Arctic Whale Ecology Study (ARCWEST)/

Chukchi Acoustics, Oceanography, and Zooplankton Study-extension (CHAOZ-X)

2015 Cruise Report

National Marine Mammal Laboratory, Alaska Fisheries Science Center
Pacific Marine Environmental Laboratory
NOAA, Seattle, WA

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SUMMARY

The 2015 Arctic Whale Ecology Study (ARCWEST)/Chukchi Acoustics, Oceanography, and Zooplankton Study-extension (CHAOZ-X) cruise took place on board the F/V *Aquila*. The cruise began in Nome, AK on 8 September 2015 and ended in Dutch Harbor, AK on 28 September 2015. Chief Scientist was Dr. Catherine Berchok, and the survey team consisted of 11 scientists representing six different laboratories or institutions (for full personnel list, see Appendix 1). In summary, a total of 24 passive acoustic, 24 oceanographic, and 4 combination (oceanographic/passive acoustic) moorings were retrieved, and 20 passive acoustic, 13 oceanographic, and 4 combination moorings were redeployed. A total of 17 CTD casts were conducted, 133 sonobuoys were deployed for 24 hour passive acoustic monitoring, over 600 nm were surveyed for marine mammals, and over 900 nm were surveyed for seabirds.

BACKGROUND

The western Arctic physical climate is rapidly changing. The summer Arctic minimum sea ice extent in September 2012 reached a new record of 3.61 million square kilometers, a further 16% reduction from a record set in 2007 (4.30 million square kilometers). This area was more than 50% less than that of two decades ago. The speed of 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. 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.

The ARCWEST study has five component projects: visual observation, satellite tagging, passive acoustics, lower trophic level sampling, and physical oceanographic sampling. Each component project is coordinated by a Project Leader with extensive experience in that discipline. 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 inter-agency agreement (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.

In addition to the funding provided by the ARCWEST Project for this cruise, funding also came from the BOEM-funded Chukchi Acoustics, Oceanography, and Zooplankton Study extension (CHAOZ-X). The focus of CHAOZ-X is to determine the circulation of water around the Hanna Shoal area, the source of this water (Chukchi Shelf or Arctic Basin), the abundance of large planktonic prey at the shoal, and the eventual destination of the water that circulates around the shoal. The dynamic nature of this circulation and prey delivery will be studied relative to whale distribution and habitat utilization in the northeastern Chukchi and extreme western Beaufort Seas. ARCWEST and CHAOZ-X share the same mooring design and sampling strategies. Thus, the cruise is referred to as the ARCWEST/CHAOZ-X survey.

As in previous years, funding was provided by the Pacific Marine Environmental Laboratory (PMEL) to retrieve and deploy the oceanographic and combination moorings in the Bering Sea. Funds were also provided by a NMML grant from the NOAA Science and Technology (S&T)/Ocean Acoustics Program to retrieve and redeploy one AURAL mooring in Norton Sound. Another NOAA S&T grant, in collaboration with Holger Klinck (PMEL-OSU/CIMRS), supported the tretrieval and redeployment of a deep water haruphone mooring to measure ambient noise in the Chukchi Sea. Funds to retrieve the NOAA Program on Innovative Technology for Arctic Exploration (PITAE) buoy were provided by NOAA Office of Exploration and Research.

OBJECTIVES

The specific objectives of the ARCWEST study 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.

The specific objectives of the CHAOZ-X study are:

1. Refocus the passive acoustic and biophysical monitoring begun under the study "COMIDA: Factors Affecting the Distribution and Relative Abundance of Endangered Whales" from the initial lease areas to Hanna Shoal.
2. Describe patterns of current flow, hydrography, ice thickness, light penetration, and concentrations of nutrients, chlorophyll, and large crustacean zooplankton around the Shoal.
3. Assess the spatial and temporal distribution of marine mammals in the region of Hanna Shoal.
4. Evaluate the extent to which variability in environmental conditions such as sea ice, oceanic currents, water temperature and salinity, and prey abundance influence whale distribution and relative abundance.
5. Develop a quantitative description of the Chukchi Sea's noise budget, as contributed by biotic and abiotic sound sources, and continuous, time-varying metrics of acoustic habitat loss for a suite of arctic marine mammal species.
6. Continue development of a near-real-time passive acoustic monitoring system that can be used as an impact mitigation tool.

OVERVIEW

An overview of the activities undertaken during the 2015 ARCWEST/CHAOZ-X cruise is represented in Figure 1. Please see the report below for descriptions of the stations and activities. This is the last field season for both ARCWEST and CHAOZ-X. While the ship time was funded by these two projects, most mooring (passive acoustic and oceanographic) redeployments were funded by the NOAA offices of Science & Technology (S&T), Exploration and Research (OER) and Oceanic & Atmospheric Research (OAR) to maintain the long-term dataset. The exceptions were the two Cornell MARU moorings and the C9 oceanographic mooring, which used CHAOZ-X funds delayed by the contracting process or banked from 2013 when the Government shut down prevented their initial deployments (respectively).

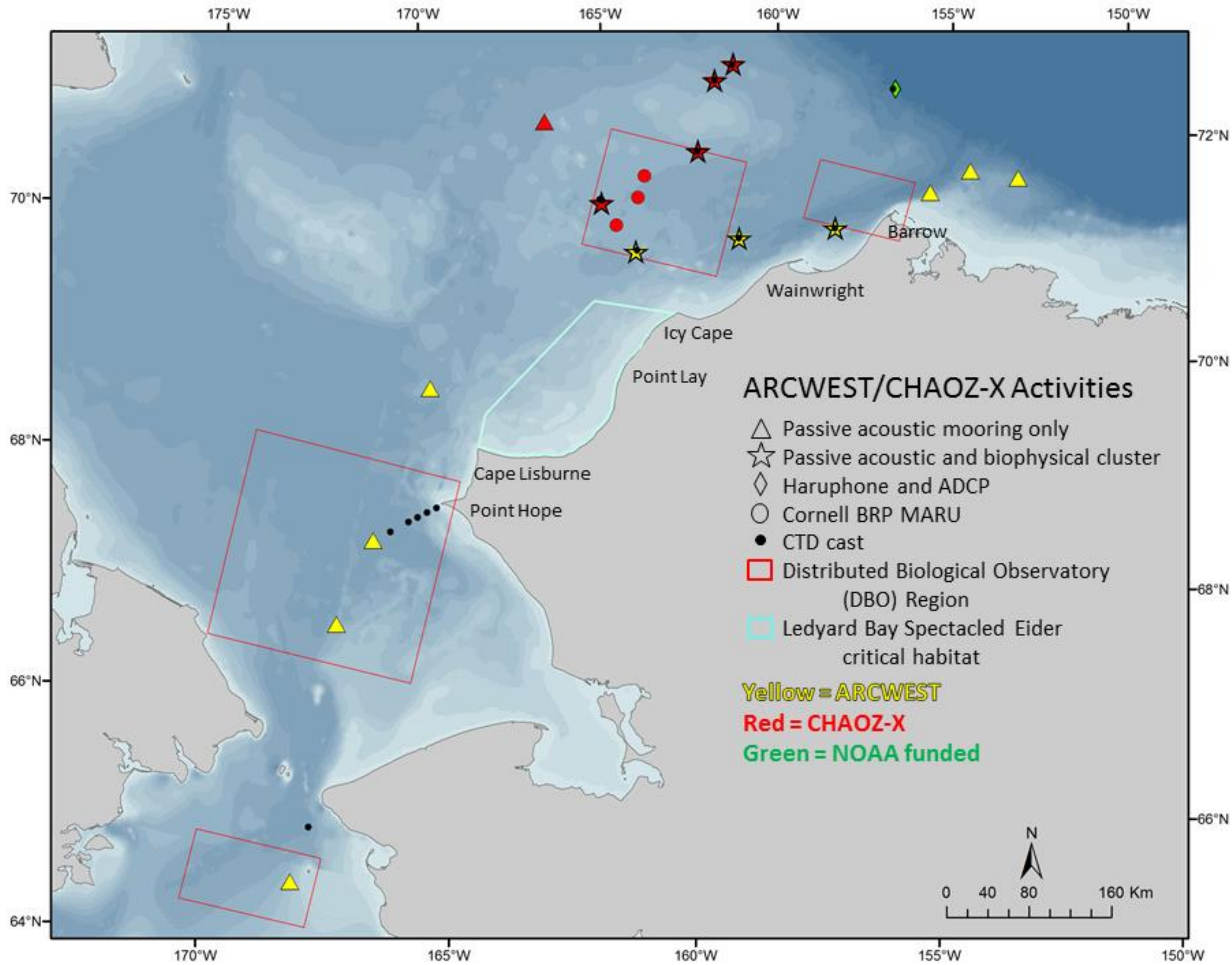

Figure 1. Overview of activities undertaken in the study area during the 2015 ARCWEST/CHAOZ-X cruise.

RESULTS

Although this is the final field season of the ARCWEST and CHAOZ-X projects, we redeployed a subset of passive acoustic recorder moorings under NOAA S&T funds, and a subset of oceanographic moorings under NOAA OAR funds to continue the long-term dataset begun with the Chukchi Acoustics, Oceanography, and Zooplankton Study (CHAOZ) project. Where appropriate, we have color-coded the mooring and station maps below with yellow symbols for ARCWEST, red for CHAOZ-X, and orange for NOAA funded redeployments.

Acoustic Component

Mooring deployments

NMML

All NMML passive acoustic recorder moorings (Figure 2, Appendix 4) use Autonomous Underwater Recorder for Acoustic Listening (AURAL, Multi-Électronique, Rimouski, QC) instruments. These AURALs record for a full year at a sampling rate of 16 kHz on a duty cycle of 80 minutes of recordings made every 5 hours. This duty cycle staggers the recording loop so that the recording period advances by one hour each day. This overall pattern repeats every six days, producing a large data set for all time periods equally.

Figure 2. Long-term passive acoustic mooring being deployed.

In 2014, 19 AURAL moorings were deployed: 14 for ARCWEST and 5 for CHAOZ-X. In addition, five[1] AURAL recorders (funded by ARCWEST) were deployed on non-BOEM, PMEL moorings in the Bering Sea (Table 1 and Figure 4, M2, M4, M5, M8), and one AURAL recorder was deployed under NOAA S&T funds in Norton Sound[2], for a total of 25 recorders deployed. All of these moorings were successfully retrieved in 2015. All but 3 of the moorings (HS1, HS2, and WT2) were redeployed in 2015 (NOAA-funded) in the same locations (Table 2; Figures 3-4).

The NMML passive acoustic moorings were spread out to cover as much of the migration routes of arctic marine mammal species as possible; they extend from Unimak Pass in the Bering Sea up to the Barrow Arch area in the western Beaufort Sea. They also continue to be collocated with the remaining Chukchi Sea biophysical mooring clusters (Table 2 & Figure 4, stars) deployed by Stabeno and Napp to allow for future correlations to be made between marine mammal calling presence and oceanographic and zooplankton measurements.

We are extremely excited to report that 24 of the 25 recorders we deployed recorded for the full duration of their deployment! One recorder (AW14_AU_NM1, Figure 3) stopped on 20 August 2014, two weeks prior to retrieval (but still lasted 11 months). See Figure A.1 for mooring design.

[1] The M2 mooring site is turned around twice a year, and so two recorders were used.

[2] Although the primary goal of the Norton Sound mooring is to record beluga calls, data on ambient noise and other marine mammals from that mooring will be used to inform ARCWEST.

Table 1. Date and location of passive acoustic mooring retrievals. Mooring cluster refers to the oceanographic site where the AURAL is co-located.

Mooring Name	Mooring Cluster	Latitude (°N)	Longitude (°W)	Depth (m)	Instrument	Deployment Date	Recovery Date	# Days Deployed
BS14_AU_02b*	M2	56.871117	164.054750	71	AURAL	10/19/2014	4/30/2015	194
AW14_AU_NM1	-	64.848633	168.390067	48	AURAL	9/20/2014	9/9/2015	355
AW14_AU_WT1	C4	71.037250	160.506067	50	AURAL	10/10/2014	9/13/2015	339
CX14_AU_IC2	C2	71.214533	164.238250	50	AURAL	9/26/2014	9/13/2015	353
AW14_AU_BF3	-	71.688283	153.177933	123	AURAL	9/30/2014	9/14/2015	350
AW14_AU_BF2	-	71.750833	154.465200	109	AURAL	9/29/2014	9/14/2015	351
AW14_AU_BF1	-	71.553133	155.531550	82	AURAL	9/29/2014	9/14/2015	351
AW14_AU_PB1	C5	71.206683	158.014067	52	AURAL	9/29/2014	9/14/2015	351
ST14_HA_NRS01	C9	72.449550	156.601833	875	Haruphone	10/1/2014	9/15/2015	350
CX14_AU_HS1	C7	72.427933	161.628767	42	AURAL	10/2/2014	9/16/2015	350
CX14_AU_HS2	C8	72.580050	161.217917	54	AURAL	10/2/2014	9/16/2015	350
CX14_AU_IC3	C3	71.831283	166.078383	51	AURAL	9/26/2014	9/17/2015	357
CX14_AU_WT2	C6	71.781667	161.858383	42	AURAL	10/4/2014	9/17/2015	349
AW14_AU_IC1	C1	70.822717	163.139283	50	AURAL	9/25/2014	9/18/2015	359
2014_MARU_1	-	71.000400	163.682000	43	Double bubble	8/20/2014	9/18/2015	395
2014_MARU_2	-	71.000000	163.653100	43	Double bubble	8/20/2014	9/18/2015	395
AW14_AU_CL1	-	69.317350	167.629850	59	AURAL	9/24/2014	9/19/2015	361
AW14_AU_PH1	-	67.907933	168.202167	68	AURAL	9/15/2014	9/20/2015	371
AW14_AU_KZ1	-	67.123550	168.604433	51	AURAL	9/24/2014	9/21/2015	363
AW14_AU_BS1	-	61.586183	171.326967	63	AURAL	10/15/2014	9/23/2015	344
ST14_AU_NS1	-	63.399783	166.240717	24	AURAL	10/14/2014	9/23/2015	345
BS14_AU_08a	M8	62.189867	174.688933	70	AURAL	10/15/2014	9/24/2015	345
BS14_AU_05a	M5	59.913150	171.708950	70	AURAL	10/16/2014	9/25/2015	345
AW14_AU_BS2	-	59.242933	169.413733	65	AURAL	10/17/2014	9/26/2015	345
BS14_AU_04b	M4	57.882350	168.879017	70	AURAL	10/17/2014	9/26/2015	345
BS15_AU_02a*	M2	56.866667	164.066667	73	AURAL	5/2/2015	9/27/2015	149
AW14_AU_BS3	-	57.643000	-164.753800	64	AURAL	10/19/2014	9/27/2015	344
AW14_AU_BS4	-	54.428283	-165.269600	165	AURAL	10/20/2014	9/28/2015	344

*Note that BS14_AU_02b was retrieved by PMEL staff on the NOAA ship *Oscar Dyson* in April 2015 and redeployed as BS15_AU_02a in May.

Table 2. Date and location of passive acoustic mooring deployments. Mooring cluster refers to the oceanographic site name where the AURAL is co-located.

