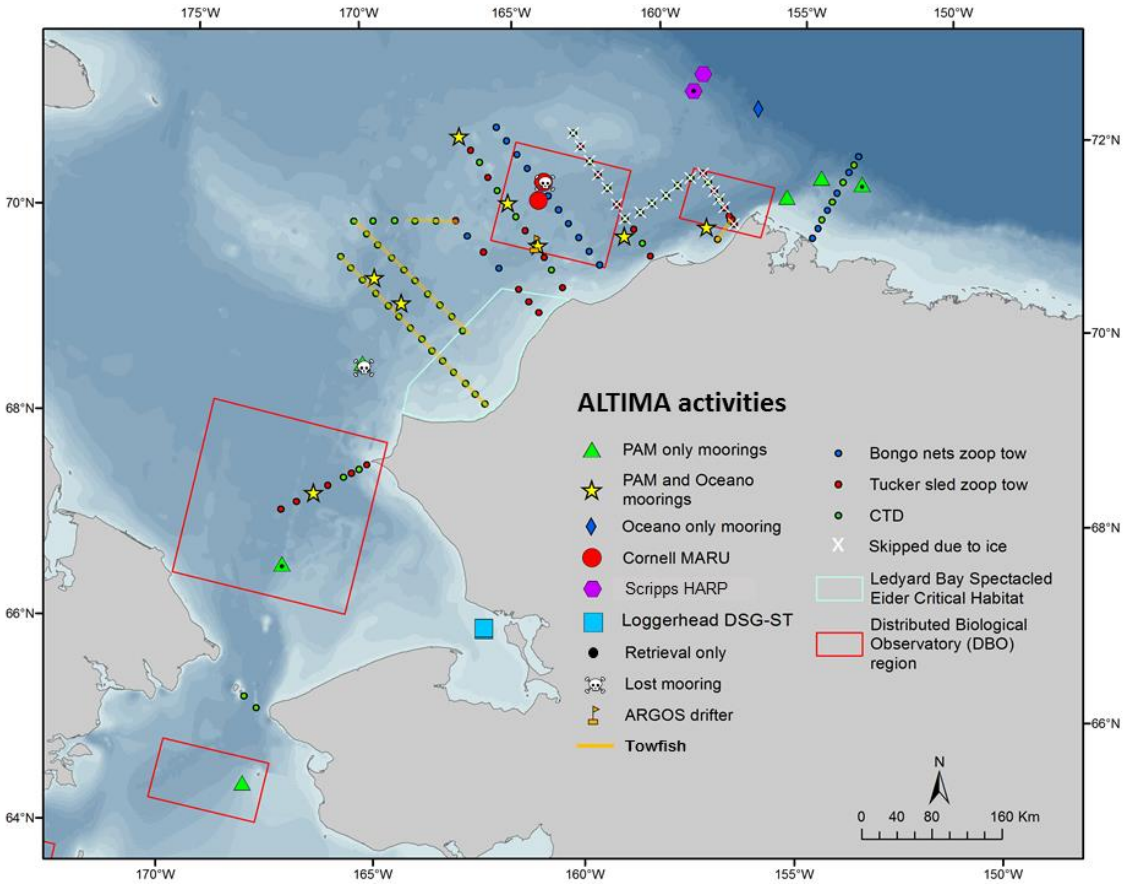

Figure 1. Cruise activities completed during the 2016 ALTIMA survey.

Data analysis results and planning

The final data analysis and synthesis work is underway and on track for the final report in 2017. The ARCWEST team plans to use the framework which was developed for the CHAOZ final report. We have already begun to plan how the ARCWEST data will be integrated to enable multi-disciplinary, synthesis analyses. Although many of the programs to run these analyses have already been written, we will continue to incorporate more robust methods where practicable. The CHAOZ final report will provide important baseline data to which ARCWEST can compare. To this end, a two-day workshop on generalized additive modeling (taught by GAM expert David L. Miller from the NEFSC and the University of St Andrews) is scheduled for 18-19 October. We will be bringing our data set to this workshop for additional insights and suggestions from Dr. Miller.

<u>Marine Mammal Component:</u>

Long-term passive acoustic recorders:

[Note: All recorders used by MML in this study are Autonomous Underwater Recorders for Acoustic Listening (AURALs, Multi-Électronique, Rimouski, QC, Canada), sampling at a rate of 16 kHz on a duty cycle of 80 minutes of recordings made every 5 hours, for an entire year].

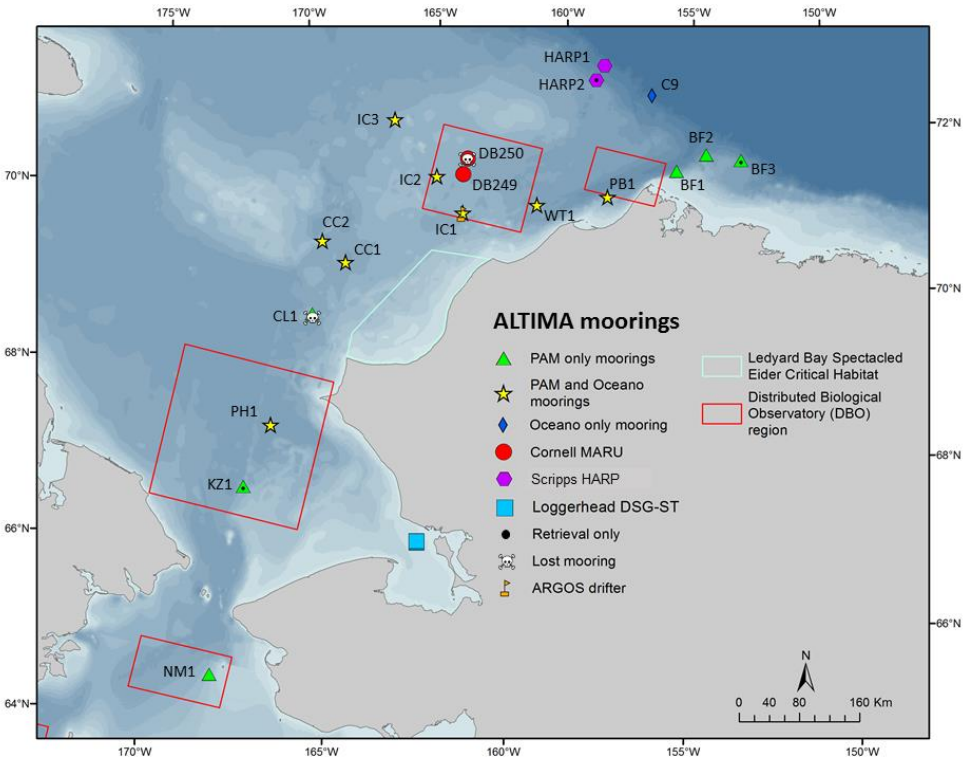

Figure 2. Passive acoustic mooring retrievals and/or deployments during the 2016 ALTIMA survey in the primary operating area of the northern Bering Sea, Chukchi Sea, and western Beaufort Sea.

