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 April through June 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 will be 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. Planning for this cruise is near complete. NOAA has contracted with KB Fisheries, Inc. to charter the F/V *Aquila* for the survey which will leave Nome, AK around 2 September and return to Dutch Harbor, AK around 28 September. This survey will allow 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.

    - There were very few acoustic detections during the 2015 field season compared to previous years. Only 18% of sonobuoys deployed in the Chukchi Sea (14 of 78) had acoustic detections, compared with 46% (69 of 149) in 2014, and 51% (64/126) in 2013. Opportunistic visual and acoustic monitoring planned for the 2016 ALTIMA survey will help determine if the trend seen in 2015 will continue.

    - The passive acoustics team (including our four excellent new analysts) 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.*, in press); 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 CHAOZ-X), 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 North Pacific Right Whales, Dana Wright, with funding from the Marine Mammal Commission, is now including additional moorings in the Northern Bering Sea and the 2014-15 mooring from Unimak Pass. To date, she has completed analysis for the M8, BS1, NS1 and BS4 (Unimak) moorings with the NM1 and KZ1 moorings to be completed 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. We have recently been awarded funding from the National Fish and Wildlife Foundation (NFWF) to hire 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). She is 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.

    - The timing of seasonal peaks in beluga whale calling correlates with satellite tag and genetic data which suggests passive acoustics can be used to monitor movements of the individual populations (Garland *et al*., 2015a). A paper on beluga whale vocalizations and call classification from the eastern Beaufort Sea population has been published (Garland *et al*., 2015b); analysis continues for the eastern Chukchi sea population.

    - 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 (battery issues from CHAOZ resulted in 9 month or less deployments). This more 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 will be a 2016 cruise for the ALTIMA project, supported by funding from NOAA/OAR (Stabeno) with supplemental funding from BOEM through ARCWEST. Planning for this cruise is near complete. NOAA has contracted with KB Fisheries, Inc. to

charter the F/V *Aquila* for the survey which will leave Nome, AK around 2 September and return to Dutch Harbor, AK around 28 September. This survey will allow 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 will be conducted as well as continuous biophysical sampling along the standard ARCWEST sampling lines (Figure 1).

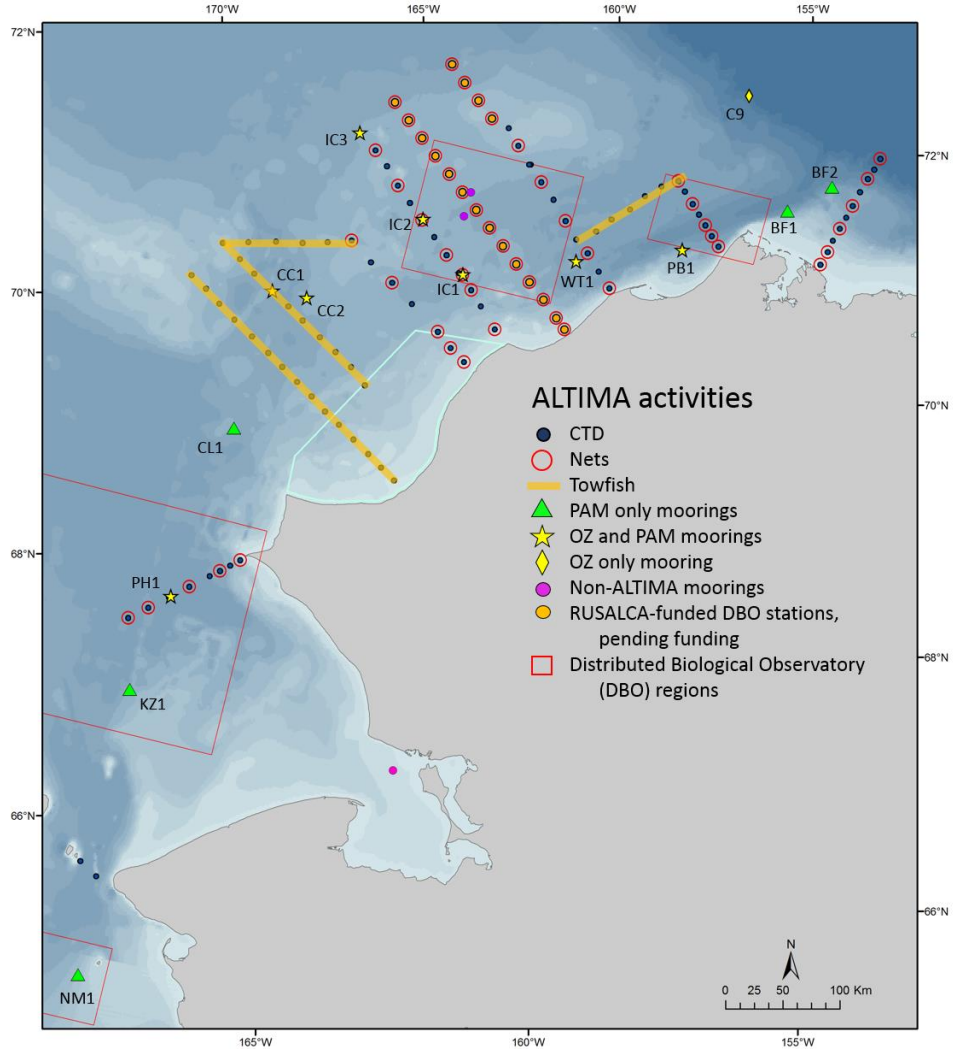

Figure 1. Tentative cruise plan for the 2016 ALTIMA survey.

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.

Marine Mammal Component:

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].

All data from the eighteen 2014-2015 ARCWEST AURALs have been extracted, converted, and processed for analysis. Our four new short-term (15 month) analysts are working hard, along with the rest of the team, 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).

Some representative samples of the long-term time series of data from IC1, PH1, and WT1 are shown in Figures 2, 3, and 4, 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.

