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), 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 January through March 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 (Stabeno) with supplemental funding from BOEM through ARCWEST. Planning for this cruise has begun; the vessel contract is currently up for solicitation and closing soon. 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 group has 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.

    - A third season of visual and acoustic observations were collected under ARCWEST funds. There were very few acoustic detections during the 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. Opportunistic visual and acoustic monitoring will occur during the 2016 ALTIMA survey.

    - The passive acoustics team continues to process the long-term time series in the Chukchi Sea. Four new short-term data analysts have been hired. 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 prep); 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 part of her work on North Pacific Right Whales, Dana Wright is analyzing data from the Bering Sea moorings (M8, BS1, KZ1, NM1) for bowhead whales among other mid-frequency species (*i.e.,* right, 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 continue this analysis on the southern Bering Sea shelf.

- 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 is ongoing for the eastern Chukchi sea population.

    - Photographs of humpback and killer 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.

    - CHAOZ found that bowhead whales remain in the Chukchi Sea until the sea ice is about 0.5 meter thick. Sea ice thickness and bowhead acoustic data from the ARCWEST moorings will be used to validate this finding, since they have greater coverage than the CHAOZ moorings.

    - 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 (2012–2014), and CHAOZ-X (2012–2014) 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 should be available by March 2016, except for the ice thickness data, which is taking longer to process and will not be available to June.

- The 2014 plankton samples from the large mesh net have been processed by the Polish Plankton Sorting and Identification Center in Szczecin, Poland, and the paper forms have been reconciled with the digital files. Uploading of the data into the database will occur in the first quarter of 2016. The 2014 chlorophyll samples were processed. An analysis contractor was hired in February to assist with getting the remaining zooplankton and chlorophyll data into our database and to begin analyzing the data.

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*), 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 (Stabeno) with supplemental funding from BOEM through ARCWEST. Planning for this cruise has begun; the vessel contract is up for solicitation and will be closing shortly. 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).

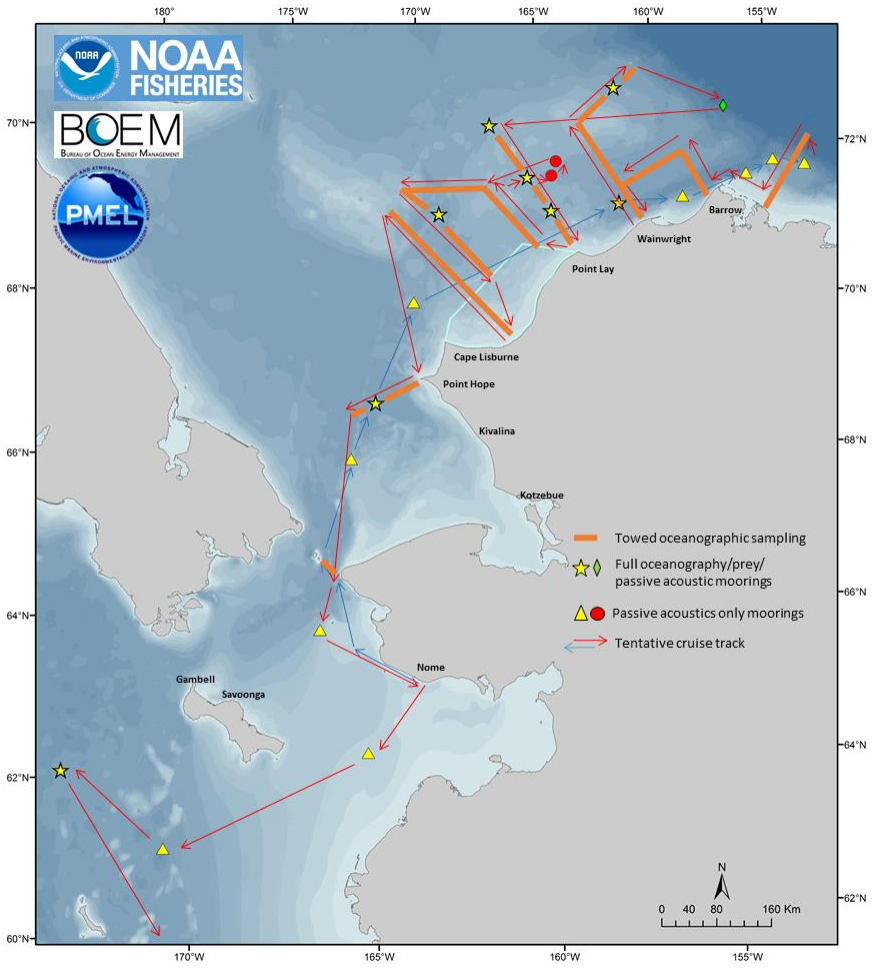

Figure 1. Tentative cruise plan for the 2016 ALTIMA survey.

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, and the programs to run these analyses have been written. 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. We have hired four new short-term (15 month) analysts to assist with finishing the analysis

of the passive acoustic data collected on the acoustic recorders 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 is well underway on the data from the moored passive acoustic recorders to obtain 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 from the 2012-13 IC1 and WT1, and the 2014-15 NS1 mooring sites 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. The NS1 mooring was funded entirely by NOAA, but its results are included here as it provides more information on the spatial extent of the species of interest to the ARCWEST project.