Mooring Name	Mooring Cluster	Latitude (°N)	Longitude (°W)	Depth (m)	Instrument	Deployment Date
AW15_AU_NM1	-	64.847600	168.389767	44	AURAL	9/9/2015
AW15_AU_WT1	C4	71.046967	160.502583	49	AURAL	9/13/2015
CX15_AU_IC2	C2	71.229367	164.226217	41	AURAL	9/13/2015
AW15_AU_BF3	-	71.686417	153.177733	102	AURAL	9/14/2015
AW15_AU_BF2	-	71.749767	154.462350	79	AURAL	9/14/2015
AW15_AU_BF1	-	71.552300	155.533050	69	AURAL	9/14/2015
AW15_AU_PB1	-	71.206283	158.015433	46	AURAL	9/14/2015
ST15_HA_NRS01	C9	72.443033	156.551683	1000	Haruphone	9/16/2015
CX15_AU_IC3	-	71.829483	166.077067	43	AURAL	9/17/2015
AW15_AU_IC1	C1	70.835533	163.109200	42	AURAL	9/18/2015
2015_MARU_1	-	71.298933	163.277183	43	Double bubble	9/18/2015
2015_MARU_2	-	71.496533	163.190817	44	Double bubble	9/18/2015
AW15_AU_CL1	-	69.317367	167.622867	49	AURAL	9/19/2015
AW15_AU_PH1	-	67.910350	168.198300	57	AURAL/microcat	9/20/2015
AW15_AU_KZ1	-	67.123600	168.604367	42	AURAL	9/21/2015
AW15_AU_BS1	-	61.585917	171.332867	52	AURAL	9/23/2015
ST15_AU_NS1	-	63.399083	166.236217	22	AURAL	9/23/2015
BS15_AU_08a	M8	62.194450	174.684150	72	AURAL	9/24/2015
BS15_AU_05a	M5	59.906883	171.733450	68	AURAL	9/25/2015
AW15_AU_BS2	-	59.242783	169.412517	53	AURAL	9/26/2015
BS15_AU_04b	M4	57.894533	168.877750	70	AURAL	9/26/2015
BS15_AU_02b	M2	56.878417	164.068500	70	AURAL	9/27/2015
AW15_AU_BS3	-	57.675033	164.718267	53	AURAL	9/27/2015
AW15_AU_BS4	-	54.428833	165.271267	166	AURAL	9/28/2015

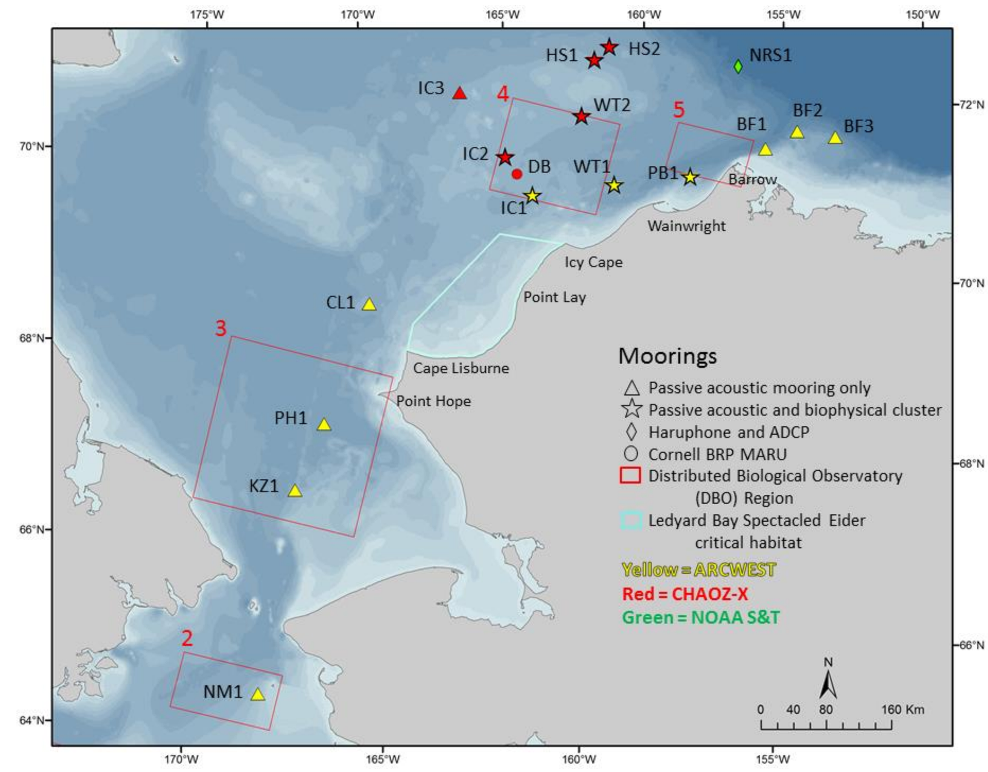

Figure 3. Location of passive acoustic moorings retrieved in the Chukchi Sea.

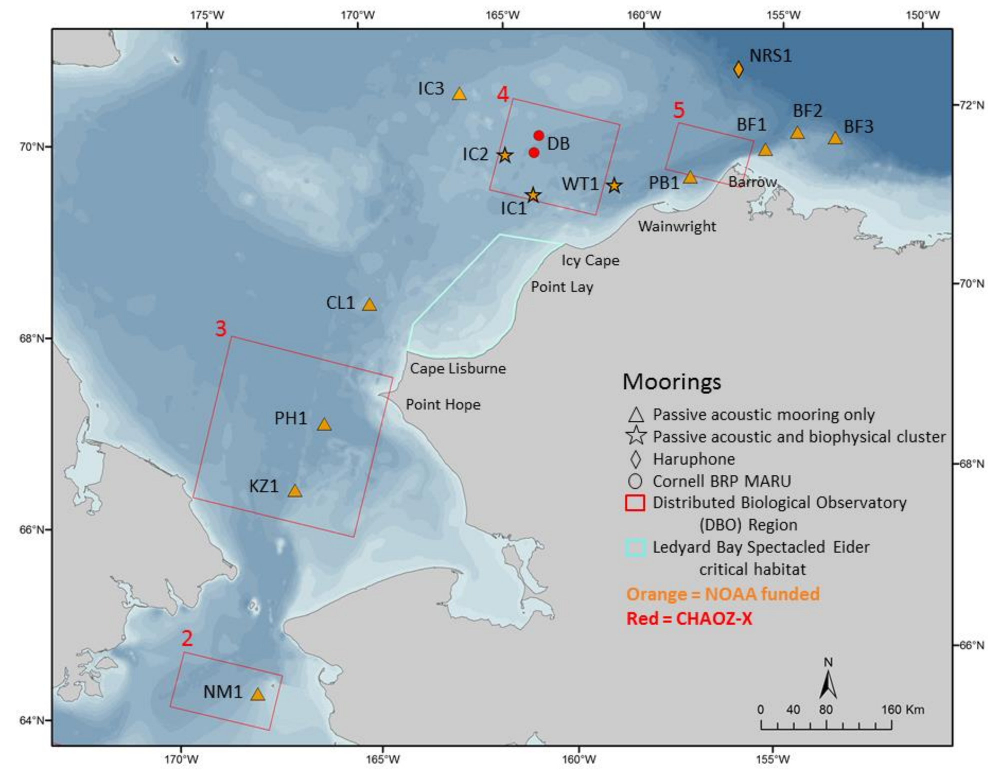

Figure 4. Location of passive acoustic moorings deployed in the Chukchi Sea in 2015. All passive acoustic recorders were deployed under NOAA S&T funding except for the MARUs which were deployed with CHAOZ-X funding. Note a microcat was placed in line with the PH1 mooring.

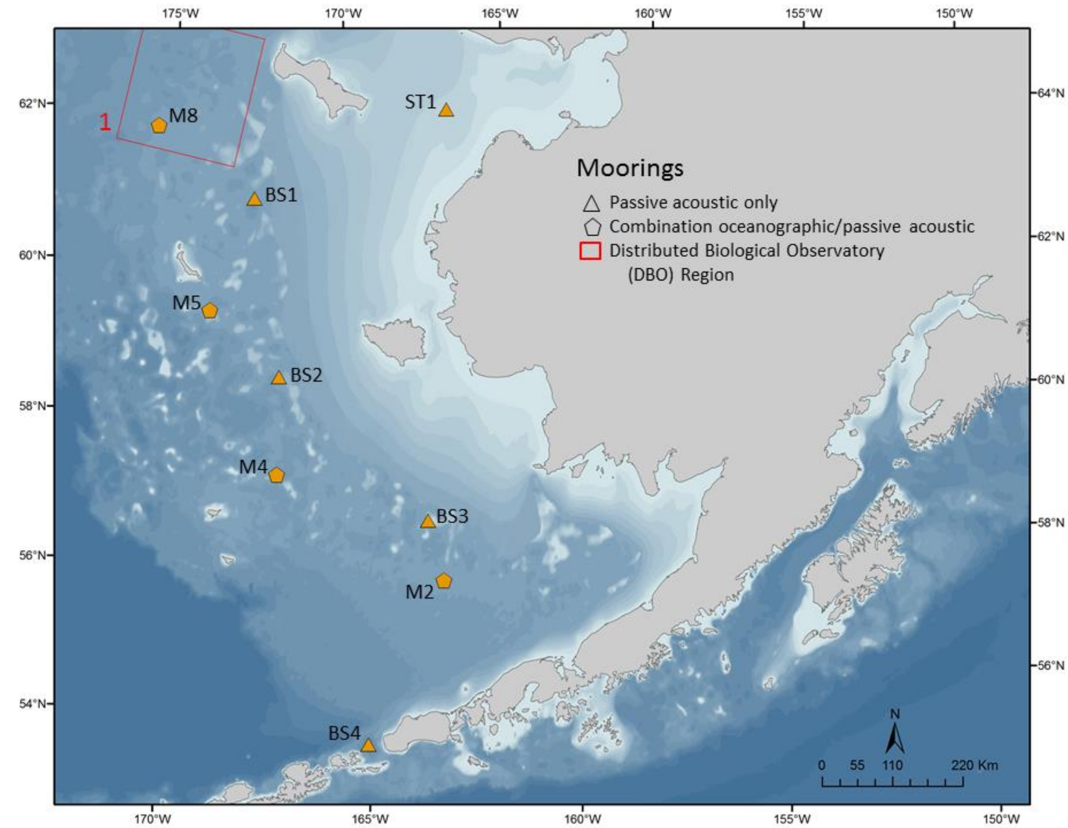

Figure 5. Location of passive acoustic moorings retrieved and redeployed in the Bering Sea. Passive acoustic moorings and recorders were funded by NOAA S&T and oceanographic moorings were funded by NOAA OAR.

Cornell

Cornell deployed two double bubble Marine Acoustic Recorder Units (MARUs) in 2014 on the R/V Westward Wind as part of the CHAOZ-X project. These were successfully retrieved (Table 1), and two new double bubbles were deployed closer to the Shell Oil drill rig in 2015 (Table 2, Figure 4 circles). These 2015 deployments used CHAOZ-X funds delayed by the contracting processes between NOAA and WHOI and WHOI and Cornell. Deployment of the Auto-detection buoy was postponed until 2016, due to logistical constraints.

Other

During the cruise, we serviced a few moorings that were along our route for other projects and/or researchers. A deep-water Noise Reference Station (NRS) mooring (Figure 3, NRS1; Figure 4) that was deployed in 2014 is a NOAA-funded collaborative effort (http://bioacoustics.oregonstate.edu/project/noaa-ocean-noise-reference-station-network) led by Holger Klinck (NOAA/Cornell) to measure deep water ambient noise throughout the United States EEZ. This recorder was retrieved and redeployed in the same location in 2015, and is located at the C9 oceanographic site.

The grand total of passive acoustic recorders retrieved and deployed during the ARCWEST/CHAOZ-X survey is therefore 28 and 24, respectively.

Sonobuoy monitoring

Figure 6. Preparing a sonobuoy for deployment.

Sonobuoys were deployed approximately every 2-3 hours, while transiting, to obtain an evenly-sampled cross-survey census of marine mammal vocalizations. Only one type of sonobuoy was used: 53F (manufactured by either Sparton (SPW) or Ultra Electronics (UND)). 53F sonobuoys have either omnidirectional or DiFAR (Directional Frequency Analysis and Recording) capabilities. Sonobuoys were deployed in DiFAR mode to obtain bearings to calling animals. In 2012, we discovered that when we pulled out the top float portion during the sonobuoy programming process, we were inadvertently pulling out and disabling the depth setting pins, which was causing the sonobuoys to deploy to their deepest depth setting of 1000ft (and therefore noisily dragging the sensor across the shallow seafloor). Thus, modifications (taping and tying) had to be made to all sonobuoys to shorten the deployment depth. Furthermore, almost all of the 53F sonobuoys had dead display batteries, which required replacement with a new battery.

There were two preamplified antennas installed on the vessel, an omnidirectional antenna as well as a Yagi directional antenna. Both antennas (and preamps) were placed up in the crow's nest of the vessel with the directional antenna facing astern (Figure 7). Theomnidirectional antenna was used primarily while we were on station for mooring/sampling activities, as the vessel was frequently changing course. It was also used in the North Pacific Right Whale Critical Habitat in the SE Bering Sea, as pairs of sonobuoys were deployed in different directions in order to localize on vocalizing right whales. The Yagi antenna was used primarily during transit when the sonobuoy was guaranteed to be behind the vessel. The acoustics station in the bridge is shown in Figure 8.

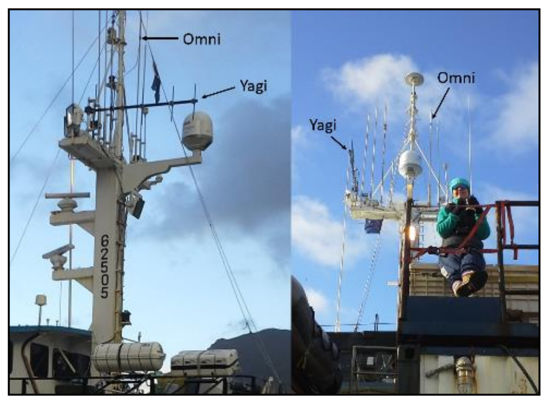

Figure 7. Sonobuoy antennas placed in the crow's nest.

Figure 8. Acoustic station.

A total of 133 sonobuoys were deployed during the cruise (Appendix 3). Of these, 114 deployed and transmitted successfully for an overall success rate of 85.7%. One batch of sonobuoys used during the first leg of the survey (Nome – Nome) had a higher number of failures, so the success rate for leg 1 was only 81%. However, the success rate for leg 2 (Nome – Dutch Harbor) was considerably higher at 94%.

