OCS Study
BOEM 2018-008

Chukchi Offshore Monitoring in Drilling Area (COMIDA): Factors Affecting the Distribution and Relative Abundance of Endangered Whales and Other Marine Mammals in the Chukchi Sea

Final Report of the Chukchi Sea Acoustics, Oceanography, and Zooplankton Study: Hanna Shoal Extension (CHAOZ-X)

Marine Mammal Laboratory
Alaska Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
7600 Sand Point Way NE, Seattle, WA 98115-6349

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3801 Centerpoint Drive, Suite 500
Anchorage, AK 99503-5823

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Prepared for:

Environmental Studies Program
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U.S. Department of Interior
3801 Centerpoint Drive, Suite 500
Anchorage Alaska 99503-5823

Submitted through:
Marine Mammal Laboratory
Alaska Fisheries Science Center
National Marine Fisheries Service, NOAA
U.S. Department of Commerce
7600 Sand Point Way NE
Seattle, Washington 98115-6349

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Email of corresponding editors: Nancy.Friday@noaa.gov and Jessica.Crance@noaa.gov

KEY PERSONNEL (IN ALPHABETICAL ORDER)

Catherine L. Berchok[1], Ph.D. – Passive acoustics P.I.

Manuel Castellote[2], Ph.D. – Acoustic environment noise analysis P.I.

Christopher Clark[3], Ph.D. – Noise Modeling and Auto-detection Buoy P.I.

Jessica L. Crance[1], M.S. – Passive acoustics, Final Report Editor

Nissa Ferm[4], M.S. – Zooplankton

Nancy A. Friday[1], Ph.D. – CART and GAM analysis

Julie A. Mocklin[2], M.S. – Program Coordinator, Final Report Editor

Jeff Napp[4], Ph.D. – Zooplankton P.I.

Dimitri Ponirakis[3], Ph.D. – Noise Modeling and Auto-detection Buoy

Brenda K. Rone[1], M.S. – Visual Survey P.I.

Yu Shiu[3], Ph.D. – Noise Modeling and Auto-detection Buoy

Adam H. Spear[4], M.S. – Zooplankton

Phyllis Stabeno[5], Ph.D. – Physical Oceanography P.I.

[1] Marine Mammal Lab (MML), Alaska Fisheries Science Center, NOAA Fisheries Service, 7600 Sand Point Way NE, Seattle, WA 98115-6349

[2] Joint Institute for the Study of the Atmosphere and Ocean (JISAO), University of Washington, 7600 Sandpoint Way NE, Seattle, WA 98195

[3] Bioacoustics Research Program (BRP), Cornell University, 159 Sapsucker Woods Road, Ithaca, NY 14850

[4] Resource Assessment and Conservation Engineering (RACE) Division, Alaska Fisheries Science Center, NOAA Fisheries Service, 7600 Sand Point Way NE, Seattle, WA 98115-6349

[5] Pacific Marine Environmental Laboratory (PMEL), Ocean Environment Research Division, 7600 Sand Point Way NE, Seattle, WA 98115-6349

I. LIST OF ACRONYMS

AB: Auto-detection buoy (sometimes with a year attached indicating when deployed and operated)

ACC: Alaska Coastal Current

ADCP: Acoustic Doppler Current Profiler

AET: Acoustic Ecology Toolbox

AFSC: Alaska Fisheries Science Center

ANOVA: Analysis of Variance statistical method

AMSR-E: Advanced Microwave Scanning Radiometer – Earth Observing System

ARCWEST: Arctic Whale Ecology Study

ARGOS: Advanced Research and Global Observation Satellite

ASAMM: Aerial Surveys of Arctic Marine Mammals

AURAL: Autonomous Underwater Recorder for Acoustic Listening

AW: Anadyr Water

BCB: Bering-Chukchi-Beaufort

BIA: Biologically Important Area

BIC: Bayesian Information Criterion

BOEM: Bureau of Ocean Energy Management

BOWFEST: Bowhead Whale Feeding Ecology Study

BW: Bering Water

CHAOZ: Chukchi Sea Acoustics, Oceanography, and Zooplankton Study

CHAOZ-X: Chukchi Sea Acoustics, Oceanography, and Zooplankton Study Extension

COMIDA: Chukchi Offshore Monitoring In Drilling Area

Cornell-BRP: Cornell-Bioacoustics Research Program

CQT: Constant-Q Transform

CS: Communication Space

CSESP: Chukchi Sea Environmental Studies Program

CTD: Conductivity, Temperature, Depth sensor instrument package

CV: Coefficient of Variation

dB: decibel

DB: Double Bubbles

DFT: Discrete Fourier Transform

DiFAR: Directional Frequency Analysis and Recording

DVM: Diel Vertical Migration

DWBA: Distorted-wave Born Approximation

EcoDAT: Recruitment Process Program Relational database

EcoFOCI: Ecosystems and Fisheries-Oceanography Coordinated Investigations

EIS: Environmental Impact Statement

EOSDIS: Earth Observing System Data and Information System

FFT: Fast Fourier Transform

FLAC: Free Lossless Audio Codec

FM: Frequency Modulated

GAM: Generalized Additive Model

GCV: Generalized Cross-Validation

GLM: Generalized Linear Model

GMT: Greenwich Mean Time

GPS: Global Positioning System

GUI: Graphical User Interface

HMM: Hidden Markov Model

HOG: Histogram of Oriented Gradient

IDL: Interactive Data Language

ISUS: In Situ Ultraviolet Spectroscopy

JISAO: Joint Institute for the Study of the Atmosphere and Ocean

LFDCS: Low-frequency Detection and Classification System

MARU: Marine Autonomous Recording Unit

MGCV: Mixed GAM Computation Vehicle

MML: Marine Mammal Laboratory

MODIS: Moderate Resolution Imaging Spectroradiometer

NARR: North American Regional Reanalysis

NARW: North Atlantic right whale

NPRW: North Pacific right whale

NCEI: National Center for Environmental Information

NCEP: National Centers for Environmental Prediction

NCEPR2: National Centers for Environmental Prediction Reanalysis 2

NEFSC: North East Fisheries Science Center

NEPA: National Environmental Policy Act

NMDS: non-metric multidimensional scaling plot

NOAA: National Oceanic and Atmospheric Administration

NPOESS: National Polar-orbiting Operational Environmental Satellite System

NSF: National Science Foundation

NSIDC: National Snow and Ice Data Center

PAM: Passive Acoustic Mooring

PAR: Photosynthetically Active Radiation

PMEL: Pacific Marine Environmental Laboratory

ROC: Receiver Operating Characteristic

SMNMS: Stellwagen Bank National Marine Sanctuary

SCM: Subsurface Chlorophyll Maximum

SBE 49: SeaBird FastCAT CTD

SECR: Spatially Explicit Capture-Recapture

SPL: Sound Pressure Level

SPW: Sparton sonobuoy

SSMI/S: Special Sensor Microwave Imager/Sounder

SBNMS: Stellwagen Bank National Marine Sanctuary

STFT: Short Time Fourier Transform

SUNA: Submersible Ultraviolet Nitrate Analyzer

TAPS6-NG: Tracor Acoustic Profiling System 6 - Next Generation

TEK: Traditional Ecological Knowledge

USGS: United States Geological Survey

USS: Undersea Sensor Systems

UTC: Coordinated Universal Time

VHF: Very High Frequency

WHOI: Woods Hole Oceanographic Institution

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V. EXECUTIVE SUMMARY

The Chukchi Sea Acoustics, Oceanography, and Zooplankton Extension study (CHAOZ-X) was initiated in May 2013 through an Interagency Agreement between the Bureau of Ocean Energy Management (BOEM) and the Alaska Fisheries Science Center Marine Mammal Laboratory (AFSC/MML). The focus of the study was to determine the circulation of water around the Hanna Shoal area, the source of this water (Chukchi Shelf, Arctic Basin, or Bering Sea), 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 was studied relative to whale distribution and habitat utilization in the northeastern Chukchi and extreme western Beaufort Seas. The goal was to shed light on the mechanisms responsible for the high biological activity around the shoal, so that we can predict, in a qualitative way, the effects of climate change on these preferred habitats. The use of moorings allowed us to quantify transport and water properties, as well as determine year-round occurrence of marine mammals, especially during > 6 months that the region is ice-covered.

The study had six principal objectives:

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 focal 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 acoustic environment, 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.

The objectives of CHAOZ-X were addressed using multiple research disciplines. The study area was in the northeastern Chukchi Sea, which encompassed the Hanna Shoal region. Data were collected both over the short-term (roughly, one month), during ship surveys, and long-term, from year-round passive acoustic and oceanographic moorings. Data were collected in three, year-long mooring deployments (2012-13, 2013-14, and 2014-15), as well as during four oceanographic field surveys in August and September (one each in 2013 and 2014, and two in 2015). Research efforts during the field seasons[1] included visual surveys, zooplankton and oceanographic sampling (CTD and Tucker sled zooplankton tows), passive acoustic monitoring (sonobuoys), drifter deployments, and a near-real-time auto-detection buoy (2014 only) that provided acoustic detections and ambient noise data via an Iridium satellite link. Research off-

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[1] A fourth non-CHAOZ-X field season in 2016 covered some of the same moorings, sampling stations, and tracklines as the CHAOZ-X study and will be included here as practicable.

season included analysis of data from long-term moorings (passive acoustic and biophysical) and noise modeling to establish baseline low-frequency acoustic environment conditions and predictions on future low-frequency acoustic conditions (<1 kHz) under a variety of possible scenarios that included biotic, abiotic and anthropogenic sound sources. All locations for data collection systems among the various research disciplines during the CHAOZ-X project are shown in Figure 1. The locations of the data collection systems for the concurrent ARCWEST (ARCtic Whale Ecology Study; Mocklin and Friday 2018) project, as well as those previously covered by the CHAOZ study (Berchok et al. 2015) are included in Figure 1 for completeness. In addition, Figure 1 also shows the study areas for the industry-sponsored Chukchi Sea Environmental Studies Program (CSESP).

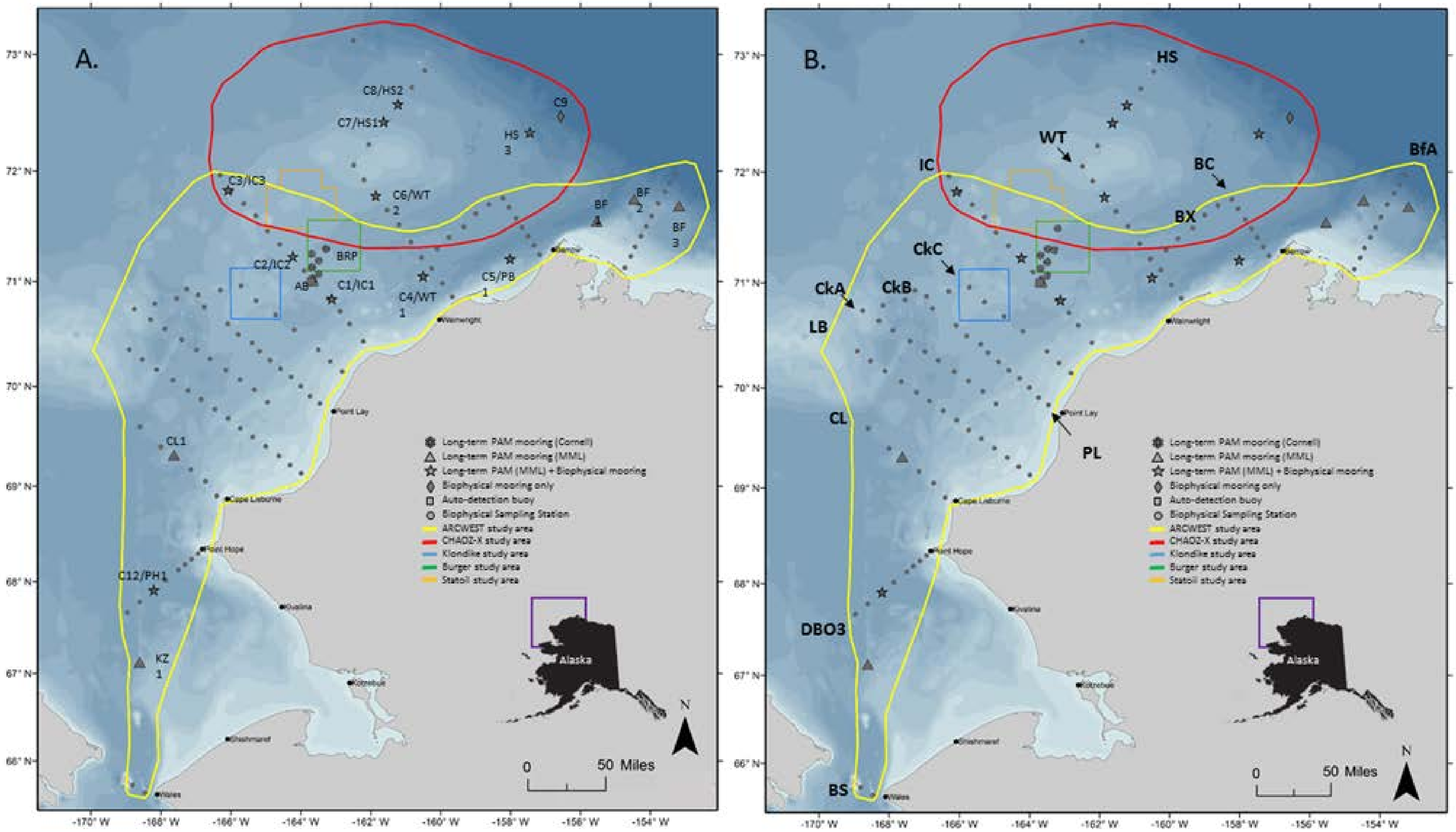
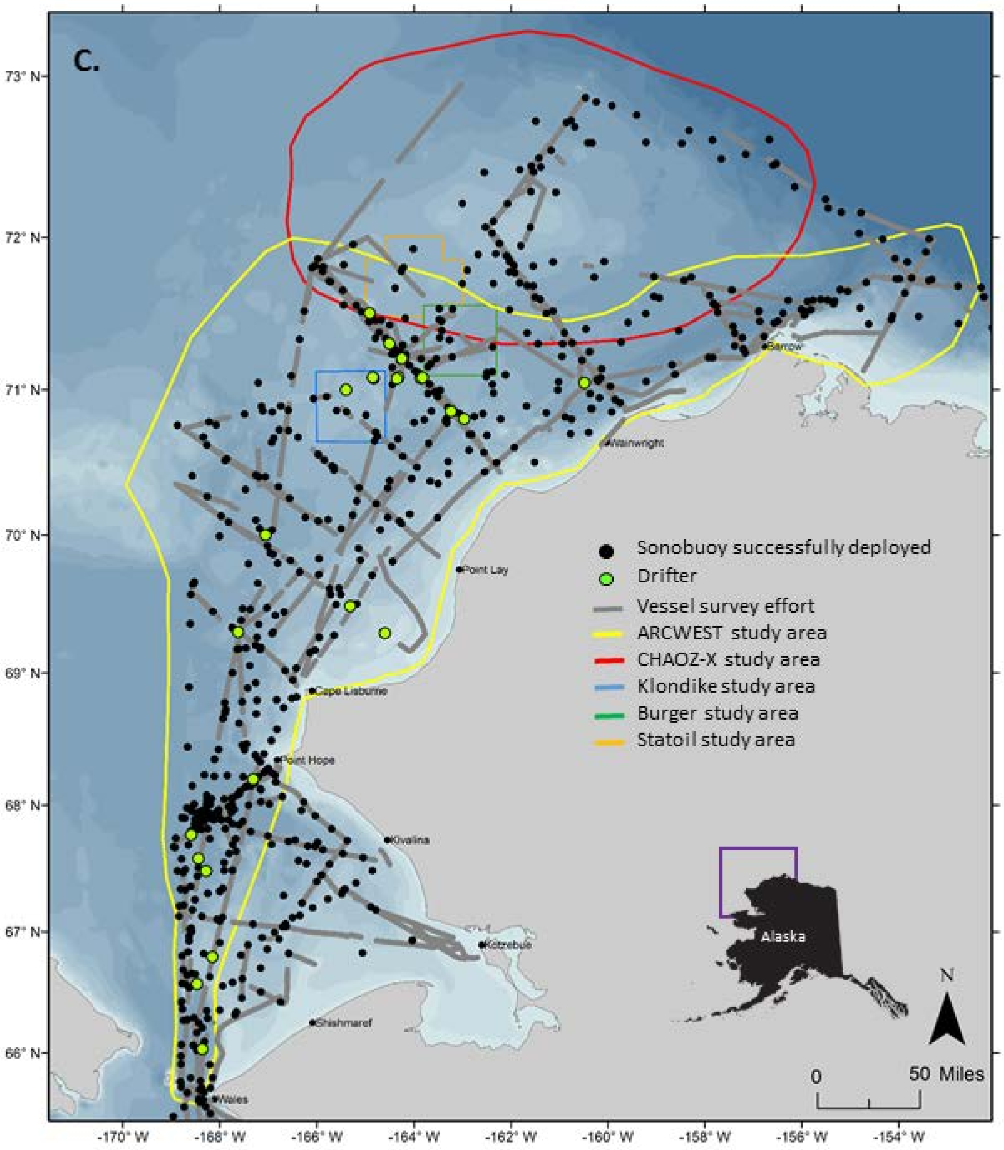


Figure 1. Map showing general study area for the CHAOZ-X project (red outline), the concurrent BOEM-funded ARCWEST project (yellow outline) and CSESP study areas (blue, green, orange outlines). A) mooring locations; B) line transect sampling stations; and C) visual survey and passive acoustic monitoring effort, 2010-2015.

Figure 1 cont.



Key Findings

The complex region encompassing the CHAOZ-X study area in the northern Chukchi Sea supports a complicated ecosystem: persistence of sea ice, weak currents supporting a retention area, landscape ecology, and regional and local meteorological and oceanographic forcing all combine to determine whether or not there will be favorable conditions for the species that live there.

The impact of Hanna Shoal (target region for CHAOZ-X study) on the rest of the Chukchi Sea shelf, is disproportionate to its physical size. Through a complicated series of physical, chemical, and biological mechanisms, the shoal affects the entire regional food web with impacts reaching all the way to humans. Biological productivity around this bathymetric feature is highly sensitive to changes in the primary physical driver in the system - sea ice. Hanna Shoal may therefore be very well suited for continued monitoring for the effects of climate variability and change. That is, it may be a sentinel site for future changes to the Chukchi Sea ecosystem due to loss of sea ice.