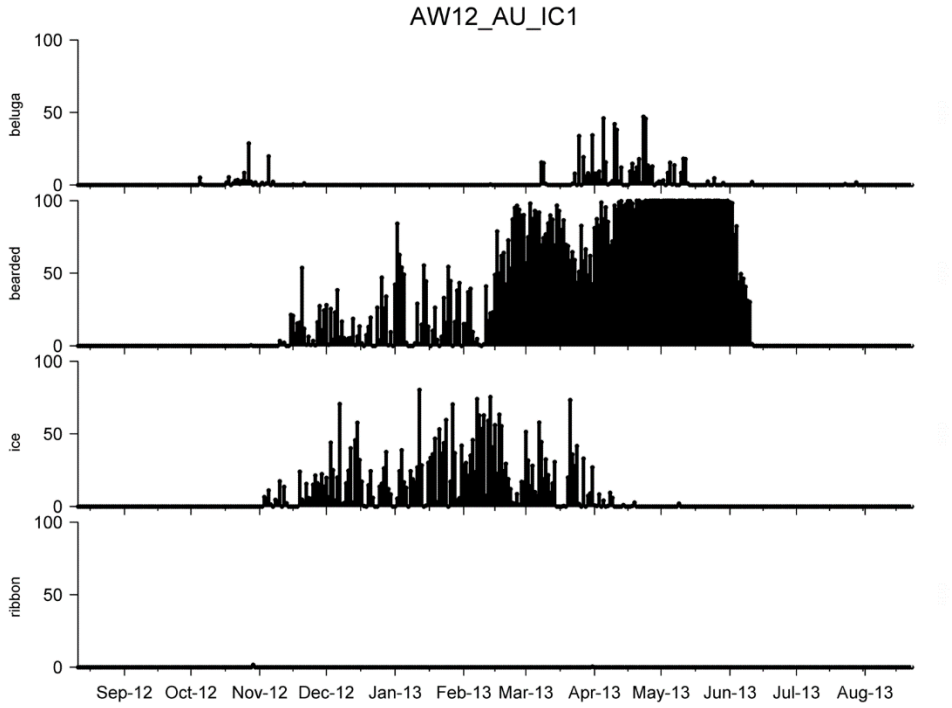

Figure 2. Marine mammal calling activity (presented as the percentage of time intervals with calls) for the inshore Icy Cape (IC1/C1) location, 2012-13. Top row: beluga whale. Second row: bearded seal. Third row: ice noise. Bottom row: ribbon seal.

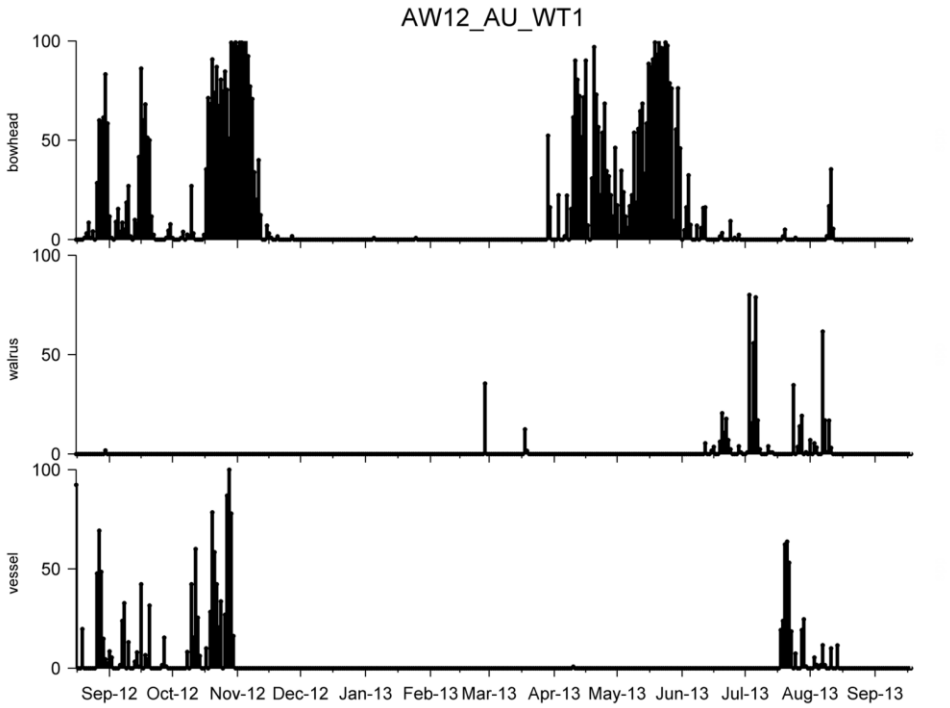

Figure 3. Marine mammal calling activity (presented as the percentage of time intervals with calls) for the inshore Wainwright (WT1/C4) location, 2012-13. Top row: bowhead whale. Middle row: walrus. Bottom row: vessel noise.