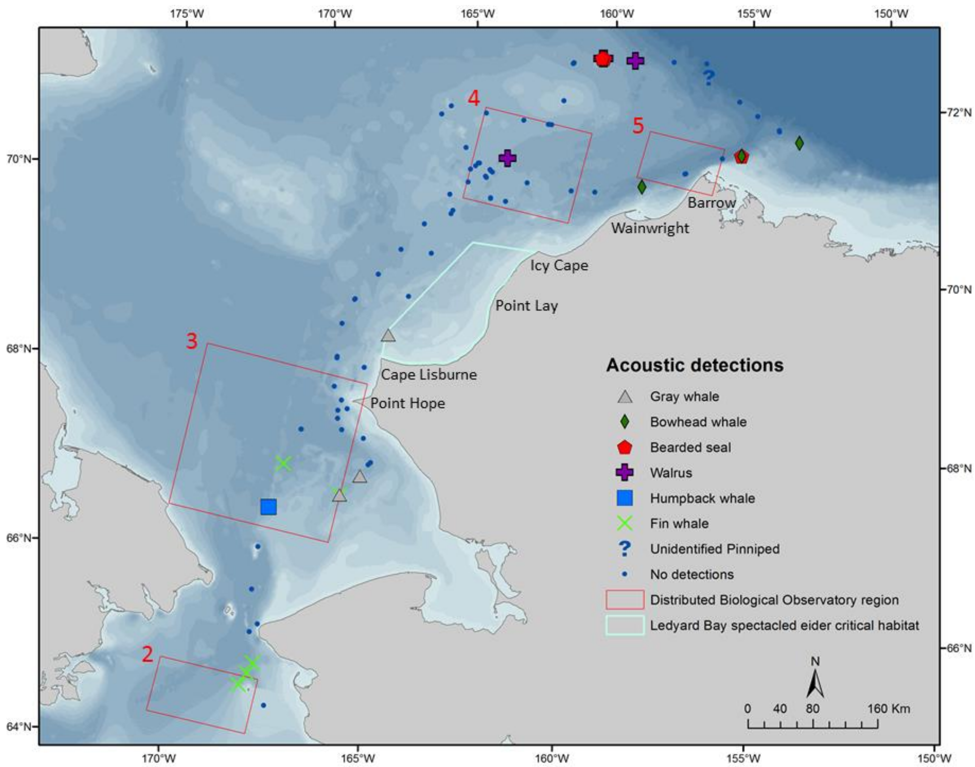

Figure 9. Sonobuoy deployment and acoustic detections in the Chukchi Sea.

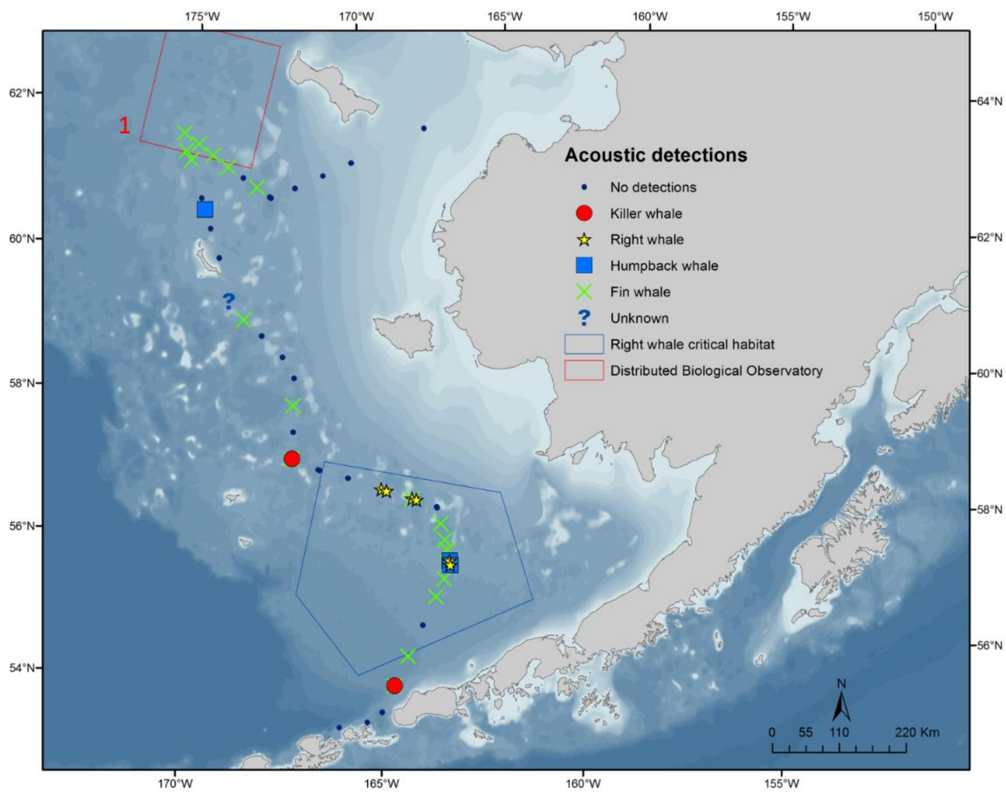

Figure 10. Sonobuoy deployment and acoustic detections in the Bering Sea.

The location of the sonobuoys and species detected are shown in Figures 9 and 10 for the Chukchi/Beaufort and Bering Seas respectively. There was a noticeable lack of acoustic detections of marine mammal species in the Arctic in 2015. The most common species detected in the Chukchi/Beaufort were fin whales, detected on 5 sonobuoys (7.2%), and walrus, detected on 4 buoys (5.8%), followed by bowhead whales, gray whales, and bearded seals, each with confirmed detections on 3 buoys (4.3%). Humpback whales were detected on one buoy, and one sonobuoy detected an unidentified pinniped. The most common species detected in the Bering Sea were fin whales, detected on 44% of sonobuoys, followed by North Pacific right whales (upsweeps and gunshot calls) on 6 sonobuoys (13%), with two possible additional unconfirmed detections. Other species detected include killer whales (4.5%), humpback whales (2% confirmed, 13% unconfirmed), and unknown sounds (8.8%).

Oceanographic Component

Long-term moorings

All moorings deployed in 2014 for ARCWEST and CHAOZ-X were successfully retrieved (Table 3) and four redeployed (C1, C2, C4, C9, Table 4).

At C1, C2, and C4, three ice and biophysical moorings were deployed (under NOAA OAR funds). The ice mooring contains an ASL upward-facing profiler to measure ice thickness as well as a Recording Current Meter (RCM) 9. The biophysical moorings included an ADCP and a linked set of instruments containing a Sea-bird (SBE) SeaCAT, an ECOfluorometer, a Photosynthetically active radiation (PAR) sensor, and an In situ ultraviolet spectrometer (ISUS) nitrate sensor (Figure 11). For a full list of instrumentation on each mooring recovered and deployed see Tables 3-6.

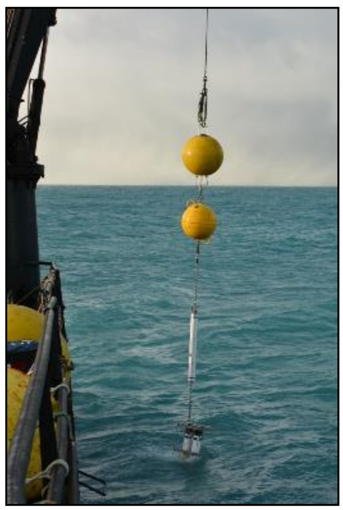

Figure 11. Oceanographic ADCP mooring being deployed.

Figure 12. TAPS-6NG being deployed.

In addition, at the C2 location, an upward-facing TAPS-6NG (Tracor Acoustic Profiling System Next Generation) instrument was deployed to measure zooplankton bio-volume and size distribution. The TAPS-6NG assembly consists of a PVC block at the top containing 6 transducers, a 40" syntactic foam ADCP float, an electronic controller pressure case (inside the float) and two PVC pressure cases containing batteries (Figure 12). These instruments are engineered to optimize the detection of krill. Because of software glitches in the past preventing the TAPS-6NG from working, this instrument was deployed on 13 September at the start of the cruise for a test period and was retrieved 6 days later. A download of data confirmed that the instrument was working successfully, and so the instrument was redeployed on 19 September to collect data for the full year.

At C9, an ADCP was redeployed (under CHAOZ-X funds) in a cluster with the deep-water Haruphone (see Acoustics section above). The moored instruments will collect various oceanographic measurements along the slope, including temperature, pressure, depth, salinity, conductivity, and fluorescence for a full year. See the PMEL mooring website (http://www.pmel.noaa.gov/foci/operations/mooring_plans/2015/aug2015_aq1501_moorings.html[3]) for information on the other instruments placed on each mooring, and Appendix 6 for mooring diagrams.

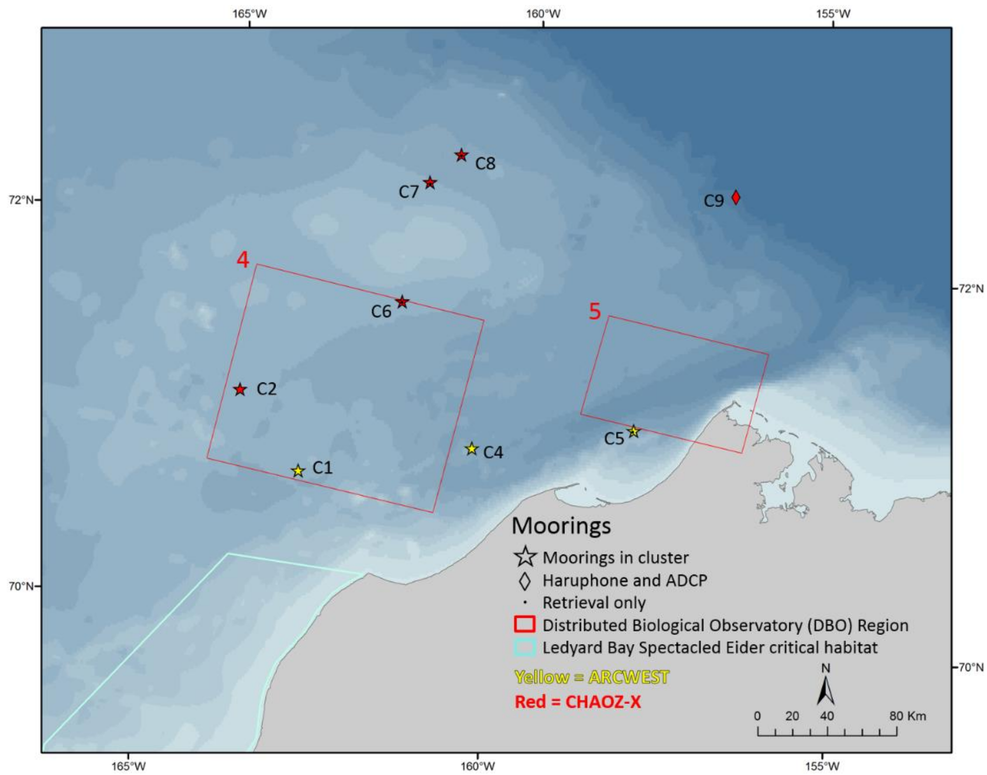

Figure 13. Location of oceanographic mooring clusters retrieved and deployed in the Chukchi Sea. Sites C1, C2, and C4 deployed under NOAA OAR funds; site C9 ADCP deployed under CHAOZ-X funds.

[3] On this webpage subsurface moorings relevant to this project are titled 15CK (i.e., Chukchi Sea 2015) and 15BS (i.e., Bering Sea 2015). The number on the end corresponds to the mooring clusters shown in Figure 13 for the Chukchi Sea (e.g., 15CKT-2A corresponds to C2) or Figure 5 for the Bering Sea (e.g., 15BS-2B corresponds to M2).

Table 3. Date and location of oceanographic moorings retrieved in the Chukchi Sea. See Appendix 2 for the definition of the instrument abbreviations.

Mooring Name	Cluster	Latitude (°N)	Longitude (°W)	Instrument	Retrieval date
14CKIP-1A	C1	70.8352°	163.115°	IPS, RCM	9/18/2015
14CKT-1A	C1	70.84°	163.122°	TAPS, SBE	9/18/2015
14CKP-1A	C1	70.83068°	163.119°	ADCP, ISUS, SBE, PAR, FLUOR	9/18/2015
14CKIP-2A	C2	71.22°	164.24°	IPS, RCM	9/13/2015
14CKT-2A	C2	71.22963°	164.213°	TAPS, SBE	9/13/2015
14CKP-2A	C2	71.22925°	164.246°	ADCP, ISUS, SBE, PAR, FLUOR	9/13/2015
15CK-PITAE	C2	71.24101°	164.3013°	*Appendix 6	9/17/2015
14CKIP-4A	C4	71.04067°	160.517°	IPS, RCM	9/13/2015
14CKT-4A	C4	71.04023°	160.495°	TAPS, SBE	9/13/2015
14CKP-4A	C4	71.04348°	160.505°	ADCP, SUNA, SBE, PAR, FLUOR	9/13/2015
14CKT-5A	C5	71.21067°	158.002°	TAPS, SBE	9/14/2015
14CKP-5A	C5	71.20662°	158.002°	ADCP, ISUS, SC, PAR, FLUOR	9/14/2015
14CKIP-6A	C6	71.77417°	161.864°	IPS, RCM	9/17/2015
14CKP-6A	C6	71.77667°	161.879°	ADCP, ISUS, SBE, PAR, FLUOR	9/17/2015
14CKT-7A	C7	72.42098°	161.631°	TAPS, SBE, RCM	9/16/2015
14CKP-7A	C7	72.42458°	161.621°	ADCP, ISUS, SBE, PAR, FLUOR	9/16/2015
14CKIP-8A	C8	72.58633°	161.215°	IPS, RCM	9/16/2015
14CKT-8A	C8	72.583°	161.226°	TAPS, SBE	9/16/2015
14CKP-8A	C8	72.583°	161.205°	ADCP, SBE, FLUOR	9/16/2015
14CKP-9A	C9	72.45788°	156.565°	ADCP, RCM, SBE	9/15/2015

Table 4. Date and location of oceanographic moorings deployed in the Chukchi Sea. See Appendix 2 for the definition of the instrument abbreviations.

Mooring Name	Cluster	Latitude (°N)	Longitude (°W)	Depth (m)	Instrument	Deployment date
15CKIP-4A	C4	71.04785	160.512	49	IPS, RCM, SBE	9/13/2015
15CKIP-2A	C2	71.23048	164.21	41	IPS, RCM, SBE	9/13/2015
15CKP-4A	C4	71.04642	160.515	49	RDI, SBE, PAR, FLUOR	9/13/2015
15CKP-2A	C2	71.23075	164.216	41	RDI, FLUOR, SUNA, SBE, PAR	9/13/2015
15CKP-9A	C9	72.46685	156.55	1000	ADCP, RCM, SBE	9/15/2015
15CKP-1A	C1	70.8385	163.105	42	RDI, ISUS, SBE, PAR, FLUOR	9/18/2015
15CKIP-1A	C1	70.83565	163.124	42	IPS, RCM, SBE	9/18/2015
15CKT-2A	C2	71.23013	164.221	42	TAPS, SBE	9/19/2015

Also recovered was a 1.5m oceanographic surface mooring deployed from the USCGC *Healy* ~75 NM North West of Icy Cape, AK in the Chukchi Sea on July 10, 2015. This radiation buoy is part of the NOAA Program on Innovative Technology for Arctic Exploration (PITAE) at PMEL with funding provided by NOAA OER. The buoy is equipped with a novel radiometer package that has the ability to gather climate quality measurements and can differentiate between direct and diffuse solar irradiance. Additional meteorological sensors measure winds, air temperature, relative humidity, and estimate cloud coverage. Below the surface are several novel technologies including NOAA-PMEL's PRAWLER and a lab on a chip (LOC) Nitrate sensor from the U.K.'s National Oceanography Center at Southampton.

Figure 14. Oceanographic mooring (M2) with surface float.