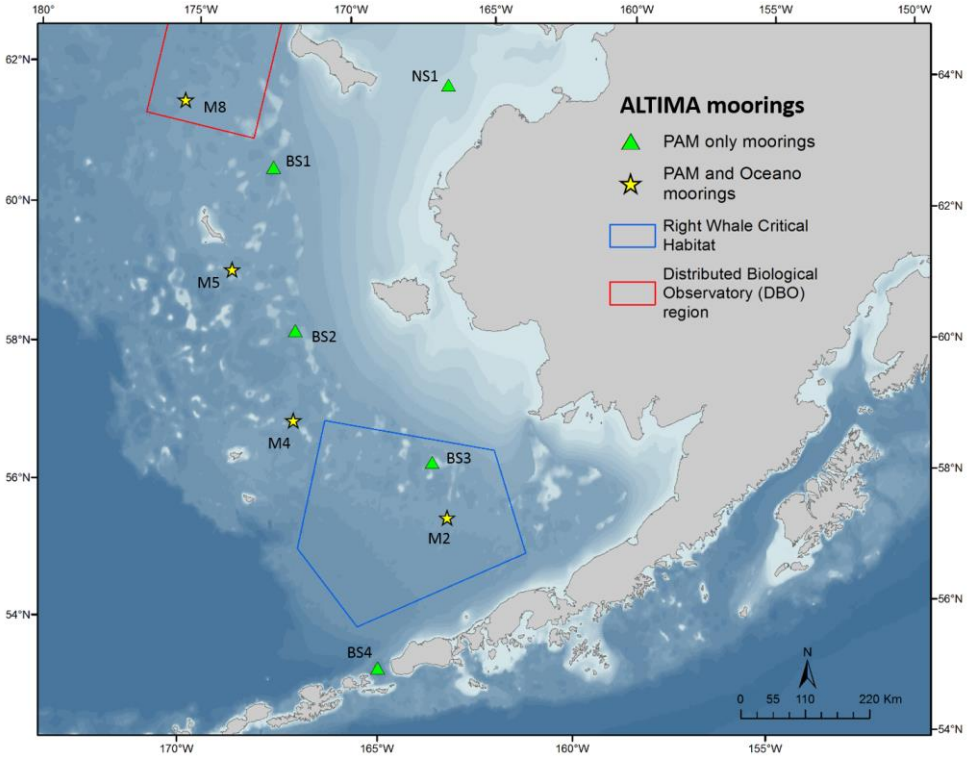

Figure 3. Passive acoustic mooring retrievals and/or deployments during the 2016 ALTIMA survey in the Bering Sea.

Although the field work portion of the ARCWEST study is complete, we recovered 11 of the 12 Arctic passive acoustic recorder moorings (the mooring off Cape Lisburne was not found after an extensive search of the area), and redeployed nine of these on the ALTIMA cruise (Figure 2). We also deployed a mooring in the central channel region that will be part of our collaboration with Chris Wilson and Alex DeRobertis (NRPB IERP) next year. Eight of the passive acoustic moorings are collocated with oceanographic moorings. Four additional moorings were deployed for other researchers/other projects (see Cruise report for details). On this same cruise we also recovered and redeployed nine passive acoustic recorders in the Bering Sea (Figure 3), four of which are on M moorings (PMEL, Stabeno). An additional mooring in Umnak Pass was deployed in the Spring on the NOAA SHIP *Oscar Dyson*.

All data from the 2015-2016 AURALs have been extracted and converted, and are awaiting processing. These data will not be included in the ARCWEST final report, but are important to maintain the time series.

Our analysts are working hard to complete the analysis of the long-term passive acoustic recorder data in time for inclusion in the ARCWEST final report. When the ARCWEST project is completed, there will be at least a six-year time series on the Icy Cape mooring line, as recordings began there in 2010 as part of the CHAOZ project. Analysis of the moored passive acoustic recorders will provide data on the seasonal distribution of the following species: bowhead, gray, fin, humpback, minke, killer, beluga, sperm, and right whales; bearded and ribbon seals, unidentified seals, and walrus. Vessel noise, airguns, and ice noise are also being analyzed. These data are analyzed using our in-house MATLAB- based analysis program (SoundChecker).

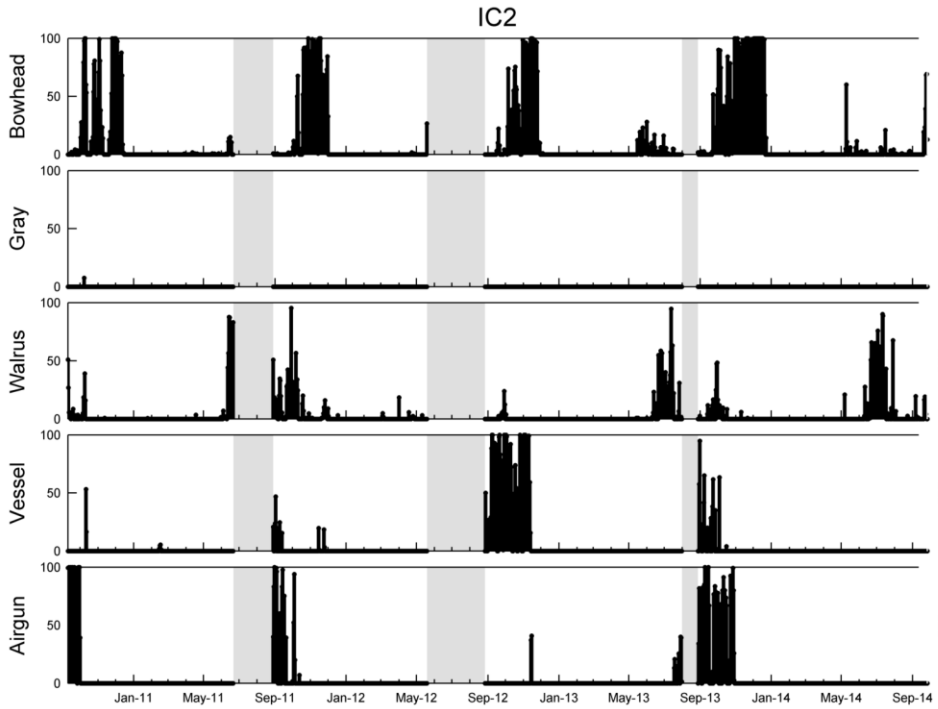

Figure 4. Long-term time series of marine mammal calling activity (presented as the percentage of time intervals with calls) for the midshore Icy Cape (IC2/C2) location, 2010-2014. From top to bottom: bowhead whale; gray whale; walrus; vessel noise; and seismic airgun noise.