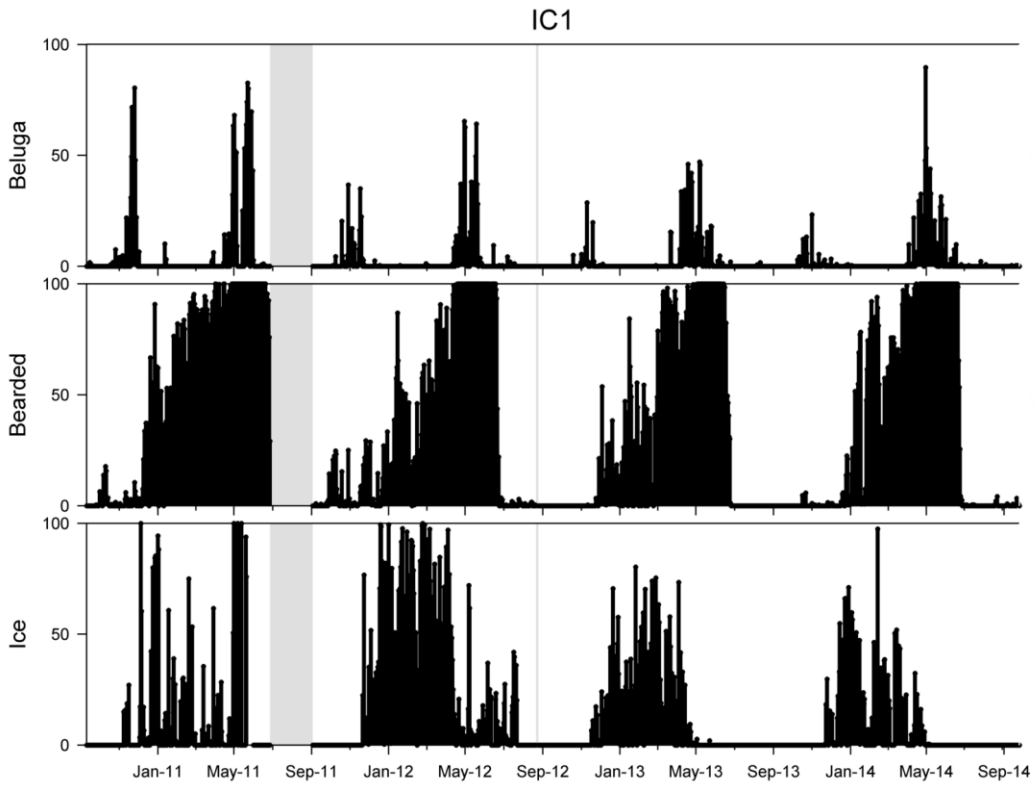

Figure 2. Long-term time series of marine mammal calling activity (presented as the percentage of time intervals with calls) for the inshore Icy Cape (IC1/C1) location, 2010-2014. Top row: beluga whale. Second row: bearded seal. Third row: ice noise.

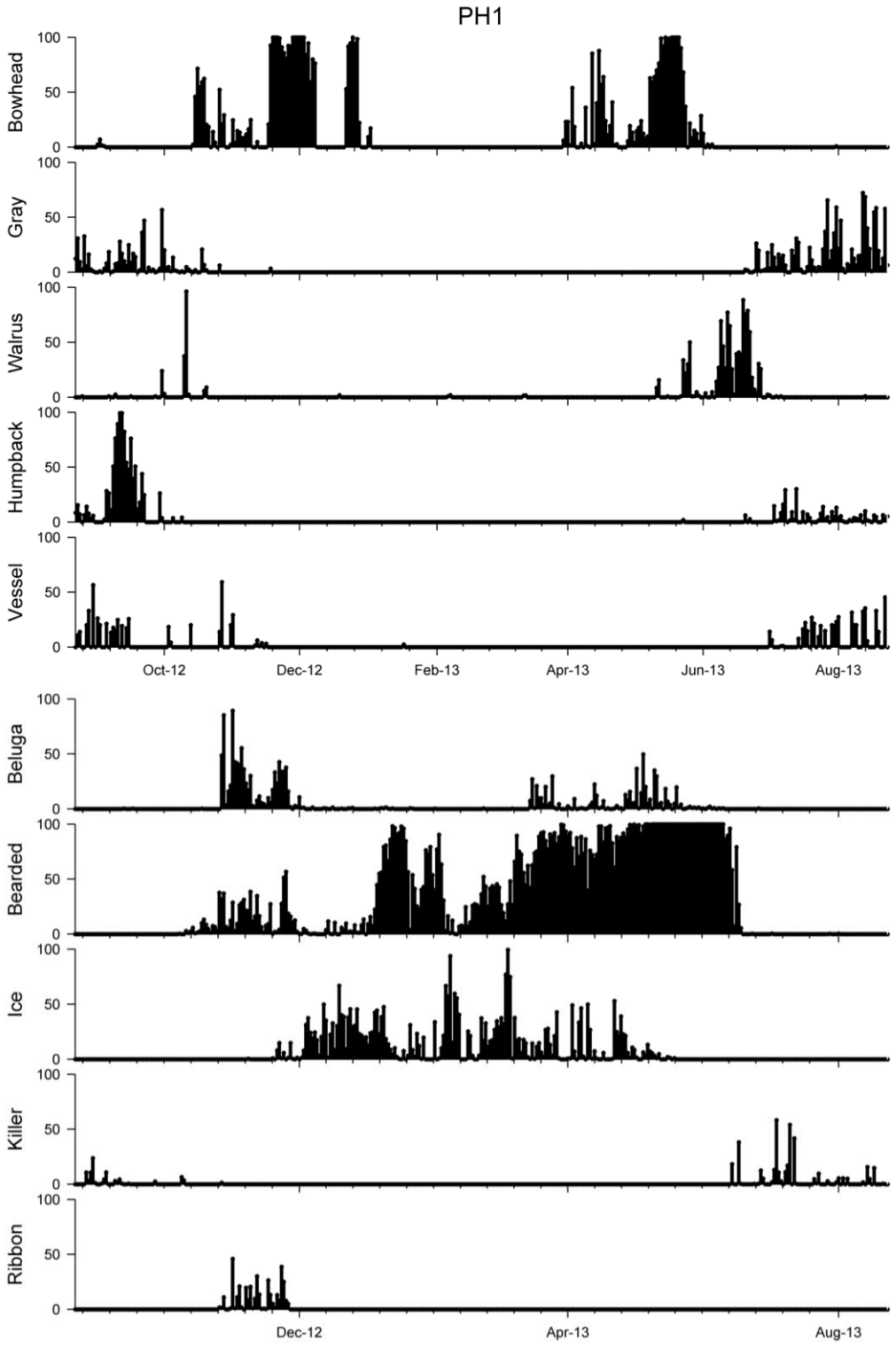

Figure 3. Marine mammal calling activity (presented as the percentage of time intervals with calls) for the Point Hope (PH1/C12) location, 2012-13, for all species. From top to bottom: bowhead whale; gray whale; walrus; humpback whale; vessel noise; beluga whale; bearded seal; ice noise; killer whale; and ribbon seal.