A substantial presence of four Arctic species (bowhead, *Balaena mysticetus*, and beluga whales *Delphinapterus leucas*; bearded seals, *Erignathus barbatus*; and walrus, *Odobenus rosmarus*) and one subarctic species (ribbon seals, *Histriophoca fasciata*) was found in this study area. Marine mammals are excellent proxies for ecosystem change, since they respond to shifts in abundance and distribution of large zooplankton and small fish taxa. Of the species detected in this study, one is planktivorous (bowhead), another predominantly piscivorous (beluga), and two are obligate benthic feeders (walrus and bearded seal). Another factor that challenges our comprehension of Chukchi Sea dynamics is the degree to which each species depends on or coexists with seasonal sea ice. Listed below are some key findings of this research.

- The relatively weak, anti-cyclonic (clockwise) currents around Hanna Shoal help to retain ice, algal cells and local primary production.
- The retention of ice over the shoal and its melting help to maintain a two layer vertical structure over the shoal.
- Sufficient concentrations of nitrate and ammonium to support primary production are found in the bottom layer even in September.
- Levels of chlorophyll, a proxy for phytoplankton biomass, are elevated during summer over the top of the shoal, and the southern and northeastern flanks
- Chlorophyll concentration were in the layer below the pycnocline. Shallow water depths and sufficient nutrient levels in this layer suggest that primary production continues throughout the summer at depth.
- The abundance of large crustacean zooplankton such as euphausiid adults and juveniles (*T. raschii)* and copepods (*Calanus glacialis*) were not enhanced over the shoal during the CHAOZ-X summer sampling periods. If anything, their abundance over the shoal was less than that from the surrounding shelf areas.
- The zooplankton community composition over the top and flanks of the shoal was not different from the assemblage of taxa observed over surrounding areas of the Chukchi Sea shelf.
- Biological production at Hanna Shoal is highly dependent on: the prolonged presence of sea ice, the strength of water column stratification, the concentration of nitrogenous nutrients in the bottom layer, and the depth of the shoal. The first three factors are all influenced by climate and local weather patterns. Therefore the role that Hanna Shoal plays in providing habitat and production to the surrounding ecosystem is susceptible to change in the future.
- Both bowhead and beluga whales undergo consistent, predictable seasonal migrations, with multimodal pulses in fall bowhead and spring beluga calling activity supporting Traditional Ecological Knowledge (TEK) and current research showing age/sex/population segregation during migration. The spring migration is not constrained to the nearshore lead. High levels of spring bowhead calling activity were detected at the continental slope site (HS3, Figure 1a).

- The gunshot call type occurred at end of the bowhead whale calling peaks, and were strongly associated with the formation of ice.
- Beluga whales were consistently detected overwinter at most moorings and most years.
- A double-knock sound (on the shoal in the spring) occurs simultaneously with beluga whale calling activity; we are currently investigating whether it could be from fish.
- Walrus were detected over winter at all Hanna Shoal and western mooring sites. The highest and most sustained winter levels were at the western mooring site (IC3, Figure 1a). Levels there steadily decreased from 2010 to 2015. Most saturated and sustained summer walrus calling activity levels were on the shoal sites.
- Bearded seal calling is ubiquitous in the CHAOZ-X study area year-round.
- Although Hanna Shoal was a prime gray whale (*Eschrichtius robustus*) feeding area in the past, there was only one day with detections on any of the mooring sites on the shoal for the entire study.
- Ribbon seals were the most commonly detected subarctic species, with half of all detection days occurring on the slope. Very few days had humpback (*Megaptera novaeangliae*) or killer whale (*Orcinus orca*) calling. No fin (*Balaenoptera physalus*[2]), minke (*Balaenoptera acutorostrata*), right (*Eubalaena japonica*), or sperm (*Physeter macrocephalus*) whales were detected.
- Airgun and vessel noise was present during the open water season; ice noise was detected over the winter. There are a few cases of airguns being detected that could not be attributed to a U.S. permitted activity on the U.S. Outer Continental Shelf.
- The PH1 site had a higher diversity of biological contributors to the acoustic environment than WT1 for both the open water and ice seasons in 2012-2013. For both locations, the dominating contributors were vessel noise, bowhead whales, bearded seals, and walrus. Bowhead whale contribution is limited to the migration periods but it is stronger than the winter-long bearded seal contribution. Vessel noise influence is stronger than any other contributor in WT1 but not PH1.
- Ambient noise during the 2012-2013 ice season was higher in PH1 than WT1 likely due to increased ice related noise.
- This study illustrates the importance of utilizing multiple survey methods. Comparison of visual survey and passive acoustic monitoring results during the fall cruises found that bowhead whales, fin whales, humpback whales, and walrus were equally likely (or for beluga and killer whales – equally unlikely) to be sighted or detected during the August-October time period of these cruises. For gray whales, bearded seals, minke whales, and the two porpoise species, however, there was not a meaningful correlation between visual sightings and acoustic detections, so a lack of acoustic detections for these species cannot be used as a proxy for their lack of occurrence in the area at this time of the year.
- An auto-detection buoy was successfully deployed, operated and recovered in the Arctic approx. 55 nm off Icy Cape. The system detected and transmitted clips of biotic and abiotic sounds as well as spectral distribution data via satellite in near-real time from 20 August through 06 October 2014. The initial bloom of bowhead call detections occurred on 18 September and was still occurring when the system was recovered on 6 October.
- A novel, automated acoustic-event detection process applied to multiple years of data revealed patterns in the numbers and types of acoustic events. Results support the possibility that this type of unsupervised detection process could be efficiently applied to

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[2] Only IC3 had analysis conducted for fin whales.

the extensive amount of acoustic data to elucidate the seasonal and spatial distributions of acoustically active marine mammals as well abiotic and anthropogenic sound sources.

- Insights into future environmental noise conditions were obtained by modeling a suite of future scenarios that included predicted wind noise under future medium and high wind conditions, vessel noise from a variety of vessel types and speeds, and noise from drilling operations. Highest levels of lost communication space are predicted to occur for calling bowheads nearest a drilling site with shipping traffic, while lowest levels are predicted to occur for singing bowheads furthest from the drilling site. Future wind conditions are predicted to have much less influence on bowhead acoustic communication than anthropogenic noise sources.

Section VII: Marine Mammal Distribution

Three year-long deployments of five long-term passive acoustic recorders, totaling 3,464 days, were made within the CHAOZ-X study area from 2012-2015. Combined with the 397 days collected in this area during the 2010-2012 CHAOZ study, 3,859 days of fully analyzed data were included in this report. Generally, the seasonal and spatial distributions of sounds from the five main Arctic marine mammal species (bowhead, beluga, and gray whales, walrus, and bearded seals), the five subarctic species (fin, killer, humpback, and minke whales, and ribbon seals), anthropogenic sources (airguns and vessel), and environmental (ice) sources in the CHAOZ-X study area were consistent with those patterns determined from aerial and vessel surveys, satellite tagging efforts, and other passive acoustic studies, as well as the natural history of these species obtained from TEK.

Bowhead whale fall and spring migrations were detected as pulses in calling activity levels. Fall migration was detected between August/September and November/December in all years at all sites except for the slope site (HS3, Figure 1a); lack of fall pulse at that site supports the bowhead migration gently fanning out once past Pt. Barrow. Fall calling activity was multimodal, supporting TEK of age/sex calls segregation during migration. Also, the gunshot call type was present near the end of each peak in fall calling activity. The presence of bowheads in the CHAOZ-X study area in the spring indicates that the spring migration does not appear to be contained entirely in the nearshore lead. This spring pulse in calling activity was shorter in duration and at lower levels than the fall pulse. High levels of spring calling were detected at the slope site (HS3, Figure 1a). As expected, bowheads leave the Chukchi Sea in the winter; no calling activity was present from January to March at any mooring in any year. However, calling activity was present in the summer, between the spring and fall pulses of calling, blurring the boundaries between them.

Two populations of beluga whales pass through the CHAOZ-X study area: eastern Chukchi Sea and Beaufort Sea). Belugas were detected in all four seasons. Fall calling activity was generally low compared to the spring, with highest levels at the offshore Icy Cape site (IC3, Figure 1a); this is consistent with satellite tagging, but not aerial survey results. Spring calling was highest from April through June at all sites and years and was timed from west to east, consistent with migration. Highest spring calling levels were seen on the slope. Furthermore, spring calling activity is far from the nearshore lead, supporting the view that belugas are not limited by high ice concentrations and can navigate through and among leads. Multimodal calling was evident in the spring, which could represent different populations, age/sex classes, and/or lead closures impeding their migration. Work is underway to classify repertoires for the two populations. Results from this work will allow investigation into whether they can be distinguished based on their call types. Summer calling activity was present, especially at the slope site (HS3, Figure 1a), consistent with the July range of the Eastern Chukchi Sea population. Presence of calling activity overwinter at most CHAOZ-X mooring locations and years suggests some beluga overwinter offshore. A double-knock sound (on the shoal in the spring) occurs simultaneously with beluga whale calling activity; we are currently investigating whether it could be from fish.

Bearded seal calling activity from fall through spring is present on every mooring in every year, providing evidence bearded seals are present in the Chukchi year-round instead of overwintering in the Bering. Calling activity increased from September through January, reached sustained and saturated levels from February through June (when calling ceased abruptly), corresponding with the whelping/mating/molting season; lowest levels were in July and August. The lowest levels and number of days with calling activity were on the slope site, HS3, possibly due to its depth (163 m) being near the edge of their preferred diving depth range.

A winter and summer pulse of walrus calling activity was seen in every CHAOZ-X location except on the slope (HS3, Figure 1a). Lack of calling on the slope was unsurprising given its depth (163 m) and their preference for water <100m deep. Overwinter calling was detected at all shoal and western mooring sites, with the highest and most sustained winter levels at the western mooring site (IC3, Figure 1a); levels steadily decreased from 2010 through 2015. The summer pulse of calling activity ranged from June through October, with most saturated and sustained levels occurring at the shoal sites.

Gray whales call infrequently during migration, and it is uncertain whether they call while feeding, making them a poor candidate for passive acoustic monitoring. However, the low detections in the CHAOZ-X study area fit with aerial survey results that show the major of sightings within 50 km of shore. Although Hanna Shoal was a prime gray whale feeding area in the past, there was only one day with detections on any of the mooring sites on the shoal for the entire study. The three days with detections in the CHAOZ-X study area were in the summer. No detections were made overwinter.

Few detections of subarctic species were made in the CHAOZ-X study area. Ribbon seals were the most commonly detected subarctic species (35 days); main calling activity was centered in October/November at all sites. Over half of all detection days were from the slope site, consistent with their preference for feeding on the continental slope. Calling was from July-September as well as April/May. Because calling is outside the spatial and temporal range for breeding season, this suggests their distinct breeding call is used for multiple purposes. Conversely, only one day had humpback calling (August 2014, IC3), and only five days had killer whale calling (April-September). No fin, minke, right, or sperm whales were detected; however, only IC3 (2010-2012) was analyzed for fin whales.

The long-term distribution of vessel, airgun, and ice noise activity was also analyzed. Airguns were detected during all open water seasons, but were the most ubiquitous during 2013 when several seismic surveys were underway in the Chukchi Sea. There are a few cases of airguns being detected that could not be attributed to a U.S. permitted activity. Vessels were also detected during the open water seasons; the highest and most ubiquitous levels occurred during 2012 and 2015 at the western and shoal locations, corresponding to the multi-vessel effort associated with the Shell exploratory drilling operations. Ice noise was present overwinter at all locations and during all years.

In addition to moored recorders, sonobuoys were deployed every three hours throughout each cruise (August-October, depending on year) to obtain an evenly sampled cross-survey census of marine mammal calling (Figure 1c). Concurrently, visual surveys were conducted to document the presence and distribution of marine mammals (Figure 1c). The cruise track needed to complete the mooring/sampling work was extensive, covering a wide spatial area at an important time of the year for many marine mammal species. A total of 79 sonobuoys were deployed and 504 nm of trackline were visually surveyed. In total, three cetacean species (bowhead, gray, and beluga whales), and three pinniped species (walrus, bearded, and ribbon seal) were acoustically detected, while one cetacean species (bowhead whale), one confirmed pinniped species (walrus), and polar bears (*Ursus maritimus*) were visually sighted in the study area. The results of these four years of shipboard surveys have shown that the CHAOZ-X study area is an important one for Arctic species in the August-October time period, including bowhead, walrus, and bearded seals. No subarctic species (e.g., fin, humpback, minke, and killer whales, as well as ribbon seals) were seen in the CHAOZ-X study area. The combination of visual and acoustic surveys is essential to maximize the detection potential for marine mammals. Either method alone runs the risk of missed detections and underestimating the importance of an area to a particular species. It is important to note that the season over which these statements are valid must be defined so that the data are not misinterpreted during other times of the year.

Section VIII: Biophysical Patterns and Trends

Each year, moorings were deployed on the shelf around Hanna Shoal and one mooring was deployed on the slope north of the shoal (Figure 1a). To avoid ice keels, each shelf mooring was only ~10 meters above the seafloor. These moorings contained instruments which collected data on over 15 different oceanographic parameters. Data were collected at least hourly and CTD and Niskin bottle casts were conducted following or preceding mooring recoveries and deployments to calibrate instruments on the moorings. Hydrographic surveys were also conducted yearly on seven hydrographic transect lines, two of which were centered on Hanna Shoal (Figure 1b). CTD deployments measured water column properties, and Niskin bottles collected water samples at various depths to measure oxygen, chlorophyll, nutrients (nitrate, phosphate, silicate, nitrite and ammonium), and salinity.

Bottom currents north of Hanna Shoal (C7 and C8) were weak and largely toward the west, as were currents to the east of the shoal (C6). The variability in currents was primarily wind-driven. Bottom temperature ranged from approximately -1.8 to ~ 0.0 °C, with maximum temperatures occurring in late August or September. Salinity ranged from < 31 to ~33 with short (days) periods of salinities as high as 34. The spring phytoplankton bloom was evident in each time series. Nitrate ranged from 0 – 20 μM; concentrations decreased from mid-spring through July or August and then increased during late winter and early spring. During the time of the shipboard surveys, the surface was largely depleted of nutrients along all lines. Sea ice arrived in early to mid-November, increased quickly to near 100% areal coverage and then declined precipitously in late May or June. Ice thickness increases to an average of ~3 m in March/April, with the thickest ice generally seen late in spring. Ice persisted on Hanna Shoal itself into the summer.

Bottom chlorophyll fluorescence was greatest with the melting of the sea ice and export ice associated production to the bottom. Shortly before the "dump" of primary production, there was a decrease in bottom PAR, likely a result of shading from particles in the water column. Accompanying the increase in fluorescence in bottom waters, there was an increase in percent oxygen saturation.

The frontal structure on the south side of Hanna Shoal was captured by a wave glider, which was deployed from 17 to 31 August, 2015 near C2 and Hanna Shoal. The sharp decrease in surface salinity was associated with colder SST. Both of these are a result of ice melt. Such technology could be used to explore the boundary between the Hanna Shoal region and the region to the south where advection of Bering water and ACW dominate the water properties.

Section IX: Ambient noise contributors and acoustic environment analysis

The marine mammal, vessel and airgun contribution to the acoustic environment as described for WT1 and PH1 for the 2012-2013 dataset. PH1 mooring location had a higher diversity of biological contributors than WT1 for both seasons. As expected, bowhead whale signals dominated the environment during the migration period in spring and fall in both mooring sites. Bearded seal signals were the main contributor during the ice season and overlapped with bowhead whale spring migration, but despite the more persistent occurrence of bearded seal signals throughout the season, bowhead whale contribution was 10-15 dB above the bearded seal spectrum. Walrus was another important contributor to the acoustic environment in WT1, particularly during the open water seasons. Other species such as beluga and humpback whales contributed substantially in PH1, in particular during the open water season. For both sites, most species contribution was within the 50th and 25th percentile of the corresponding seasonal ambient noise levels, except bowhead whale signals that could reach or exceed the 75th percentile.

The open water season was noisier in WT1 due to the influence of atmospheric processes, but also because of the increased vessel traffic in the area. These contributors exceeded the acoustic influence of ice-generated noise in winter. In contrast, the ambient noise in PH1 did not differ as much between seasons. These differences could be due to higher ice related noise in PH1 than WT1. Vessels provided a lower contribution to the acoustic environment in PH1 than in WT1, although for both sites the 50th spectral percentile for vessel noise often exceeded that for marine mammal species. The PH1 mooring is closer to the Bering Strait and acoustic data from this site would be expected to show a stronger vessel traffic influence, however, WT1 is exposed to the traffic related to oil and gas operations in the Chukchi Sea leases because Wainwright is a main logistics hub for those areas.

The manual analysis of passive acoustic data to detect, classify and describe seasonality, provided a powerful basis to characterize the ambient noise and the acoustic contribution of the different sound sources identified at these two mooring locations for the 2012-2013 deployment period. The spectral percentile analysis applied to this data allowed an informative description of each of the acoustic contributors and their seasonal importance in the acoustic environment in these two locations.

Section X: New Passive Acoustic Methods (Autobuoy, detection clustering analysis)

The auto-detection buoy systems (AB) successfully monitored for the occurrence of acoustically active bowhead whales and provided ambient noise measurements in near-real-time during the late summer into early fall season within the Chukchi Sea region in which seismic airgun surveys and initial drilling operations were expected to occur. As expected there were some logistical challenges in this effort, including difficult weather and ice conditions, the availability of an appropriate vessel and crew, and technical failures. When the system was operational in 2014, it operated as expected, with a detection performance of 70-93%, providing detections of bowhead sounds that indicated bowheads in the area starting in mid-September through early October, when the AB was recovered. There is every reason to conclude that future AB systems could be improved to yield even higher performance metrics. Given the dramatic technical improvements in battery technology, power efficiencies, data processing, and satellite transmission, this initial partially successful effort in the Chukchi Sea will eventually be viewed as pioneering, but relatively primitive.