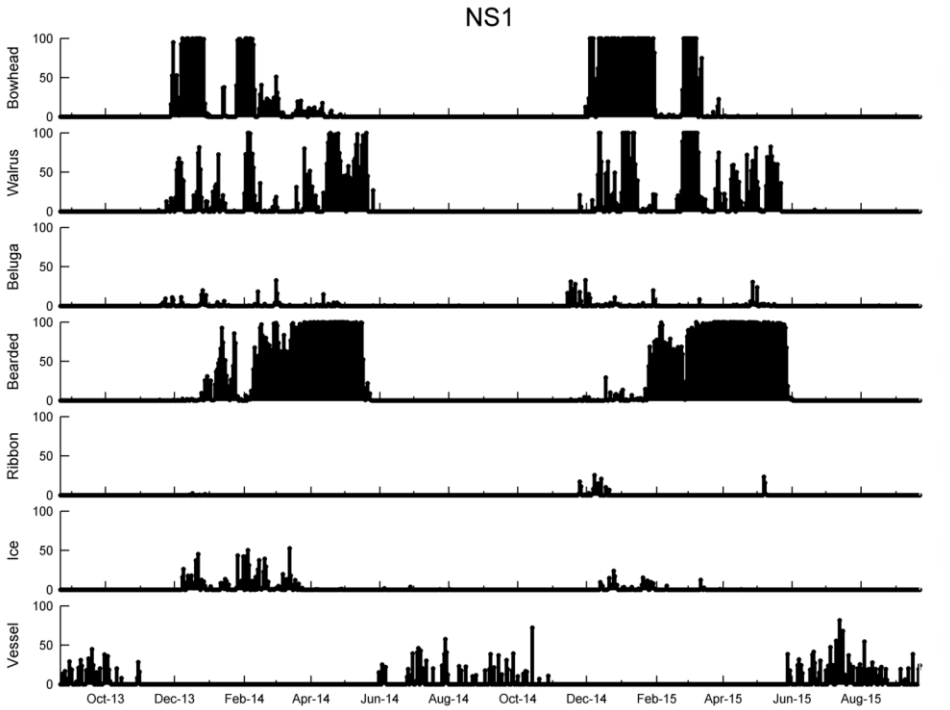

Figure 5. Marine mammal calling activity (presented as the percentage of time intervals with calls) for the Norton Sound (NS1) location, 2013-15, for all species. From top to bottom: bowhead whale; walrus; beluga whale; bearded seal; ribbon seal; ice noise; and vessel noise.

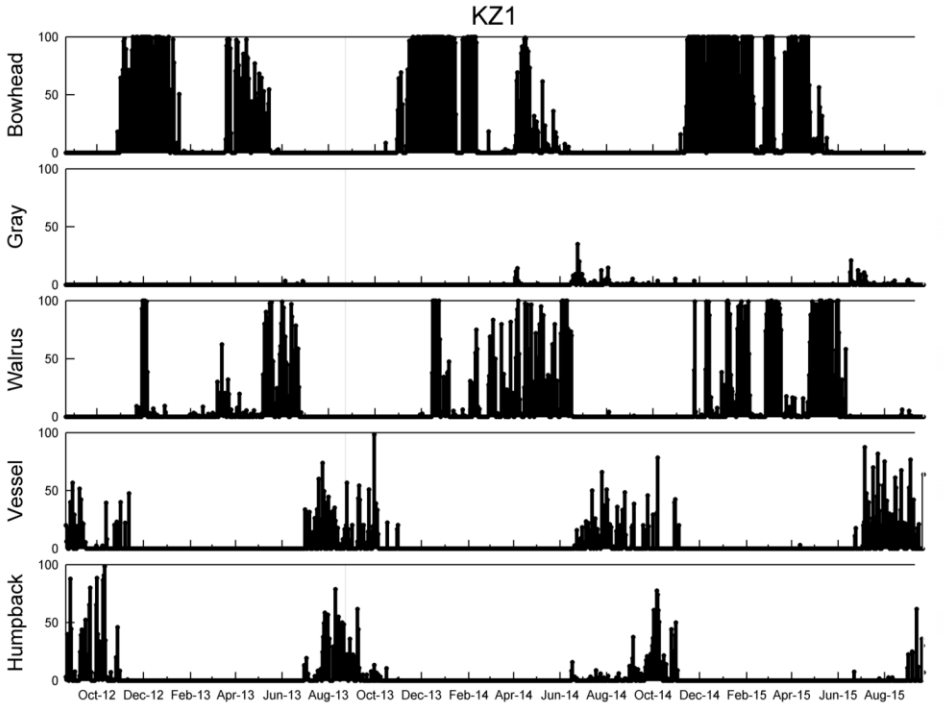

Figure 6. Long-term time series of marine mammal calling activity (presented as the percentage of time intervals with calls) for the Kotzebue (KZ1) location, 2012-2015. From top to bottom: bowhead whale; gray whale; walrus; vessel noise, and humpback whale.

Some representative samples of the long-term time series of data from IC2, NS1, and KZ1 are shown in Figures 4, 5, and 6, respectively. All species/sound sources not shown in those figures had either no or a negligible amount of detections and were not included in the interest of space.

This analysis will add to the results obtained from the CHAOZ study, continuing one of the longest full-year records of baleen and odontocete whales, ice seals, walrus, vessels and airguns, and ice noise in the Chukchi Sea. These data are the only of their kind in the Chukchi lease area as they are concurrently collected with collocated oceanographic moorings, allowing for examination of the effects of oceanographic conditions on marine mammal distribution. Results from these ARCWEST recorders will not only increase the time series at this important area in the Chukchi Sea, but will also increase the geographic extent beyond this Icy Cape line. These results, along with those from CHAOZ and CHAOZ-X, will be presented by Crance at the 2016 Acoustical Society of America conference in November in Honolulu, HI.

Although we have had limited success implementing the low-frequency detection and classification system (LFDCS by Mark Baumgartner, Woods Hole Oceanographic Institution) onto our dataset (for bowhead and fin whales), we continue to collaborate and work with colleagues to try and streamline our analyses. Data were sent to Chris Clark, (Bioacoustics Research Program, Cornell University) to test the efficacy of their bowhead detector. The results were poor, and so auto-detection with their bowhead detector is no longer being pursued. Instead a different method, acoustic class detection, is being tested as part of the CHAOZ-X project. We have also sent some of our data to Xavier Mouy (JASCO Applied Sciences) and Cheryl Aday to test the efficacy of their fin whale detectors on our recordings. Cornell has also offered to run their fin detector on these data as well, and we have asked them to do so with the recordings we have already sent. A few of the ARCWEST recorders (PH1 and CL1; both 2012-14) have now been manually analyzed for fin whale presence, thanks to the work of some dedicated volunteers. These data will be compared to the auto-detection results when completed.

Associated acoustic analyses:

Work continues on the beluga whale study begun by Ellen Garland, our former NRC postdoctoral fellow. The main goal of this study is to provide baseline information on the migration timing and call characteristics of the three migratory beluga populations (eastern Beaufort, eastern Chukchi, and eastern Bering; O'Corry-Crowe *et al.*, 1997) that reside in, and traverse, the Bering, Chukchi, and Beaufort seas. The IC1 mooring (formerly CHAOZ and now ARCWEST) is a big part of this study. To date, Garland's results suggest that migratory timing of Arctic beluga whales can be identified by peaks in seasonal call detections and that the eastern Beaufort and eastern Chukchi populations migrate north through the eastern Chukchi (inshore IC1) at distinct times (Garland *et al.*, 2015a). She has also developed a preliminary repertoire for the eastern Beaufort Sea beluga population providing a proof of concept in measuring and statistical analysis of call types (Garland *et al.*, 2015b), and is in the process of completing the preliminary repertoire for the eastern Chukchi Sea population, and determining how it varies inter-annually. To this end, work is underway to extract beluga detections off the same mooring site in the Beaufort Sea (BF3) over multiple years to determine the amount of repertoire drift.

Dana Wright is working on an analysis of Bering Sea moorings for a project funded by the International Fund for Animal Welfare (IFAW) and the Marine Mammal Commission (MMC) on the North Pacific Right Whale (NPRW). While the project is externally-funded, the mooring deployments and/or recorders were funded by ARCWEST (or other MML/BOEM studies). Because of the similarities in call types between the NPRW, humpbacks, and bowhead whales, Dana is analyzing the data sets for all of these

species as well as gray whales, walrus, and vessel and airgun noise. A side product of this effort will be a description of the spatio-temporal distribution of bowheads on their wintering grounds in the Bering Sea. Her first year of effort (IFAW-funded) focused on the southern and northern Bering Sea shelf (the Aleutian passes, near St. Lawrence Island, and in Norton Sound). To date, she has completed analysis for the M8, BS1, NS1, BS4 (Unimak), and KZ1 moorings with the NM1 moorings to be completed by the end of the year. We have recently been awarded funding from the National Fish and Wildlife Foundation (NFWF) and have hired two additional analysts to expand this analysis on the critical mid-latitudes of the Bering Sea shelf (i.e., M2, M4, M5, BS2, and BS3). All analysts are using data from recorders that have been funded by various BOEM projects.