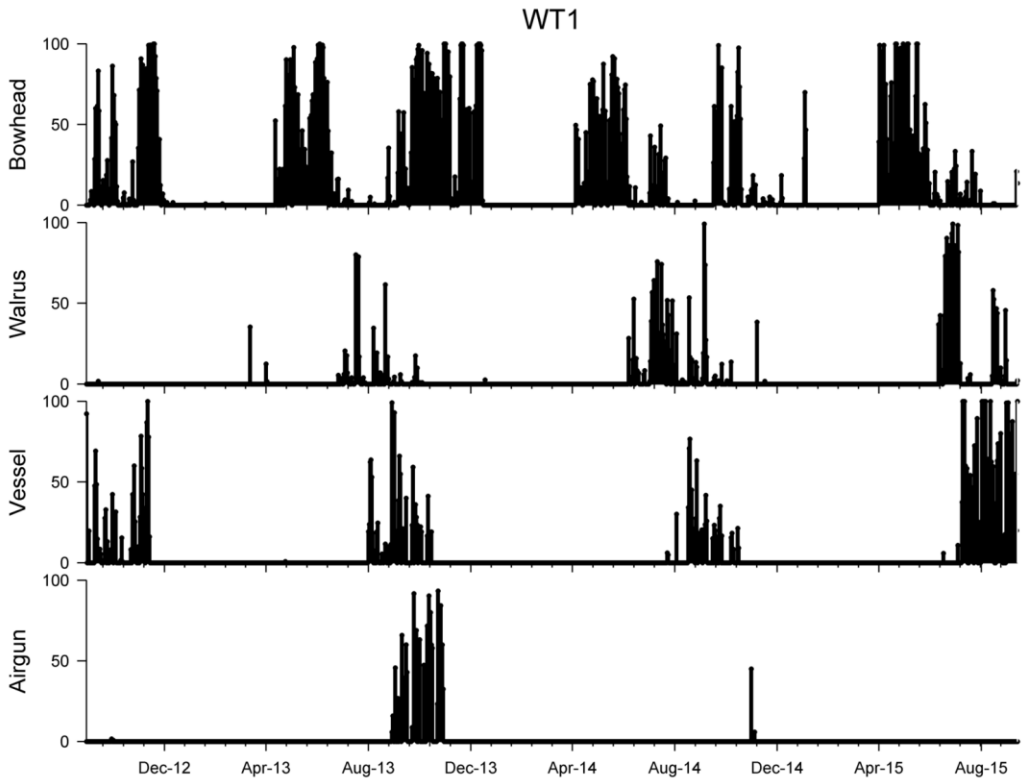

Figure 4. Long-term time series of marine mammal calling activity (presented as the percentage of time intervals with calls) for the Wainwright (WT1/C4) location, 2012-2015. Top row: bowhead whale. Second row: walrus. Third row: vessel noise. Bottom row: seismic airguns.

This analysis will add to the results obtained from the CHAOZ study; continuing one of the longest full-year record 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.

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, we continue to collaborate and work with colleagues to try and streamline our analyses. To this end, we have sent some of our data to Chris Clark (Bioacoustic Research Program, Cornell University), Xavier Mouy (JASCO Applied Sciences), and Cheryl Aday to test the efficacy of their bowhead (Cornell) and fin detectors (JASCO, Aday) on our recordings. We have finished manually analyzing three moorings in the southern Chukchi for fin whale calls, and are in the process of using these data to improve the fin whale call library. Whichever method (LFDCS, Aday, or JASCO) works the best will be run on all datasets (including those from CHAOZ-X), with a randomized subsample manually checked to ground-truth the detector data. This will greatly reduce the overall time to analyze each mooring. A few of the ARCWEST recorders (PH1 and CL1; both 2012-14) have now been manually analyzed, thanks to the work of some dedicated volunteers.

As 2015 was the final field season for ARCWEST, no passive acoustic moorings were redeployed using ARCWEST funds. However, a small grant from NOAA/S&T was obtained to redeploy all fourteen of these moorings (see ARCWEST-CHAOZ-X 2015 Cruise Report for additional details and maps, http://www.afsc.noaa.gov/nmml/PDF/ARCWEST-CHAOZ-X_CruiseReport2015.pdf), plus five recorders on the four Pacific Marine Environmental Laboratory (PMEL) oceanographic moorings in the Bering Sea (two recorders are swapped out at M2 per year). Several of these recorders (IC1/C1, WT1/C4, PB1/C5) have been collocated with a cluster of biophysical moorings, and one (PH1) was redeployed with a microcat on the mooring in 2015. We plan to retrieve and redeploy these moorings in 2016 during the NOAA/BOEM funded ALTIMA cruise to maintain our long-term time series (Figures 5 & 6). These locations will be the same as in 2015 with a few exceptions. The BF3 and KZ1 moorings will be eliminated, the mooring maintained in Norton Sound (NS1) will now be turned around under the ALTIMA project, and an additional mooring will be deployed in Umnak Pass (BS6). Furthermore, the oceanography clusters will return to our IC3/C3 location, and a full cluster will be deployed at the PH1/C12 location, along with two mooring clusters in the Central Channel (CC1/C10, occupied by a UW AURAL recorder, and CC2/C11 occupied by one of our recorders).

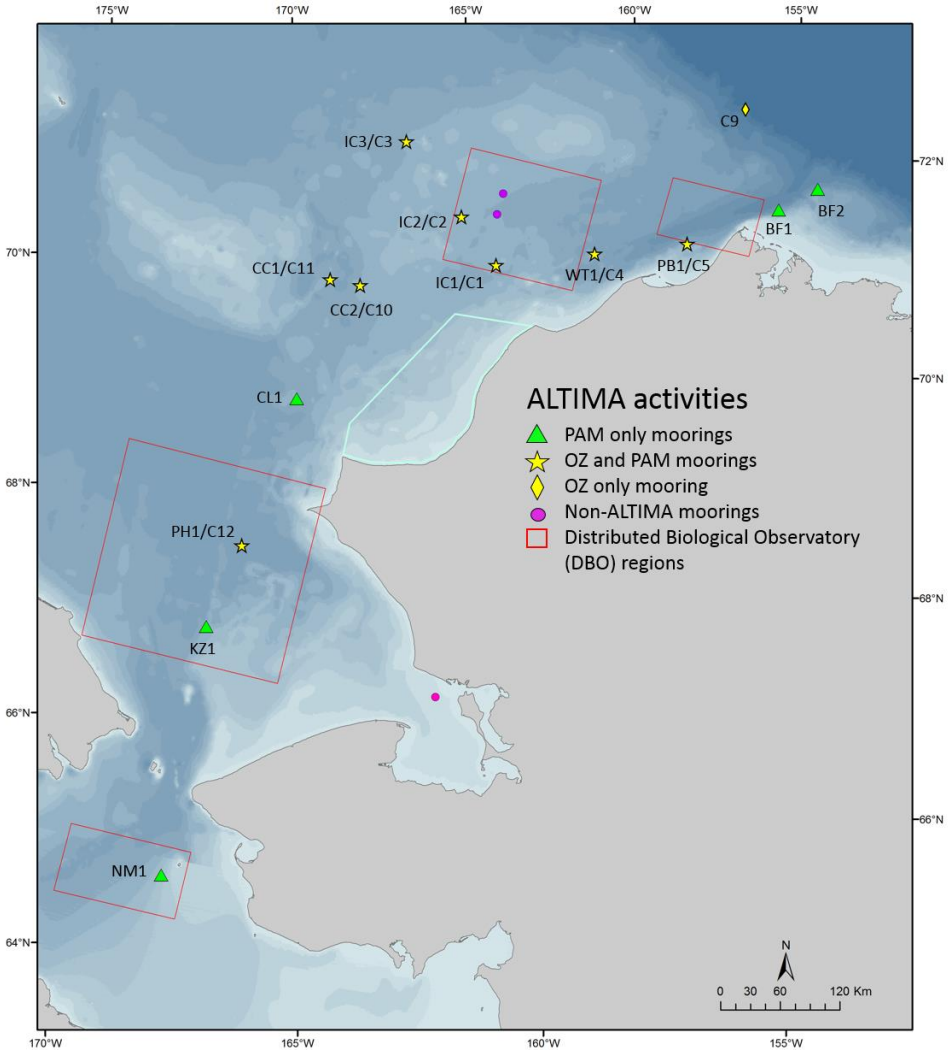

Figure 5. Planned passive acoustic mooring retrievals and/or deployments for the 2016 field survey. Top panel: primary operating area of the northern Bering Sea, the Chukchi Sea, and the western Beaufort Sea; bottom panel: Bering Sea.