In addition to the Chukchi Sea moorings, during the return transit from Nome to Dutch Harbor, we retrieved and redeployed eight oceanographic moorings at four different sites (two moorings at each location) along the 70m isobath (M2, M4, M5, M8, Table 5; Figure 4, pentagons). This included the retrieval of the large surface float mooring at M2 (Figure 14).

Table 5. Date and location of oceanographic mooring recovered in the Bering Sea. See Appendix 2 for the definition of the instrument abbreviations.

Mooring Name	Cluster	Latitude (°N)	Longitude (°W)	Instrument	Retrieval date
14BSP-8A	M8	62.339	174.759	ADCP, AURAL, AWCP	9/24/15
14BS-8A	M8	62.369	174.697	SBE, FLUOR	9/24/15
14BS-5A	M5	62.343	174.941	FLUOR, SBE, MC	9/25/15
14BSP-5A	M5	60.090	171.768	ADCP, AURAL, AWCP, PAL	9/25/15
14BS-4B	M4	60.015	171.735	SBE, FLUOR, MTR	9/26/15
14BSP-4A	M4	57.994	168.953	RDCP, AURAL	9/26/15
15BSP-2A	M2	58.070	169.051	ADCP, AWCP, SAMI	9/27/15
15BSM-2A	M2	56.933	164.322	Weatherpak, Eppley, MTR, ISUS, SBE, FLUOR, Wetstar/SC	9/27/15

Table 6. Date and location of oceanographic mooring deployments in the Bering Sea. See Appendix 2 for the definition of the instrument abbreviations.

Mooring Name	Cluster	Latitude (°N)	Longitude (°W)	Depth (m)	Instrument	Deployment date
15BS-8A	M8	62.19268	174.688	72	SBE, FLUOR, SAMI PCO2, SeaFET	9/24/2015
15BSP-8A	M8	62.19445	174.684	72	ADCP, AURAL	9/24/2015
15BSIP-8A	M8	62.1929	174.683	72	IPS	9/24/2015
15BS-5A	M5	59.9114	171.735	68	SBE, FLUOR	9/25/2015
15BSP-5A	M5	59.90688	171.733	68	ADCP, AURAL, AWCP, PAL	9/25/2015
15BS-4B	M4	57.88995	168.872	70	SBE, FLUOR, MTR	9/26/2015
15BSP-4A	M4	57.89453	168.878	70	ADCP, AURAL	9/26/2015
15BS-2C	M2	56.87062	164.066	70	FLUOR, SBE, RCM, MTR, ISUS, SAMI, SeaFet	9/27/2015
15BSP-2B	M2	56.87842	164.069	70	ADCP, AURAL, AWCP, PAL	9/27/2015

CTD stations

At each mooring site and along the Point Hope transect line, hydrographic data (temperature, conductivity, O_2, PAR, Flouresence) were collected and samples take (nutrients, and chlorophyll, Tables 7 and 8, Figures 15 and 16). Methods included high-resolution vertical profiling of water properties (including temperature, salinity, chlorophyll fluorescence, PAR, and dissolved O_2) to within 4m of the bottom using a Seabird 911Plus CTD (Figure 15) with dual temperature, conductivity, and oxygen sensors. Nutrient and chlorophyll samples were collected with water bottles at discrete depths and frozen for analysis at a later date at the NOAA laboratories in Seattle, WA. Dissolved oxygen samples were taken to calibrate CTD oxygen sensors. Two-thirds of the way through the Point Hope transect line, the CTD began having issues and broke after the cast at the M8 site in the Bering Sea. Due to this, no CTD or surface sample was taken at M5. At the remaining two M sites (M2 and M4) bucket samples were collected. In total, 17 CTD casts were conducted and two bucket samples were collected (Table 7).

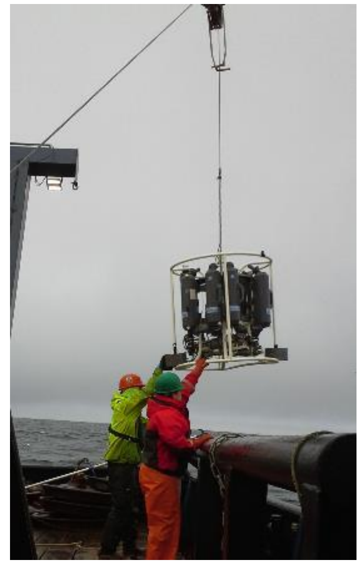

Figure 15. CTD being deployed.

Table 7. Summary of hydrographic operations

Station	Type	Latitude (°N)	Longitude (°W)	Date	Time	Depth (m)	Site Name
1	CTD	71.2295°	164.23°	9/13/2015	09:03	42	CK-2
2	CTD	71.04767°	160.52°	9/13/2015	21:27	50	CK-4
3	CTD	71.2025°	158.03°	9/14/2015	04:45	46	CK-5
4	CTD	72.4715°	156.64°	9/15/2015	22:17	612	CK-9
5	CTD	72.58183°	161.19°	9/16/2015	17:57	47	CK-8
6	CTD	72.425°	161.62°	9/16/2015	21:55	44	CK-7
7	CTD	71.77467°	161.87°	9/17/2015	04:40	42	CK-6
8	CTD	71.23183°	164.28°	9/17/2015	22:30	45	CK-PITAE
9	CTD	70.8335°	163.12°	9/18/2015	19:21	43	CK-1
10	CTD	71.2285°	164.22°	9/19/2015	03:04	42	CK-2
11	CTD	68.29917°	166.93°	9/20/2015	14:03	35	PH-01
12	CTD	68.24267°	167.12°	9/20/2015	15:16	43	PH-02
13	CTD	68.1865°	167.31°	9/20/2015	16:19	48	PH-03
14	CTD	68.13017°	167.50°	9/20/2015	17:22	50	PH-04
15	CTD	68.01267°	167.86°	9/20/2015	22:36	51	PH-05
16	CTD	65.34417°	168.26°	9/21/2015	17:46	54	test
17	CTD	62.19383°	174.68°	9/24/2015	20:06	72	BS-8
18	Bucket Sample	57.8945°	168.88°	9/26/2015	23:06	70	BS-4
19	Bucket Sample	56.87383°	164.06°	9/27/2015	22:59	70	BS-2

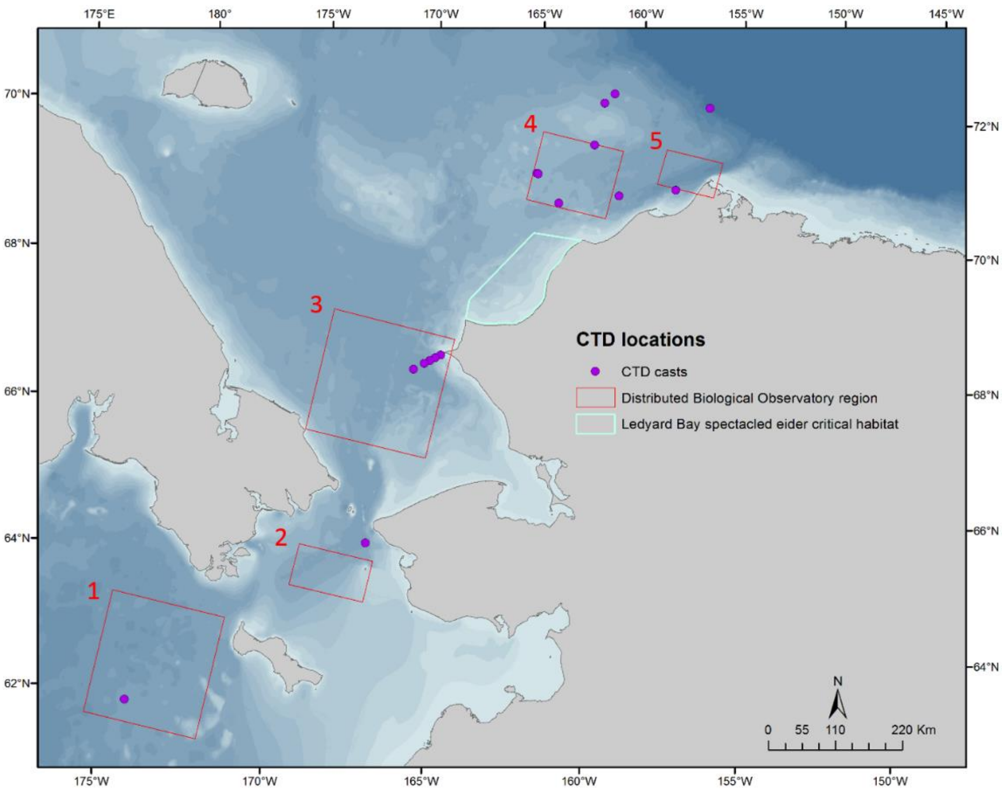

Figure 16. Location of all CTD casts in the Chukchi and Bering Seas.

Table 8. Number of samples collected from hydrographic stations.

	Salinity	Nutrients	O_2	Chlorophyll
Samples Collected	18	76	19	74

Although no drifters were deployed from the F/V Aquila this year due to the late timing of the cruise, eight drifers were deployed from USCGC *Healy* the and four from NOAA Ship *Ronald H. Brown.* An animation showing drifter tracks and ice extent can be viewed at the following website under the heading *Chukchi drifters, ice*: http://www.ecofoci.noaa.gov/efoci_drifters.shtml

Marine Mammal Component

All operations were performed according to regulations and restrictions specified in the existing permits issued by the NMFS to the National Marine Mammal Laboratory (permit #14245).

Marine mammal observations

Visual effort was conducted by a team of two scientists. Operations were conducted during daylight hours, or as long as weather and light conditions would allow, while transiting between mooring stations. On-effort status was defined as a visibility greater than 2 nautical miles (nm) and Beaufort sea state ≤ 5. Visual operations were considered 'on-effort' when either one or both scientists were observing inside the bridge using naked eye and 7x50 binoculars or with one observer outside using 25x 'big-eye' or 7x50 binoculars, and one scientist inside the bridge to observe and record. Off-effort watch (sea state 6 or greater and/or visibility less than 2 nm) was conducted by either one or both scientists to monitor whether conditions improved and visual surveys could continue. When a sighting was detected, the primary observer conveyed the horizontal angle and number of reticles from the horizon of the initial sighting to the recorder. Sighting cue, course and speed, species identity, and best, high, and low estimates of group size were also recorded. The computer program *WinCruz* (https://swfsc.noaa.gov/uploadedFiles/Divisions/PRD/WinCruz.pdf) was used to record all sighting, effort, and environmental data (e.g., cloud cover, precipitation, and sea conditions).

Figure 17. Marine mammal observer Ulmke using the Big Eye binoculars.

The visual team surveyed 629 nm of on-effort trackline (Figures 18 and 19). There were a total of 28 sightings (41 individuals) of 8 confirmed marine mammal species; these consisted of killer, humpback, and minke whales, harbor and Dall's porpoise, Northern fur and bearded seals, and walrus (Table 8, Figures 18 and 19). Additionally, there were 39 sightings (39 individuals) of unidentified cetaceans and pinnipeds (Table 9, Figures 18 and 19).

Table 9. Marine mammal sightings (individuals) from the ARCWEST 2015 research cruise.

Species	**On-Effort**	**Off-Effort**	**Total**
Cetaceans			
Humpback Whale	2(6)	3(4)	5(10)
Minke Whale	1(1)	0	1(1)
Harbor Porpoise	2(2)	0	2(2)
Dall's Porpoise	1(3)	0	1(3)
Killer Whale	1(2)	0	1(2)
Unid Large Whale	1(1)	1(1)	2(2)
Unid Small Whale	0	1(1)	1(1)
Unid Porpoise	1(1)	0	1(1)
Total Cetacean	*9(16)*	*5(6)*	*14(22)*
Other			
Fur Seal	1(2)	3(5)	4(7)
Walrus	4(6)	0	4(6)
Bearded Seal	10(10)	0	10(10)
Unid Seal	34(34)	1(1)	35(35)
Total Other	*49(52)*	*4(6)*	*53(58)*
Total	**58(68)**	**9(12)**	**67(80)**

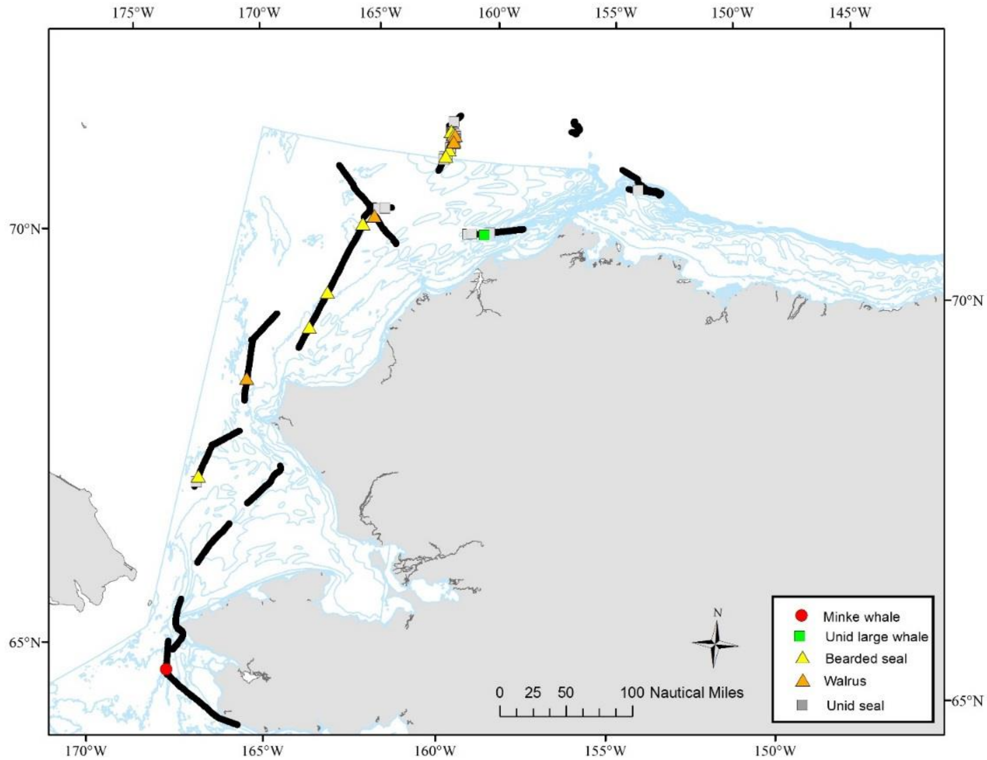

Figure 18. Marine mammal on-effort sightings and effort data from the ARCWEST/CHAOZ-X 2015 research cruise, Beaufort Sea to Bering Strait.