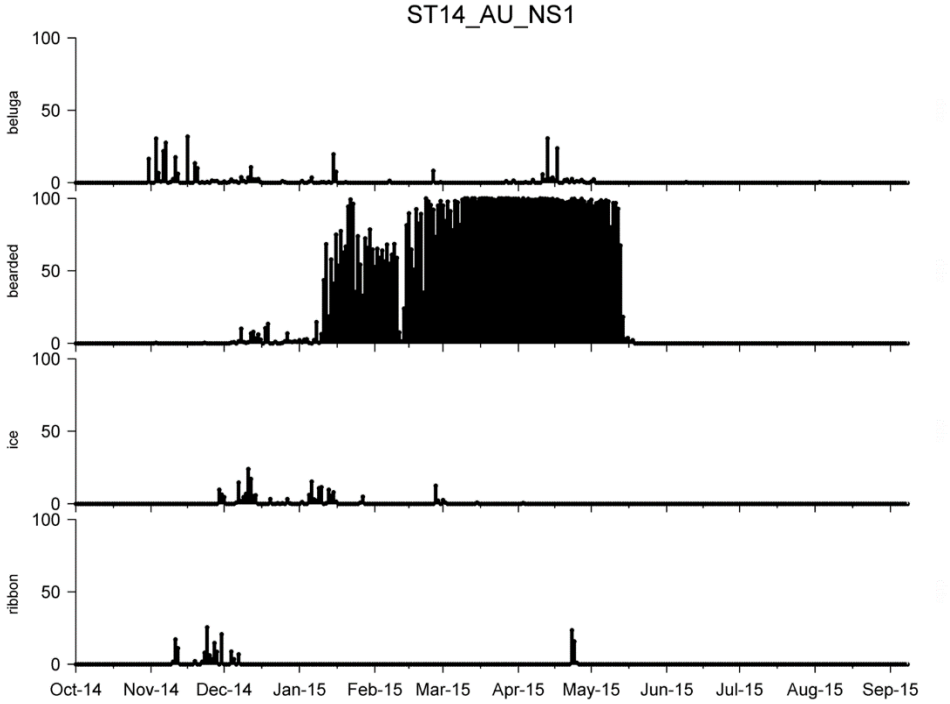

Figure 4. Marine mammal calling activity (presented as the percentage of time intervals with calls) for the Norton Sound (NS1) location, 2014-15. Top row: beluga whale. Second row: bearded seal. Third row: ice noise. Bottom row: ribbon seal.

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.

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), 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 (Figure 5). 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).

Publication plans:

Several publications are being prepared using data from ARCWEST recorders. Carol Ladd (PMEL) is submitting a publication on polynya formation and its correlation to oceanographic features. 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.