We have sent data recordings (some ARCWEST, but all BOEM-funded) from the Bering, Beaufort, and southern Chukchi seas to Heloise Frouin-Mouy (JASCO Applied Sciences) for her work on the spatio-temporal distribution of ribbon seals in Alaskan waters. We will continue to collaborate with scientists from JASCO as our combined analyses develop.

Our final collaboration is with Aaron Thode (Scripps Institution of Oceanography) and Julien Bonnel (Université Européenne de Bretagne), who have used some of our (BOEM-funded) Bering Sea moorings as part of an NPRB project examining upsweep vocalizations from North Pacific right (NPRW), bowhead, and humpback whales, and gunshot calls from the NPRW and bowhead whales (these call types are often confused among the species). By analyzing the multi-path arrivals of the signals, they have been able to determine both the depth at which the call was produced and the range of the call to the hydrophone. Issues with seasonally changing sound speed profiles had complicated their efforts, but these have been resolved. The gunshot call was best suited to this method, and plans have been discussed to continue this work with a broader data set (and more intensive collaboration with Dana Wright). They are in the process of submitting their final report to NPRB at which time a copy will be sent to BOEM.

Sonobuoys:

We deployed 142 sonobuoys during the 2016 ALTIMA cruise on the F/V *Aquila*. Very few marine mammals were detected (Figure 7). In the ARCWEST study area bowhead whales, gunshot calls, gray whales, walrus, bearded and ribbon seals, seismic airguns, and an unidentified anthropogenic signal (~250 Hz and 1 min long - possibly from the Canada Basin Acoustic Propagation Experiment (CANAPE)) were the species/signals heard. For more details see the cruise report: ALTIMA2016_CruiseReport.pdf.

Visual Observations Component:

A team of two visual observers surveyed 1140 nm of on-effort trackline during the ALTIMA research cruise on the F/V *Aquila*. In the ARCWEST study area bowhead, gray, minke, and killer whales, harbor porpoise, walrus, bearded, ringed, and spotted seals, and unidentified cetaceans and pinnipeds were sighted (Figure 8). For more details see the cruise report: ALTIMA2016_CruiseReport.pdf.

The distribution of cetaceans in the Arctic using visual data collected from the CHAOZ, ARCWEST, and CHAOZ-X surveys will be combined with the satellite tagging data into one manuscript. Noteworthy results from photo-ID analysis will be incorporated as well. The one humpback photographed in the Chukchi Sea on September 16, 2014 was matched against the SPLASH (Structure of Populations, Level of Abundance and Status of Humpbacks); no match was found. Killer and gray whale photo analyses are still ongoing and are summarized below (Table 1).

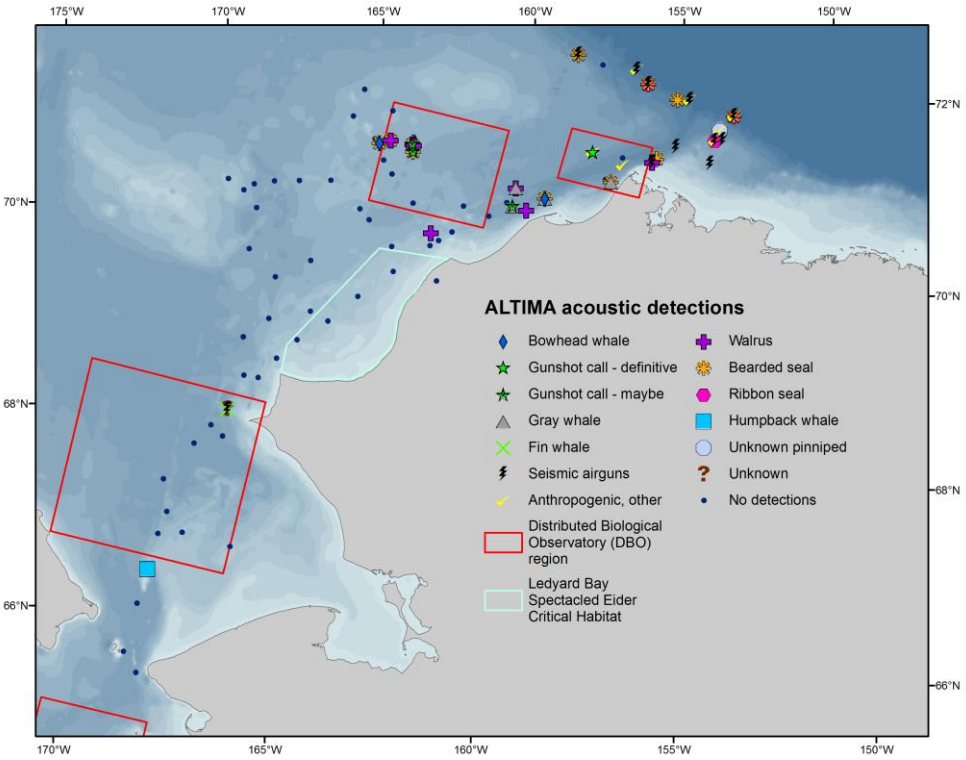

Figure 7. Sonobuoy deployment and acoustic detections from the ALTIMA 2016 research cruise in the Chukchi Sea.

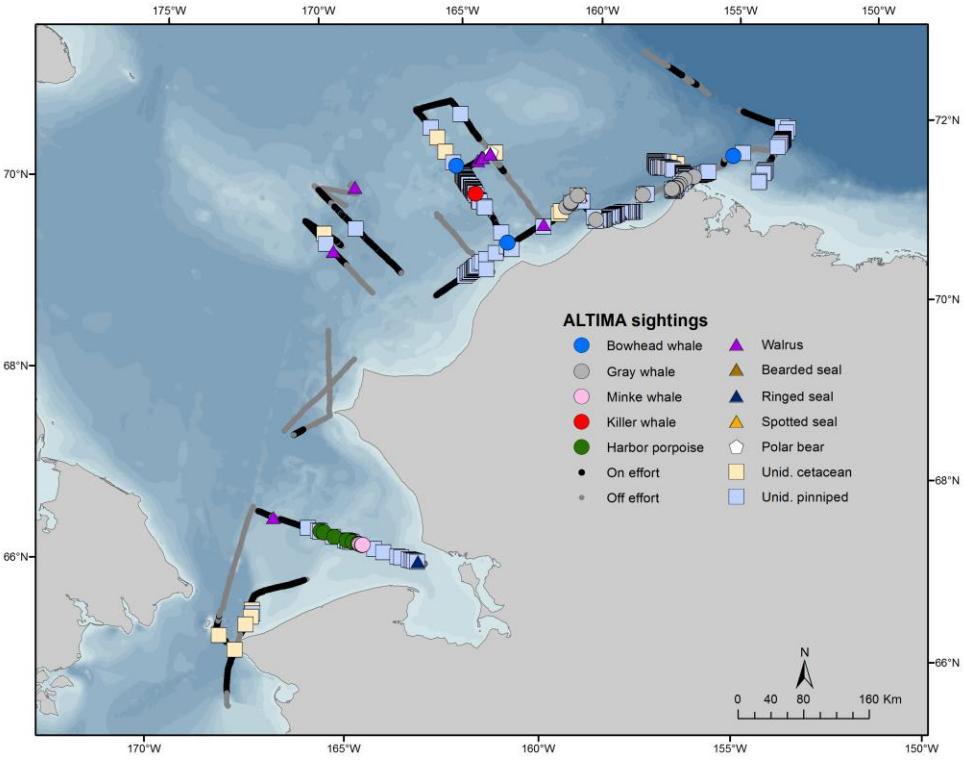

Figure 8. Marine mammal on-effort sightings and effort data from the ALTIMA 2016 research cruise in the Chukchi Sea.