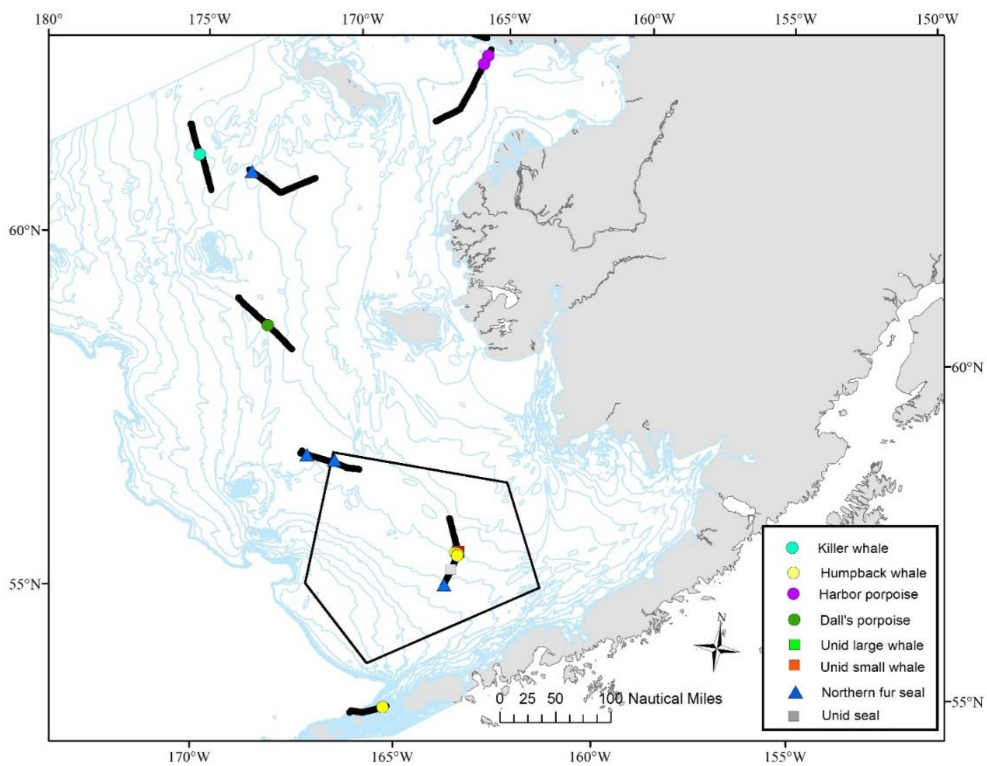

Figure 19. Marine mammal on-effort sightings and effort data from the ARCWEST/CHAOZ-X 2015 research cruise, Bering Sea.

Photo-identification

Attempts were made to collect identification photographs of target species to allow evaluation of movements of animals during the survey and comparison to existing catalogs. Priority species for photo-identification on the ARCWEST survey were killer, fin, gray, and humpback whales, but of these only killer and humpback whales were seen. When the observers located a target species, visual survey effort was suspended, and the primary survey vessel was directed to obtain photographs of the animals. The vessel was positioned for the best lighting and angle so that photographs could be obtained of each species' identifiable marks. Photographs were taken using Nikon D200 and D300 autofocus digital SLR cameras equipped with 80-200 mm zoom lens. All photographs were reviewed, and the highest quality identification photograph(s) of each animal will be compared to existing photo-identification catalogs from the Bering and Chukchi Seas and along the Aleutian Chain. Photographs were obtained from two killer whales and four humpback whales. Photographs will be matched to existing catalogs and archived for future photo-identification projects.

Seabird observations

In conjunction with the 2015 ARCWEST/CHAOZ-X projects, marine bird and mammal surveys were conducted by N. Hajdukovich onboard the F/V Aquila. The cruise began on 9 September in Nome, AK and continued to the westernmost end of the Beaufort Sea, then returned south through the Bering Sea, ending in Dutch Harbor on 28 September. The majority of surveys were conducted in the Chukchi Sea, but surveys were also conducted throughout the Bering Sea. The data obtained during these surveys will be processed and archived in the North Pacific Seabird Database (USFWS and USGS, Anchorage, Alaska) and with the Bureau of Ocean Energy Management (BOEM). These surveys were funded by BOEM under project title 'Seabird Distribution and Abundance in the Offshore Environment' (study AK-10-10).

Figure 20. Seabird observer Nick Hajdukovich.

Surveys were conducted using U.S. Fish and Wildlife Service Protocols. Observations were made from the port side of the bridge during daylight hours while the ship was underway. The observer scanned the water ahead of the ship using hand-held 10x binoculars if necessary for identification and recorded all birds and mammals within a 300 m, 90^o arc from the bow to the beam. We used strip transect methodology and three distance bins extending from the vessel: 0-100 m, 101-200 m, and 201-300 m and recorded the animal's behavior (flying, on water, on ice, foraging). During this cruise we occasionally had to reduce the transect window to 200 m or 100 m due to rough seas or fog, and at times we could not conduct surveys. Rare birds, large flocks, and mammals beyond 300 m or on the starboard side (off-transect) were also recorded but will not be included in density calculations. Birds on the water or on ice, or actively foraging were counted continuously. Flying birds were recorded during quick 'Scans' of the transect window, with scan intervals based on ship speed (typically about 1 per min). Observations were entered directly into a GPS-integrated laptop computer using the program DLOG3 (A.G. Ford Consultants, Portland, OR). Location data was also recorded automatically at 20 sec intervals, providing continuous records on weather, Beaufort Sea State, ice coverage, glare, and observation conditions. Survey efforts in the Bering Sea were difficult this year due to severe weather, heavy seas, and fog that often limited visibility.

Table 10. Birds seen on-transect during the 2015 ARCWEST cruise.

		CHUKCHI		**NBSEA**		**SBSEA**		**All Regions**	
Common Name	**Scientific Name**	#	%	#	%	#	%	#	%
Pacific Loon	*Gavia pacifica*	112	3.1%	14	0.3%	2	0.1%	128	1.13%
Red-throated Loon	*Gavia stellata*	2	0.1%	1	0.0%		0.0%	3	0.03%
Yellow-billed Loon	*Gavia adamsii*		0.0%	2	0.0%	1	0.0%	3	0.03%
Loon spp	*Gavia spp*	15	0.4%	1	0.0%	1	0.0%	17	0.15%
Red-necked Grebe	*Podiceps grisegena*		0.0%	1	0.0%		0.0%	1	0.01%
Northern Fulmar	*Fulmarus glacialis*	22	0.6%	231	4.1%	610	28.2%	863	7.60%
Black-footed Albatross	*Phoebastria nigripes*		0.0%		0.0%	2	0.1%	2	0.02%
Laysan Albatross	*Phoebastria immutabilis*		0.0%	10	0.2%	9	0.4%	19	0.17%
Fork-tailed Storm-Petrel	*Oceanodroma furcata*		0.0%	1	0.0%	71	3.3%	72	0.63%
Mottled Petrel	*Pterodroma inexpectata*		0.0%	1	0.0%		0.0%	1	0.01%
Short-tailed Shearwater	*Puffinus tenuirostris*	492	13.7%	3075	54.9%	690	31.9%	4257	37.50%
Dark Shearwater	*Puffinus spp*	71	2.0%	1623	29.0%		0.0%	1694	14.92%
Pelagic Cormorant	*Phalacrocorax pelagicus*		0.0%	42	0.8%		0.0%	42	0.37%
Harlequin Duck	*Histrionicus histrionicus*		0.0%		0.0%	4	0.2%	4	0.04%
Long-tailed Duck	*Clangula hyemalis*	111	3.1%	13	0.2%		0.0%	124	1.09%
Northern Pintail	*Anas acuta*		0.0%		0.0%	20	0.9%	20	0.18%
King Eider	*Somateria spectabilis*	31	0.9%	6	0.1%		0.0%	37	0.33%
Common Eider	*Somateria mollissima*	1	0.0%	1	0.0%		0.0%	2	0.02%
Spectacled Eider	*Somateria fischeri*	1	0.0%		0.0%		0.0%	1	0.01%
Eider spp	*Somateria spp*		0.0%	3	0.1%		0.0%	3	0.03%
Duck spp	*Anatinae spp*		0.0%	2	0.0%		0.0%	2	0.02%
Peregrine Falcon	*Falco peregrinus*		0.0%	1	0.0%		0.0%	1	0.01%
Red Phalarope	*Phalaropus fulicarius*	3	0.1%	1	0.0%	3	0.1%	7	0.06%
Red-necked Phalarope	*Phalaropus lobatus*	5	0.1%		0.0%	1	0.0%	6	0.05%
Phalarope spp	*Phalaropus spp*	44	1.2%		0.0%	10	0.5%	54	0.48%
Shorebird spp	*Charadriiforme spp*		0.0%	1	0.0%		0.0%	1	0.01%
Parasitic Jaeger	*Stercorarius parasiticus*	31	0.9%	2	0.0%	1	0.0%	34	0.30%
Pomarine Jaeger	*Stercorarius pomarinus*	24	0.7%	8	0.1%	2	0.1%	34	0.30%
Jaeger spp	*Stercorarius spp*	2	0.1%	4	0.1%		0.0%	6	0.05%
Black-legged Kittiwake	*Rissa tridactyla*	435	12.1%	162	2.9%	42	1.9%	639	5.63%
Red-legged Kittiwake	*Rissa brevirostris*		0.0%	7	0.1%	13	0.6%	20	0.18%
Kittiwake spp	*Rissa spp*		0.0%		0.0%	1	0.0%	1	0.01%
Glaucous Gull	*Larus hyperboreus*	24	0.7%	23	0.4%	5	0.2%	52	0.46%
Glaucous-winged Gull	*Larus glaucescens*		0.0%		0.0%	18	0.8%	18	0.16%
Herring Gull	*Larus argentatus*		0.0%	54	1.0%	8	0.4%	62	0.55%
Sabine's Gull	*Xema sabini*	3	0.1%	5	0.1%		0.0%	8	0.07%
Slaty-backed Gull	*Larus schistisagus*		0.0%	5	0.1%		0.0%	5	0.04%
Thayer's Gull	*Larus thayeri*	1	0.0%		0.0%		0.0%	1	0.01%
Gull spp	*Laridae spp*	1	0.0%	2	0.0%		0.0%	3	0.03%
Common Murre	*Uria aalge*	124	3.5%	19	0.3%	177	8.2%	320	2.82%
Thick-billed Murre	*Uria lomvia*	53	1.5%	18	0.3%	116	5.4%	187	1.65%
Murre spp	*Uria spp*	133	3.7%	14	0.3%	79	3.7%	226	1.99%
Ancient Murrelet	*Synthliboramphus antiquus*	196	5.5%	63	1.1%	81	3.8%	340	3.00%
Kittlitz's Murrelet	*Brachyramphus brevirostris*	35	1.0%		0.0%		0.0%	35	0.31%
Cassin's Auklet	*Ptychoramphus aleuticus*		0.0%		0.0%	2	0.1%	2	0.02%
Crested Auklet	*Aethia cristatella*	1119	31.2%	9	0.2%	12	0.6%	1140	10.04%
Least Auklet	*Aethia pusilla*	400	11.1%	26	0.5%	6	0.3%	432	3.81%
Parakeet Auklet	*Aethia psittacula*	54	1.5%	31	0.6%	42	1.9%	127	1.12%
Whiskered Auklet	*Aethia pygmaea*		0.0%		0.0%	16	0.7%	16	0.14%
Auklet spp	*Aethia spp*	6	0.2%	5	0.1%	1	0.0%	12	0.11%
Horned Puffin	*Fratercula corniculata*	7	0.2%	57	1.0%	22	1.0%	86	0.76%
Tufted Puffin	*Fratercula cirrhata*	2	0.1%	54	1.0%	75	3.5%	131	1.15%
Alcid spp	*Alcidae spp*	31	0.9%	2	0.0%	13	0.6%	46	0.41%
Passerine spp	*Passeriforme spp*		0.0%		0.0%	4	0.2%	4	0.04%
		3591		**5600**		**2160**		**11351**	

A total of 96 transects covering 1680 km were surveyed during the cruise. By geographic region, this survey effort included 46 transects covering 903 km in the Chukchi Sea, 31 transects covering 575 km in the northern Bering Sea, and 13 transects covering 202 km in the southern Bering Sea. In this report, we summarize the total number (raw counts) of birds and marine mammals detected and the sub-totals for each region.

A total of 54 species of birds comprised of 11,351 individuals were recorded on-transect (Table 10). The most numerous species (in order of number of observations) included: short-tailed/sooty shearwater (*Puffinus tenuirostris/griseus*), crested auklet (*Aethia cristatella*), northern fulmar (*Fulmarus glacialis*), black-legged kittiwake (*Rissa tridactyla*), least auklet (*Aethia pusilla*), ancient murrelet (*Synthliboramphus antiquus*), and common and thick-billed murres (*Uria spp*).

This year, short-tailed/sooty shearwaters comprised the majority (52%) of observations (Table 10), with highest numbers just south of the Bering Strait (Figure 21). Crested auklets were the next most abundant species, comprising 10% of total birds throughout the cruise (Table 10). This is in strong contrast to the 2014 ARCWEST cruise when the most abundant species observed were least and crested auklets, and shearwaters were only 2% of the total number of birds observed.

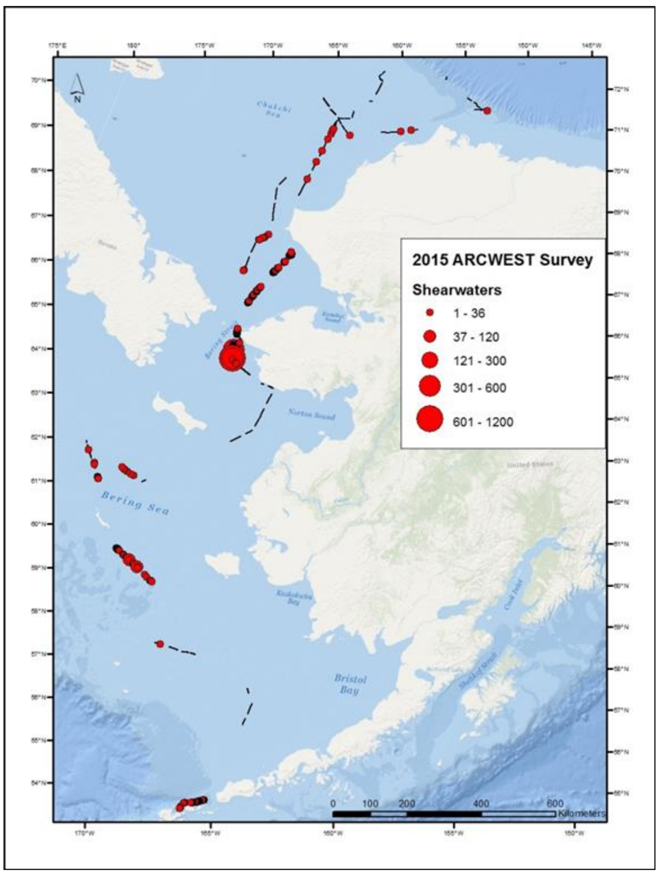

Figure 21. Distribution of short-tailed/sooty shearwaters (*Puffinus tenuirostris/griseus*) observed during the 2015 ARCWEST/CHAOZ-X cruise.

Crested auklets were the most numerous species in the Chukchi Sea, with the largest concentrations around Hanna Shoal, between Point Hope and Point Barrow (Figure 2). Birds were loosely distributed in small to large groups and almost all individuals appeared to be flightless. Although heavy molt was not observed, it is assumed that they were either molting and/or too overweight from feeding to lift off the water. Least auklets became more frequent as we transited south between Point Hope and the Bering Strait and they were the most numerous species on several transects over Hope Basin (Figure 22). Ancient murrelets were also observed in relatively high numbers, with highest numbers in the Chukchi Sea, where they comprised ~6% of total birds (Table 10).