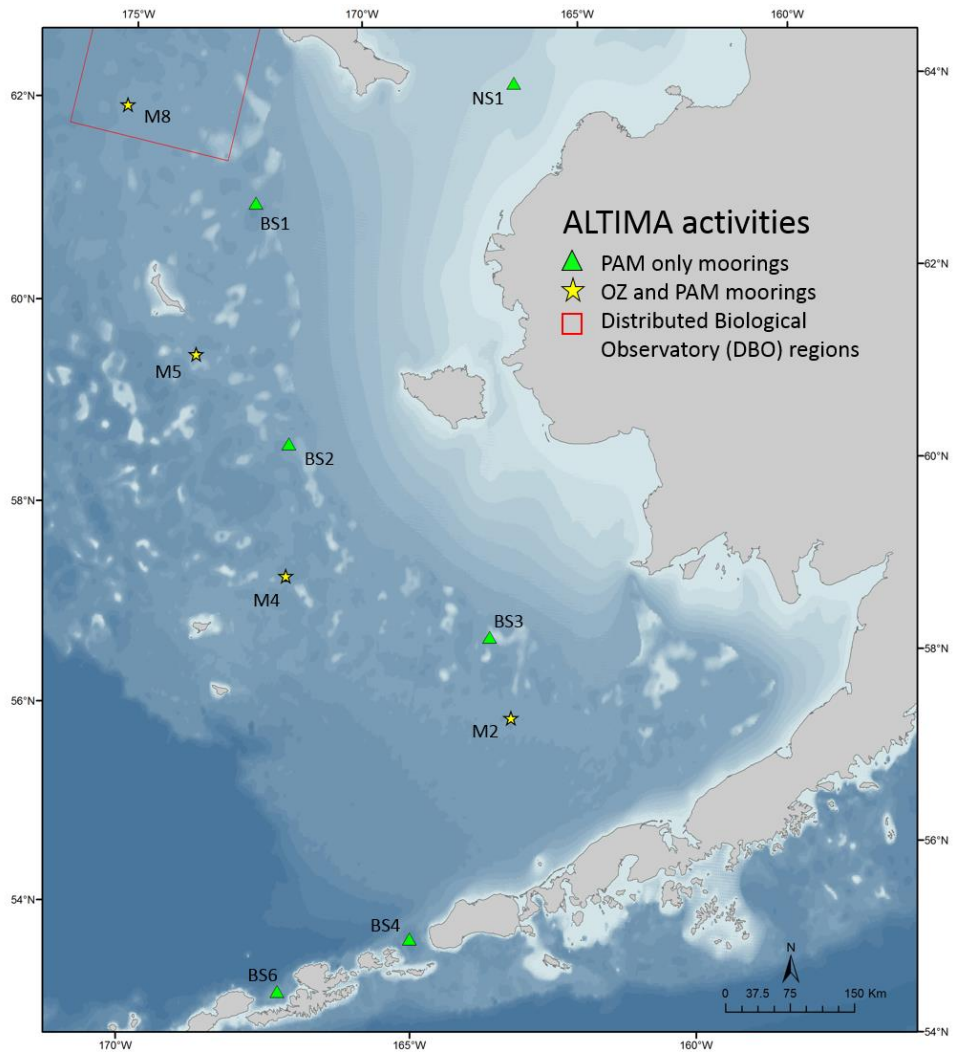

Figure 6. Planned passive acoustic mooring retrievals and/or deployments for the 2016 field survey. Top panel: primary operating area of the northern Bering Sea, the Chukchi Sea, and the western Beaufort Sea; bottom panel: Bering Sea.

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 accepted. 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.

Associated 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 well 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. 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). She is halfway into her second year of analysis (MMC-funded) continuing this work with the data retrieved this past season at the same sites as in the first year of analysis (M8, NS1, BS1, and BS4) as well as at a few more sites further north (NM1, KZ1). To date, she has completed analysis for the M8, NS1, BS1, and BS4 (Unimak) moorings with the NM1 and KZ1 moorings to be completed by the end of the year. We have just obtained funding from NFWF to allow two additional analysts to work on the critical mid-latitudes of the Bering Sea shelf (i.e., M2, M4, M5, BS2, and BS3) to complete the overall picture of the spatio-temporal distribution of these species on the Bering Sea shelf. These analysts will begin in the fall.

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 are using some of our (BOEM-funded) Bering Sea moorings to analyze 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 hope to be able to determine the depth at which the call was produced, and use this information to potentially distinguish among species. Preliminary results show great success at determining gunshot calling depth of NPRW. They are still in the process of analyzing bowhead whale gunshot calls for a comparison of results between the two species.

Sonobuoys:

We received one pallet of new sonobuoys from the Navy this spring. These will add to our stock of sonobuoys, which we use every year during our field season. We will have a sufficient number of sonobuoys for the 2016 ALTIMA cruise.

Visual Observations Component:

A manuscript on the distribution of cetaceans in the Arctic using visual data collected from the CHAOZ, ARCWEST, and CHAOZ-X surveys is being prepared. 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. The status of killer and gray whale photo analyses are summarized below (Table 1).

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 7). 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 8 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. 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.

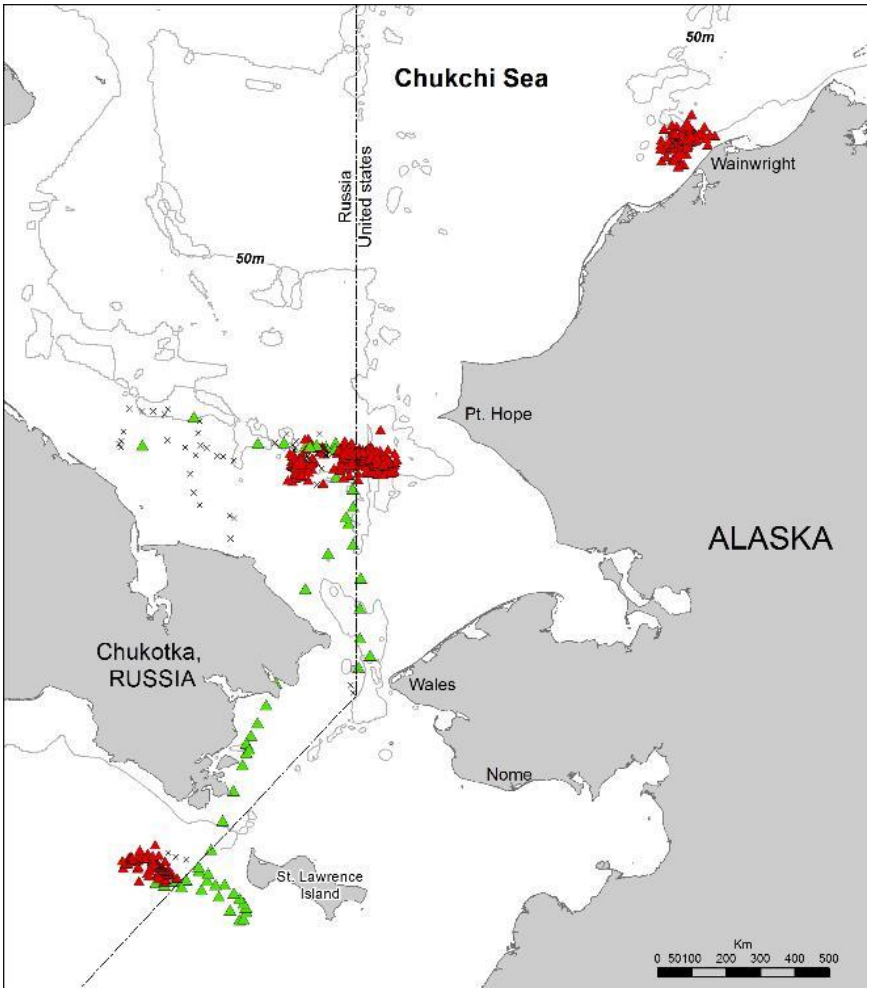

Figure 7. Habitat-use model results. Each triangle represents a switching state-space modeled position at a 6 hour time-step. Red triangles indicate where whales were engaging in area-restricted search (often associated with foraging) and green triangles indicate travel mode.