To develop and implement a process by which to automatically detect acoustic events and describe their seasonal occurrence, we took a novel approach. This approach does not rely on human analysts moving methodically through a data stream in search of pre-defined types of sounds (for example, bowhead calls or bearded seal songs). Instead it utilized a well-known technique used for automated visual recognition. Also, it is important to note that an algorithm for this approach could be inserted onto the auto-buoy detection system. For this approach, we converted the sound data into a continuous visual representation of the sound stream (i.e., a spectrogram), automatically detected the occurrence of acoustic events in the stream and ascribed each event to one of n event types (n = 100). We observed structure in the results without tuning our original parametric settings: a result that is very promising. An attribute of this unsupervised approach is that one does not presume to know how many sound event types there are, except to limit the total number of possible types. Another notable benefit is that the detection analysis proceeds without the need for a human "expert", a condition that considerably reduces processing time, which reduces the cost of analysis. This does not imply that there is no need for an analyst, rather that the analyst is needed at the higher levels of analysis; i.e., the tuning of the model and parameter values, data synthesis and interpretation. Thus, for example, we can process an entire year of acoustic data for acoustic events in a matter of a few hours rather than months. However, it is important to note that at this early stage in this evolving process, those automated results need to be authenticated with detections validated by human experts. The CHAOZ and CHAOZ-X projects have very large sets of such validated detection types, so that we are now in a prime position to merge the validated data with the automatic acoustic event detection outputs to tune the event detection process.

From a relatively high level of analysis, we used passive acoustics data to describe the seasonal and spatial occurrences of bioacoustic events within the Beaufort Sea acoustic environment. We can now apply this analytical paradigm at spatial (e.g., 100 km^2, 100,000 km^2) and temporal (e.g., daily, monthly, yearly, decadal) resolutions to match the resolutions for other core components of the CHAOZ-X project. Thus, for example, it is now quite reasonable to apply high level data analytics to find structure in the passive acoustic data and use clues from those results to look for links with the oceanographic data at regional, yearly, and decadal resolutions. This process can then be tuned to explore further relationships between physical and biological factors at different spatial-temporal resolutions. The meticulously difficult work of annotating validated marine mammal acoustic detections has been accomplished (see Section VII.A). Through those results we have a clear pathway by which to tune, test and quantitatively validate results from the unsupervised, acoustic event detection approach. With this combination of assets, there is a very real chance for significant advances in understandings of relationships between arctic oceanography and biology at multiple trophic levels

Section XI. Synthesis

Patterns of marine mammal distribution to biophysical parameters

Regression tree and Generalized Additive Model (GAM) analyses were conducted on the long-term passive acoustic (for bowhead, beluga, and gray whales, bearded seals, and walrus) and biophysical datasets. These analyses were hindered by differences in instrument failure rates, which reduced the full suite of co-located data. This resulted in some important biophysical parameters being eliminated from the analysis (e.g., ice thickness, ADCP data which could be used as a proxy for zooplankton, and bottom oxygen). Future analyses with this dataset will focus on shorter time periods to increase the overlap in data availability among parameters. In addition, future studies must include prey fields (e.g., ADCP results) as well as include new technologies to measure zooplankton directly. Moreover, current GAM methods require the passive acoustic data to be reduced to binary presence/absence, and so these results should be considered tentative.

The most prominent result from the current analysis is the importance of month and ice for all species studied. Month accurately distinguishes what we know about the distribution and migration of each species. Unfortunately, it is unknown whether month is a proxy for other variables, such as prey fields, which are driving distribution and migration or whether there is an endogenous driver. The relationship between calling activity and ice concentration varied by species; this can be explained by smaller open water features such as leads and polynyas being missed by the coarse resolution of the satellite-derived data. The presence of these smaller features were often suggested by the importance of other oceanographic factors (e.g., salinity, PAR, and temperature) that can serve as proxies for ice formation or decline (whether heat or mechanically driven).Because of the importance of ice at Hanna Shoal and in the Chukchi Sea, being able to add ice thickness back into this analysis is critical to future modeling efforts.

Biological hotspots

There were a limited number of transects done around Hanna Shoal because of heavy ice during the summer field surveys. It is also important to note that these surveys provide only a brief snapshot of the ecosystem; less than a day was spent on each line per year, reducing the chances of overlap between oceanographic/zooplankton sampling and whale presence. Furthermore, the long-term passive acoustic results show the only species expected on the shoal during the field season are bowhead whales (at low levels), bearded seals, and walrus. Regardless of these difficulties, the concurrent shipboard sampling methods found four types of transect lines (see Figure 1) through the CHAOZ-X study area.

Two of these lines (Wainwright (WT) and Hanna Shoal (HS)) intersected over the shoal. At this location, lower flow and the presence of nutrients supports primary productivity and a high export of ice algae during most years, which in turn supports secondary benthic productivity. Aggregations of walrus and bearded seals, both benthic feeders, were observed. The observations in 2013 from this hotspot area were more distinct than in the other years; the difference in zooplankton abundance in the region of ice versus elsewhere). In contrast, distributions of zooplankton in 2014 and 2015 (mainly on the WT line) were more uniform.

Benthic hotspots can also form when subsurface phytoplankton blooms and/or irregular export of ice algae fuel benthic secondary productivity, resulting in a tight benthic-pelagic coupling that sustains the higher trophic levels. The Icy Cape (IC) line, at the western edge of study area, is an example of this ephemeral hotspot. The remaining transect lines on the periphery of the CHAOZ-X study are strongly influenced by bottom topography and currents. The Barrow Canyon (BC) line is situated in an area where these factors combine to bring nutrients (and prey) up from the deep basin, forming temporary hotspots by trapping prey for the upper trophic level pelagic-feeding species. The final transect line type is represented by the Box (BX) transect line. As an along-shore line, the homogeneity seen in the measurements collected for this transect line was expected, as was the absence of any hotspot areas.

Winter residence by walrus

The combined seven years of data from the CHAOZ, CHAOZ-X, and ARCWEST studies were able to provide the first evidence of walrus overwintering in the northeastern Chukchi Sea. This calling activity, though sustained at high levels for the first two years of monitoring, decreased in persistence and level throughout the next four years until the 2016-17 season saw its return to high levels. Detections were limited mostly to the offshore Icy Cape mooring location (IC3) at 120 nm off the coast. This overwintering presence was found under 100% ice concentrations, and did not show a correlation with ice thickness. True color satellite imagery, however, shows the presence of a vast network of leads and polynyas that can facilitate passage of the walrus to this offshore area both northward from polynyas on the Chukotka and western Alaskan coast, as well as laterally from Wrangell Island and Herald and Hanna Shoals, routes shown by previous tagging studies to be used during the open water season. It is unclear who these individuals are. They could be non-breeding subadults that use the presence of the non-multiyear fractured and thin ice to reach their preferred bivalve patches in the Chukchi Sea. They could also be adults adjusting to a ‘New Normal’, increasing their energy reserves by feeding at these hotspots in the off season. Finally, they also could be a seal-eating ecotype that has always prowled the waters of the north.

Long range predictions

The timing of ice retreat and advance is critical to structuring Arctic ecosystems - from the timing of the phytoplankton blooms, to controlling the timing of migrations and distributions of marine mammals. We explored two extremes: an ice retreat primarily caused by winds and a retreat primarily a result of ice melt. When compared to the first scenario increased ice melt would result in stronger vertical stratification, bigger dump of carbon to the ocean bottom, prolonged subsurface bloom, and perhaps a stronger fall bloom, all of which have implications for the ecosystem.

Future noise conditions

The Acoustic Ecology Toolbox (AET) was used to model future noise conditions in two stages: aggregate noise conditions from wind, commercial vessel traffic and offshore drilling activities (physical acoustic stage) and the influence of the aggregate noise on bowhead whale acoustic communication space (bioacoustic stage). For the physical acoustic stage, the type of sound propagation model and the empirical fidelity of the model's physical parameters determine most of the uncertainty in results. In the bioacoustic stage, data for the species of concern determine most of the uncertainty in the results. Not surprisingly, when considering the combined physical acoustic and bioacoustic stages, biological factors dominate model outcomes. Model results reveal that:

1. The greatest predictor of noise condition influence on bowhead communication is whether a whale is producing a low-intensity call or high-intensity call (i.e., singing);
2. Wind-generated ambient noise has only a minor influence, with greater variation on low-intensity calls than high-intensity calls;
3. Vessel traffic noise has moderate, but highly variable influence (because vessels are transiting through the area) with greater influence and variation on low-intensity calls than high-intensity calls, and relatively little influence from vessel proximity; and
4. Drilling operations noise has the highest and least variable influence, with greater influence and variation on an animal producing low-intensity calls and closer to the drilling site than on an animal producing high-intensity calls and further from the drilling site.

The results showing that wind-generated ambient noise had only a minor influence are not surprising. Of far greater importance are the results showing how much greater the noises are from commercial vessels and drilling operations than from wind. The combination of a drilling operation and bowheads producing low-intensity calls, not high-intensity songs reduces a whale's communication space by > 90%. This highlights the critical importance of understanding the circumstances under which anthropogenic noise influences bowhead whale acoustic habitat, a concern that is not new and has been supported by empirical results (e.g., Blackwell et al. 2015).

The long-term, biological implications of this noise influence is not known, and may never be known with enough certainty, especially given the complexity of changes in the Arctic marine environment, to convince us to reduce our impacts on that environment. What is certain is that the fundamental mechanisms for conducting a relative evaluation of combinations of noise factors under a variety of natural and anthropogenic conditions is available and provides a logical means by which to assess potential influences of aggregate noise conditions relative to a natural noise condition.

Recommendations

The data collected for this study demonstrate the utility and benefits of concurrent zooplankton, oceanography, and acoustic monitoring of marine mammals and ambient noise, combined with climate modeling. These data, including those collected in the past for the BOEM-funded CHAOZ study represent the only long-term integrated dataset of its kind for the northeast Chukchi Sea and U.S. Arctic. As additional years of data are added, they can be compared with, and then incorporated into, these long-term trends. Given the rate at which the ecosystem is changing, it is imperative that the most current information is available on marine mammal spatio-temporal distribution when making management decisions in this region. We therefore recommend continuation of the long-term mooring deployments. Moorings should be deployed not only in locations where the biggest changes in oceanographic and marine mammals and prey distribution are expected to occur, but also across a broad spatial range (as was done with the ARCWEST/CHAOZ-X projects). This will ensure that critical migration timing and distribution patterns are fully documented.

We also recommend continuation of the integrated biophysical shipboard surveys conducted during this study and the integration of new technologies (such as the wave glider, Prawler, acoustic sensors, etc.) into such surveys. These surveys provide data on the fine-scale vertical resolution of zooplankton abundance as they correlate with oceanographic indices, nutrients, chlorophyll, and distribution of marine mammals. To maximize marine mammal detections during shipboard surveys, it is essential to have both passive acoustic monitoring and visual survey components. Since each method is well-suited to particular species, together they provide a more complete picture of marine mammal distribution. In addition, joint passive acoustic/visual survey focal follows enable future calculations of relative abundance. The addition of co-located instrumentation to concurrently sample the benthos (e.g., Berchok et al. 2015; Grebmeier et al. 2015; Dunton et al. 2016) would help to address prey availability (along similar spatial and temporal scales) for those mammals that feed on benthic epifauna and infauna.

Because this area is predicted to undergo rapid climate change, it is critical to know what is happening to currents and ice cover during the crucial spring and fall months. Unfortunately, because of the ice cover these seasons are currently inaccessible with present technologies, excepting passive acoustic recorders. To help increase our understanding and knowledge of oceanographic conditions and to collect the necessary suite of data, investments to advance existing and develop new technologies are necessary: for example, in the form of advanced moorings and autonomous subsurface gliders/AUVs. Furthermore, animal-borne sensors should be utilized to take advantage of real-time discrete sampling and gain valuable information on marine mammal habitat utilization during these dynamic seasons.

Marine mammal occurrence has typically been investigated by aerial surveys, which can cover wide areas, but are temporally constrained and limited to animals at the surface. Telemetry data provide good spatial and temporal resolution of movements, but only for a limited number of individuals from a subset of species. Passive acoustic data provide year-round sampling of a great variety of species, but are constrained by the behavior and detection radii of acoustically active individuals. By integrating information from these many sampling methods, the strengths of each can be combined to better understand the seasonal distributions of marine mammals in the U.S. Arctic.

Finally, the modeling exercise using the Acoustic Ecology Toolbox to compare the influences of different future noise scenarios on bowhead whales provides a basic mechanism by which agencies can evaluate the relative impacts of different aggregate noise conditions on different marine mammals under different behavioral contexts (e.g., communicating, echolocating for food). This ability would be especially valuable for agencies needing to evaluate individual or aggregate impacts from proposed anthropogenic activities on a scale relative to some existing or future ambient noise condition.

VI. INTRODUCTION

A. Background

The Hanna Shoal region in the northeast Chukchi Sea is a relatively shallow (<30 m) area near the boundary between Chukchi Sea and Arctic Basin waters. These shallow waters have long been known to trap sea ice, which can ground on the shoal, resulting in low benthic abundance. In contrast, the deeper (>40 m) waters surrounding the shoal are highly productive, but the reason for this productivity has been poorly understood. Biological "hot spots" in the Chukchi Sea are thought to be related to strong coupling between pelagic and benthic productivity. High pelagic phytoplankton concentrations, possibly associated with an ice edge, reach the seabed mostly ungrazed, resulting in high concentrations of labile carbon and nitrogen within and just above the seafloor. The high carbon and nitrogen concentrations fuel benthic productivity and support high biomass of benthic organisms. The Hanna Shoal region also possesses unique sea-ice conditions compared to the surrounding area. In the winter, a recurring polynya forms down-current of the grounded sea ice. In recent years, floating pack ice in summer has persisted in this area longer than elsewhere in the Chukchi Sea, often surrounded by open water to the north. These combined factors have resulted in Hanna Shoal being an area with concentrated walrus foraging activity (Jay et al. 2012). The importance of the Hanna Shoal region to other marine mammal species is not well known.

The focus of this study was to determine the circulation of water in the area around the Hanna Shoal, the source of this water (Chukchi Shelf or Arctic Basin), its eventual destination, and the abundance of large planktonic prey at the shoal. The dynamic nature of this circulation and prey delivery was studied relative to whale distribution and habitat utilization in the northeastern Chukchi and extreme western Beaufort Seas. When possible, we incorporated and expanded from the results reported within the Dunton et al. (2016) Hanna Shoal Ecosystem Study.

The CHAOZ-X study had three component projects: marine mammal distribution (passive acoustics and visual methods), biophysical patterns and trends (moored and shipboard observations of oceanography and zooplankton), and ambient noise dynamics (near real-time passive acoustics and acoustic ecology noise modeling). Passive acoustic moorings provided data for year-round assessments of the seasonal occurrence of marine mammals and their responses to environmental change, as well as seasonal changes in the natural environment (i.e., ice, wind) and in anthropogenic (i.e., airguns, vessels) noise in this planning area. Concurrently deployed biophysical moorings provided important information on oceanographic conditions including current flow and water properties. The passive acoustic recordings also provided baseline information on ambient noise levels throughout this area, which is undergoing rapid change, and empirical data for modeling predictions of future ambient noise conditions.

Our goal was to use the Chukchi Acoustics, Oceanography, and Zooplankton Extension study (CHAOZ-X) sampling tools to understand the mechanisms responsible for the high biological activity around the shoal, so that we can predict, in a qualitative way, the effects of climate change on these preferred habitats for certain protected species.

B. Objectives of study

The overall goal of this multi-year, interdisciplinary study was to document the temporal and spatial distribution of marine mammals near Hanna Shoal in the northeast Chukchi Sea and to relate variability in animal occurrence to oceanographic, atmospheric, and sea-ice conditions, indices of prey density, and anthropogenic activities to improve understanding of the mechanisms responsible for the observed high levels of biological activity around the shoal. The specific objectives were:

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 historical oil and gas 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, prey abundance, and noise conditions 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.

C. Summary of research effort

The CHAOZ-X project shared ship time with the BOEM-funded ARCtic Whale Ecology STudy (ARCWEST) and, when possible, used NOAA funded operations to reduce costs to all projects. In most years a single vessel was used, but in 2015 NOAA ship time was obtained to augment the project. The cruise plan for each year strove to balance the constraints of maximizing project funds by reducing the number of sea days needed, collecting as much data as possible within a time frame that respected the subsistence hunting exclusion. As a result, the cruise track and research operations frequently alternated between the two projects as well as the subcomponents of each project (visual observation, sonobuoy, tagging, mooring deployment and recovery, hydrography, and plankton sampling). In addition, the C2/IC2 mooring site, while funded by CHAOZ-X, was found to be part of the ARCWEST study area, after the transport and current data analyses were complete, and so is included in the ARCWEST report. The same was true for the C3/IC3 mooring site, although it was found to be contained in both study areas and is therefore included in both reports.

In total, the two projects combined had four[3] field seasons during the months of August, September and October: the 2013 survey occurred from 13 August through 18 September on board the R/V *Aquila;* the 2014 survey occurred from 7 September through 20 October on the R/V *Aquila*; the 2015 survey occurred from 6 August through 4 September onboard the NOAA Ship *Ronald H. Brown* and 8-28 September on the R/V *Aquila.* A total of 124[4] passive acoustic (118 year-long, and 6 short-term) and 43 oceanographic moorings were deployed, a combined total of 287 hydrographic and 155 zooplankton sampling stations were conducted resulting in 470 preserved samples, and 24 satellite-tracked drifters were deployed (Figure 2). A total of 717 sonobuoys were deployed and monitored, and 4,593 nm of trackline were visually surveyed for marine mammal and bird[5] observations. A total of 38 scientists from 16 organizations or institutions participated in these cruises.

Specifically within the CHAOZ-X study area (the area encompassed by the red line in Figure 2, stretching from offshore Icy Cape to Point Barrow), a total of 12 passive acoustic[6] and 13 oceanographic moorings were deployed. A total of 79 sonobuoys were deployed during the 24-hour passive acoustic sampling periods, and 504 nm of trackline were surveyed for marine mammal and bird observations.

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[3] In 2016, funds from NOAA/OAR (with supplemental funds from the ARCWEST project) were available to conduct a fourth field season. Although no funds were provided by the CHAOZ-X project, some of the CHAOZ-X stations/mooring were sampled/redeployed; these field efforts are included here at no-cost to the CHAOZ-X project, and select results (primarily CTD and sonobuoy/visual survey data) are provided when available.

[4] This includes the moorings deployed in 2012 on the CHAOZ cruise, but paid for and analyzed with CHAOZ-X funding, 5 moorings that failed, and additional moorings that were deployed in the Bering Sea but analyzed with other funds.

[5] The ARCWEST/CHAOZ-X field cruises hosted a seabird observer from the US Fish and Wildlife Service (PI: K.Kuletz) for all years of these studies.

[6] 10 additional passive acoustic moorings (2 Auto-detection buoys and 8 autonomous recorder moorings) were deployed by the CHAOZ-X project for the auto-detection buoy and noise modeling components of this project, respectively. At the time of deployment and with input from BOEM, it was decided that the most critical spot for this work was between the former Burger and Klondike lease areas. Therefore, these 10 recorders were located within the main ARCWEST study area, but will be included in this report.