Table 1. Photo-Analysis update for humpback, killer, and gray whales photographed on ARCWEST and CHAOZ-X, 2013-2014. Notes: SPLASH = Structure of Populations, Levels of Abundance, and Status of Humpbacks, PCFG= Pacific Coast Feeding Group, CRC= Center for Coastal Studies.

Species	Year	Date	Ecotype	Photographed Individuals	Status	Matches	Catalogs
Killer whales	2013	Aug-14	Resident	14	Analyzing		MML Western Resident
		Aug-19	Resident	6	Analyzing		MML Western Resident
		Sep-02	Transient	14	Analyzing	WT142; WT59	MML Western Transient
		Sep-08	NA	NA	Unmatchable	NA	NA
	2014	Oct-15	NA	6	Poor quality; Unmatchable	NA	NA
Humpback whale	2014	Sep-16	NA	1	Complete	0	SPLASH; MML
Gray whales	2013	Aug-24	NA	11	Analyzing		PCFG; CRC
		Aug-22	NA	3	Analyzing		PCFG; CRC
		Aug-21	NA	1	Analyzing		PCFG; CRC
		Sep-8	NA	19	Analyzing		PCFG; CRC
		Sep-7	NA	15	Analyzing		PCFG; CRC
	2014	Sep-10	NA	1	Analyzing		PCFG; CRC
		Sep-11	NA	7	Analyzing		PCFG; CRC
		Sep-12	NA	1	Analyzing		PCFG; CRC
		Sep-15	NA	1	Analyzing		PCFG; CRC
		Sep-14	NA	3	Analyzing		PCFG; CRC
		Sep-21	NA	6	Analyzing		PCFG; CRC

Satellite Tagging Component:

Analysis of the telemetry data collected in 2012 and 2013 is ongoing. Movement models (e.g., Jonsen *et al*., 2007; Johnson *et al*., 2008) have been applied to these data to evaluate fine scale habitat use (Figure 9). Preliminary results show distinct regions of area-restricted search (ARS) off Wainwright, southwest of Pt. Hope, and west of St. Lawrence Island. ARS indicate areas where movement is typically slow and erratic and are often associated with foraging habitats (e.g., Jonsen *et al*., 2007; Bailey *et al*., 2010). Figure 10 shows a detailed kernel density estimate for the high-use area southwest of Pt. Hope and near Wainwright. These preliminary results are consistent with results from aerial surveys and other telemetry project regarding preferred habitats used by gray whales in the Chukchi Sea.

An abstract with results from satellite tag data obtained during ARCWEST was presented at the Society for Marine Mammalogy's Biennial Conference in December 2015. An abstract detailing the preliminary results from the visual surveys and telemetry results was submitted to the Alaska Marine Science symposium. In addition, a manuscript is in preparation for publication of these results. The telemetry manuscript submission is dependent on the analysis of overlapping oceanographic and acoustics data and will occur after those results are available.

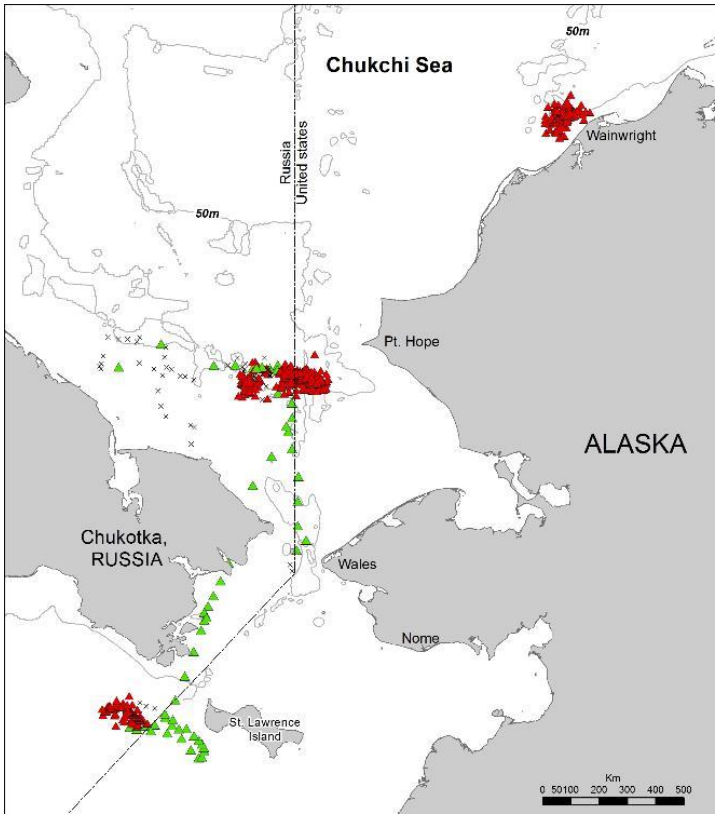

Figure 9. Habitat-use model results. Each triangle represents a switching state-space modeled position at a 6 hour time-step. Red triangles indicate where whales were engaging in area-restricted search (often associated with foraging) and green triangles indicate travel mode.

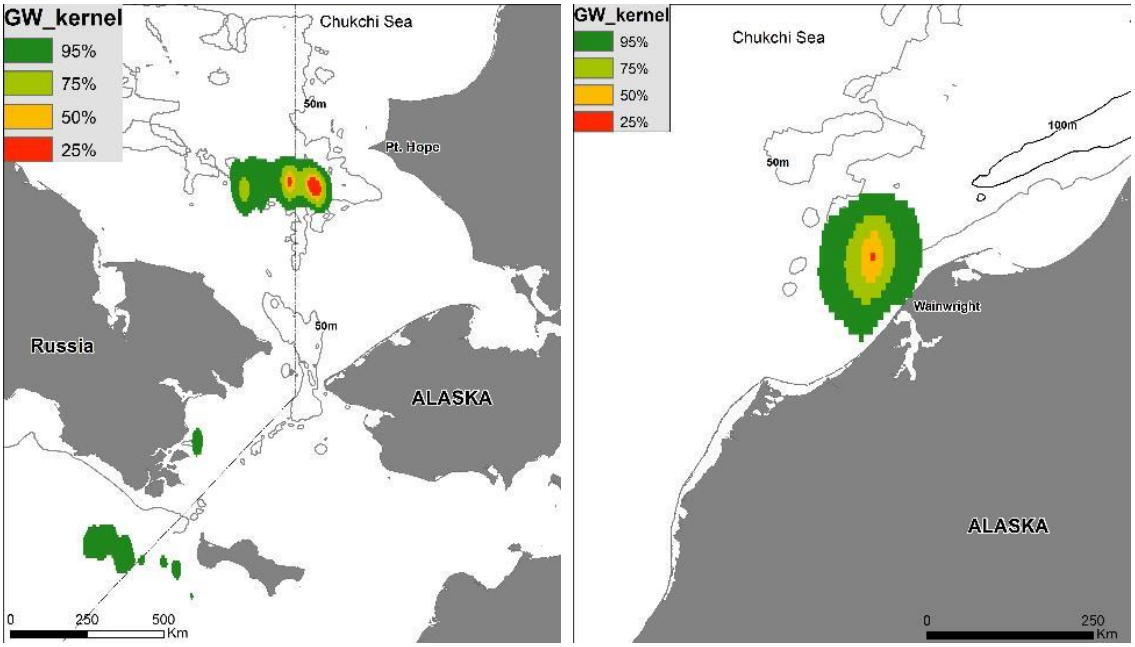

Figure 10. Kernel density estimate of the high-use area off Pt. Hope (2013 data, left) and Wainwright (2012 data, right). Colors indicate the percentage of time a whale is predicted to use each region.