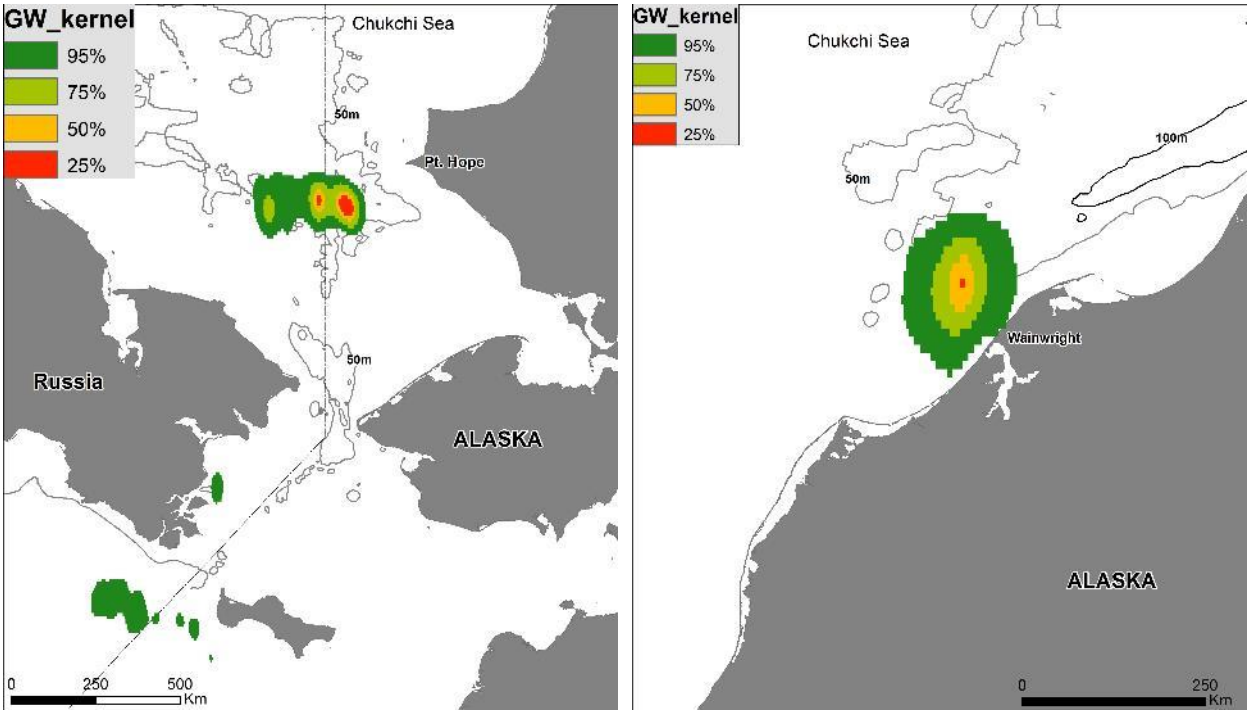

Figure 8. Kernel density estimate of the high-use area off Pt. Hope (2013 data, left) and Wainwright (2012 data, right). Colors indicate the percentage of time a whale is predicted to use each region.

Oceanographic and Lower Trophic Level Component:

A single cruise will be conducted in September 2016 on the F/V *Aquila* that will occupy most of the ARCWEST stations and recover biophysical moorings.

Moorings:

In 2015, seven of the ARCWEST biophysical moorings were redeployed at C1, C2, C4 and C9. In addition, an upward looking active acoustic TAPS-6NG (Tracor Acoustic Profiling System, Next Generation) instrument was deployed at C2 (Figure 5) to measure zooplankton bio-volume and size distribution.

Intrusions of Atlantic water were observed at C1 in 2014, but more surprisingly, extremely high salinity was observed at salinity sensors. The extremely cold temperatures indicate that this water was a result of freezing ice (Figure 9).

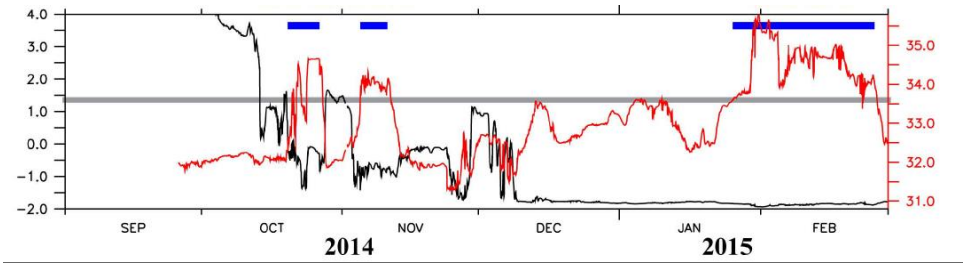

Figure 9. Temperature (black) and salinity (red) at C1. These are the highest salinities (35.9) that we have observed in the mooring recorders in the Chukchi Sea.

In addition to the ARCWEST moorings, a surface mooring was deployed in July and recovered in September, together with two wave gliders (Figure 10). These instruments were deployed as part of a proposal with NOAA's Office of Ocean Exploration and Research to examine solar heat fluxes. These data will be integrated with BOEM data sets.

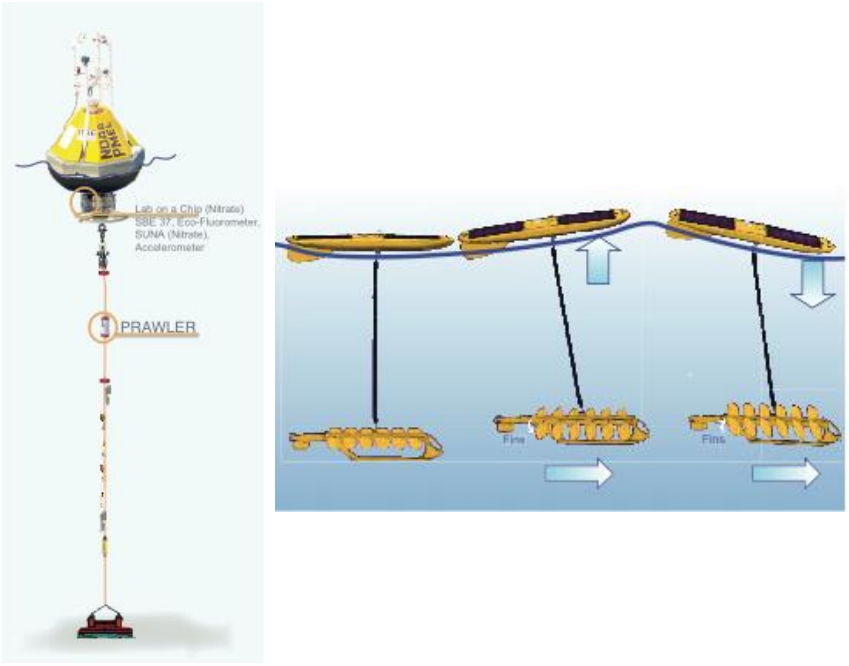

Figure 10. Schematic of PRAWLER mooring which profiles the upper water column and Wave Glider (NOAA-PMEL) which is a remotely controlled autonomous vehicle consisting of a surfboard-like surface float with solar panels to power communications and instrumentation.