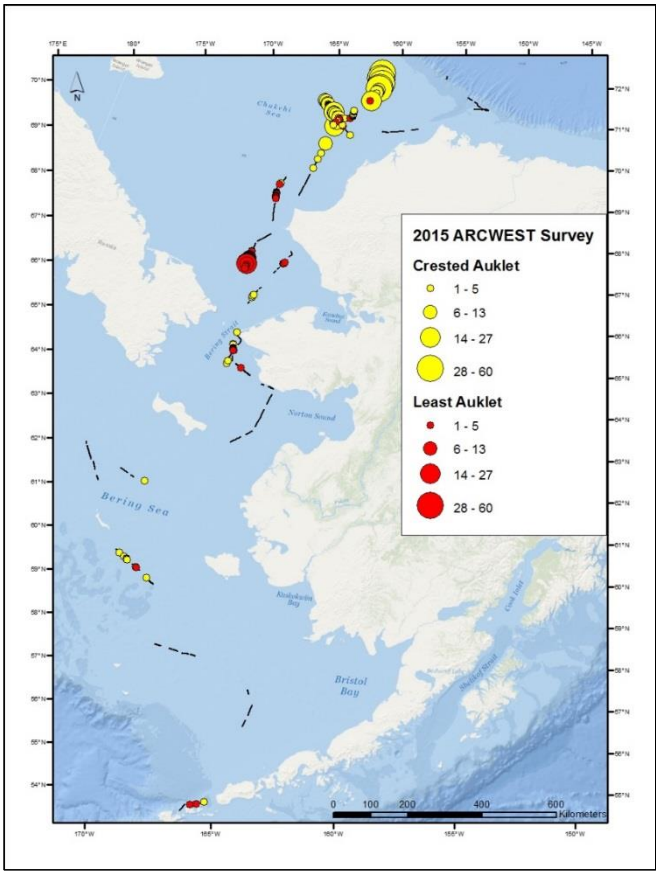

Figure 22. Distribution of crested auklet (*Aethia cristatella*) and least auklet (*Aethia pusilla*) observed during the 2015 ARCWEST/CHAOZ-X cruise.

Northern fulmars were consistently observed throughout the study area, with a notable shift in color morphs from light morph in the north to dark morph in the south. In the Chukchi Sea, over 90% of the birds were light morph, which shifted to ~ 50/50 mix in the northern Bering Sea and up to 90% dark morph birds in the southern Bering Sea.

Both common murres (*Uria aalge*) and thick-billed murres (*Uria lomvia*) were observed throughout most of the study area and made up 2.8% and 1.7% of the total number of birds observed, respectively. Thick-billed murres were concentrated north of St. Matthew Island in the Bering Sea and around Point Hope in the Chukchi Sea, while common murres predominated in the southern Bering Sea and near Bering Strait (Figure 23). The majority of murres observed were either in small groups (5-8) or in pairs consisting of an adult (likely male) and a hatch-year bird. In both murre species, the male parent completes raising their single chick at sea once the chick is fully feathered.

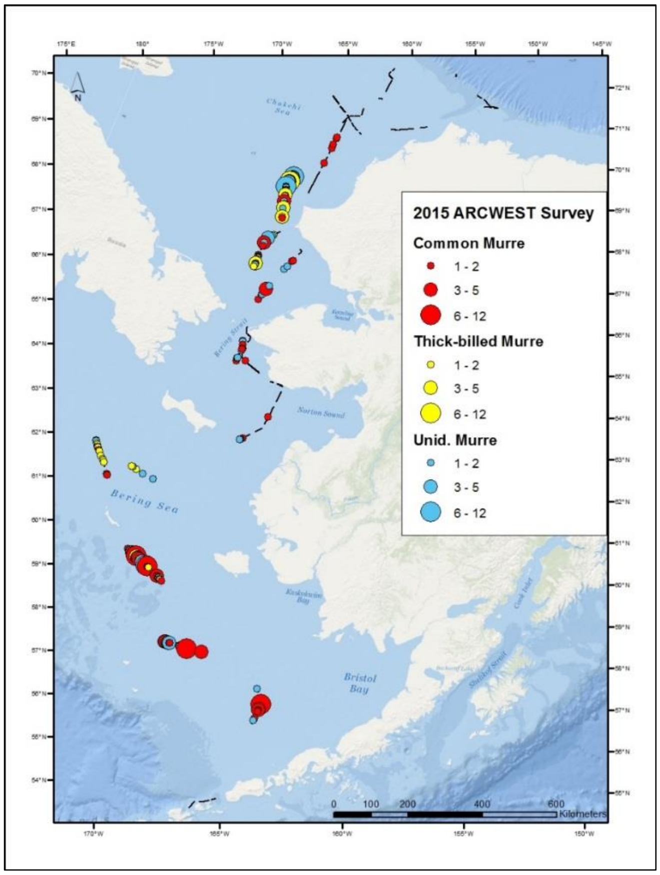

Figure 23. Distribution of common murre (*Uria aalge*) and thick-billed murre (*Uria lomvia*) observed during the 2015 ARCWEST/CHAOZ-X cruise.

One of the most widespread species in the study area, black-legged kittiwakes were 5.6% of the total number of birds observed, with the highest numbers, and greatest percentage of total birds occurring in the Chukchi Sea (Table 10). We observed several less common or rare species of note. In the northern Bering Sea, over 90% of the 54 herring gulls (*Larus argentatus*) observed appeared to belong to the Siberian subspecies, *vegae*, and five slaty-backed gulls (*Larus shistisagus*), another Siberian taxa, were also observed. A single Thayer's gull (*Larus thayeri*) in the Chukchi Sea was recorded; this is typically a more easterly (Canadian Arctic) species, although it has been seen in small numbers at Barrow in the fall in recent years. A single mottled petrel (*Pterodroma inexpectata*) was observed between St. Matthew and St. Lawrence islands, which is at the northern extent of the species' range. A single sub-adult short-tailed albatross (*Phoebastria albatrus*) was observed off-transect in the southern Bering Sea.

The seabird observations in 2015 differed in species composition and numbers of birds from those recorded during the 2014 ARCWEST survey. These differences were likely due at least in part to temporal and spatial differences in survey effort. In 2015 surveys were distributed between the Chukchi and Bering seas, whereas in 2014 bird surveys were conducted almost solely in the Chukchi Sea. In the Chukchi Sea, which was surveyed both years, the most obvious difference between years was the near absence of short-tailed shearwaters in 2014. The 2014 cruise occurred several weeks later than in 2015, and thus shearwaters might have already begun to migrate out of the area towards breeding grounds in the southern hemisphere.

Dragging and recovery attempts

A small array of three long-term passive acoustic AURAL recorders was deployed for the BOWFEST project in 2008. Recovery efforts from the USCGC *Healy* in 2009 were unsuccessful, and time constraints prevented dragging operations during that cruise. These recorders were located closer to the edge of Barrow Canyon than in previous years, and it is thought that either the strong currents worked off the flotation or a landslide occurred, the result being that two moorings were found to be horizontal when they were interrogated prior to recovery in 2009. Only one of these recorders is still in a position to allow for dragging operations. Unfortunately this year we did not have sufficient time to attempt to recover this mooring. However, we successfully dragged for, and retrieved, the long oceanographic mooring at the M4 site in the Bering Sea that did not release (Figure 24).

Figure 24. Successful dragging attempt and retrieval of mooring through A-frame.

ACKNOWLEDGMENTS

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APPENDICES

Appendix 1. List of personnel

Position	Name	Institution
Chief Scientist, Lead Acoustics	Catherine Berchok	NMML/AFSC
Lead Oceanography	Geoff Lebon (on behalf of Stabeno)	PMEL
Acoustician	Jessica Crance	NMML/AFSC
Acoustician	Stephanie Grassia	NMML/AFSC
Mammal Observer	Eliza Ives	NMML/AFSC
Mammal Observer	Alex Ulmke	NMML/AFSC
Oceanography	Dan Langis	PMEL/NOAA Corps.
Seabird observer	Nick Hajdukovich	U.S. Fish and Wildlife Service
Independent acoustician*	Charlie Muirhead	BRP, Cornell University
Independent acoustician**	Danielle Cholewiak	NEFSC
Independent oceanographer**	Natalie Monacci	Univ. Alaska Fairbanks

*On board for Chukchi Sea leg only, 9-22 September
**On board for Bering Sea leg only, 22-28 September

Appendix 2. Abbreviations for instruments.

Abbreviation	Name of Instrument
IPS	Ice Profiler
TAPS	Tracor Acoustic Profiler System
ADCP	Acoustic Doppler Current Profiler
PAR	Photosynthetically active radiation
SUNA	Submersible Ultraviolet Nitrate Analyzer
RDCP	Recording Doppler Current Profiler
RCM	Recording Current Meter
SBE	Seabird Electronics Temperature Recorder and SBE SeaCAT Conductivity and Temperature Recorder
ISUS	In situ ultraviolet spectrometer nitrate sensor
FLUOR	Environmental Characterization Optics Fluorometer
MTR	Mini Temerature Recorder
MC	MicroCAT Conductivity and Temperature Recorder
SAMI	Submersible Autonomous Moored Instrument for pH and pCO2
SeaFET	Sea field effect transistor pH Sensor
AURAL	NMML Autonomous Underwater Recorder for Acoustic Listening
Eppley	Eppley Radiometer Package

Appendix 3. Sonobuoy deployment date, time, position (decimal degrees), and species detected (1=detected, 0=not detected, 2=maybe)

Station #	Date	Time	Latitude	Longitude	Depth (m)	Gunshot	RW	Bow	Hump	Fin	Orca	Gray	Bearded	Walrus	Unk. Pinn.	Other	Unknown
1	9/9/2015	10:51:32	65.0012	-168.3446	51	0	0	0	0	1	0	0	0	0	0	0	0
2	9/9/2015	14:07:12	65.2681	-168.0947	54	0	0	0	0	1	0	0	0	0	0	0	0
3	9/9/2015	21:13:53	65.70187	-168.19382	44	0	0	0	0	0	0	0	0	0	0	0	0
4	9/11/2015	0:00:00	67.2907	-166.68273	46	0	0	0	0	1	0	1	0	0	0	0	0
5	9/11/2015	17:05:04	67.5414	-166.21112	48	0	0	0	0	0	0	1	0	0	0	0	0
6	9/11/2015	20:00:16	67.67962	-166.0361	42	0	0	0	0	0	0	0	0	0	0	0	0
7	9/11/2015	20:29:16	67.70817	-165.98302	50	0	0	0	0	0	0	0	0	0	0	0	0
8	9/11/2015	23:07:25	67.95953	-166.3145	42	0	0	0	0	0	0	0	0	0	0	0	0
9	9/12/2015	2:11:30	68.33267	-167.16047	42	0	0	0	0	0	0	0	0	0	0	0	0
10	9/12/2015	5:12:44	68.74183	-166.68543	38	0	0	0	0	0	0	0	0	0	0	0	0
11	9/12/2015	8:02:52	69.14998	-166.13708	28	0	0	0	0	0	0	1	0	0	0	0	0
12	9/12/2015	10:58:04	69.615	-165.73907	40	0	0	0	0	0	0	0	0	0	0	0	0
13	9/12/2015	14:17:44	70.13888	-165.26175	44	0	0	0	0	0	0	0	0	0	0	0	0
14	9/12/2015	17:21:50	70.61603	-164.84675	46	0	0	0	0	0	0	0	0	0	0	0	0
15	9/12/2015	17:36:43	70.65408	-164.80875	48	0	0	0	0	0	0	0	0	0	0	0	0
16	9/12/2015	19:50:03	71.0017	-164.45648	44	0	0	0	0	0	0	0	0	0	0	0	0
17	9/12/2015	19:55:01	71.1483	-164.44443	44	0	0	0	0	0	0	0	0	0	0	0	0
18	9/13/2015	2:23:19	71.1751	-163.79872	45	0	0	0	0	0	0	0	0	0	0	0	0
19	9/13/2015	2:30:44	71.16325	-163.75097	45	0	0	0	0	0	0	0	0	0	0	0	0
20	9/13/2015	2:37:00	71.15318	-163.71057	46	0	0	0	0	0	0	0	0	0	0	0	0
21	9/13/2015	5:08:59	71.08708	-162.50537	48	0	0	0	0	0	0	0	0	0	0	0	0
22	9/13/2015	8:13:09	71.05292	-161.01543	54	0	0	0	0	0	0	0	0	0	0	0	0
23	9/13/2015	14:17:52	71.06722	-160.22652	54	0	0	0	0	0	0	0	0	0	0	0	0
24	9/13/2015	17:29:01	71.16675	-158.6714	94	0	0	1	0	0	0	0	0	0	0	0	0
25	9/13/2015	23:02:06	71.3421	-157.25982	100	0	0	0	0	0	0	0	0	0	0	0	0
26	9/13/2015	23:07:05	71.34728	-157.22837	104	0	0	0	0	0	0	0	0	0	0	0	0
27	9/14/2015	2:08:42	71.5333	-156.01422	170	0	0	0	0	0	0	0	0	0	0	0	0
28	9/14/2015	5:05:03	71.56897	-155.34873	74	0	0	1	0	0	0	0	1	0	0	0	0
29	9/14/2015	14:36:46	71.7198	-153.37875	100	0	0	1	0	0	0	0	0	0	0	0	0
30	9/14/2015	17:09:47	71.85213	-154.06662	200	0	0	0	0	0	0	0	0	0	0	0	0
31	9/14/2015	17:16:00	71.86295	-154.07863	218	0	0	0	0	0	0	0	0	0	0	0	0
32	9/14/2015	20:05:25	72.02258	-154.82037	458	0	0	0	0	0	0	0	0	0	0	0	0
33	9/14/2015	22:44:52	72.18537	-155.45963	480	0	0	0	0	0	0	0	0	0	0	0	0
34	9/15/2015	5:13:00	72.4552	-156.57823	900	0	0	0	0	0	0	0	0	0	1	0	0
35	9/15/2015	21:07:35	72.612	-156.67433	1000	0	0	0	0	0	0	0	0	0	0	0	0
36	9/15/2015	23:19:10	72.60945	-157.8433	250	0	0	0	0	0	0	0	0	0	0	0	0
37	9/16/2015	2:05:26	72.5961	-159.21598	69	0	0	0	0	0	0	2	0	1	0	0	0
38	9/16/2015	5:04:14	72.59233	-160.32853	49	0	0	0	0	0	0	0	1	1	0	0	0
39	9/16/2015	5:18:17	72.5919	-160.40795	48	0	0	0	0	0	0	0	1	1	0	0	0
40	9/16/2015	11:02:01	72.50823	-161.39255	43	0	0	0	0	0	0	0	0	0	0	0	0
41	9/16/2015	11:09:09	72.50348	-161.40605	43	0	0	0	0	0	0	0	0	0	0	0	0
42	9/16/2015	11:03:49	72.49797	-161.42123	43	0	0	0	0	0	0	0	0	0	0	0	0
43	9/16/2015	17:27:03	72.06332	-161.60182	27	0	0	0	0	0	0	0	0	0	0	0	0
44	9/16/2015	20:57:05	71.7747	-161.92958	40.1	0	0	0	0	0	0	0	0	0	0	0	0