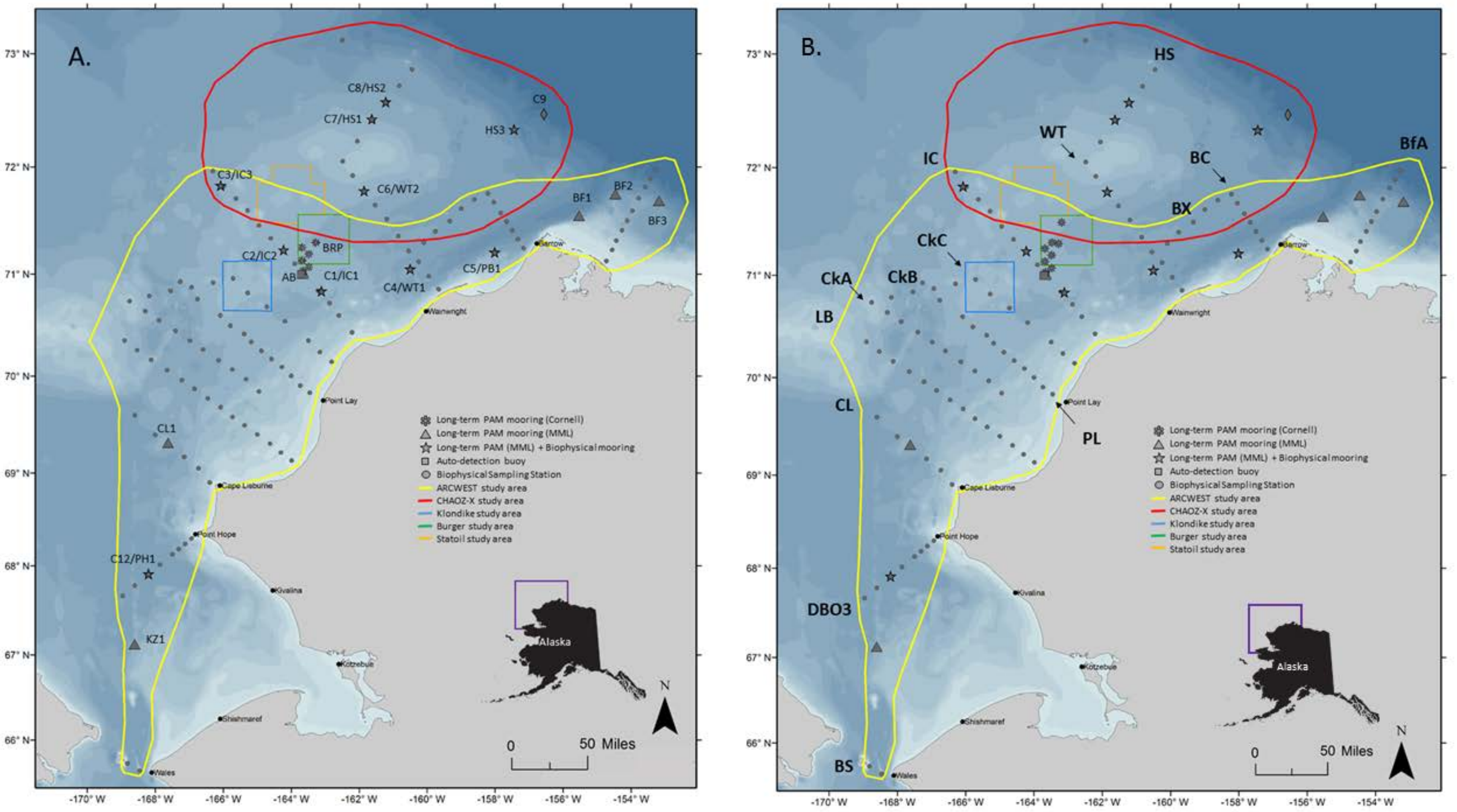
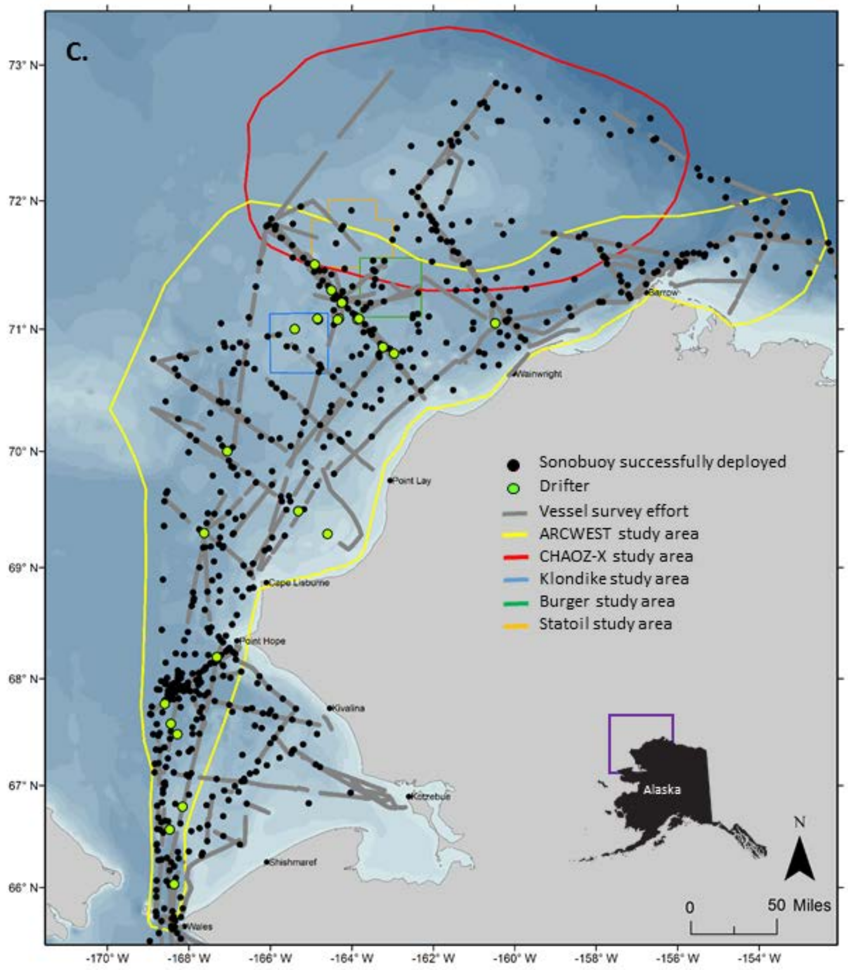


Figure 2. Map showing general study area for the CHAOZ-X project (red outline), the concurrent BOEM-funded ARCWEST project (yellow outline) and CSESP study areas (blue, green, orange outlines). A) mooring locations; B) line transect sampling stations; and C) visual survey and passive acoustic monitoring effort, 2010-2015.

Figure 2 cont.



D. Structure of report

This report is divided into a number of sections, each designed to be read as a stand-alone report. Sections VII-IX deal with marine mammal distribution, biophysical patterns, and ambient noise dynamics. Section X presents the results and implications from near-real-time acoustic monitoring and advancements in analytical paradigms for assessing acoustic environments within an acoustic ecology context. Section XI synthesizes the research by focusing on four main topics: patterns of marine mammal distribution relative to biophysical parameters, over-wintering walrus in the Chukchi Sea, long-range predictions for the CHAOZ-X environment, and modeling future noise conditions in bowhead whale (*Balaena mysticetus*) acoustic habitat under different noise scenarios (wind noise, shipping and drilling operations). The report culminates with Section XII which contains a summary of this study, a list of National Environmental Policy Act (NEPA) and Environmental Impact Statement (EIS) related considerations, and recommendations for the future.

NOTE: Although the CHAOZ-X and ARCWEST studies were separate research projects encompassing different study areas (waters feeding Hanna Shoal versus Barrow Canyon), data from each study add value to the other. To include these data without unnecessary duplication, the following guidelines were followed. Each report will include results from all moorings located within the study area for that project. If the data from a mooring indicate that the currents are relevant to both study areas, that mooring is included in both reports. A comparison of the mooring data between the two study areas will be included in the discussion sections of both reports when appropriate. Because it is more informative to display all the spatial data as a whole, marine mammal (sonobuoy and visual survey) and zooplankton results will be included in both reports with the two project study areas overlain. Likewise, the transport/currents results could be obtained only from integration of the mooring and drifter data from both projects, and are included in both reports. The discussion in each report, however, will focus on the results obtained from that project's study area, before a comparison between study areas is discussed.

VII. MARINE MAMMAL DISTRIBUTION (OBJECTIVES 1, 3)

A. Moored observations (Moorings: C3/IC3, C6/WT2, C7/HS1, C8/HS2, HS3)

1. Methods

Equipment

Three deployments of five long-term passive acoustic recorder moorings were made within the CHAOZ-X study area over the course of this project (Figure 3, Table 1). All acoustic moorings were located in close proximity to (or in the case of HS3[7] - directly on) oceanographic moorings. Table 1 lists the deployment and recording information for these moorings. These bottom-mounted moorings were comprised of an anchor, chain, acoustic release, passive acoustic recorder, and 30” steel subsurface float (Figure 3b, total length of mooring ~8 m; hydrophone ~6 m off the seafloor). Autonomous Underwater Recorders for Acoustic Listening (AURAL, Multi-Électronique, Rimouski, QC, Canada) were used on these subsurface moorings. The AURALs recorded for an entire year at a sampling rate of 16 kHz, with 16-bit resolution and 16 dB gain, on a duty cycle of 85 min of recording every 5 hours (28%). With these settings the AURALs had a spectral noise floor of 52 dB re 1 μPa^2 /Hz (Kinda et al. 2013) and a maximum input pressure (a signal saturation level) of 154 dB re 1 μPa, for a dynamic range of 90 dB over the effective bandwidth of the system. In addition to the passive acoustic data, each AURAL was equipped with a built-in temperature (-10° C to 40° C, resolution 0.0625° C, accuracy ± 0.5° C) and pressure (0 to 1000 psi [0~682 m], resolution 1.3 cm, accuracy ± 0.25% max) sensors which each sampled once per recording period. Detection ranges, or the distance at which a calling animal or signal on a recorder can be detected by expert analysts, are highly variable. They depend on several factors, including the source level of the signal (how loud the call or noise is), ambient noise levels, and the sound speed profile of the water column and seafloor. The sound speed profile of the water column varies depending on the oceanographic conditions (e.g., temperature, salinity, pressure, currents, fronts, etc.) at that time (Stafford et al. 2007a). Underwater sounds travel greater distances when the region is ice-covered (Urick 1983); thus, we would expect greater detection ranges in the winter ice-covered months. However, if ice moves or shifts, this creates an increase in ambient noise levels (sometimes substantially), further illustrating the highly variable nature of detection ranges.

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[7] This mooring was maintained by Robert Pickart (WHOI) as part of the "Characterization of the Circulation on the Continental Shelf Areas of the Northeast Chukchi and Western Beaufort Seas", contract M12AC00008 from the Bureau of Ocean and Energy Management.

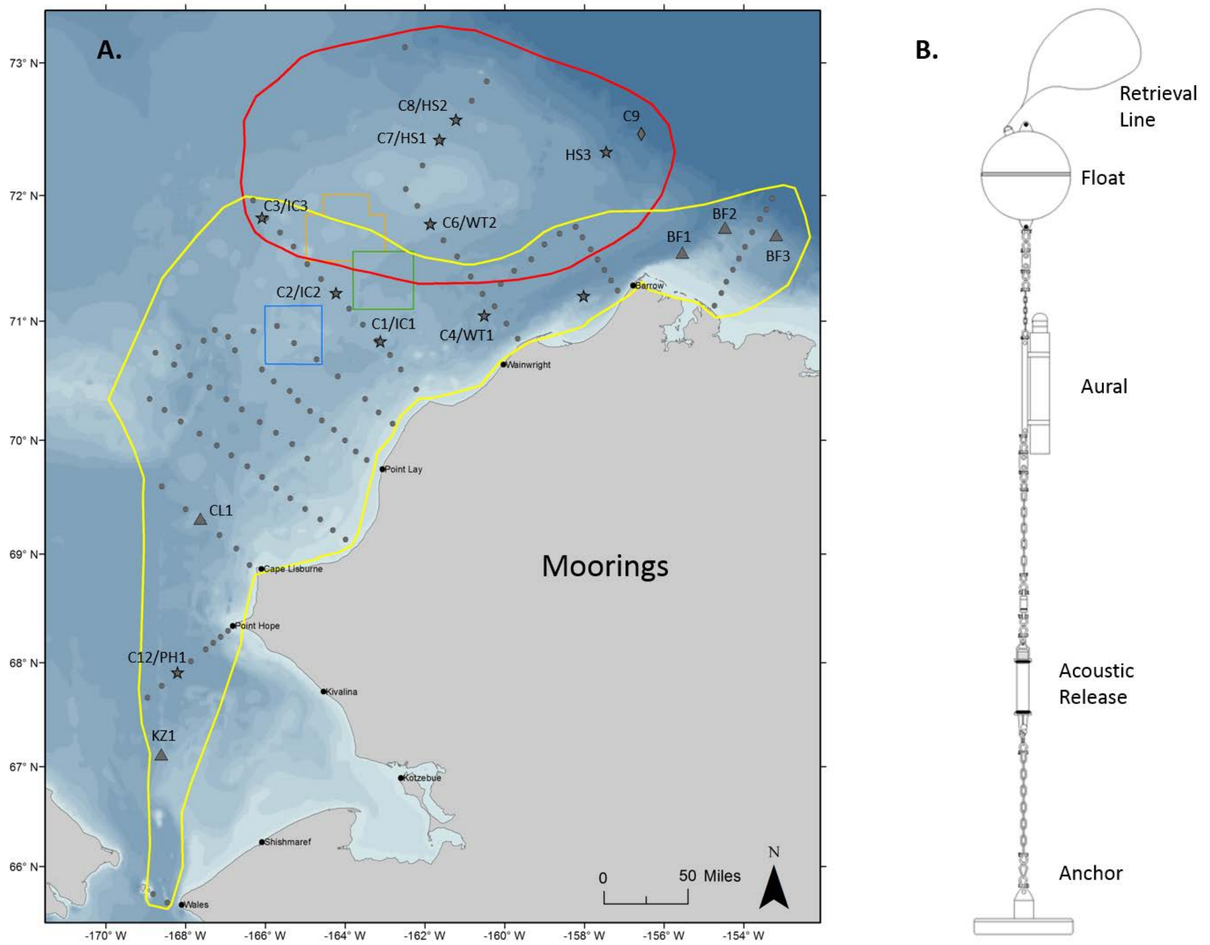

Figure 3. Location of long-term acoustics moorings in the Chukchi Sea red = CHAOZ-X study area, yellow = ARCWEST study area, blue box = KLONDIKE study area, orange box = STATOIL study area, green box = BURGER study area, triangles = passive acoustics mooring only, stars = passive acoustics and oceanographic mooring clusters, dots = sampling stations (a). Passive acoustic recorder mooring diagram (b).

Table 1. List of all passive acoustic recorders and deployment information, 2012-2016 . * = mooring analyzed for this report. P= Pickart mooring.

Mooring	Mooring Cluster	Latitude (°N)	Longitude (°W)	Water depth (m)	Recorder Start Date	Recorder End Date	Number of Days with Data	Sampling Rate (Hz)	Duty Cycle (min on/ min total)	Deployment Date	Retrieval Date
CX12_AU_IC3*	C3	71.82922	166.07158	42	8/28/2012	8/26/2013	363	16384	85/300	8/22/2012	8/26/2013
CX12_AU_WT2*	C4	71.78230	161.84885	41	8/30/2012	8/28/2013	363	16384	85/300	8/26/2012	8/28/2013
CX13_AU_HS1*	C7	72.42692	161.62862	45	8/30/2013	10/2/2014	398	16384	80/300	8/28/2013	10/2/2014
CX13_AU_HS3*	P	72.33625	157.44822	163	10/29/2013	9/22/2014	328	16384	80/300	10/12/2013	9/22/2014
CX13_AU_IC3*	C3	71.83138	166.07368	45	8/28/2013	9/26/2014	394	16384	80/300	8/26/2013	9/26/2014
CX13_AU_WT2*	C4	71.78028	161.85502	45	8/30/2013	11/14/2013	76	16384	80/300	8/28/2013	10/4/2014
CX14_AU_HS2*	C8	72.58005	161.21792	54	10/4/2014	9/16/2015	347	16384	80/300	10/2/2014	9/16/2015
CX14_AU_HS1*	C7	72.42793	161.62877	42	10/4/2014	9/16/2015	347	16384	80/300	10/2/2014	9/16/2015
CX14_AU_IC3*	C3	71.83128	166.07838	51	9/27/2014	9/17/2015	355	16384	80/300	9/26/2014	9/17/2015
CX14_AU_WT2*	C6	71.78167	161.85838	42	10/6/2014	9/17/2015	346	16384	80/300	10/4/2014	9/17/2015
CX15_AU_IC3	C3	71.82948	166.07707	43	9/18/2015	9/14/2016	362	16384	80/300	9/17/2015	9/13/2016
AL16_AU_IC3	C3	71.82903	166.07923	43	9/15/2016	-	-	16384	80/300	9/14/2016	-

Data Processing

After the recorders were retrieved, the hard drives were removed and the raw data were immediately backed up onto an external hard drive. The original drives were saved as master copies of the data. The data were then processed in two steps. First, the raw sound files were converted into ten-minute files, renamed with intuitive file names containing recorder type, project and mooring name, date, and time (in GMT) information (i.e., AU-CXHS01-130908-051000.wav is an AURAL recorder deployed for the CHAOZ-X project at the Hanna Shoal 1 mooring site (HS01) on September 8, 2013 at 05:10 am GMT). These data were also backed up to external hard drives and sent to the Northeast Fisheries Science Center (NEFSC, Sofie Van Parijs) to have a duplicate copy offsite. Image files (.png) of spectrograms were then pre-generated from recordings (FFT 1024, 0.85 overlap, Hamming window). These image files displayed either 300 s of data from 0 to 250 Hz (low-frequency signals), 225 s of data from 0 to 800 Hz (mid-frequency signals), or 90 s of data from 0 to 8.192 kHz (high-frequency signals). These bin lengths were chosen to allow for the analyst to view the maximum amount of data for that frequency band in a single frame, without needing to continually expand the data using the zoom function. After the analyses were complete, the data results were re-compiled into ten-minute bins, which is the ***analysis interval length*** of the study. Given the staggered duty cycle of the recorders, the results were normalized by dividing the number of analysis intervals with calls detected for that day by the number of available intervals for that day. The results that follow are hence presented as ***calling activity***, which is defined as the percentage of time intervals with calls for each day. It is important to note that calling activity does not indicate the number of call detections or number of animals vocalizing.