Hydrography & Plankton Sampling:

2015 nutrient samples were processed on board and have been incorporated into the hydrographic files. Data will be uploaded to the database in the winter. Chlorophyll samples (N > 400) were collected and are stored in a freezer in Seattle. Chlorophyll samples were 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.

Satellite Tracked Drifters:

Satellite-tacked drifters were deployed (Figure 11) from the USCGC *Healy* (eight in July) and NOAA Ship *Ronald H. Brown* (four in August). Previous 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 at this site, 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)*. Several of the drifters are still transmitting, and the final data will not be uploaded to our website until they finish transmitting (likely June).

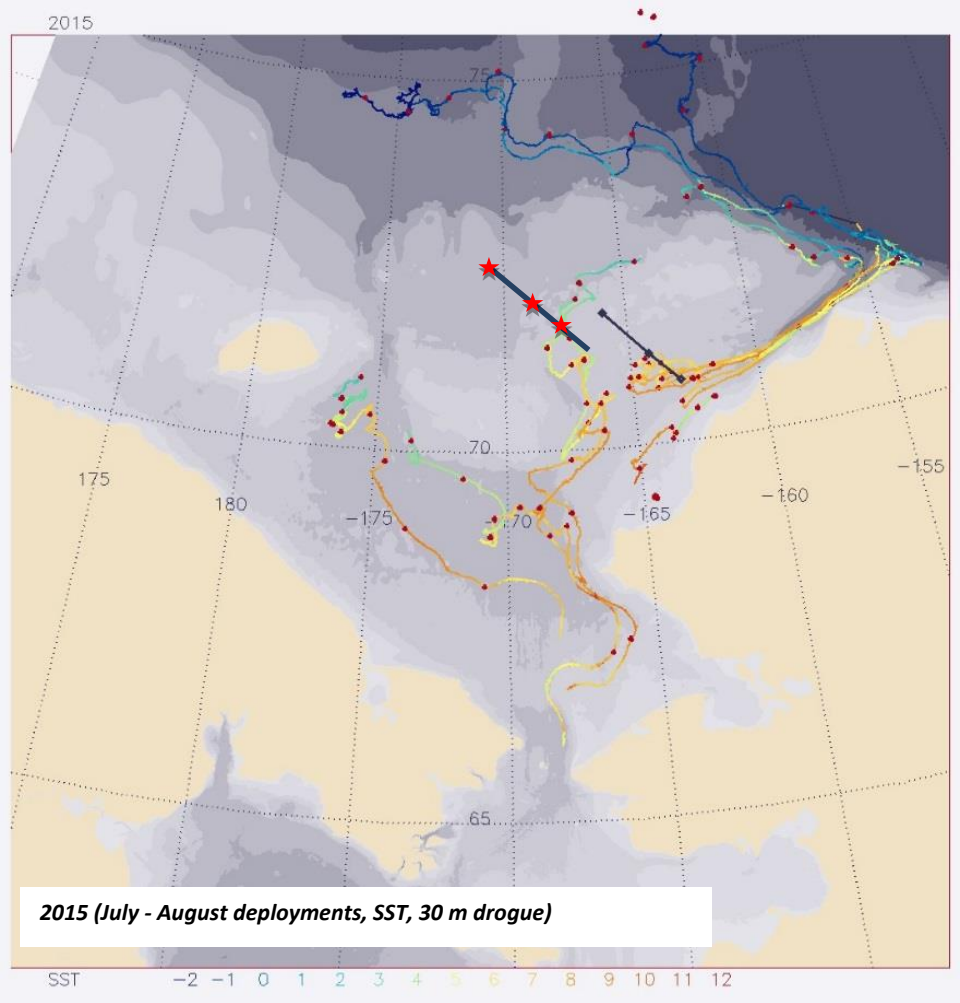

Figure 11. 2015 US Arctic Drifter Composite. The color coding indicates the near surface temperature collected by the drifter. Eight drifters were deployed in July and the rest in early August. Note that temperatures reached 9°C in August. The westward flow Chukchi Slope Current is evident from Barrow Canyon to 177°W along the north slope of the Chukchi Sea.

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.

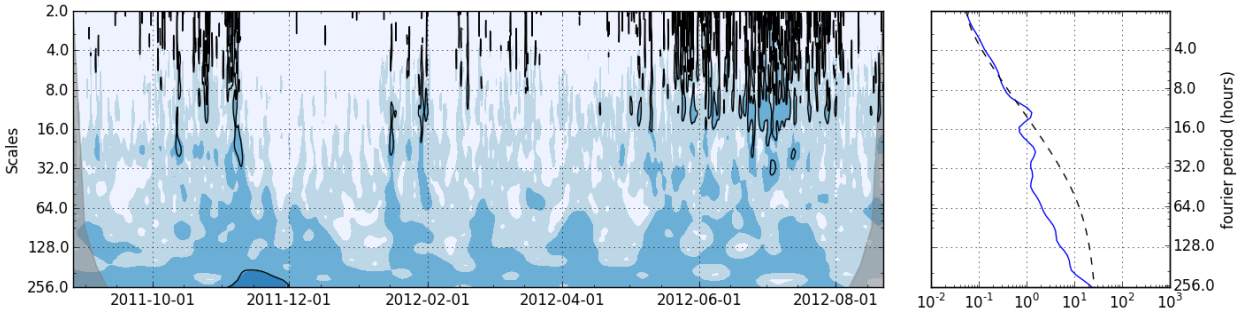

Figure 12. Wavelet analysis of ADCP data. Shown is an analysis of data at 28 m from the instrument deployed at site C3 in 2011. Diel vertical migration, when present, would show in the left panel as dark blue contours between 16 and 32 hrs on the (vertical) "Scales" axis. If diel vertical migration were 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).

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 were 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).