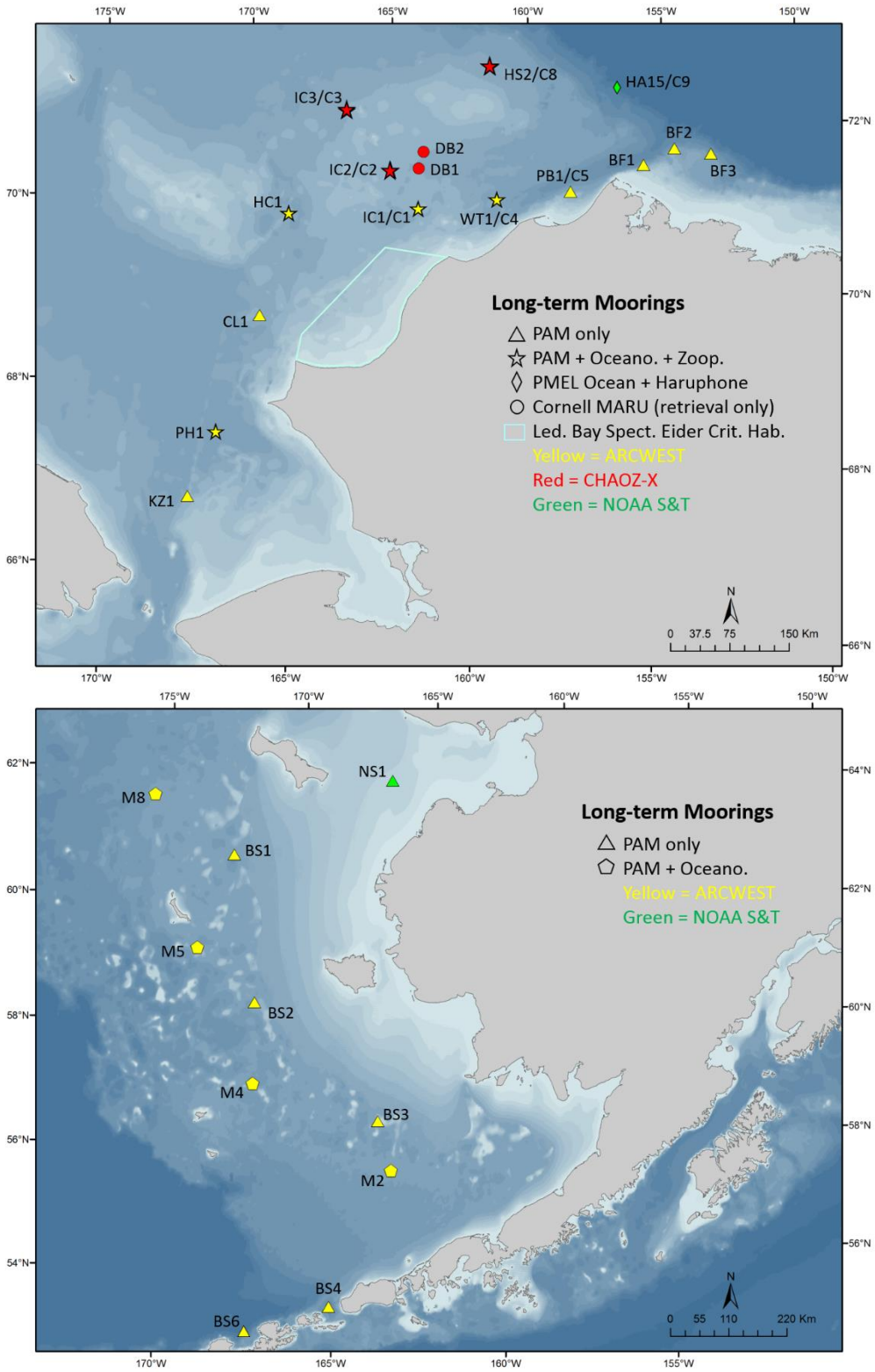

Figure 5. Planned passive acoustic mooring retrievals and/or deployments for the 2016 field survey. Yellow symbols indicate ARCWEST moorings. Red symbols indicate CHAOZ-X moorings. Note: all moorings will be retrieved and redeployed using NOAA funds; color-coding only indicates location affiliation with the project. Top panel: primary operating area of the northern Bering Sea, the Chukchi Sea, and the western Beaufort Sea; bottom panel: Bering Sea.

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 interannually. To this end, work has begun on extracting 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 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 has begun 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 as well as at a few more sites further north. We have just obtained funding from NFWF to allow two additional analysts to work on the critical mid-latitudes of the Bering Sea shelf to complete the overall picture of the spatio-temporal distribution of North Pacific right whales and bowhead whales on the Bering Sea shelf. These analysts will begin in early summer.

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 in the process of analyzing bowhead whale gunshot calls for a comparison of results between the two species.

Sonobuoys:

We are receiving one pallet of new sonobuoys from the Navy this spring, which will be picked up in mid-May. These will add to our stock of sonobuoys, which we use every year during our field season. We have a sufficient number of buoys for the 2016 ALTIMA survey.

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.

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 6). 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 7 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.

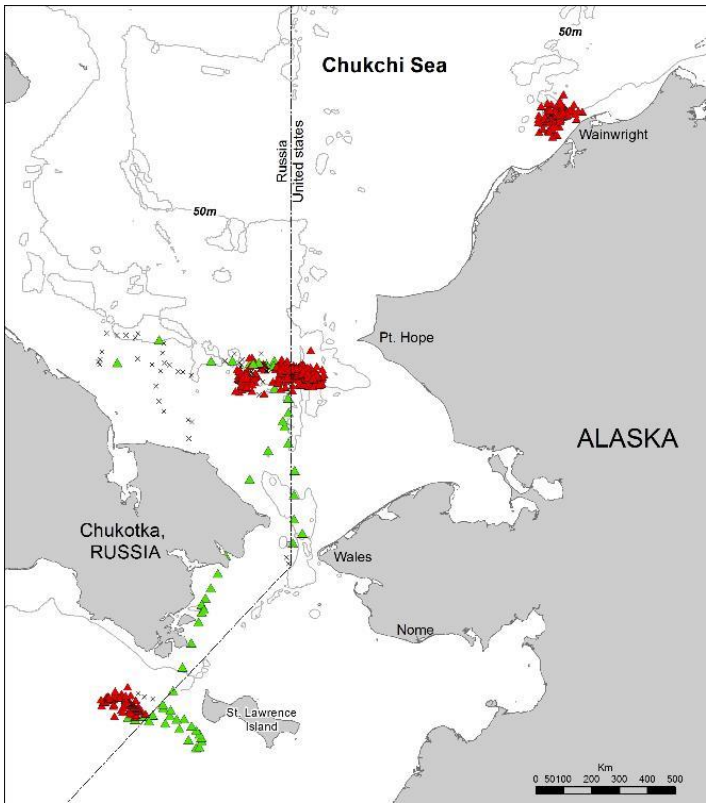

Figure 6. Habitat-use model results. Each triangle represents a switching state-space modeled position at a 6 hour time-step. Red triangles indicate where whales were engaging in area-restricted search (often associated with foraging) and green triangles indicate travel mode.