Oceanographic and Lower Trophic Level Component:

The ALTIMA research cruise concluded in September 2016 where most of the ARCWEST stations were sampled and all moorings deployed in 2015 were recovered.

Moorings:

In 2016, eight biophysical moorings were redeployed at ARCWEST sites IC1, IC2, WT1, PB1 and C9, plus new biophysical moorings were deployed at 3 new sites (CC2, CC1, and PH1). In addition, an upward looking active acoustic TAPS-6NG (Tracor Acoustic Profiling System, Next Generation) instrument was deployed at IC2 (Figure 2) to measure zooplankton bio-volume and size distribution.

Hydrography & Plankton Sampling:

2016 nutrient samples were processed on board the F/V *Aquila* and have been incorporated into the hydrographic files. Data were uploaded to the PMEL database. Chlorophyll samples (N = 423) were collected and are stored in a freezer in Seattle. Chlorophyll samples will be analyzed in January/February and our new contractor will help upload these data into the database and produce figures describing the distribution and concentration of chlorophyll a across the region.

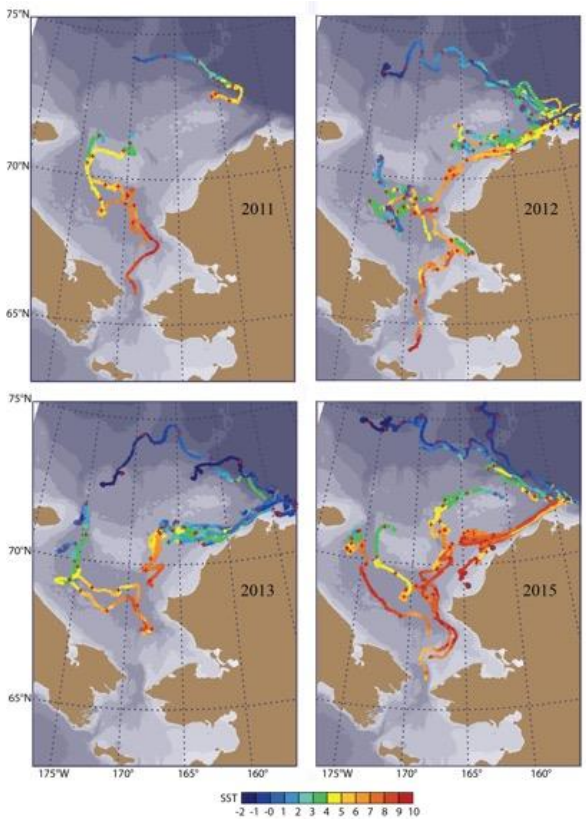

Figure 11. Drifter trajectories for those deployed in 2011, 2012, 2013 and 2015. The color coding indicates the near surface temperature collected by the drifter. The westward flow Chukchi Slope Current is evident from Barrow Canyon to 177°W along the north slope of the Chukchi Sea.

Satellite Tracked Drifters:

Satellite-tacked drifters were deployed in 2011, 2012, 2013, 2015, and 2016 (Figure 11). All movies showing drifter tracks since 2011 can be viewed at the following website under the heading *Drifter Movies/Chukchi Sea/2015:* http://www.ecofoci.noaa.gov/efoci_drifters.shtml. Also, movies showing drifter tracks with ice extent in 2011, 2012-2013, and 2013-2014 can be downloaded under the heading *Chukchi Sea Drifters with Ice Movies (M4V)*.

Active Acoustics:

A new, simpler, control board was designed, built and preliminarily tested for the TAPS-6NG during 2015. Tests were accomplished on the bench and on a short deployment in Lake Washington. Based on those tests we decided to attempt a redeployment of the instrument in the Chukchi. The instrument was deployed at site C2 as the ship made it way eastward. The F/V *Aquila* returned to the site 6 days later, retrieved the instrument, downloaded data, and then redeployed the instrument for the winter. It appears that the instrument collected data during the entire 6 day deployment. We have examined the data collected during those 6 days and are encouraged by the result. Further testing of the instrument with the new controller board took place in January-February 2016 in Puget Sound. Initial results of that test show that it functioned properly, however the signal-to-noise ratios were somewhat low. We will attempt another test deployment in 2016 using an increased pulse length to compensate for the poor signal-to-noise ratios. Our initial plan is to redeploy an instrument at C2 again this year.

An ADCP was deployed near one of the TAPS6-NG instruments, in the Icy Cape mooring cluster, in August 2011 and retrieved in 2012. The ADCP intended use is to measure current velocities, thus it is not calibrated to provide information regarding the size or abundance of organisms. However, due the relatively high vertical resolution, the ADCP data can be used to help reveal whole water column volume backscatter patterns, such as diel vertical migration of zooplankton, when paired with the TAPS-6NG instruments. The ADCP data has been fully processed and converted from echo intensity units to volume backscatter. Wavelet analysis was performed on the ADCP volume backscatter data to examine the dominant modes of temporal variation and to determine strength of these modes across the observation period (Figure 12). Initial examination of the data shows intermittent diel vertical migration. The analysis presented here is from the CHAOZ study, but similar analyses are being conducted with ARCWEST data.

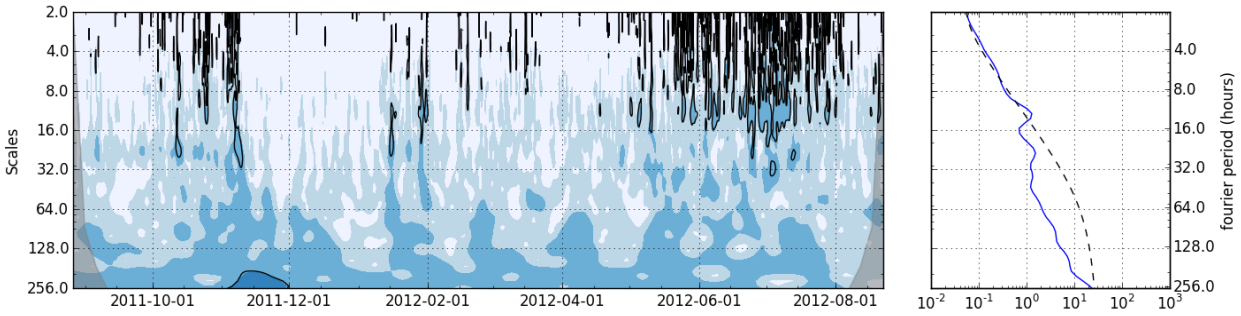

Figure 12. Wavelet analysis of ADCP data. Shown is an analysis of data at 28 m from the instrument deployed at site C3 in 2011. Diel vertical migration, when present, would show in the left panel as dark blue contours between 16 and 32 hrs on the (vertical) "Scales" axis. If diel vertical migration were a significant source of variability over the entire deployment, it would appear in the right panel as a peak on the blue line exceeding the dotted line in the same period (between 16 and 32 hours).