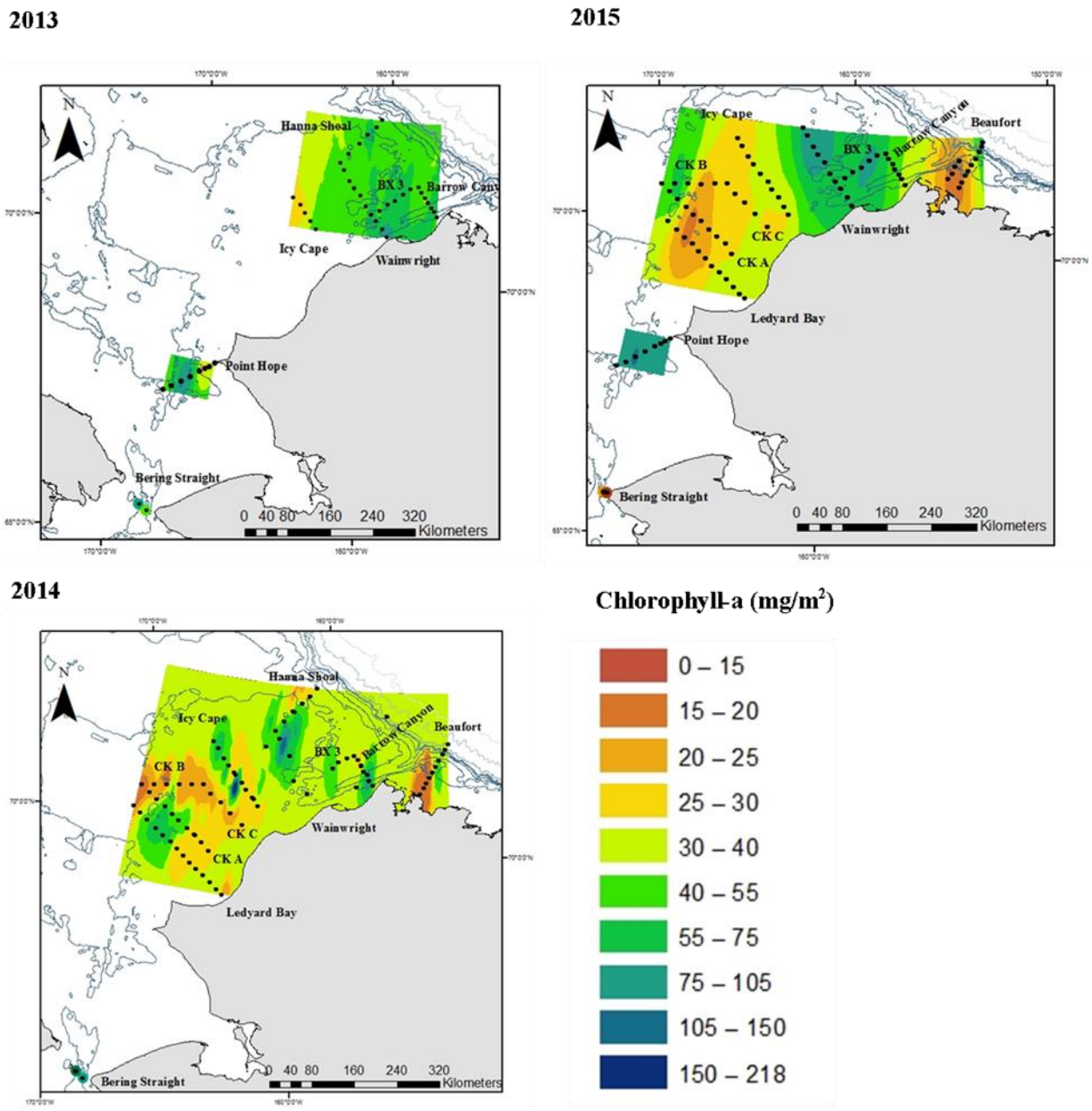

Figure 13. Maps display interpolated integrated chlorophyll-*a* (mg/m^2). Average integrated chlorophyll-*a* was similar for all years with 2013 (SD) at 51.5 (± 23.2), 37.5 (± 23.2) for 2014, and 48.9 (± 39.5) for 2015. The lowest record was in 2014 with 4.8 mg/m^2 at the first nearshore station of the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

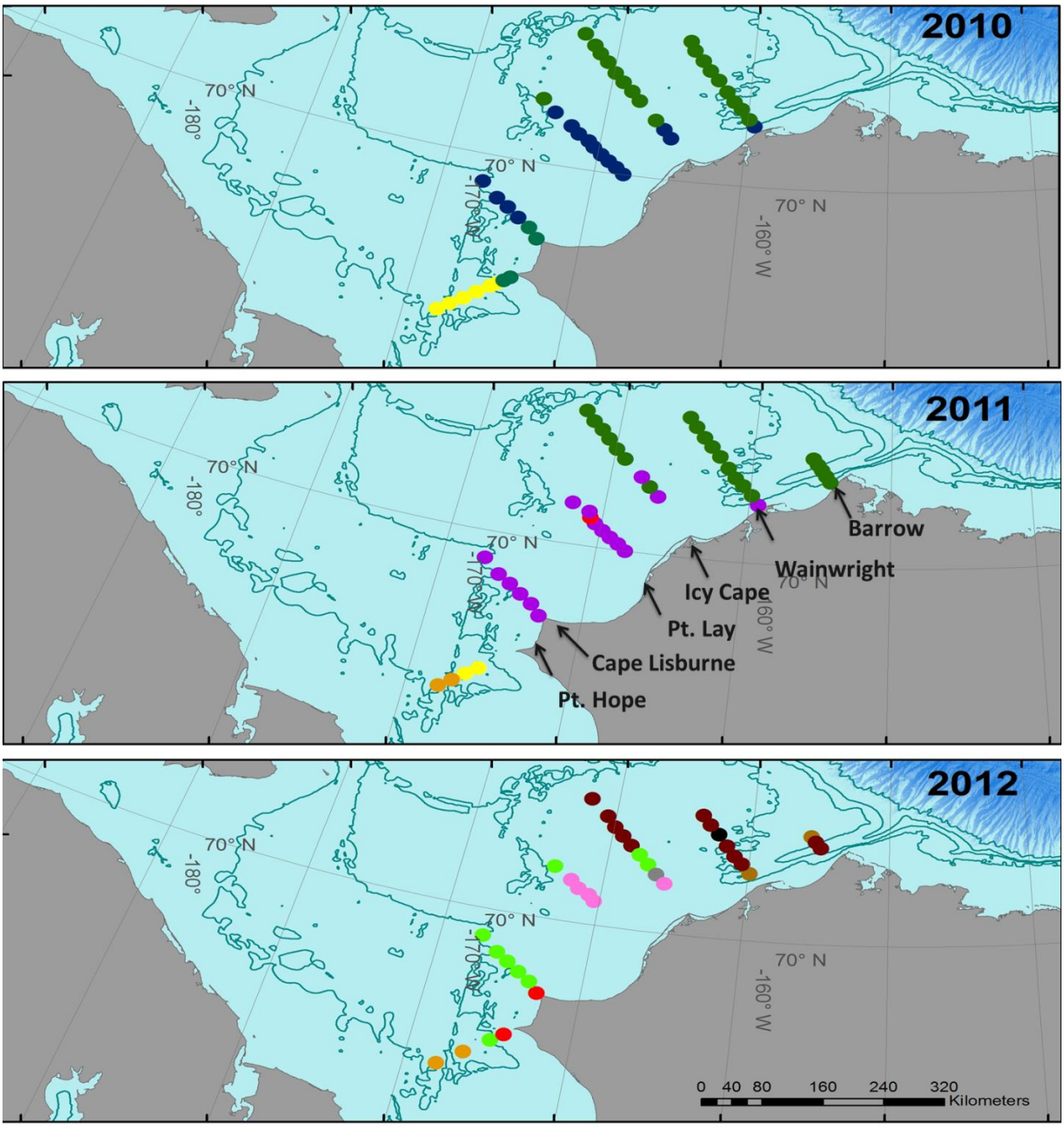

Figure 14. Results of the zooplankton community cluster analysis 2010-2012. Different colored circles indicate different assemblages of zooplankton.