Data Analysis

An in-house, MATLAB-based program (SoundChecker) was used for the long-term mooring data analysis. SoundChecker operates on the pre-generated image files (described above), which reduces the computational time needed to generate spectrograms during analysis. The image files are indexed to allow for zoom and playback functioning during analysis. For each image file, the analyst selects one of four options: yes, no, maybe, and no-with-noise to indicate whether a species was detected in that file. The no-with-noise option is selected when the presence of high levels of noise mask potential calls from that species or sound source. It is important to note that analysts were highly conservative when assigning yes designations; if there was any doubt as to the source of the calls within an image file, that image file was marked as maybe. The results below use only those image files marked as yes. Future studies using these data will be expedited as only the image files marked with yeses and maybes will need to be included and the full data set will not need to be re-analyzed.

All acoustic data were analyzed for the presence of the following: fin whales[8] *(Balaenoptera physalus)* in the low frequency band; bowhead, right *(Eubalaena japonica)*, humpback *(Megaptera novaeangliae)*, gray *(Eschrichtius robustus)*, and minke whales *(Balaenoptera acutorostrata)*, walrus *(Odobenus rosmarus)*, unidentified pinnipeds, as well as vessel noise and seismic airguns in the mid-frequency band; and beluga *(Delphinapterus leucas)*,

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[8] No CHAOZ-X moorings were analyzed for fin whales. An attempt to use autodetectors was unsuccessful (see section on Autodetection algorithms below). We have been working with Cornell to revisit the efficacy of using autodectors for fin whales. The CHAOZ-X mooring data will be processed for both fin whale 20-Hz song notes and mid-frequency calls (90-30 Hz band) using multiple detectors on a Cornell autodetection system at a later time.

killer whale *(Orcinus orca)*, minke whale (boing call), bearded *(Erignathus barbatus)* and ribbon seals *(Histriophoca fasciata)*, and environmental noise (ice) in the high frequency band.

Substantial overlap of call repertoires among baleen whales in the Arctic and subarctic, a lack of true stereotyped calls for most species (most have a repertoire that evolves seasonally), and an inability to include contextual clues have resulted in poor performance from auto-detection routines (Mocklin et al. 2016). In addition, while many signals cannot be distinguished visually on a spectrogram, a human analyst may be able to distinguish them aurally. For these reasons, all (100% of the image files) of the long-term species analysis was done manually by experienced Arctic analysts using a combination of common call characteristics and contextual clues, including season, inter-call-interval, association with conspecific sounds, song structure, repetition, and frequency, slope, amplitude modulation, and length of calls (McSweeney et al. 1989; Crane and Lashkari 1996; Matthews et al. 2001; McDonald and Moore 2002; Mellinger et al. 2004). The typical call characteristics associated with each species that can help to identify, or at least eliminate, certain species during the passive acoustic analysis are listed below. Spectrograms of exemplar calls for each species are presented in Figures 4-6.

Species/sound source differentiation:

Fin whale calls are distinguished easily from all other species as they are stereotyped, short (≤ 1 s) downsweeps with most of the call frequency bandwidth below 50 Hz (Figure 4; Watkins et al. 1987; Edds 1988).

Bowhead, North Pacific right (NPRW), gray, and humpback whales all make similar sounds that can sometimes be confused. Bowhead whales were identified by their song, characterized by repetitive, high frequency (up to several kHz), exaggerated, curving calls, and multiple singers (Figure 5a; Clark et al. 1996; Blackwell et al. 2007; Stafford et al. 2008; Delarue et al. 2009; Hannay et al. 2013; Johnson et al. 2014). However, bowhead whales can also produce individual calls unassociated with song (~50-500 Hz; Clark and Johnson 1984), complicating passive acoustic analyses.

Humpback whales also make a large variety of similar frequency modulated (FM) sounds in the range of 30 Hz to 10 kHz+, usually with some degree of amplitude modulation (Figure 5c; Thompson et al. 1986; McSweeney et al. 1989). They typically repeat the same call multiple times in a row, with less than five seconds between calls. Although well known for their singing at low-latitude breeding grounds, humpback whales also sing at high latitude feeding grounds (McSweeney et al. 1989; Clark and Clapham 2004; Wright 2015). All singers sing the same version of the song for that year, unlike bowheads who can sing a multitude of songs in a single season (Stafford et al. 2012).

Due to the large overlap in call repertoires among species, only two FM call types were used to distinguish NPRW: (1) up-calls with variable frequency and sweep rate characteristics on average from 80-160 Hz, approximately 1 s in length (Figure 5b); (2) down-up calls that sweep from approximately 100 Hz to 80 Hz before becoming like a typical up-call (McDonald and Moore 2002; Munger et al. 2008). Compared with that from humpback whales, NPRW calling has irregular timing (calls are made in bouts of 3-15 with inter-call spacing greater than 5 s and with inter-bout intervals ranging from 3 to 60+ minutes) and very little (to no) amplitude modulation (Mellinger et al. 2004). Right whales also do not sing (Clark 1983; Munger et al. 2008). In addition to FM calls, NPRW produce brief (~ 400 ms), broadband, impulsive sounds

(20 Hz - 10 kHz) termed gunshot calls (Figure 5d; Crance et al. 2017). The impulsive gunshot call has also been recorded from bowhead whales in spring and summer months off Barrow, AK, (note: the city name changed to Utqiaġvik in 2016 but we refer to it as Barrow in this report since the name change occurred after this study), in the Beaufort Sea (Clark and Johnson 1984; Clark et al. 1996; Shelden and Mocklin 2013; Berchok et al. 2015). Since either species could have produced gunshot calls in this dataset, gunshots were denoted but not identified to species.

Gray whale calls were defined as shorter (<1 s) frequency-modulated moans (30-200 Hz) characterized by multiple harmonics, and higher frequency impulsive sounds (e.g., bongo call) (Figure 5e; Cummings et al. 1968; Moore and Ljungblad 1984; Stafford et al. 2007b). Gray whale moans have a distinctive aural growl, which was the predominant method of confirming questionable identifications. Visually, gray whale moans were distinguished from NPRW based on: the starting frequency of gray whale fundamental harmonic (~30-100 Hz) compared with NPRW (~80 - 120 Hz), the slope of the call, and the presence of harmonics. Gray whale moans were distinguished from humpback whales based on: the temporal separation from humpback-like sounds, and the frequency of gray whale fundamental harmonics (~30 – 100 Hz) compared with humpback whale (100 – 400 Hz). Gray whale moans were distinguished from bowhead whale calls based on the frequency of the fundamental harmonic (bowhead: 100 – 500 Hz) and the prominence of growl.

Walrus calls included short (< 1 s) pulses, termed knocks that were often accentuated by bell or gong sounds, ‘ou-ou’ moans, and a variety of grunts (Figure 5f; Fay 1982; Stirling et al. 1983, 1987). Walrus knocks were distinguished from gunshot calls and gray whale bongo calls both visually (e.g., walrus calls are cleaner and often occur in rapid succession with pattern) and aurally (e.g., walrus knocks sound hollow, gunshots sound reverberant, and bongos sound poppy).

Minke whales can make a variety of sounds, including non-descript FM downsweeps (300-40 Hz; Edds-Walton 2000) and pulse trains (Risch et al. 2013) in the low-frequency band, and unique boing noises, 2-3 s pulsed calls, in the higher frequencies (0.3 - 4 kHz, Figure 6e; Rankin and Barlow 2005; Delarue et al. 2013b).

Bearded seals were identified by their characteristic long-duration trills (Figure 6c; Risch et al. 2007; MacIntyre et al. 2015). Ribbon seals produce distinct vocalizations during the spring mating season, including downsweeps, roars, and grunts (Watkins and Ray 1977). The call used to identify ribbon seals within this study was an intense downward frequency sweep (Figure 6d). Pinnipeds as a whole also produce a set of very non-descript sounds including barks, grunts, growls, and snorts (Figure 5g). These types of sounds were marked as unidentified pinniped.

Although killer whales and belugas both produce signals in a similar frequency band, these two species were usually easy to distinguish based on a number of parameters. Killer whale calls are typically stereotyped, pulsive, and short in duration (i.e., <1.5 s, Figure 6b; Deecke et al. 2005). They sound more nasally than humpback whale cries. Beluga whale calls (whistles, pulsed calls, noisy calls, combined calls, and echolocation clicks) can be similar to killer whales, but are more strongly modulated and normally co-occur more frequently with whistles than killer whale calls (Figure 6a; Sjare and Smith 1986; Garland et al. 2015a). Most echolocation clicks from both killer and beluga whales exceeded the frequency range that was recorded by the long-term recorders. Beluga and killer whales acoustically detected in Kotzebue Sound in other studies (Castellote et al. 2015) were almost exclusively comprised of echolocation signals and few high frequency whistles. This has been identified as a predator-prey avoidance behavior where both try to be acoustically silent to avoid being detected (Castellote et al. 2013).

Ice, the most dynamic of the high frequency signals, is easily recognizable by the combination of long duration (i.e., >5 s), highly variable signals and impulsive sounds (e.g., cracking and popping, Figure 6f). Vessel noise was easily recognized by the presence of multiple narrowband tonal sounds that appear as lines on the spectrogram, as well as broadband sounds, created from a combination of propeller cavitation and vibration, other propulsion sources, and internal machinery (Figure 5h). Typically larger vessels created louder, lower frequency sounds than smaller ships (Richardson et al. 1995). Seismic airguns produce loud, impulsive, broadband signals that may sound and look spectrographically similar to gunshots (Figure 5i). However, airgun pulses are produced at very patterned and regular intervals for very long periods of time (Guerra et al. 2011).

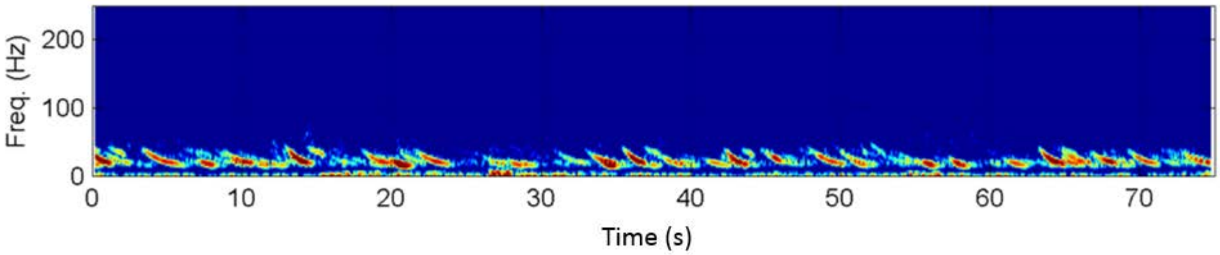

Figure 4. Spectrogram of exemplar 20 Hz song notes used to identify fin whales, a low-frequency species. In this example there are multiple singers.

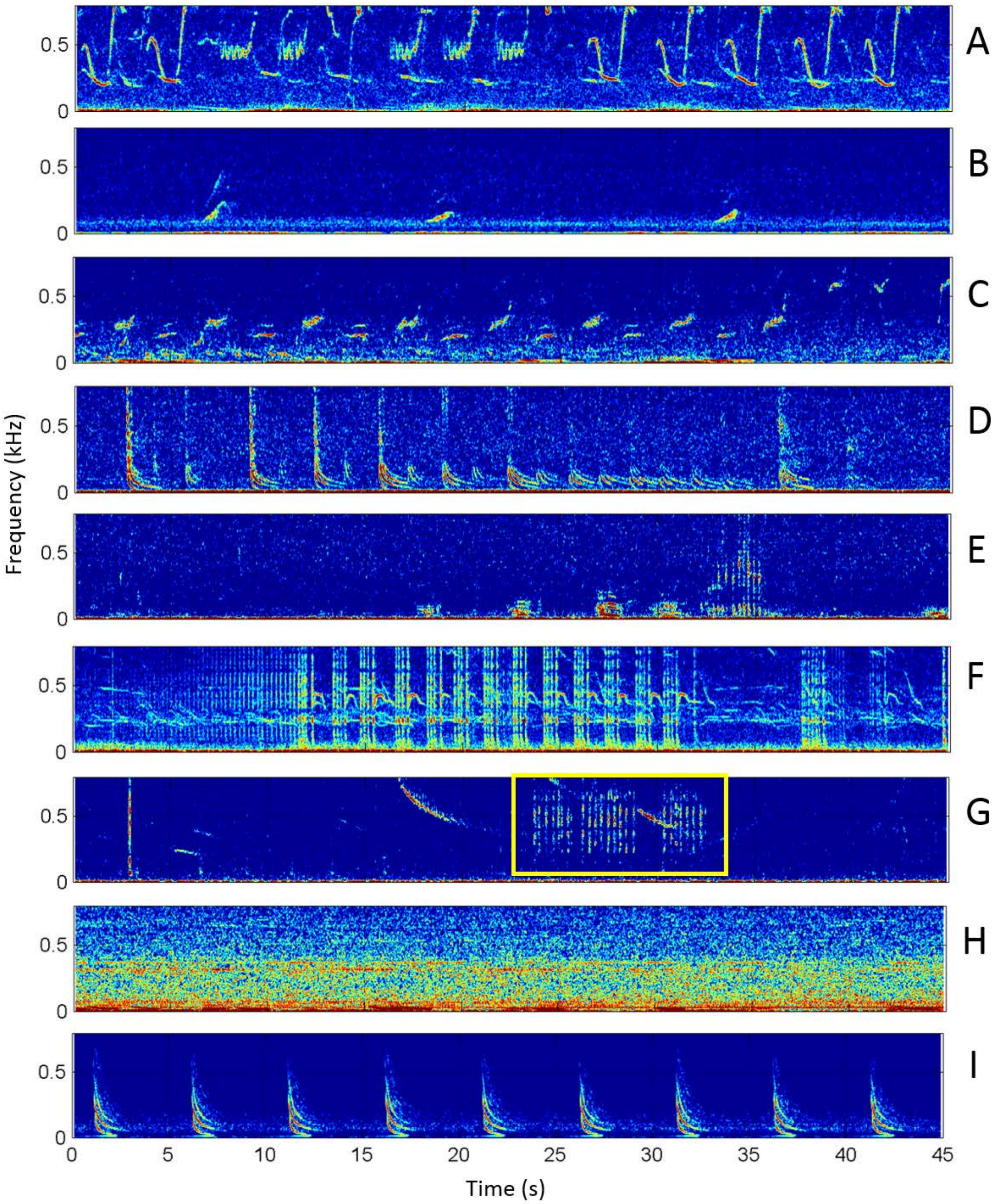

Figure 5. Spectrogram examples of sounds used to identify species. From top to bottom: (A) a portion of a bowhead whale song, (B) NPRW upcalls, (C) humpback whale calls, (D) gunshot sounds, (E) gray whale moans and bongo calls, (F) walrus knocks and bell calls, (G) unidentified pinniped grunts and barks, outlined in yellow box, (H) vessel noise, and (I) seismic airguns.

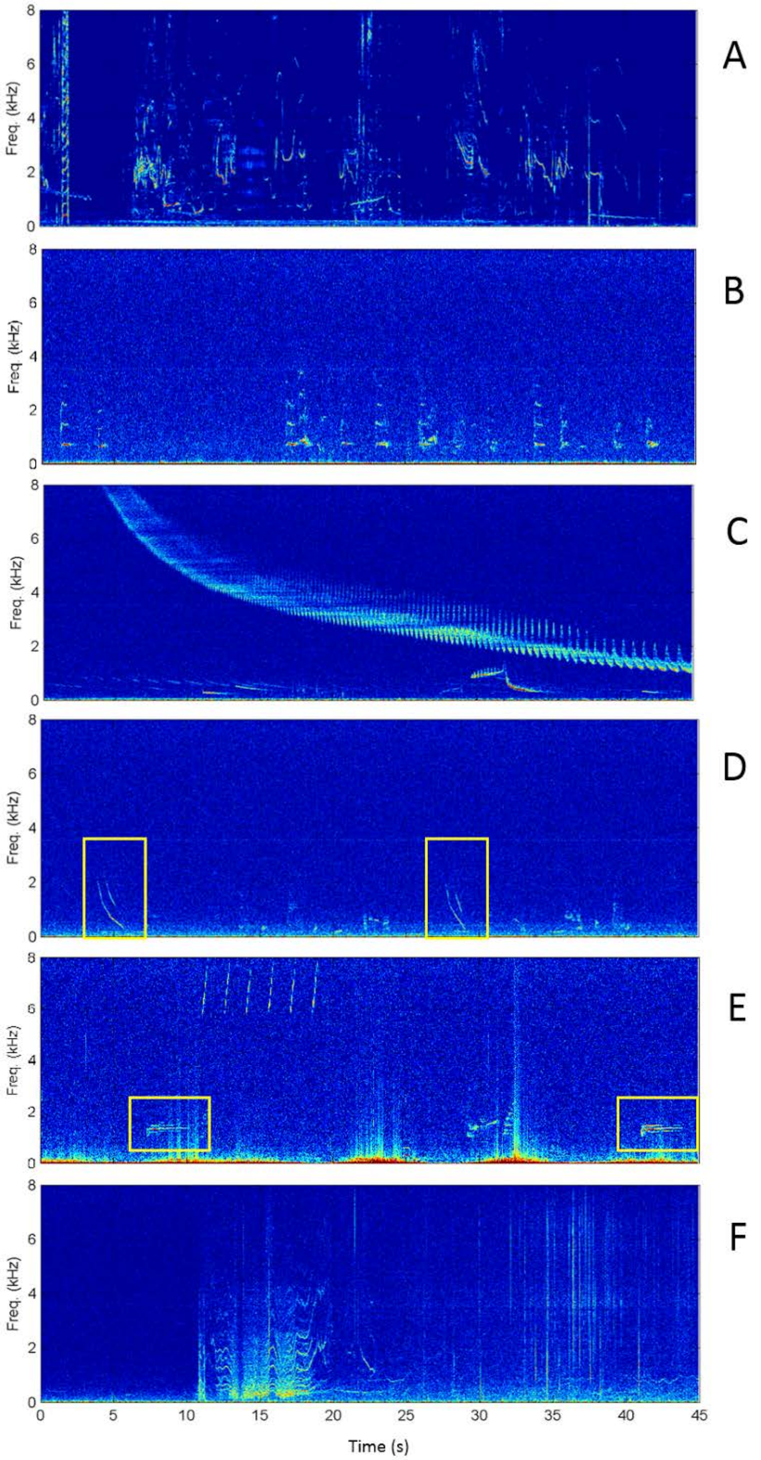

Figure 6. Spectrogram examples of sounds used to identify high-frequency species. From top to bottom: (A) beluga whale calls, (B) killer whale calls, (C) bearded seal song trill, (D) ribbon seal calls, outlined in yellow boxes, (E) minke whale boing, outline in yellow boxes, and (F) ice noise, visible as long duration, variable, and impulsive sounds.