ADCP backscatter data (2013-2015) have been processed to contribute to the GAM model. Wavelet analysis of the ADCP backscatter data (2013-2015) has also been achieved. TAPS-NG data from the 2013-2014 deployment (13CKT5A) are in the process of being analyzed. Thus far, we've determined that the instrument functioned from late August to early December, but only the lowest 3 frequencies are usable.

Lower Trophic Level Sample and Data Analyses:

Zooplankton samples were sent to the Polish Plankton Sorting and Identification Center in Szczecin, Poland, and counts of organisms will be returned to us by May of 2016. Analysis of the 2013-2015 chlorophyll data was completed. Initial results show that mean integrated chlorophyll-*a* was similar for all three years (Figure 13). There was consistently higher than average integrated chlorophyll values within the Wainwright and BX3 transects for all three years. In addition, the lowest integrated chlorophyll values were located at the nearshore stations of the Beaufort line. The zooplankton data for the years 2013-2014 has been uploaded to the database. Early results (Table 2) show that the mean total abundance in 2014 is more than double than in 2013. This was mostly due to an increase in abundance of small copepods (e.g. *Pseudocalanus* spp).

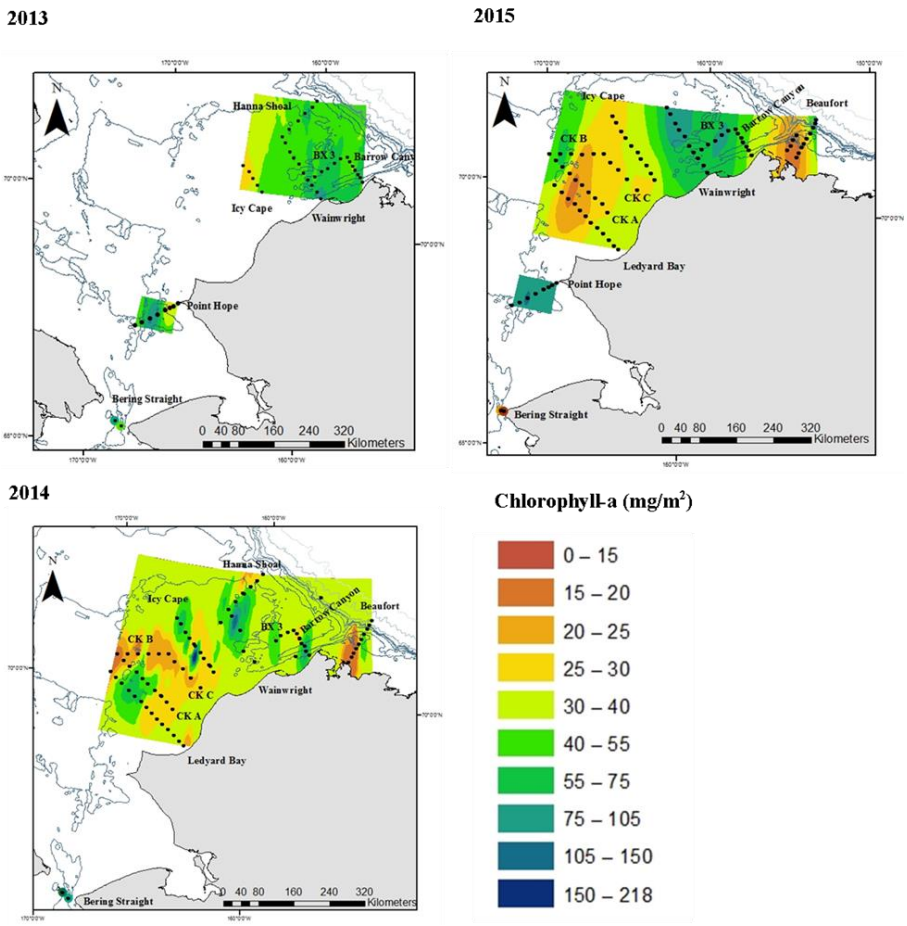

Figure 13. Maps display interpolated integrated chlorophyll-*a* (mg/m^2). Average integrated chlorophyll-*a* was similar for all years with 2013 (SD) at 51.5 (± 23.2), 37.5 (± 23.2) for 2014, and 48.9 (± 39.5) for 2015. The lowest record was in 2014 with 4.8 mg/m^2 at the first nearshore station of the Beaufort line. The highest record was in 2015 with 217.9 mg/m^2 at the offshore stations of the Wainwright line.

Table 2. Mean zooplankton per cubic meter (Individuals m^{-3}) and percent composition for all stations. Zooplankton taxa that were less than 1% of the total were lumped into other.

		2013		2014	
		Mean	**%**	**Mean**	**%**
Benthic	*Total*	*17.6*	-	*26.9*	-
	Chaetognatha	14.8	84.6	21.7	80.5
	Euphausiid (adult/juvenile)	0.2	0.9	3.2	11.9
	Appendicularians (>5mm)	1.5	8.5	< 0.1	< 0.1
	Copepoda (>5mm)	0.4	2.5	1.2	4.6
	Gammerid Amphipods	0.2	1.2	0.7	0.3
	Carideans (adult/juvenile)	< 0.1	0.3	0.3	1.0
	Other	0.4	2.0	0.5	1.7
Planktonic	*Total*	*2505.7*	-	*7486.8*	-
	Copepoda (< 2mm)	1255.4	50.1	4214.8	56.3
	Bivlave (veligers)	93.6	3.7	2022.4	27.0
	Copepoda (2 –5mm)	424.6	16.9	200.2	2.7
	Appendicularians (<5mm)	242.6	9.7	414.2	5.5
	Limacina helacina	22.6	0.9	252.8	3.4
	Barnacles (nauplii/cyprids)	87.6	3.5	30.7	0.4
	Echinodermata (larvae)	44.1	1.8	15.7	0.2
	Other	26.6	1.1	108.8	1.5

In addition, we have begun to apply multi-variate community analysis tools to the CHAOZ data from 2010-2012. Initial results show similar zooplankton assemblages in 2010 and 2011 in the north east Chukchi (Figure 14, dark green circles) which were characterized by larvaceans, cnidarians, cirripedia, and smaller copepods. In 2012, a dissimilar north east assemblage (Figure 14, dark red circles) was characterized by lower numbers of the above mentioned species and a significant increase in *Calanus glacialis,* a lipid-rich Arctic copepod species. There was also a greater heterogeneity in the species assemblages in 2012 compared to previous years. Overall, these assemblage patterns are highly influenced by advection from the Bering Strait, northwest advection on the shelf, as well as the timing of sea ice melting. Once these data analysis templates are completed and all of the zooplankton data are uploaded to the database, we will apply the same techniques to the ARCWEST and CHAOZ-X data.