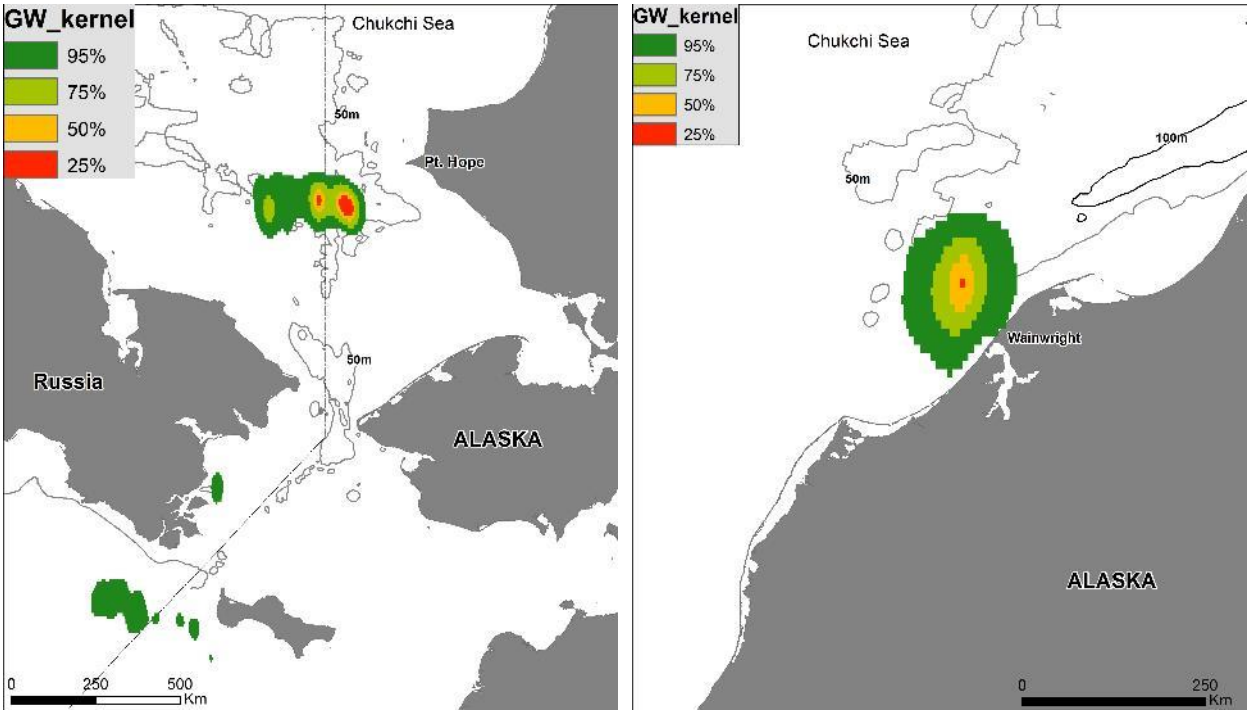

Figure 7. Kernel density estimate of the high-use area off Pt. Hope (2013 data, left) and Wainwright (2012 data, right). Colors indicate the percentage of time a whale is predicted to use each region.

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. We expect submission will occur within the next several months, pending the analysis of overlapping oceanographic and acoustics data.

Oceanographic and Lower Trophic Level Component:

We engaged in two cruises this past summer, a biophysical sampling cruise and a biophysical mooring cruise (see the ARCWEST/CHAOZ-X 2015 Cruise Report and Eco-FOCI's 2015 Arctic Cruise Report for additional details). The first cruise was aboard the NOAA Ship *Ronald H. Brown* occupied lower trophic level and physical/chemical oceanographic sampling onshore and offshore, with the inshore portions of many of the transects being ARCWEST stations. Oceanographic mooring work was conducted on a second cruise on the F/V *Aquila*.

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 8).

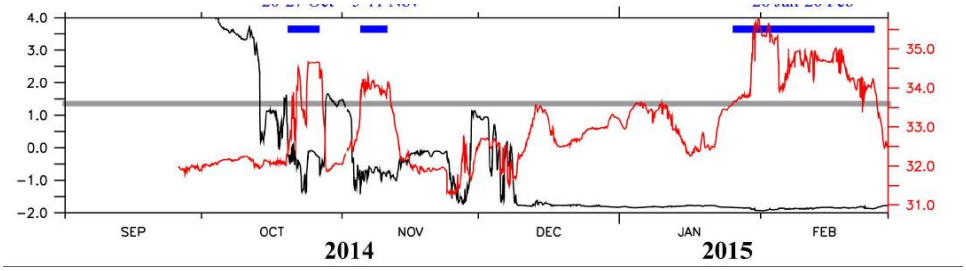

Figure 8. Temperature (black) and salinity (red) at C1. These are the highest salinities (35.9) that we have observed in the mooring recorders in Chukchi.

In addition to the ARCWEST moorings, a surface mooring was deployed in July and recovered in September, together with two wave gliders (Figure 9). These instruments were deployed as part of Ocean Exploration to examine solar heat fluxes. These data will be integrated with BOEM data sets.