Data Quality Control

Thorough reviews of analyst results were conducted by in-house senior analysts during the training process, and mooring results were reviewed by those senior analysts, with specific segments verified, for data quality control purposes. Additionally, analysts took a calibration test, where each analyst analyzed the same dataset. This calibration test dataset consisted of a randomized portion of data from each mooring. By having every analyst analyze the same dataset, we compared results and obtained accuracy measurements of analyst agreement.

Autodetection algorithms

Throughout the CHAOZ-X study we have attempted to implement an autodetection software program for fin whale sounds. The low-frequency detection and classification system (LFDCS; Mark Baumgartner, WHOI) was used to automatically detect fin whale vocalizations. The LFDCS is an Interactive Data Language (IDL)-based program that uses manually created call libraries to apply discriminant function analysis across seven measurements, referred to as sound attributes, taken from each auto-detected sound. The analyst selects exemplary sounds, in this case fin whale sounds, to create a sound exemplar library. The LFDCS discriminant function analysis is then run on a novel data set, using the sound library as the basis in the analytical comparison to classify all the auto-detections. Over two-hundred exemplars were carefully selected for the fin whale sound exemplar library. The library was then put through comprehensive and iterative logistical regression analysis, to determine its efficacy for application on novel data sets. Unfortunately, results were not promising with many of the analyst detected calls missed by the autodetection program.

Future auto-detection analysis of fin whale sounds (song notes, songs and calls) will be conducted at Cornell using a suite of detector algorithms developed during a variety of other projects. For detecting fin whale song, either at the song note or song levels, Cornell has had good success using a form of template detection that takes advantage of the hierarchical nature of the song structure. For detecting fin whale calls, Cornell has developed several detection algorithms that utilize an extensive set of acoustic features as input to the detection algorithms, which are trained with both supervised and unsupervised filters. In a manner somewhat similar to the LFDCS process, detection performance is enhanced by confirmed exemplars of the signal of interest, but discriminant analysis is avoided. Initial work with these autodetectors have yielded a very high level of false positives, so further development of the fin whale call detectors is needed.

2. Results

A total of 3,859 days of acoustic data were included in this report. 3,462 days were analyzed from the five CHAOZ-X long-term passive acoustic recorders deployed from 2012 through 2015. An additional 397 days of CHAOZ data results (i.e., from the 2010 and 2011 IC3 mooring deployments) are reproduced here, for consistency as well as ease of accessibility. Each recorder was analyzed fully for the following species/signals: bowhead, beluga, gray, humpback, minke, killer, right, and sperm whales, bearded, ribbon, and unidentified seals, walrus, vessel, airgun, and ice noise. Fin whales were not analyzed at these moorings for this report (see Footnote 8 above).

Because of the staggered duty cycle used for the recordings, there was differing sampling effort among days. This was normalized by dividing the number of ten-minute sound files with calls[9] detected for that day by the number of available ten-minute sound files for that day. The results that follow are presented for each mooring in two ways. First, in the daily bar plots (e.g., Figure 7), data are presented as the percentage of ten-minute time intervals with calls for each day. This will be referred to as ***calling activity*** for the remainder of this report. It is important to note that calling activity indicates the duration of sustained calling for that day, not the number of call detections or number of animals vocalizing. For example, if a day shows 100% beluga calling activity that means that 100% of the ten-minute time bins in that day contained at least one beluga call. Any day that has detections in 50% or more of its ten-minute time bins is considered a day with ***peak calling***. Second, in the monthly calling distribution plot figures (and in Appendix E.1 through E.30), data are presented as the percentage of days per month with detections from that species or sound source. Again, these are meant to show the sustained presence of the species/sound sources within the area and not the number of call detections or number of sources present.

The results for the species/signals analyzed were divided into Arctic and subarctic species. The Arctic species included bowhead and beluga whales, bearded seals, walrus and gray whales. These species are good proxies for Arctic ecosystem change because they represent a variety of differing habitat and dietary niches. As such, this results section will focus on these five species (Table 2). The subarctic species detected in the CHAOZ-X study area, humpback whales, killer whales, and ribbon seals, had minimal amounts of calling activity; their results will be presented following those for the Arctic species.

Bowhead whales

Bowhead whale calling activity was detected on all the CHAOZ-X study area moorings for all years where data were available (Figures 7-13; Table 2). Among the mooring sites, the recorder with the highest proportion of bowhead calling activity was the western-most site, IC3, while the lowest were the two on the northeast flank of Hanna Shoal (HS1 & HS2; Table 3). Peak calling for all sites occurred on approximately half the days with calling activity present, with the exception of the HS1 and HS3 sites.

Calls were detected between April and December, with no detections made between January and March (Figures 7-13; Table 4). The highest monthly averages varied longitudinally among mooring sites, with the HS3 (near eastern slope) location showing maximum averages from May through July, while maximum averages for the HS1 and HS2 (shoal) sites were September and October, and October and November for western (IC3) and shoal (WT2) sites. A fall pulse in calling activity is seen in every year on every mooring where data are available (Figure 7). However, for the majority of these moorings/years, it is very difficult to determine when the spring pulse ends and the fall pulse starts, as calling activity occurs in between. The date ranges for those pulses listed in Table 5, therefore, should be considered rough estimates. The only location to show a clear separation between the spring and fall pulses is WT2 in 2013. With the exception of the HS3 site, calling activity levels on days (and the number of days with calling activity) within the spring pulses were lower than those documented for the fall pulses

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[9] In the context of this report we define calls and calling activity to include any and all sounds produced by an animal.

(Figure 7). In most years and locations, the fall pulse of calling was actually composed of multiple pulses (Figure 7).

Table 2. Yearly averages of calling activity for bowhead whale, beluga whale, bearded seal, walrus, and gray whale, 2010-2015, for all CHAOZ-X mooring locations. Number of days with calling activity (#), number of days with recordings (Eff), percent of days with calling activity per month (%).

Species	Year	IC3			WT2			HS1			HS2			HS3		
		#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**
Bowhead	2010	60	113	**53**	0	0	-	0	0	-	0	0	-	0	0	-
Bowhead	2011	40	284	**14**	0	0	-	0	0	-	0	0	-	0	0	-
Bowhead	2012	82	261	**31**	61	124	**49**	0	0	-	0	0	-	0	0	-
Bowhead	2013	97	364	**27**	58	317	**18**	51	124	**41**	0	0	-	2	64	**3**
Bowhead	2014	84	365	**23**	40	87	**46**	33	364	**9**	18	89	**20**	62	265	**23**
Bowhead	2015	42	260	**16**	10	260	**4**	16	259	**6**	15	259	**6**	0	0	-
Beluga	2010	8	113	**7**	0	0	-	0	0	-	0	0	-	0	0	-
Beluga	2011	19	284	**7**	0	0	-	0	0	-	0	0	-	0	0	-
Beluga	2012	30	261	**11**	2	124	**2**	0	0	-	0	0	-	0	0	-
Beluga	2013	57	364	**16**	36	317	**11**	4	124	**3**	0	0	-	12	64	**19**
Beluga	2014	92	365	**25**	3	87	**3**	10	364	**3**	3	89	**3**	103	263	**39**
Beluga	2015	21	260	**8**	35	260	**13**	15	259	**6**	19	259	**7**	0	0	-
Bearded	2010	26	113	**23**	0	0	-	0	0	-	0	0	-	0	0	-
Bearded	2011	224	284	**79**	0	0	-	0	0	-	0	0	-	0	0	-
Bearded	2012	226	261	**87**	86	124	**69**	0	0	-	0	0	-	0	0	-
Bearded	2013	223	364	**61**	228	317	**72**	65	124	**52**	0	0	-	5	64	**8**
Bearded	2014	203	365	**56**	68	87	**78**	215	364	**59**	12	89	**13**	151	263	**57**
Bearded	2015	177	260	**68**	189	260	**73**	193	259	**75**	181	259	**70**	0	0	-
Walrus	2010	38	113	**34**	0	0	-	0	0	-	0	0	-	0	0	-
Walrus	2011	106	284	**37**	0	0	-	0	0	-	0	0	-	0	0	-
Walrus	2012	76	261	**29**	43	124	**35**	0	0	-	0	0	-	0	0	-
Walrus	2013	81	364	**22**	122	317	**38**	60	124	**48**	0	0	-	0	64	**0**
Walrus	2014	88	365	**24**	9	87	**10**	136	364	**37**	15	89	**17**	0	265	**0**
Walrus	2015	45	260	**17**	94	260	**36**	119	259	**46**	94	259	**36**	0	0	-
Gray	2010	0	113	**0**	0	0	-	0	0	-	0	0	-	0	0	-
Gray	2011	0	284	**0**	0	0	-	0	0	-	0	0	-	0	0	-
Gray	2012	0	261	**0**	0	124	**0**	0	0	-	0	0	-	0	0	-
Gray	2013	0	364	**0**	0	317	**0**	0	124	**0**	0	0	-	0	64	**0**
Gray	2014	1	365	**0**	0	87	**0**	1	364	**0**	0	89	**0**	0	265	**0**
Gray	2015	1	260	**0**	0	260	**0**	0	259	**0**	0	259	**0**	0	0	-

Table 3. Total bowhead whale calling activity, 2010-2015, for all CHAOZ-X mooring locations. Number of days with recordings (Eff), number of days with calling activity (#), number of days with calling activity > 50% (#pk), percent of days with calling activity (%), percent of days with calling activity > 50% (%pk).

Mooring	Eff	#	# pk	%	% pk
IC3	1647	405	219	25	13
WT2	788	169	87	21	11
HS1	747	100	25	13	3
HS2	348	33	14	9	4
HS3	329	64	16	19	5

Table 4. Average monthly bowhead whale calling activity, 2010-2015, for all CHAOZ-X mooring locations. Number of days with calling activity (#), number of days with recordings (Eff), percent of days with calling activity per month (%).

Month	IC3			WT2			HS1			HS2			HS3		
	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**
Jan	0	155	**0**	0	62	**0**	0	62	**0**	0	31	**0**	0	31	**0**
Feb	0	141	**0**	0	56	**0**	0	56	**0**	0	28	**0**	0	28	**0**
Mar	0	155	**0**	0	62	**0**	0	62	**0**	0	31	**0**	0	31	**0**
Apr	0	150	**0**	0	60	**0**	0	60	**0**	1	30	**3**	0	30	**0**
May	2	138	**1**	8	62	**13**	6	62	**10**	2	31	**6**	19	31	**61**
Jun	2	98	**2**	10	60	**17**	2	60	**3**	3	30	**10**	13	30	**43**
Jul	19	93	**20**	0	62	**0**	4	62	**6**	0	31	**0**	19	31	**61**
Aug	35	99	**35**	0	63	**0**	6	64	**9**	1	31	**3**	7	31	**23**
Sep	54	158	**34**	18	77	**23**	32	76	**42**	8	16	**50**	4	22	**18**
Oct	120	155	**77**	78	88	**89**	40	61	**66**	17	28	**61**	0	3	**0**
Nov	125	150	**83**	48	74	**65**	10	60	**17**	1	30	**3**	2	30	**7**
Dec	48	155	**31**	7	62	**11**	0	62	**0**	0	31	**0**	0	31	**0**

Table 5. Key timing events for bowhead whale calling activity. Underlined dates are recorder limited. Ice start and end dates were obtained from satellite-derived ice concentration data. *These dates were obtained by estimating the dates for the main pulses in Figure 7.

Year	Mooring	Calling		Peak Calling		Spring Pulse* Dates		Fall Pulse* Dates		Ice End Date	Ice Start Date
		Start	End	Start	End	Start	End	Start	End		
2010	IC3	22-Sep	12-Dec	6-Oct	10-Dec	-	-	22-Sep	12-Dec	16-Jul	31-Oct
2011	IC3	20-Sep	3-Dec	10-Oct	30-Nov	-	-	29-Sep	3-Dec	5-Jul	22-Nov
2012	IC3	28-Aug	29-Nov	21-Sep	25-Nov	-	-	28-Aug	29-Nov	27-Jul	3-Nov
	WT2	23-Sep	25-Nov	2-Oct	21-Nov	-	-	23-Sep	25-Nov	17-Aug	31-Oct
2013	IC3	9-Jul	23-Dec	28-Aug	23-Dec	-	-	14-Aug	23-Dec	21-Jul	26-Oct
	WT2	21-May	14-Nov	13-Jun	14-Nov	21-May	19-Jun	29-Sep	14-Nov	11-Aug	24-Oct
	HS1	30-Aug	14-Nov	1-Oct	13-Nov	-	-	30-Aug	14-Nov	30-Aug	22-Oct
	HS3	13-Nov	14-Nov	-	-	-	-	-	-	3-Aug	23-Oct
2014	IC3	19-May	11-Dec	30-Jul	10-Dec	-	-	22-Sep	11-Dec	30-Jul	3-Nov
	WT2	6-Oct	7-Dec	6-Oct	2-Dec	-	-	6-Oct	7-Dec	10-Aug	31-Oct
	HS1	19-May	1-Nov	5-Oct	31-Oct	-	-	23-Sep	1-Nov	15-Aug	23-Oct
	HS2	4-Oct	1-Nov	4-Oct	31-Oct	-	-	4-Oct	1-Nov	15-Aug	22-Oct
	HS3	7-May	21-Sep	19-May	6-Aug	7-May	21-Sep	-	-	7-Aug	19-Oct
2015	IC3	29-May	16-Sep	4-Jul	11-Sep	-	-	-	-	30-Jun	12-Nov
	WT2	9-Jun	15-Sep	6-Sep	10-Sep	9-Jun	9-Jun	5-Sep	15-Sep	17-Jul	7-Nov
	HS1	5-May	15-Sep	-	-	-	-	-	-	16-Jul	5-Nov
	HS2	24-Apr	14-Sep	7-Jun	7-Jun	24-Apr	8-Jun	31-Aug	14-Sep	2-Aug	27-Oct

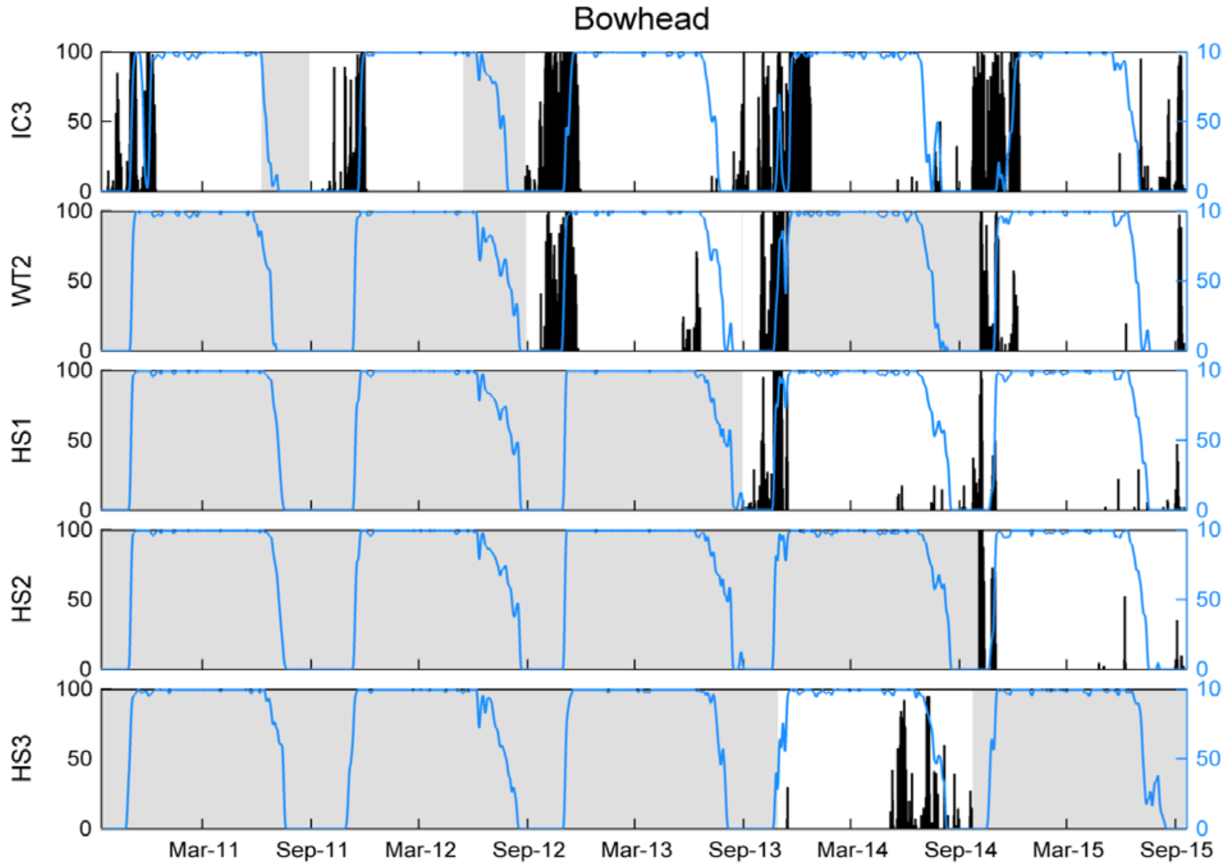

Figure 7. Bowhead whale calling activity (presented as the percentage of ten-minute time intervals with calls) for the five CHAOZ-X locations (see Figure 3A), 2012-2015. Blue line indicates percent ice cover (zero-phase, three-day moving average). Gray shading indicates no data.