Station #	Date	Time	Latitude	Longitude	Depth (m)	Gunshot	RW	Bow	Hump	Fin	Orca	Gray	Bearded	Walrus	Unk. Pinn.	Other	Unknown
45	9/16/2015	21:08:22	71.77552	-162.00973	40.8	0	0	0	0	0	0	0	0	0	0	0	0
46	9/16/2015	21:12:04	71.77578	-162.03572	41	0	0	0	0	0	0	0	0	0	0	0	0
47	9/16/2015	23:08:53	71.78712	-162.89552	33.8	0	0	0	0	0	0	0	0	0	0	0	0
48	9/17/2015	1:59:32	71.80595	-164.21122	38	0	0	0	0	0	0	0	0	0	0	0	0
49	9/17/2015	5:07:25	71.8231	-165.44563	40	0	0	0	0	0	0	0	0	0	0	0	0
50	9/17/2015	8:48:38	71.7129	-165.7186	41	0	0	0	0	0	0	0	0	0	0	0	0
51	9/17/2015	11:39:40	71.38208	-164.71617	40	0	0	0	0	0	0	0	0	0	0	0	0
52	9/17/2015	15:09:24	71.23165	-164.22088	41	0	0	0	0	0	0	0	0	0	0	0	0
53	9/17/2015	15:14:38	71.23312	-164.19643	42	0	0	0	0	0	0	0	0	0	0	0	0
54	9/17/2015	15:18:46	71.23435	-164.1771	42	0	0	0	0	0	0	0	0	0	0	0	0
55	9/17/2015	19:50:26	71.33158	-163.26553	43.5	0	0	0	0	0	0	0	0	1	0	0	0
56	9/17/2015	23:04:09	71.34573	-163.46845	42	0	0	0	0	0	0	0	0	0	0	0	0
57	9/18/2015	2:12:06	71.08165	-163.88322	41.1	0	0	0	0	0	0	0	0	0	0	0	0
58	9/18/2015	5:09:06	70.86048	-163.64267	43	0	0	0	0	0	0	0	0	0	0	0	0
59	9/18/2015	5:12:38	70.85603	-163.6396	43	0	0	0	0	0	0	0	0	0	0	0	0
60	9/18/2015	11:39:39	70.8449	-163.13447	41	2	0	0	0	0	0	0	0	0	0	0	0
61	9/18/2015	16:04:14	71.0945	-163.91208	41	0	0	0	0	0	0	0	0	0	0	0	0
62	9/18/2015	20:19:00	71.19517	-164.29185	42.9	0	0	0	0	0	0	0	0	0	0	0	0
63	9/18/2015	23:02:22	70.82965	-164.98732	37.6	0	0	0	0	0	0	0	0	0	0	0	0
64	9/19/2015	2:03:28	70.45095	-165.64745	41	0	0	0	0	0	0	0	0	0	0	0	0
65	9/19/2015	5:04:09	70.12288	-166.23875	43	0	0	0	0	0	0	0	0	0	0	0	0
66	9/19/2015	8:02:57	69.7971	-166.80708	44	0	0	0	0	0	0	0	0	0	0	0	0
67	9/19/2015	11:02:27	69.47555	-167.36027	45	0	0	0	0	0	0	0	0	0	0	0	0
68	9/19/2015	11:06:55	69.46745	-167.3739	45	0	0	0	0	0	0	0	0	0	0	0	0
69	9/19/2015	14:45:06	69.17812	-167.60645	49	0	0	2	0	0	0	0	0	0	0	0	0
70	9/19/2015	17:25:01	68.80248	-167.54468	45	0	0	0	0	0	0	0	0	0	0	0	0
71	9/19/2015	17:32:36	68.78692	-167.54318	45	0	0	0	0	0	0	0	0	0	0	0	0
72	9/19/2015	20:08:17	68.46702	-167.45075	42	0	0	0	0	0	0	0	0	0	0	0	0
73	9/19/2015	23:05:25	68.12498	-167.1667	47	0	0	0	0	0	0	0	0	0	0	0	0
74	9/20/2015	2:07:39	68.00855	-166.97945	53	0	0	0	0	0	0	0	0	0	0	0	0
75	9/20/2015	5:07:22	68.25078	-166.94193	35	0	0	0	0	0	0	0	0	0	0	0	0
76	9/20/2015	7:44:23	68.21533	-167.20433	43	0	0	0	0	0	0	0	0	0	0	0	0
77	9/20/2015	13:03:59	67.92168	-168.15153	56	0	0	0	0	0	0	0	0	0	0	0	0
78	9/20/2015	13:07:55	67.92445	-168.14253	56	0	0	0	0	0	0	0	0	0	0	0	0
79	9/20/2015	18:55:13	67.51002	-168.43892	46.5	0	0	0	0	1	0	0	0	0	0	0	0
80	9/20/2015	23:00:59	67.00053	-168.57965	39.4	0	0	0	1	1	0	0	0	0	0	0	0
81	9/21/2015	2:03:30	66.54055	-168.62945	49.2	0	0	0	0	0	0	0	0	0	0	0	0
82	9/21/2015	5:06:58	66.06412	-168.5491	51	0	0	0	0	0	0	0	0	0	0	0	0
83	9/21/2015	8:06:05	65.59655	-168.36227	47	0	0	0	0	0	0	0	0	0	0	0	0
84	9/21/2015	11:09:01	65.14328	-168.18985	48	0	0	0	0	1	0	0	0	0	0	0	0
85	9/21/2015	14:08:04	64.83213	-167.58522	32	0	0	0	0	0	0	0	0	0	0	0	0
86	9/22/2015	20:10:12	63.10238	-167.08998	21.8	0	0	0	0	0	0	0	0	0	0	0	0
87	9/23/2015	5:07:57	62.37275	-169.15478	32.1	0	0	0	2	0	0	0	0	0	0	0	0
88	9/23/2015	8:11:16	62.0906	-169.92917	41	0	0	0	0	0	0	0	0	0	0	0	0
89	9/23/2015	11:07:36	61.81578	-170.69358	47	0	0	0	0	0	0	0	0	0	0	0	0
90	9/23/2015	14:12:04	61.58825	-171.34593	52	0	0	0	0	0	0	0	0	0	0	0	0

Station #	Date	Time	Latitude	Longitude	Depth (m)	Gunshot	RW	Bow	Hump	Fin	Orca	Gray	Bearded	Walrus	Unk. Pinn.	Other	Unknown
91	9/23/2015	14:27:35	61.5963	-171.39055	52	0	0	0	0	0	0	0	0	0	0	0	0
92	9/23/2015	17:21:00	61.68748	-171.8408	56	0	0	0	2	1	0	0	0	0	0	0	0
93	9/23/2015	20:07:04	61.7658	-172.33855	59.1	0	0	0	0	0	0	0	0	0	0	0	0
94	9/23/2015	23:05:16	61.86015	-172.87898	59.1	0	0	0	2	1	0	0	0	0	0	0	0
95	9/24/2015	2:04:09	61.96612	-173.43653	60	0	0	0	0	1	0	0	0	0	0	0	0
96	9/24/2015	5:08:31	62.06207	-173.97435	63	0	0	0	0	1	0	0	0	0	0	0	0
97	9/24/2015	8:01:58	62.15557	-174.50102	71	0	0	0	0	1	0	0	0	0	0	0	0
98	9/24/2015	15:02:24	61.90852	-174.28608	73	0	0	0	0	1	0	0	0	0	0	0	0
99	9/24/2015	16:30:43	61.80693	-174.0428	72	0	0	0	0	1	0	0	0	0	0	0	0
100	9/24/2015	20:08:12	61.31023	-173.4006	72.1	0	0	0	0	0	0	0	0	0	0	0	0
101	9/24/2015	21:11:51	61.16475	-173.20573	71.4	0	0	0	1	0	0	0	0	0	0	0	0
102	9/24/2015	23:04:30	60.9167	-172.87575	64.2	0	0	0	0	0	0	0	0	0	0	0	0
103	9/25/2015	2:02:53	60.53995	-172.3793	54.4	0	0	0	0	0	0	0	0	0	0	0	0
104	9/25/2015	6:54:44	59.96028	-171.75722	65	0	0	0	2	0	2	0	0	0	0	1	1
105	9/25/2015	14:26:08	59.75398	-171.1787	70	0	0	0	0	1	0	0	0	0	0	0	0
106	9/25/2015	17:02:13	59.58948	-170.55877	66	0	0	0	0	0	0	0	0	0	0	0	0
107	9/25/2015	20:01:51	59.36317	-169.8211	58.5	0	0	0	0	0	0	0	0	0	0	0	0
108	9/25/2015	23:02:04	59.10165	-169.35697	53.4	0	0	0	0	0	0	0	0	0	0	0	0
109	9/26/2015	2:08:12	58.69833	-169.19792	61.1	0	0	0	0	1	0	0	0	0	0	0	0
110	9/26/2015	5:09:21	58.32057	-169.02985	66	0	0	0	0	0	0	0	0	0	0	0	0
111	9/26/2015	8:01:29	57.93242	-168.89367	67	0	0	0	0	1	1	0	0	0	0	0	0
112	9/26/2015	17:24:25	57.86162	-168.12257	68	0	0	0	0	0	0	0	0	0	0	0	0
113	9/26/2015	17:33:51	57.8586	-168.07342	68	0	0	0	0	0	0	0	0	0	0	0	0
114	9/26/2015	20:04:10	57.8291	-167.26342	64.7	0	0	0	0	0	0	0	0	0	0	0	0
115	9/26/2015	23:05:59	57.76652	-166.28208	64.7	1	1	0	0	0	0	0	0	0	0	0	0
116	9/26/2015	23:34:36	57.7576	-166.13303	61.9	1	1	0	0	0	0	0	0	0	0	0	0
117	9/27/2015	1:59:41	57.71277	-165.39773	58.4	1	0	0	0	1	0	0	0	0	0	0	0
118	9/27/2015	2:23:50	57.70558	-165.27082	57.1	1	0	0	0	0	0	0	0	0	0	0	0
119	9/27/2015	7:02:34	57.65538	-164.69842	53	0	0	0	0	0	0	0	0	0	0	0	0
120	9/27/2015	7:09:20	57.639	-164.68518	54	0	0	0	2	0	0	0	0	0	0	0	0
121	9/27/2015	8:39:56	57.4181	-164.50792	64	2	0	0	0	1	0	0	0	0	0	0	0
122	9/27/2015	10:12:35	57.18878	-164.3248	66.7	0	0	0	0	1	0	0	0	0	0	0	0
123	9/27/2015	11:09:20	57.04977	-164.21815	66	0	2	0	0	1	0	0	0	0	0	0	0
124	9/27/2015	12:06:47	56.90025	-164.1087	68	1	1	0	1	1	0	0	0	0	0	0	1
125	9/27/2015	12:44:28	56.83845	-164.07073	70	1	1	0	1	2	0	0	0	0	0	0	1
126	9/27/2015	18:18:35	56.62048	-164.17833	78	0	0	0	0	1	0	0	0	0	0	0	0
127	9/27/2015	20:18:06	56.34182	-164.33035	85.9	0	0	0	0	1	0	0	0	0	0	0	0
128	9/27/2015	23:09:00	55.89657	-164.55342	93.1	0	0	0	0	0	0	0	0	0	0	0	0
129	9/28/2015	2:01:39	55.40875	-164.7996	102	0	0	0	0	1	2	0	0	0	0	0	0
130	9/28/2015	5:06:32	54.94437	-165.02468	96.3	0	0	0	0	1	1	0	0	0	0	0	0
131	9/28/2015	8:09:25	54.5279	-165.22523	110	0	0	0	2	0	0	0	0	0	0	0	0
132	9/28/2015	11:00:46	54.3438	-165.55787	101	0	0	0	0	0	0	0	0	0	0	0	0
133	9/28/2015	14:17:26	54.19342	-166.2271	218	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 4. Mooring designs (all mooring designs provided by Mike Craig from the PMEL mooring shop at NOAA (Seattle, WA)).

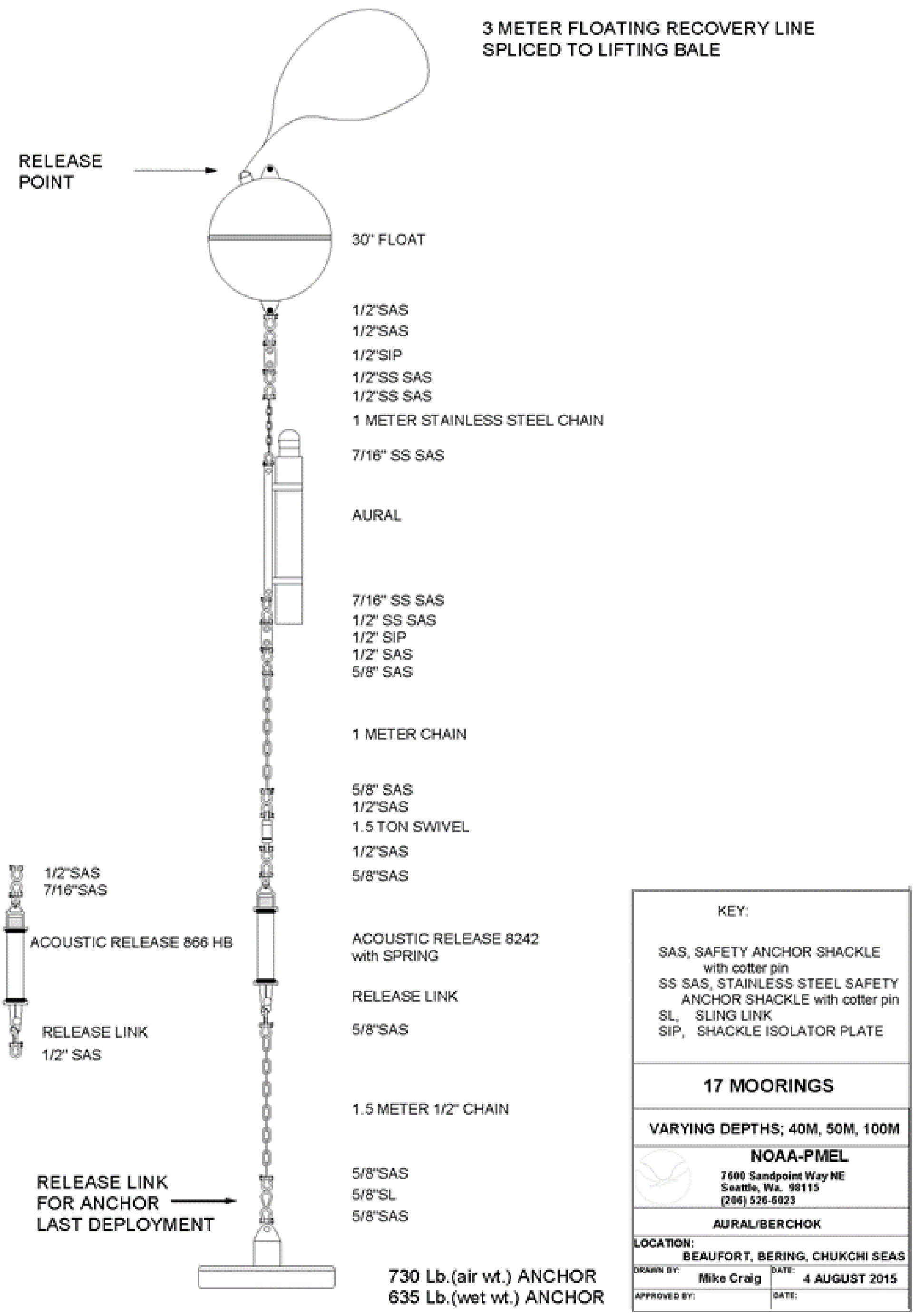
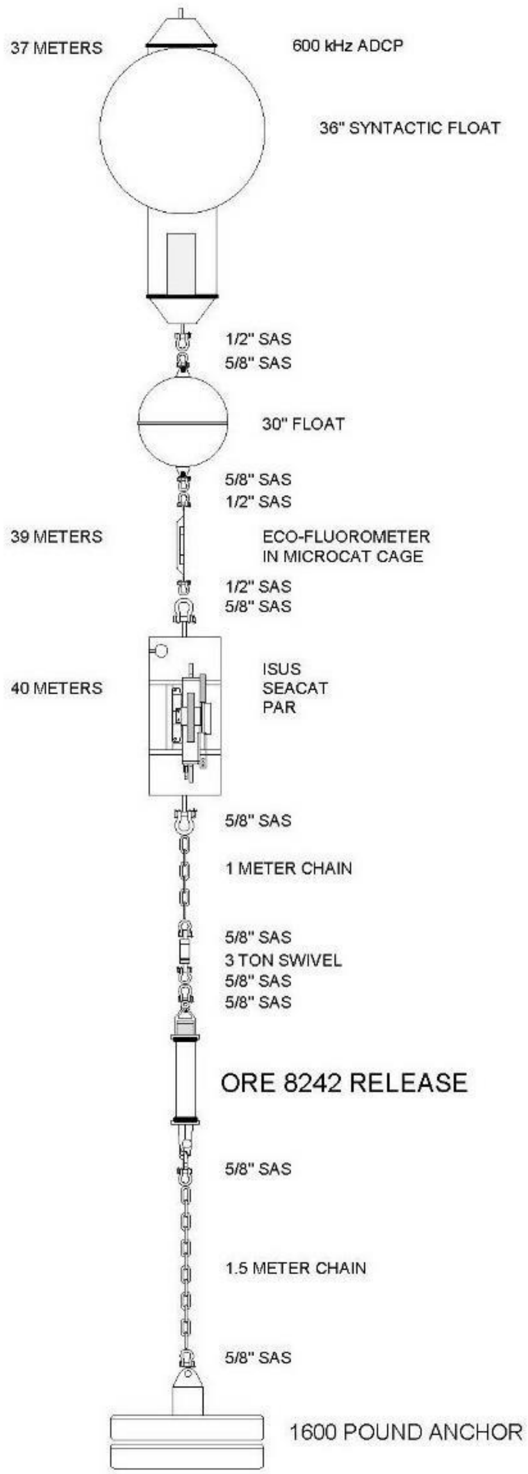