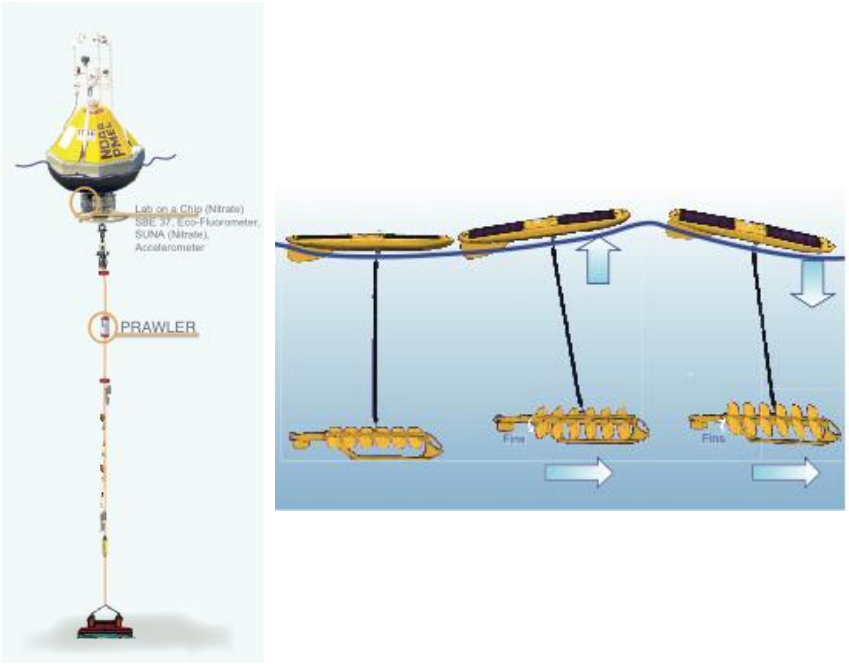

Figure 9. Schematic of Prawler mooring which profiles the upper water column and Wave Glider (CWG & EWG; NOAA-PMEL) which is a remotely controlled autonomous vehicle consisting of a surfboard-like surface float with solar panels to power communications and instrumentation. The two wave gliders were outfitted with different sensors (carbon and ecosystem).

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 10) 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).

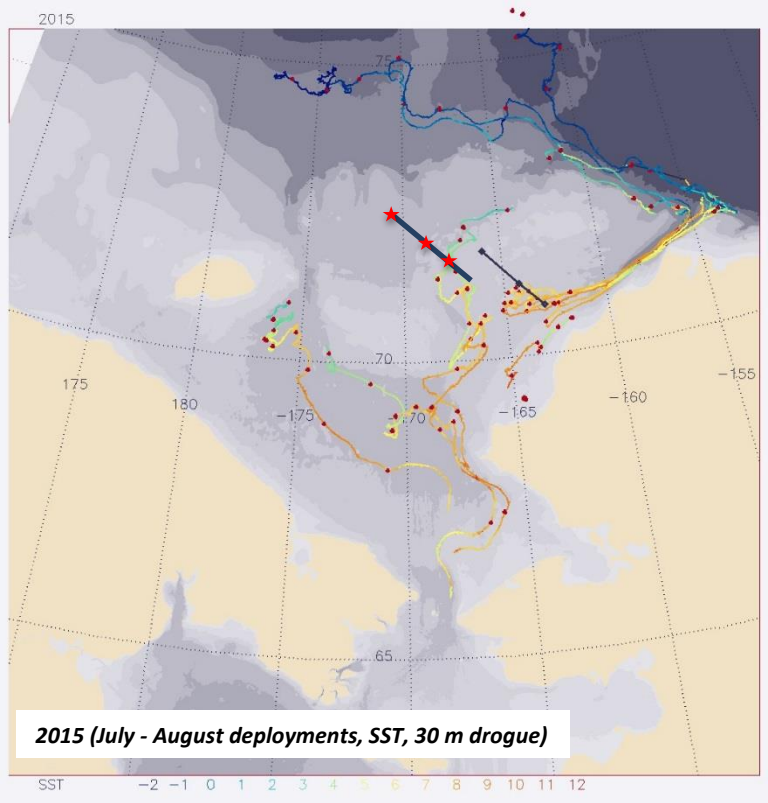

Figure 10. 2015 US Arctic Drifter Composite. 2015 deployment locations of the 12 drifters can be found in Figure 8a. The color coding indicates the near surface temperature collected by the drifter. Eight drifters were deployed in July and the rest in early August. Note that temperatures reached 9°C 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 May-June 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 11). 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.