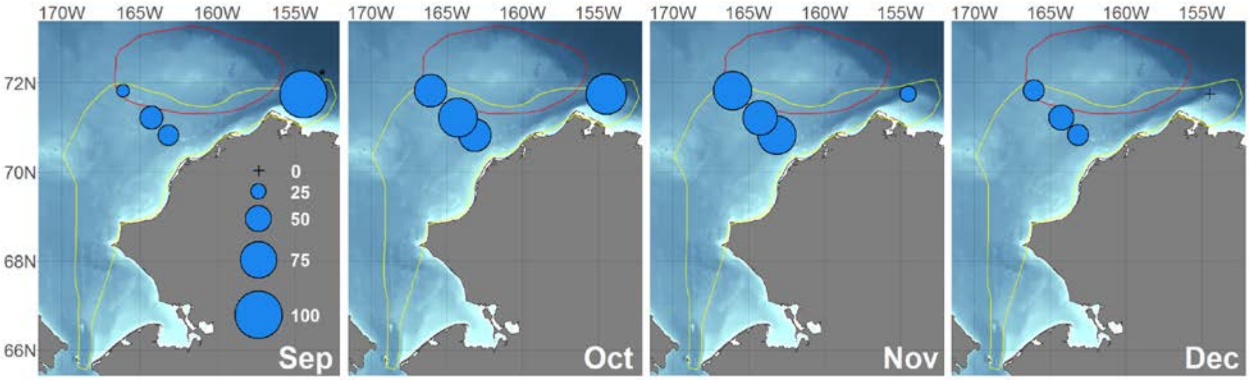

Figure 8. Monthly bowhead whale calling distribution, 2010. Graduated scale in the September panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *, Appendix C.3 for numbers used to generate figure.

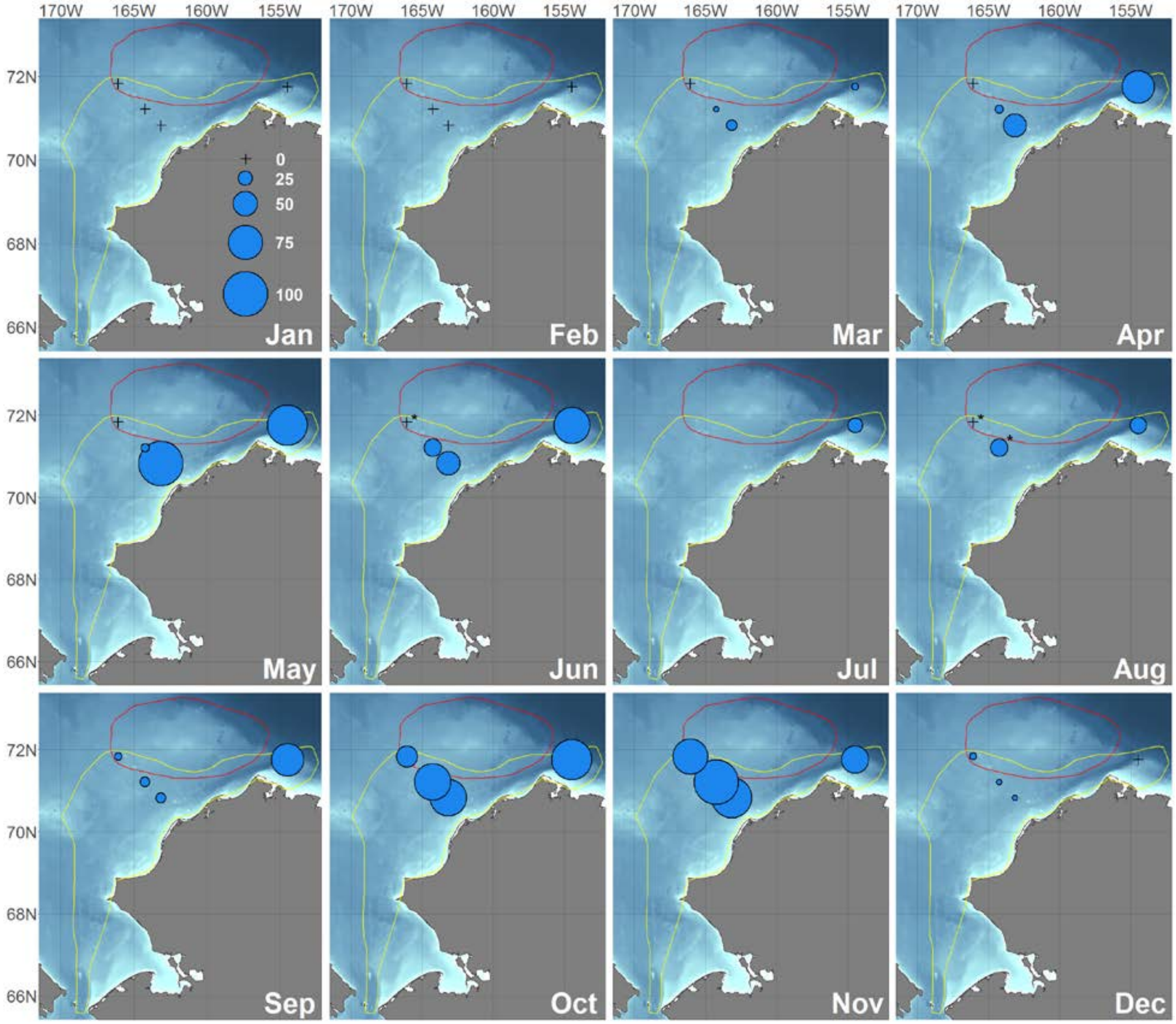

Figure 9. Monthly bowhead whale calling distribution, 2011. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *, see Appendix C.3 for numbers used to generate figure.

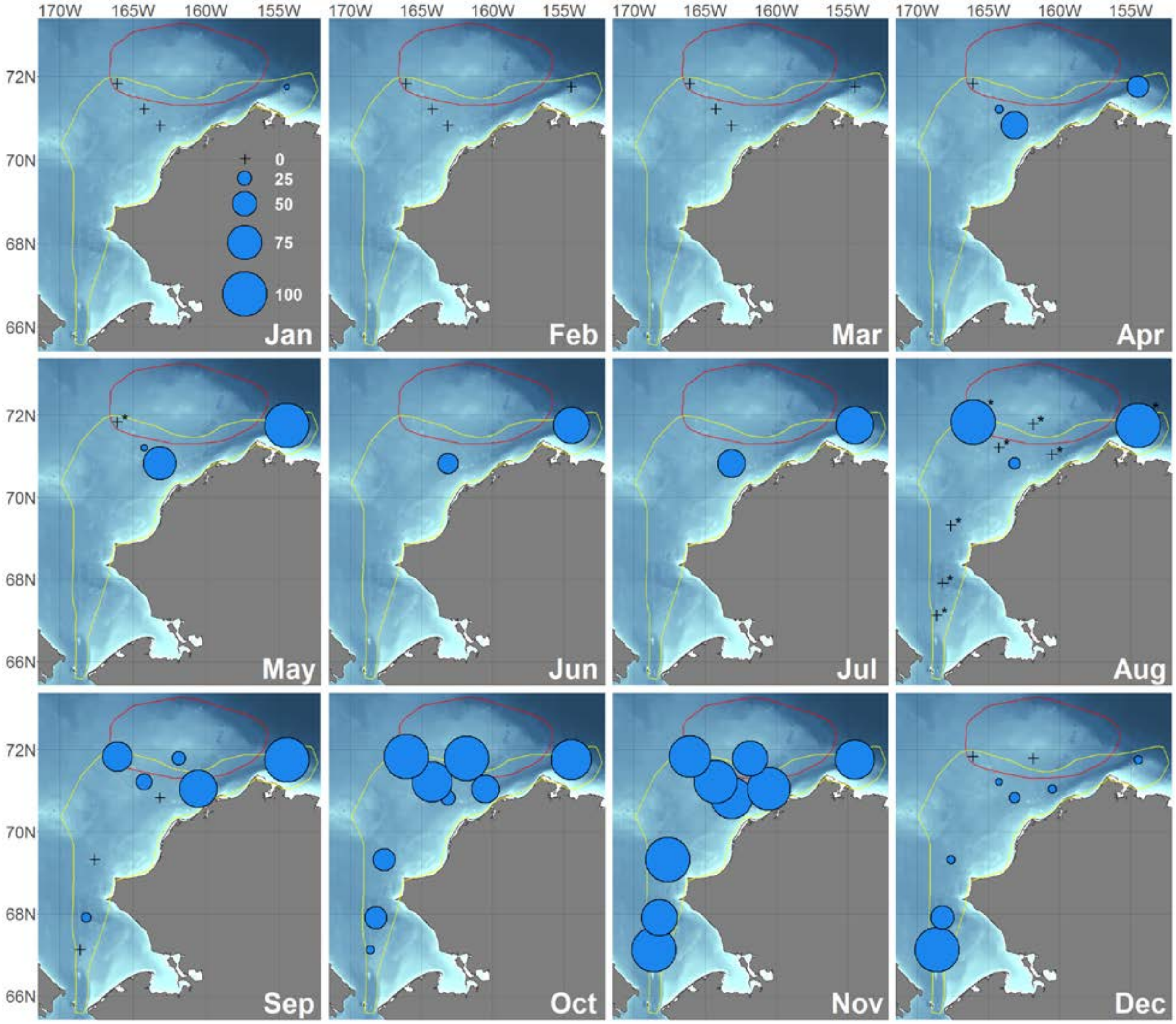

Figure 10. Monthly bowhead whale calling distribution, 2012. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *, see Appendix C.3 for numbers used to generate figure.

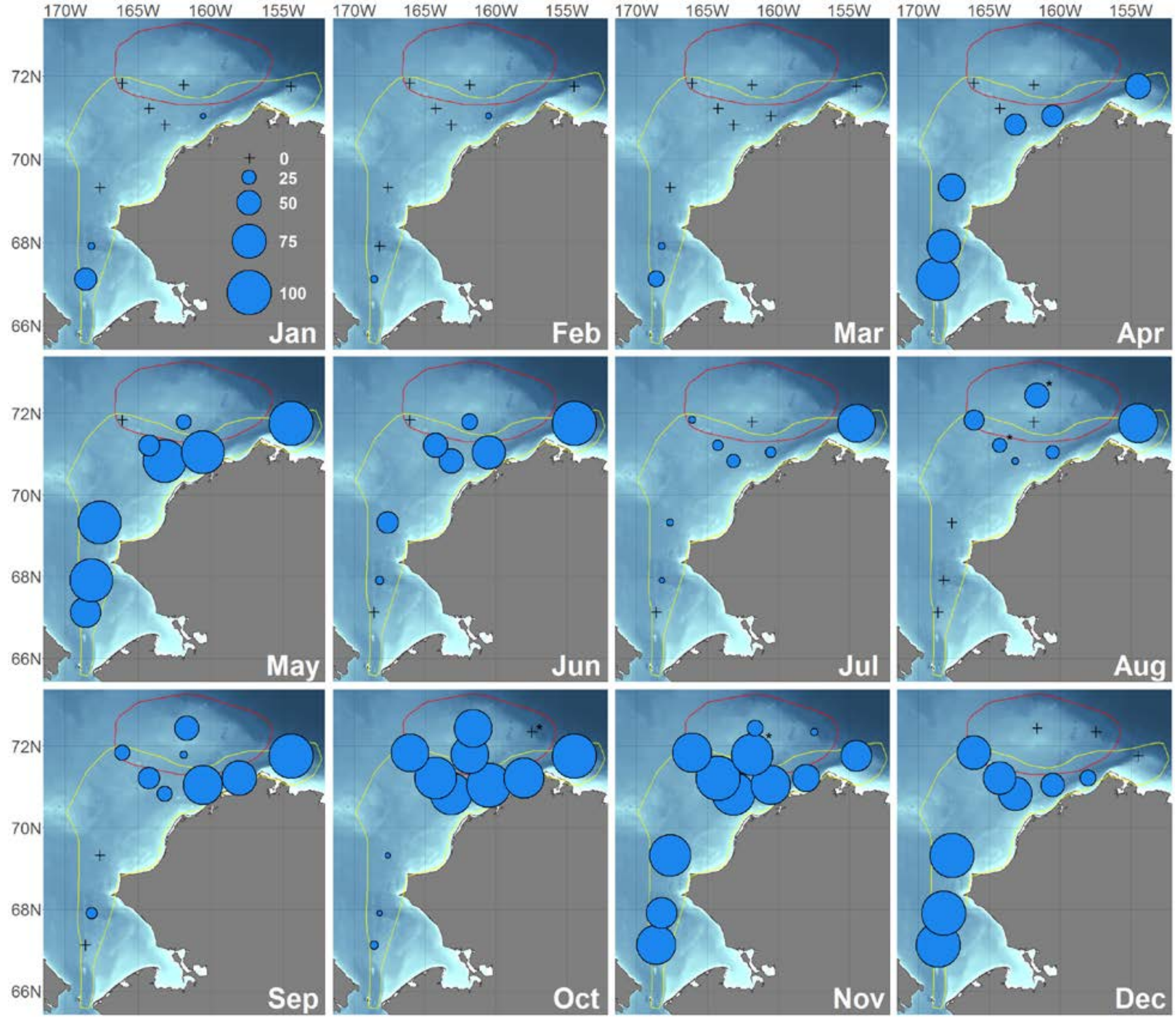

Figure 11. Monthly bowhead whale calling distribution, 2013. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *, see Appendix C.3 for numbers used to generate figure.

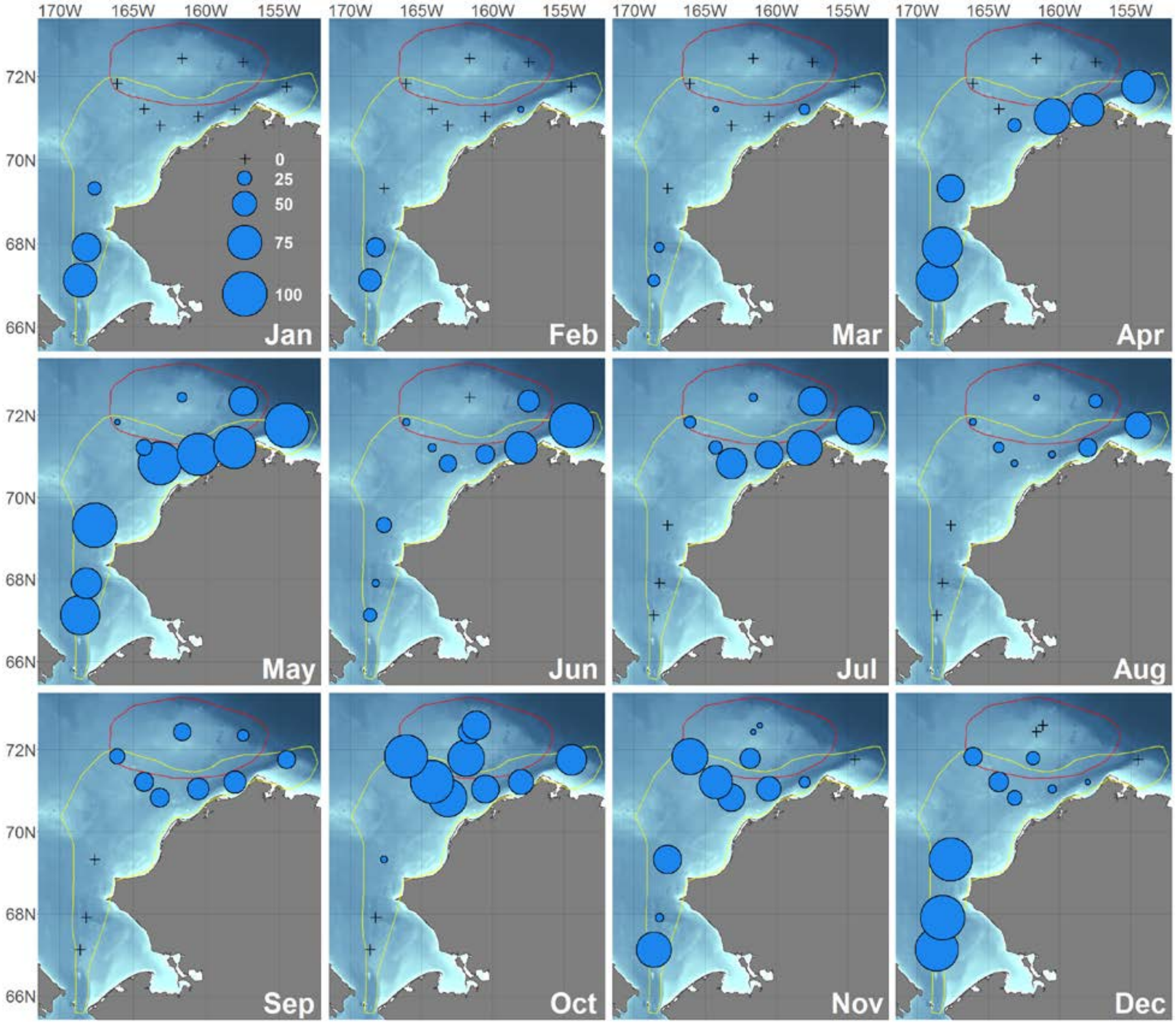

Figure 12. Monthly bowhead whale calling distribution, 2014. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *, see Appendix C.3 for numbers used to generate figure.