Publication plans:

In addition to the final report due next year, several publications are being prepared using data from ARCWEST recorders. Carol Ladd's (PMEL) publication on polynya formation and its correlation to oceanographic features was recently published. We will write a follow-up paper which will tie marine mammal data from the inshore moorings (BF2, PB1, WT1, and IC1) to her polynya results. Kennedy is writing a manuscript on gray whale satellite telemetry from the ARCWEST tagging efforts, including the whales tagged off Wainwright and Point Hope. We will be contributing long-term gray whale acoustic detections from our Point Hope (PH1) and Wainwright (WT1) moorings for the respective years tagging took place. Finally, Berchok is spearheading a manuscript combining all international efforts of the Distributed Biological Observatory (DBO) Region 3, which will integrate marine mammal, oceanographic, and lower trophic level data for an ecosystem-wide analysis of the Point Hope region. Stabeno is currently working to finish her manuscript on Chukchi Sea currents from 2010-2015 which will be submitted to the Journal of Geophysical Research.

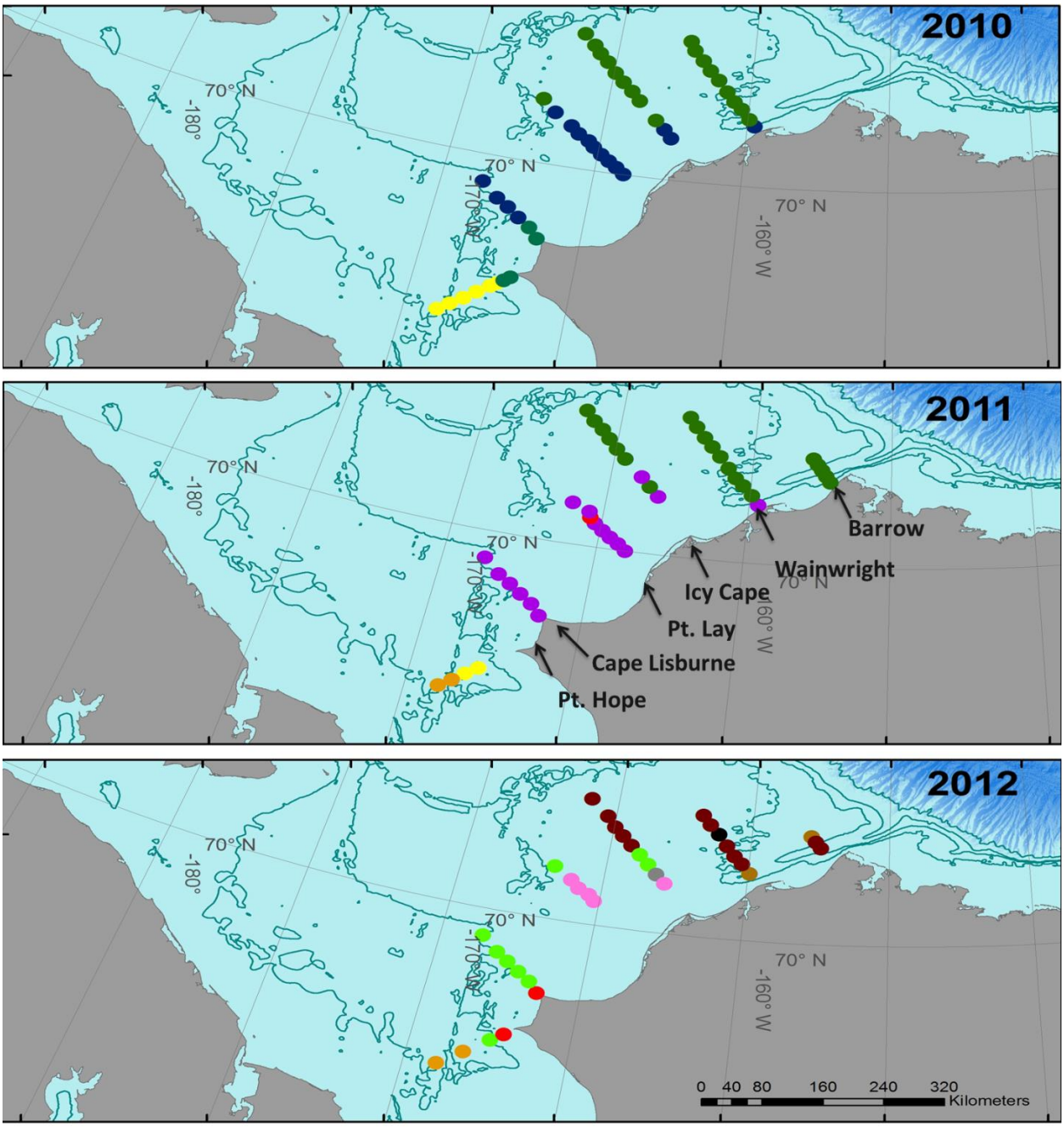

Figure 14. Results of the zooplankton community cluster analysis 2010-2012. Different colored circles indicate different assemblages of zooplankton.

Contribution of data to the Distributed Biological Observatory (DBO)

The ARCWEST program contributes data to the DBO Workspace, supported by AOOS/AXIOM. ARCWEST principal investigators were invited to join the password-protected workspace in December 2013 and have contributed data and data products (maps and figures) as are other DBO contributors. The development of the Workspace is an activity of the DBO Implementation Team (http://www.arctic.noaa.gov/dbo) and is in its early stages. The contribution of information from the

ARCWEST program is considered foundational to the development of the workspace, especially for the visual and acoustic data provided on marine mammals. Because we have to make our data accessible to the public through PARR (see below), we will be linking the DBO data website to the PARR location to reduce duplicating data storage efforts.

Contribution of data to meet Public Access of Research Results (PARR) compliance

The metadata record for the long-term passive acoustic recorders is being refined, and data about the acoustic recordings will be submitted to National Centers for Environmental Information (NCEI) in the future. NMFS is working on a process for making acoustics data available to the public which is complicated by the size of the data files. The metadata records for the sonobuoy data (https://inport.nmfs.noaa.gov/inport/item/17346), the visual sightings (https://inport.nmfs.noaa.gov/inport/item/17941), and the gray whale satellite telemetry (https://inport.nmfs.noaa.gov/inport/item/28151) are now available. In addition, the processed data for the sonobuoy deployments for all BOEM-funded MML data (http://data.nodc.noaa.gov/cgi-bin/iso?id=gov.noaa.nodc:0138863), the visual sightings data for ARCWEST and CHAOZ (http://data.nodc.noaa.gov/cgi-bin/iso?id=gov.noaa.nodc:0137906), and the gray whale satellite telemetry data (http://data.nodc.noaa.gov/cgi-bin/iso?id=gov.noaa.nodc:0139361) have been published at NCEI. Metadata and data about the photo-identification data are still under development. EcoFOCI/PMEL is in the process of compiling all metadata into an in-house ISO-friendly metadata document and format. Data are being gathered together and staged for submit as processing and QC steps are finished. Preliminary action has occurred within the NCEI S2N interface toward submittal of all data sets to NCEI.

Significant technical, schedule, or cost problems encountered

None.

Significant meetings held or other contacts made

27 July 2016: Berchok, Clark, Crance, Ferm, Friday, Mocklin, Napp, Rone, Spear, Stabeno, Tabisola meet to discuss the ARCWEST and CHAOZ-X projects, current status, data analysis results, report construction, and other general project updates.

25 August 2016: Berchok, Crance, Ferm, Friday, Kennedy, Mocklin, Napp, Stabeno, Tabisola meet to discuss the ARCWEST and CHAOZ-X projects, current status, data analysis results, report construction, and other general project updates.

Presentations and Publications

Ladd, C., Mordy, C.W., Salo, S.A. and Stabeno, P.J. 2016. Winter water properties and the Chukchi polynya. J. Geophys. Res., 121(8), 5516–5534, doi: 10.1002/2016JC011918.

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