Figure A 4.1. Mooring design for the passive acoustic moorings. Two different types of acoustic releases were used among the moorings.



INSTRUMENT	DEPTH M	SERIAL NO.
600kHzADCP	37	
ECOFLO	39	
ISUS	40	
SEACAT	40	
PAR	40	
BOTTOM	44	

NOAA-PMEL-FOCI
7600 Sandpoint Way NE
Seattle, Wa. 98115
(206) 526-6175

MOORING: 12CKP-2A

LOCATION:

DRAWN BY: Rick Miller DATE: 9 MAY 2012

APPROVED BY: DATE:

Figure A 4.2. Mooring design for 14CKP moorings. In addition to the 600 kHz ADCP (currents), this mooring contains instruments to measure nitrate (ISUS), temperature and salinity (Seacat), fluorescence (EcoFluorometer) and Photosynthetically Active Radiation (PAR).

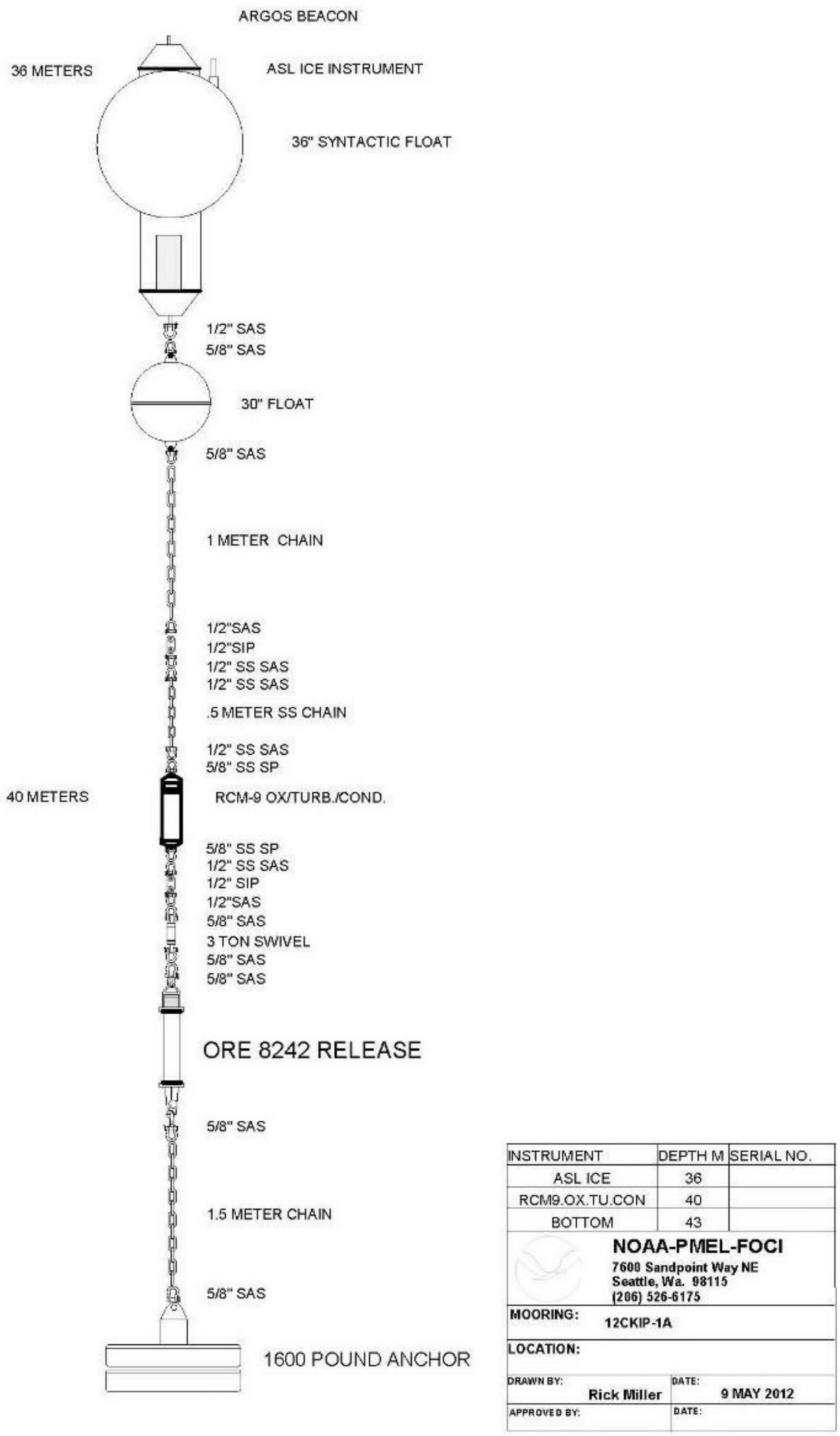


Figure A 4.3. Mooring design for 14CKIP moorings. In addition to the ASL ice instrument (measures ice thickness), this mooring contains an RCM9 that measures currents, temperature, oxygen, and turbidity.

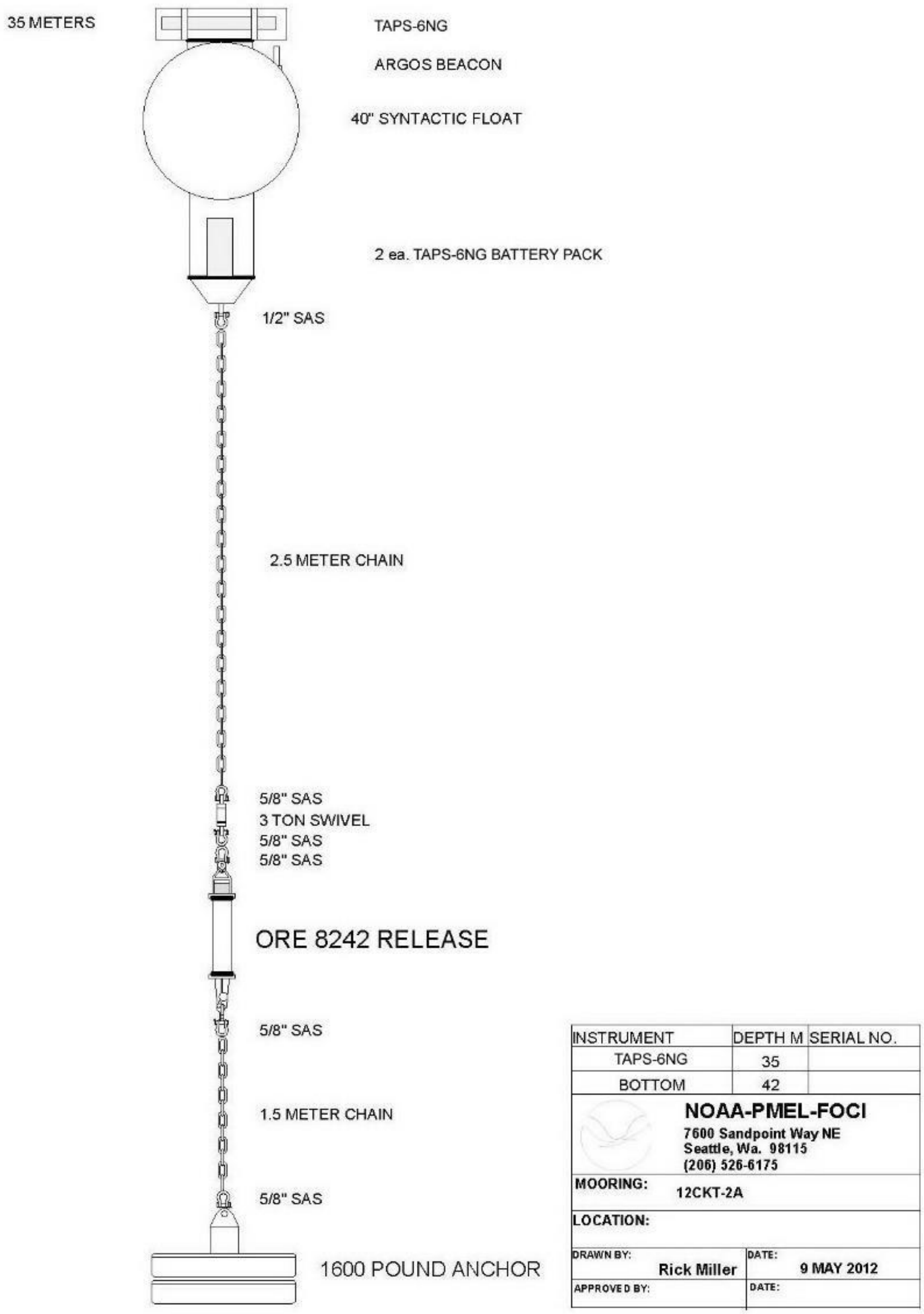


Figure A 4.4. Design for 14CKT moorings. The TAPS-6NG is an instrument that acoustically measures zooplankton bio-volume and is optimized to detect krill.

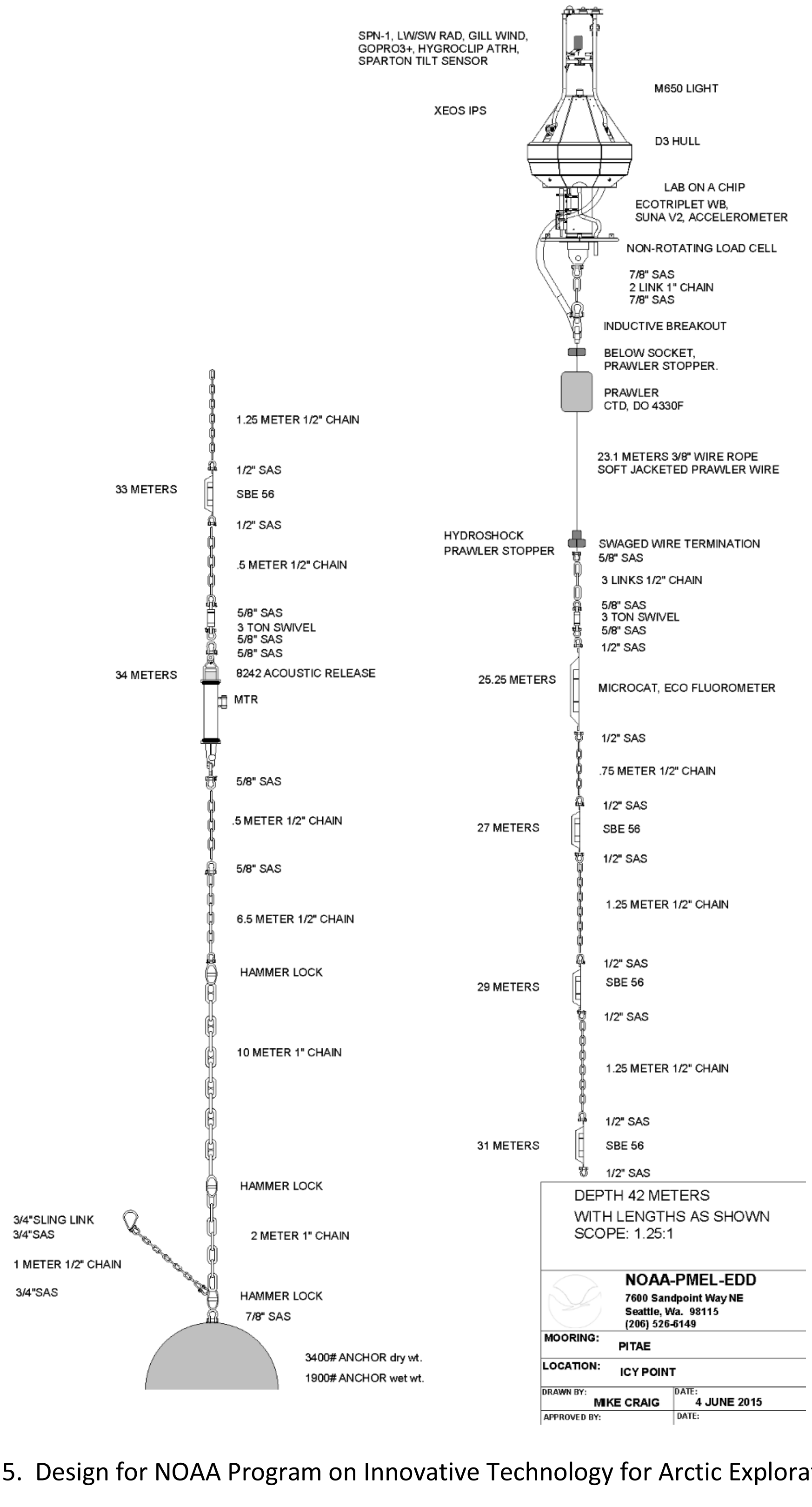


Figure A 4.5. Design for NOAA Program on Innovative Technology for Arctic Exploration (PITAE)mooring.