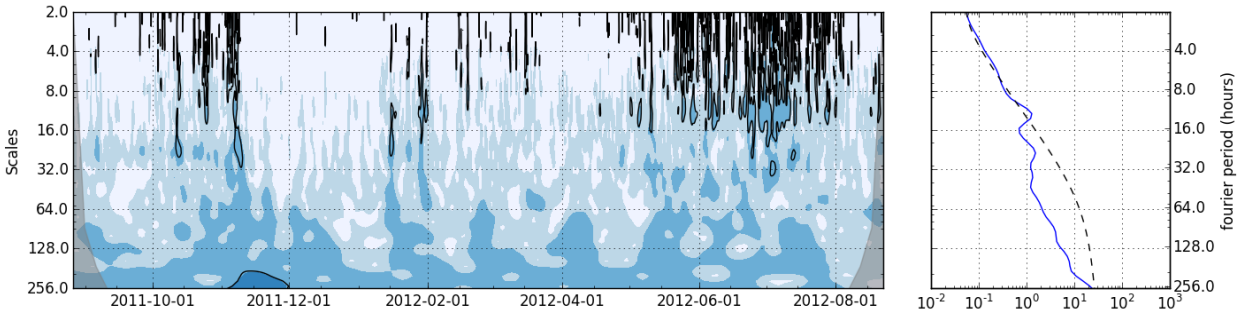

Figure 11. Wavelet analysis of ADCP data. Shown is an analysis of data at 28 m from the instrument deployed at site C3 in 2011. Diel vertical migration, when present, would show in the left panel as dark blue contours between 16 and 32 hrs on the (vertical) "Scales" axis. If diel vertical migration were 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:

Chlorophyll samples from 2015 were processed and in the database. 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. In the first quarter of 2016, we hired a contractor to load the remaining chlorophyll and zooplankton data into our database and produce maps and tables of the data to begin describing patterns. Analysis of the 2013-2015 chlorophyll data will be completed by the end of April 2016. The contractor has completed the full QA/QC process for zooplankton data for the years 2012-2014. Our intention is to have those data uploaded to the database by the end of April 2016. In addition, Mr. Adam Spear has 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 12, dark green circles) which were characterized by larvaceans, cnidarians, cirripedia, and smaller copepods. In 2012, a dissimilar north east assemblage (Figure 12, 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.

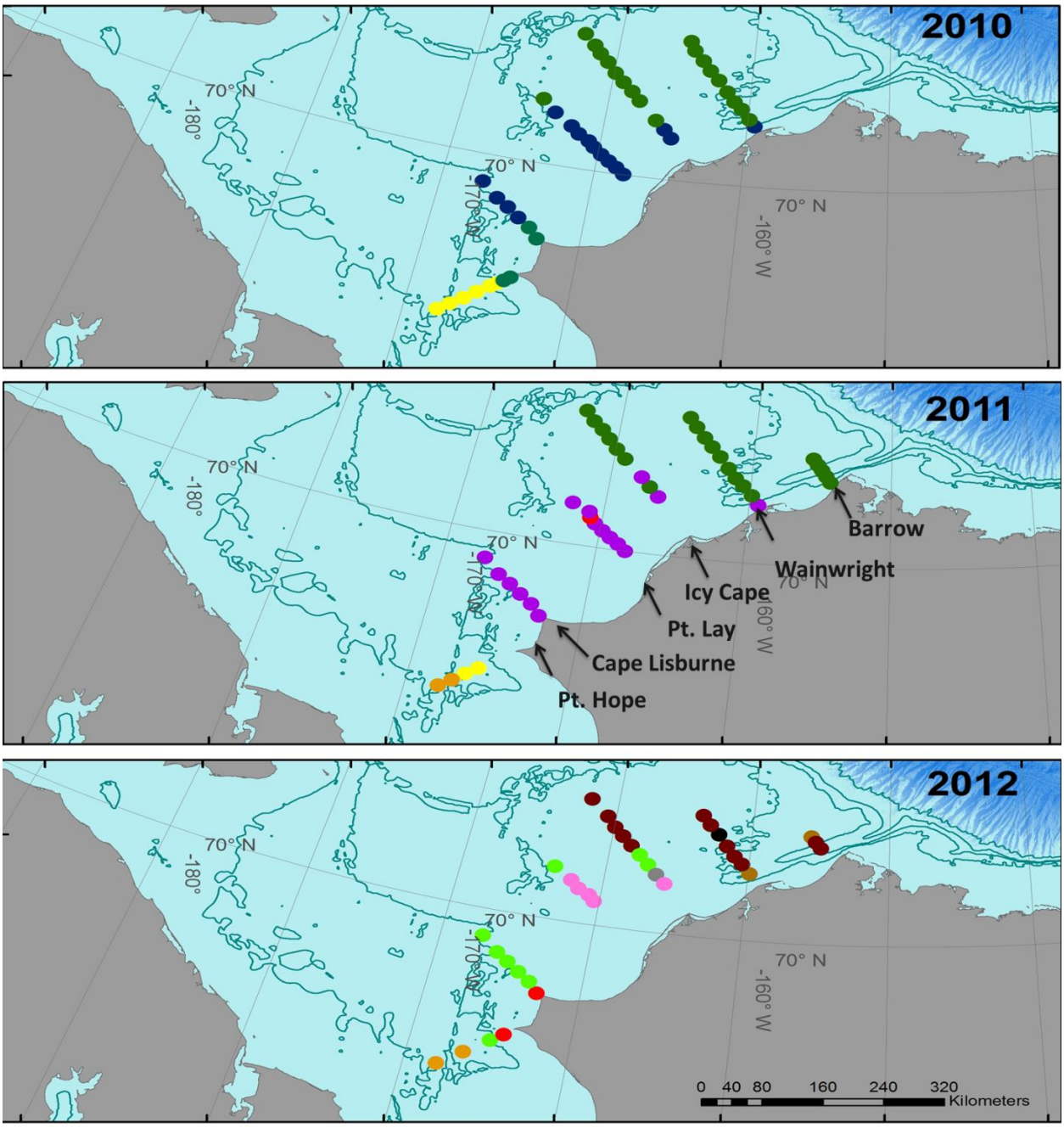

Figure 12. Results of the zooplankton community cluster analysis 2010-2012. Different colored circles indicate different assemblages of zooplankton.