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 are in the process of contributing 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 near 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. FOCI/PMEL is in the process of refining some of the metadata and all data will be submitted to public data base by end of June.

Significant technical, schedule, or cost problems encountered

We feel that the continuation of our multi-disciplinary, long-term time series, begun in 2010, is critical for monitoring this ecosystem as the Arctic environment continues to change. To this end, a revised supplemental funding request was submitted to Carol Fairfield on 30 November 2015 and accepted by BOEM which will enable us to retrieve and redeploy biophysical mooring clusters (oceanography, zooplankton, and passive acoustics) in 2016 and continue the biophysical sampling stations and underway marine mammal monitoring for an additional year. These funds will supplement funds provided by NOAA/OAR for the 2016 ALTIMA survey. These funds will extend the ARCWEST objectives in an opportunistic manner, but not change the timing of any of the ARCWEST deliverables.

The analysis of ice-thickness data is taking much longer than anticipated due to the complexity of the information. We now anticipate this data to be available in the fall of 2016.

Significant meetings held or other contacts made

7 April 2016: Berchok, Crance, Friday, Kimmel, Mocklin, Napp, Stabeno, Tabisola, and Zerbini met to discuss the ARCWEST and CHAOZ-X projects, current status, data analysis results, report construction, and other general project updates and integration. Stabeno presented oceanographic results and Napp presented zooplankton results.

16 June 2016: Berchok, Ferm, Friday, Kennedy, Mocklin, Napp, Spear, and Stabeno met to discuss the ARCWEST and CHAOZ-X projects, current status, data analysis results, report construction, and other general project updates and integration. Ferm presented zooplankton results.

Presentations and Publications

Berchok, C.L., B. Rone, J. Napp, P. Stabeno, M. Wang, and C. Clark. 2016. CHAOZ in a nutshell: Five years of work in eight minutes. Presented to the IARPC Chukchi & Beaufort Sea Ecosystem Collaboration Team, March 2, 2016.

Crance, J.L., C.L. Berchok, E.C. Garland, J. Napp, and P.J. Stabeno. 2016. Five years of CHAOZ in the Arctic: Results from a multi-disciplinary study in the Alaskan Chukchi Sea. Presented to the IARPC Chukchi & Beaufort Sea Ecosystem Collaboration Team, June 1, 2016.

Kennedy, A.S., Rone, B.K., Zerbini, A.N., Clapham, P.J. 2016. Fine-scale movement and dive behavior of gray whales satellite-tracked in the northern Bering and Chukchi Seas. Oral presentation at the AFSC Cetacean Spatial Analysis Webinar, Seattle, WA, 26 April, 2016.

Ladd, C., C. Mordy, S. Salo, and P. Stabeno. In Press. Winter water properties and the Chukchi polynya, *J. Geophys. Res. - Oceans*.

Martini, K.I., P.J. Stabeno, C. Ladd, P. Winsor, T.J. Weingartner, C.W. Mordy, and L.B. Eisner. 2016. Dependence of subsurface chlorophyll on seasonal water masses in the Chukchi Sea. *J. Geophys. Res.*, *121*, doi:10.1002/2015JC011359.

Spear, A., J. Napp, J. Duffy-Anderson, S. Salo, and P.J. Stabeno. 2016. Spatial and Temporal Variability of Zooplankton Community Structure in the Chukchi Sea (2010-2012). Poster presentation at the 2016 Ocean Sciences Meeting, New Orleans, LA., February 21-26.

Spear, A., J. Napp, J. Duffy-Anderson, S. Salo, and P.J. Stabeno. 2016. Spatial and Temporal Variability of Zooplankton Community Structure in the Chukchi Sea (2010-2012). Poster presentation at ICES/PICES 6th Zooplankton Production Symposium "New Challenges in a Changing Ocean," May 9-13, Bergen, Norway.

Stabeno, P., Ladd, C., McCabe, R. and Marini, K. in prep. Five years of current measurements in the Chukchi Sea. *J. of Geophysical Research.*

Stabeno, P., C. Berchok, B. Rone, J. Napp, M. Wang, and C. Clark. 2016. CHAOZ, ARCWEST, and CHAOZ-X: A Summary. Presented at NPRB Arctic IERP Meeting. Anchorage, AK. 22 June 2016.

Literature Cited

Bailey, H., Mate, B.R., Palacios, D.M., Irvine, L., Bogard, S.J. and Costa D.P. 2010. Behavioural estimation of blue whale movements in the Northeast Pacific from state-space model analysis of satellite tracks. *Endangered Species Research* 10:93-106.

Clarke J.T., K. Stafford, S.E. Moore, B. Rone, L. Aerts, and J. Crance. 2013. Subarctic cetaceans in the southern Chukchi Sea: evidence of recovery or response to a changing ecosystem. Oceanography 26:136–149. doi:10.5670/oceanog.2013.81

Crance, J., C.L. Berchok, J. Bonnel, and A.M. Thode. 2015. Northeastern most record of a North Pacific fin whale (Balaenoptera physalus) in the Alaskan Chukchi Sea. Polar Biology 38(10): 17671773.

Delarue J., B. Martin, D. Hannay, and C.L. Berchok. 2013. Acoustic occurrence and affiliation of fin whales detected in the northeastern Chukchi Sea, July to October 200710. Arctic 66(2): 159172.

Garland, E.G., Berchok, C.L. and Castellote, M. 2015a. Temporal peaks in beluga whale (*Delphinapterus leucas*) acoustic detections in the northern Bering, northeastern Chukchi, and western Beaufort Seas: 2010-2011. *Polar Biology*. DOI: 10.1007/s00300-014-1636-1.

Garland, E.C., Castellote, M. and Berchok, C.L. 2015b. Beluga whale (*Delphinapterus leucas*) vocalizations and call classification from the eastern Beaufort Sea population. *Journal of the Acoustical Society of America* 137: 3054-3067.

Jonsen, I.D., Myers, R.A. and James, M.C. 2007. Identifying leatherback turtle foraging behaviour from satellite telemetry using a switching state-space model. *Marine Ecology Progress Series* 337: 255-264.

Johnson, D.S., London, J.M., Lea, M.A. and Durban, J.W. 2008. Continuous-time correlated random walk model for animal telemetry data. Ecology 89(5): 1208-1215.

Ladd, C., C. Mordy, S. Salo, and P. Stabeno. In Press. Winter water properties and the Chukchi polynya, *J. Geophys. Res. - Oceans*.

O'Corry-Crowe, G.M., R.S. Suydam, A. Rosenberg, K.J. Frost, and A.E. Dizon. 1997. Phylogeography, population structure and dispersal patterns of the beluga whale *Delphinapterus leucas* in the western Nearctic revealed by mitochondrial DNA. Molecular Ecology 6: 955–970.

Tsujii, K., M. Otsuki, T. Akamatsu, I. Matsuo, K. Amakasu, M. Kitamura, T. Kikuchi, K. Miyashita, and Y. Mitani. 2016. The migration of fin whales into the southern Chukchi Sea as monitored with passive acoustics. ICES Journal of Marine Science, doi: 10.1093/icesjms/fsv271.

Wang, M. and J.E. Overland. 2009. A sea ice free summer Arctic within 30 years? Geophys. Res. Lett., 36, L07502, doi: 10.1029/2009GL037820.