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.

Significant meetings held or other contacts made

20 October, 2015: Berchok, Clark, Friday, Kennedy, Mocklin, Napp, and Stabeno attended an ARCWEST/CHAOZ-X meeting to coordinate data organization and to plan for the final report.

12 February, 2016: Berchok, Friday, Kennedy, Mocklin, Stabeno, Spear, and Napp attended an ARCWEST/CHAOZ-X meeting to coordinate the synthesis of results and plan for the final report. Kennedy presented her gray whale satellite tagging analysis and the team discussed the synthesis of these results with other information.

9-10 March, 2016: Berchok, Crance, and Kennedy attend the 3rd workshop for the Distributed Biological Obervatory (DBO) hosted by PMEL at AFSC/NOAA in Seattle, WA. Berchok organized a presentation on upper trophic level data (marine mammals (aerial, visual, tagging, and passive-acoustic), birds, fish, and crabs) from multiple speakers, and presented results on marine mammal long-term mooring and short-term visual/sonobuoy survey data from the CHAOZ-X and ARCWEST projects at the workshop. Kennedy presented the satellite telemetry data.

25 March, 2016: Berchok and Crance participate in Expanding Your Horizons, an outreach program designed to encourage 7th and 8th grade girls to pursue careers in STEM.

7 April, 2016: Berchok, Crance, Friday, Kimmel, Mocklin, Napp, Stabeno, Tabisola, and Zerbini, meet 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.

Presentations and Publications

Berchok, C.L., C.W. Clark, J.L. Crance, E.C. Garland, J.A. Mocklin, S.E. Moore, P.J. Stabeno, B.K. Rone, A.H. Spear, and M. Wang. 2016. CHAOZ in a nutshell: Five years of work in sixteen square feet. Poster presentation at the Alaska Marine Science Symposium, 25-29 January, Anchorage, AK.

Berchok, C.L., J. Clarke, C. Coon, A. Kennedy, K. Kuletz, L. Logerwell, S. Moore, and K. Stafford. 2016. Upper Trophics: Marine mammals, birds, fish, and other things large. Oral presentation at the 3rd DBO Workshop: Data synthesis and 10-year plan. 9-10 March 2016, Seattle, WA.

Crance, J.L., C.L. Berchok, E.C. Garland, J. Napp, and P.J. Stabeno. 2016. Finding the calls in the CHAOZ: Marine mammals and oceanographic conditions off Alaska's northern slope. Oral presentation for EcoFOCI Spring Seminar Series, 13 January, Seattle, WA.

Crance, J.L., C.L. Berchok, E.C. Garland, J. Napp, and P.J. Stabeno. 2016. Finding the calls in the CHAOZ: Marine mammals and oceanographic conditions off Alaska's northern slope. Poster presentation at the Alaska Marine Science Symposium, 25-29 January, Anchorage, AK.

Ladd, C., C. Mordy, S. Salo, and P. Stabeno. in prep. Winter water properties and the Chukchi polynya, *J. Geophys. Res. - Oceans*. To be submitted in April, 2015.

Ladd, C., S. Salo, P. Stabeno, and C. Mordy. 2016. Atlantic Water and the Chukchi Polynya. Oral presentation at the AGU Ocean Sciences Meeting, 21-26 February, New Orleans, LA.

Ladd, C., S. Salo, P. Stabeno, and C. Mordy. 2016. Atlantic Water and the Chukchi Polynya. Oral presentation at AFSC's Mini-AMSS, 18 February, Seattle, WA.

Ladd, C., P. Stabeno, C. Mordy, and S. Salo. 2016. Time series of currents and water masses on the Chukchi Shelf. Oral presentation at the Alaska Marine Science Symposium, 25-29 January, Anchorage, AK.

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.

Mordy, C.W., K. Martini, P. Proctor, P. Stabeno, C. Ladd, S. Salo, E. Wisegarver, L. Eisner, and P. Winsor. 2016. Variability of flow, nutrients and chlorophyll in the eastern Chukchi Sea. Oral presentation at the Alaska Marine Science Symposium, 25-29 January, Anchorage, AK.

Mordy, C.W., P. Stabeno, C. Ladd, L. Eisner, M.W. Sullivan, and K. Martini. 2016. Spatiotemporal variability of nutrients and chlorophyll in the Chukchi Sea. Presentation at the AGU Ocean Sciences Meeting, 21-26 February, New Orleans, LA.

Spear, A., Napp, J., Duffy-Anderson, J.T. Spatial and temporal variability of zooplankton community structure in the Chukchi Sea (2010-2012. AGU/ASLO Ocean Sciences Meeting, February 2016

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

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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.