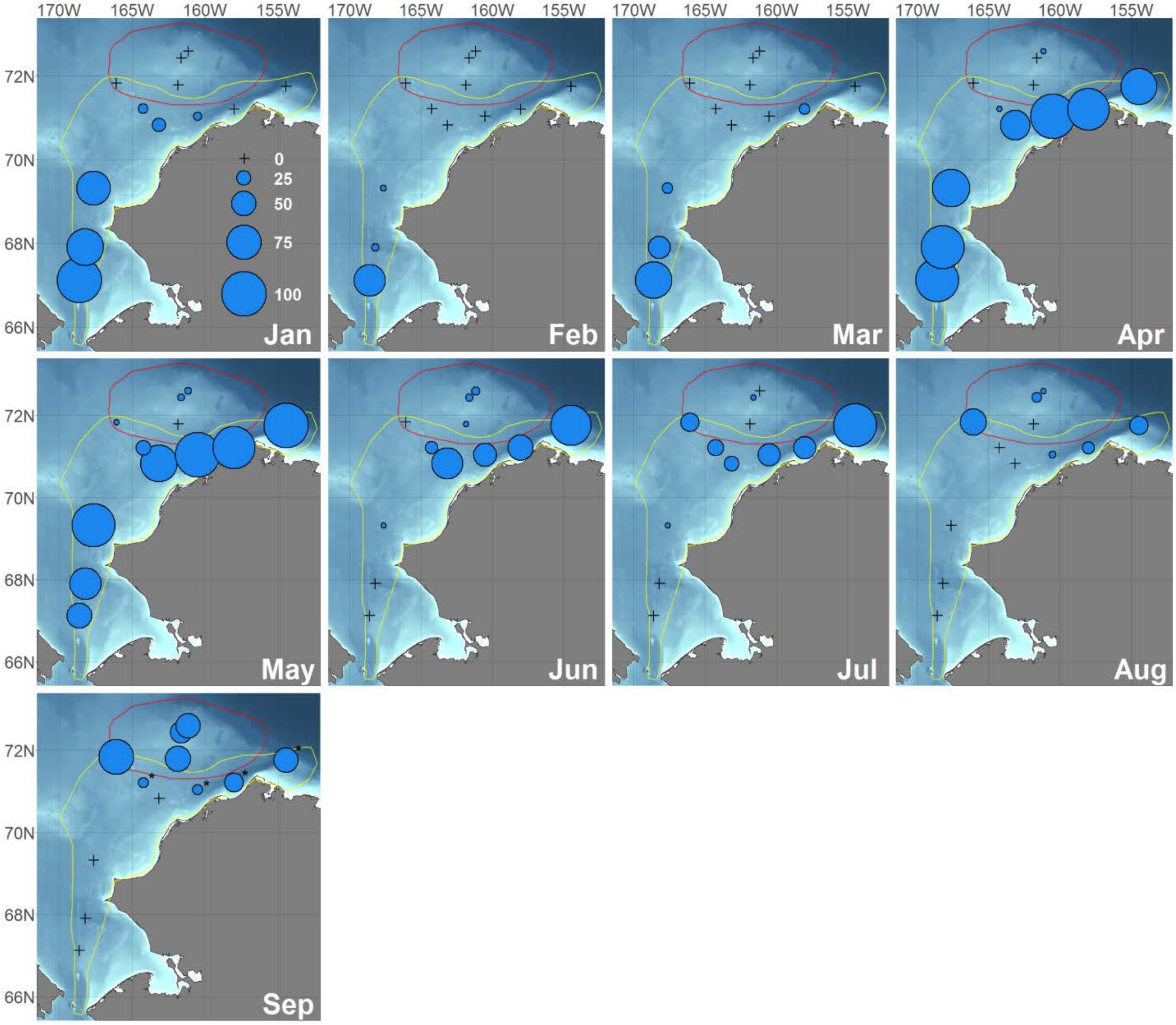

Figure 13. Monthly bowhead whale calling distribution, 2015. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *, see Appendix C.3 for numbers used to generate figure.

Analysts also flagged image files containing gunshot calls, an impulsive call type produced by both bowhead and right whales (Clark 1983; Würsig and Clark 1993; Parks et al. 2005). Although it is attributed to bowhead whales in the Arctic, this call type was flagged separately from the other bowhead calls because of our ongoing effort in the Bering Sea to differentiate bowhead and right whale gunshot calls. For all years and mooring locations, gunshot call activity (Figure 14, green) coincided with general bowhead calling activity, although there were considerably fewer days with gunshot call activity and lower levels of calling activity on those days. The peaks in gunshot call activity occurred near the end of each peak in bowhead calling activity in all cases where data are available in the fall during the start of the ice period. This was not as noticeable during the spring thaw period, perhaps because the pulse of bowhead calling is not as pronounced, but is present in approximately one half of the spring periods (Figure 14). The highest and more sustained peaks in gunshot call activity were found at the western CHAOZ-X site, IC3, and the shoal site WT2. The two sites on the northeast flank of Hanna Shoal, HS1 and HS2, showed considerably reduced levels, and none were present on the slope site, HS3, although most of the fall migration pulse was missed (Figure 14, green).

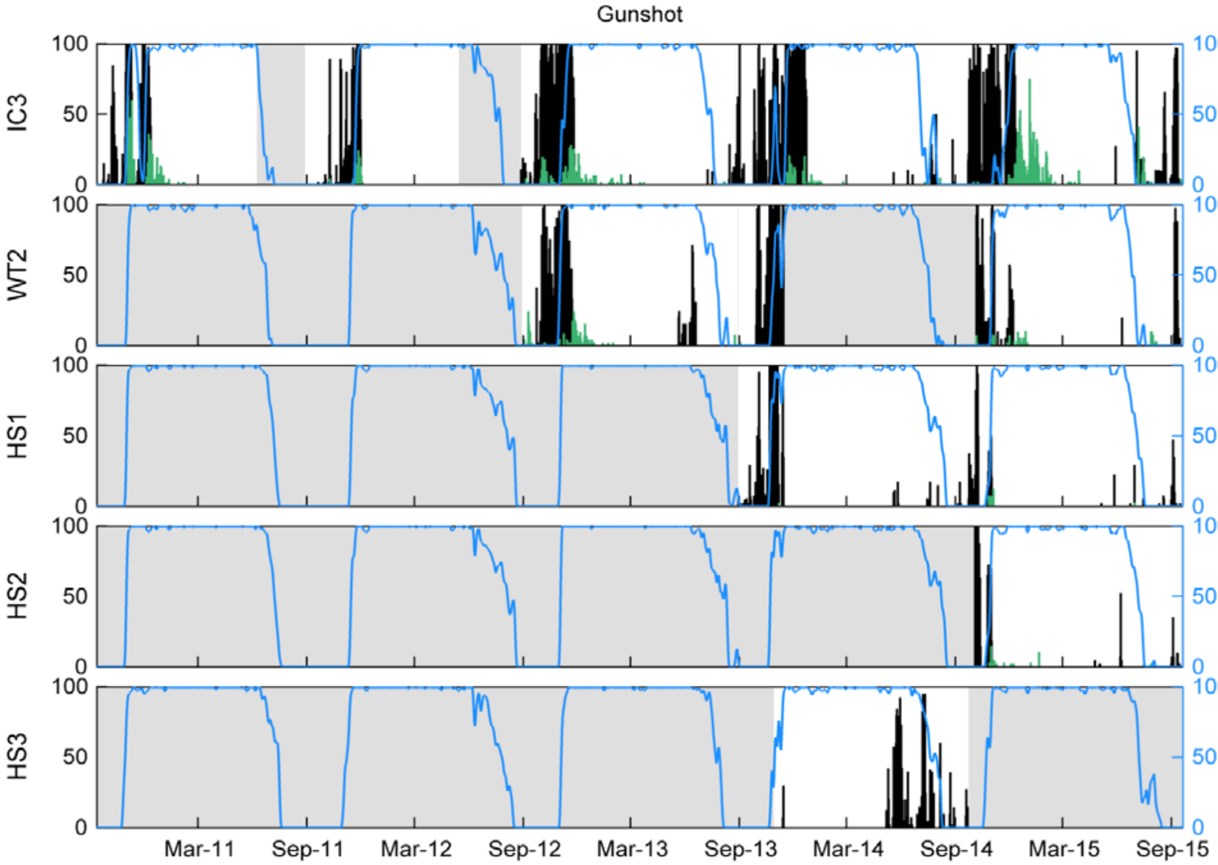

Figure 14. Gunshot call activity (green) overlaid on bowhead whale calling activity (presented as the percentage of ten-minute time intervals with calls) for the five CHAOZ-X locations (see Figure 3A), 2010-2015. Blue line indicates percent ice cover (zero-phase, three day moving average) Gray shading indicates no data.

Beluga whales

Like bowhead whales, beluga whale calling activity was detected on all the CHAOZ-X study area moorings for all years where data were available (Figures 15-21; Table 2). Among the mooring sites, the slope site (HS3) by far had the greatest proportion of days with calls as well as days with peak calling. The western (IC3) and shoal (WT2) sites had calling activity levels half that of the slope site (Table 6), and sites on the northeastern flank of Hanna Shoal (HS1 and HS2) had the lowest levels. Peak calling was very low for all sites except HS3.

Figure 15 and Table 7 show beluga whale calling activity in all months for IC3 and WT2. The slope site (HS3) had calling in February and from April to November. Calling activity at the sites on the northeastern flank of the shoal (HS1 and HS2) varied, with HS1 having two pulses of calling activity: April-July and October-January, and HS2 having calling from April-August and

October. The months with the highest levels of calling activity were fairly consistent between mooring sites: April through June and around October. The only exception was the slope site (HS3), which had high levels of calling activity April-May and also July-November (Table 7).

Beluga whale spring calling activity was seen at all CHAOZ-X mooring sites in all years where data are available (Figure 15); however, a fall pulse in calling was noticeably present only at the slope (HS3) and the western (IC3) sites. Because of the presence of beluga whale calling activity in the ice-free period of summer and the overwinter period between the fall and spring pulses, it is difficult to precisely define the edges of those pulses. The date ranges for those pulses listed in Table 8 therefore, should be considered rough estimates. In general, the spring pulse of calling commenced at approximately the same time (but with a slight longitudinal delay of a few days) at all mooring sites when data were available; this start was progressively delayed over the course of the study, shifting from the beginning of April in 2011 to the end of April in 2015. The slope site (HS3) is notable for having two distinct pulses prior to and during the spring period of ice break-up. As mentioned above, the fall pulse of beluga calling activity was not commonly detected; where it was detected, its start varied between early October and early November, ending between early to late November.

Table 6. Total beluga whale calling activity, 2010-2015, for all CHAOZ-X mooring locations. Number of days with recordings (Eff), number of days with calling activity (#), number of days with calling activity > 50% (#pk), percent of days with calling activity(%), percent of days with calling activity > 50% (%pk).

Mooring	Eff	#	# pk	%	% pk
IC3	1647	227	7	14	0
WT2	788	76	1	10	0
HS1	747	29	1	4	0
HS2	348	22	0	6	0
HS3	327	115	20	35	6

Table 7. Average monthly beluga whale calling activity, 2010-2015, for all CHAOZ-X mooring locations. Number of days with calling activity (#), number of days with recordings (Eff), percent of days with calling activity per month (%).

Month	IC3			WT2			HS1			HS2			HS3		
	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**
Jan	11	155	**7**	1	62	**2**	1	62	**2**	0	31	**0**	0	31	**0**
Feb	5	141	**4**	2	56	**4**	0	56	**0**	0	28	**0**	2	28	**7**
Mar	4	155	**3**	2	62	**3**	0	62	**0**	0	31	**0**	0	31	**0**
Apr	42	150	**28**	15	60	**25**	5	60	**8**	4	30	**13**	9	30	**30**
May	40	138	**29**	22	62	**35**	9	62	**15**	8	31	**26**	26	31	**84**
Jun	22	98	**22**	15	60	**25**	4	60	**7**	1	30	**3**	5	30	**17**
Jul	6	93	**6**	3	62	**5**	2	62	**3**	4	31	**13**	22	31	**71**
Aug	3	99	**3**	1	63	**2**	0	64	**0**	2	31	**6**	28	31	**90**
Sep	2	158	**1**	1	77	**1**	0	76	**0**	0	16	**0**	11	20	**55**
Oct	24	155	**15**	8	88	**9**	5	61	**8**	3	28	**11**	2	3	**67**
Nov	59	150	**39**	5	74	**7**	2	60	**3**	0	30	**0**	10	30	**33**
Dec	9	155	**6**	1	62	**2**	1	62	**2**	0	31	**0**	0	31	**0**

Table 8. Key timing events for beluga whale calling activity. Underlined dates are recorder limited. Ice start and end dates were obtained from satellite-derived ice concentration data. *These dates were obtained by estimating the dates for the main pulses in Figure 15.

Year	Mooring	Calling		Peak Calling		Spring Pulse* Dates		Fall Pulse* Dates		Ice End Date	Ice Start Date
		Start	End	Start	End	Start	End	Start	End		
2010	IC3	8-Nov	21-Dec	-	-	-	-	8-Nov	1-Dec	16-Jul	31-Oct
2011	IC3	3-Apr	23-Nov	-	-	3-Apr	21-Apr	3-Nov	23-Nov	5-Jul	22-Nov
2012	IC3	18-Jan	15-Nov	14-Nov	14-Nov	12-Apr	7-May	3-Nov	15-Nov	27-Jul	3-Nov
	WT2	24-Oct	9-Nov	-	-	-	-	-	-	17-Aug	31-Oct
2013	IC3	1-Jan	29-Dec	4-Nov	4-Nov	9-Apr	12-Jun	30-Sep	27-Nov	21-Jul	26-Oct
	WT2	10-Feb	6-Nov	16-May	16-May	12-Apr	16-Jun	3-Oct	6-Nov	11-Aug	24-Oct
	HS1	4-Oct	9-Dec	-	-	-	-	-	-	30-Aug	22-Oct
	HS3	30-Oct	21-Nov	-	-	-	-	30-Oct	21-Nov	3-Aug	23-Oct
2014	IC3	3-Jan	3-Dec	26-Nov	27-Nov	18-Apr	29-Jun	6-Oct	3-Dec	30-Jul	3-Nov
	WT2	31-Oct	2-Dec	-	-	-	-	-	-	10-Aug	31-Oct
	HS1	8-Jan	16-Nov	-	-	-	-	-	-	15-Aug	23-Oct
	HS2	8-Oct	17-Oct	-	-	-	-	-	-	15-Aug	22-Oct
	HS3	16-Feb	19-Sep	26-Apr	6-Sep	25-Apr	19-Sep	-	-	7-Aug	19-Oct
2015	IC3	4-Jan	20-Jul	25-Apr	27-Apr	24-Apr	19-Jun	-	-	30-Jun	12-Nov
	WT2	21-Jan	13-Sep	-	-	23-Apr	6-Jul	-	-	17-Jul	7-Nov
	HS1	24-Apr	21-Jul	5-May	5-May	24-Apr	18-Jun	-	-	16-Jul	5-Nov
	HS2	26-Apr	5-Aug	-	-	26-Apr	22-May	-	-	2-Aug	27-Oct

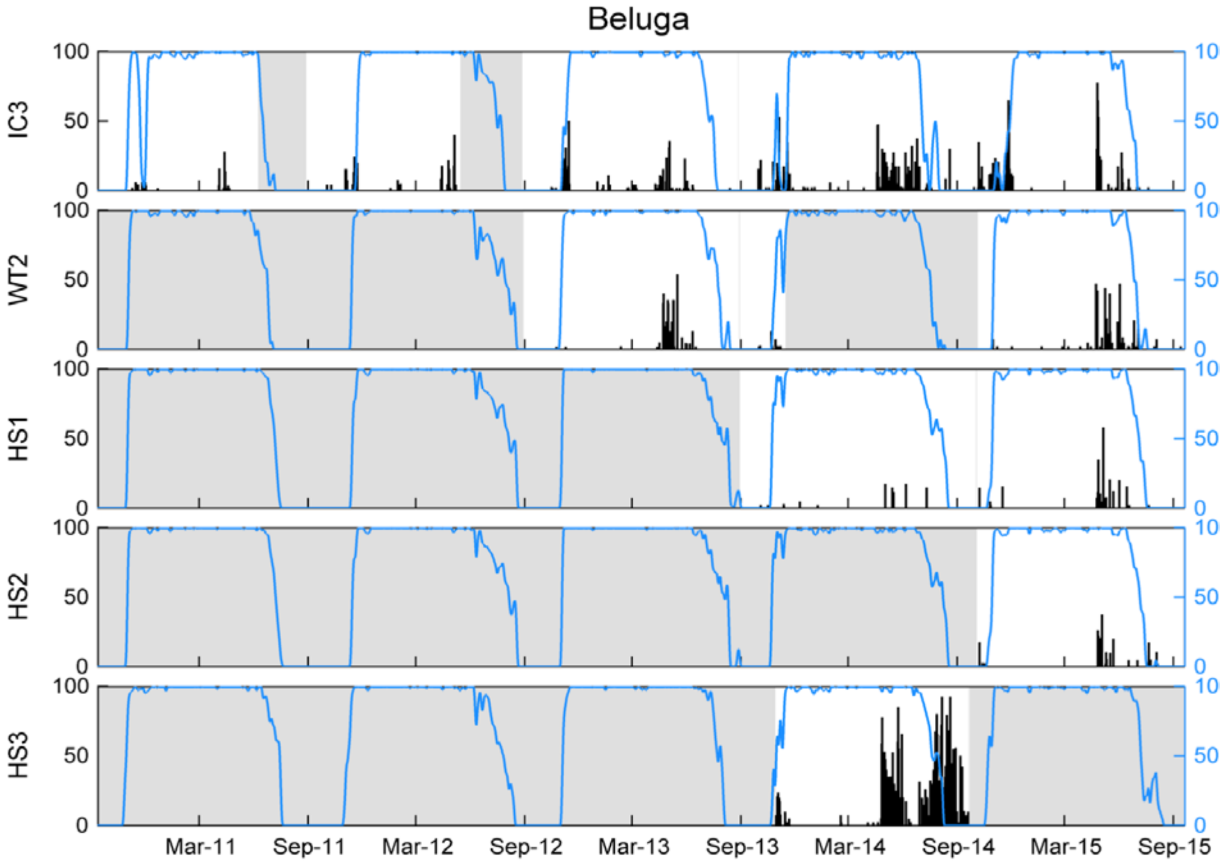

Figure 15. Beluga whale calling activity (presented as the percentage of ten-minute time intervals with calls) for the five CHAOZ-X locations (see Figure 3A), 2012-2015. Blue line indicates percent ice cover (zero-phase, three-day moving average). Gray shading indicates no data.

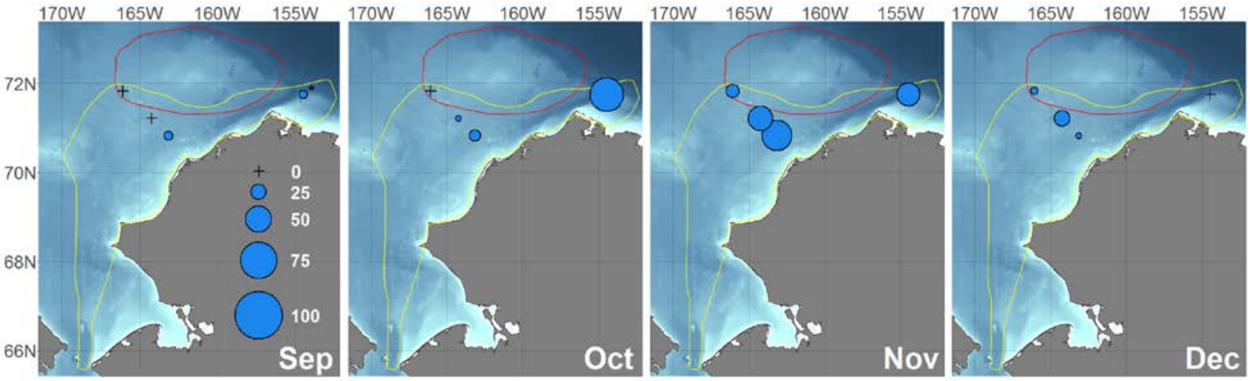

Figure 16. Monthly beluga whale calling distribution, 2010. Graduated scale in the September panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.4 for numbers used to generate figure.

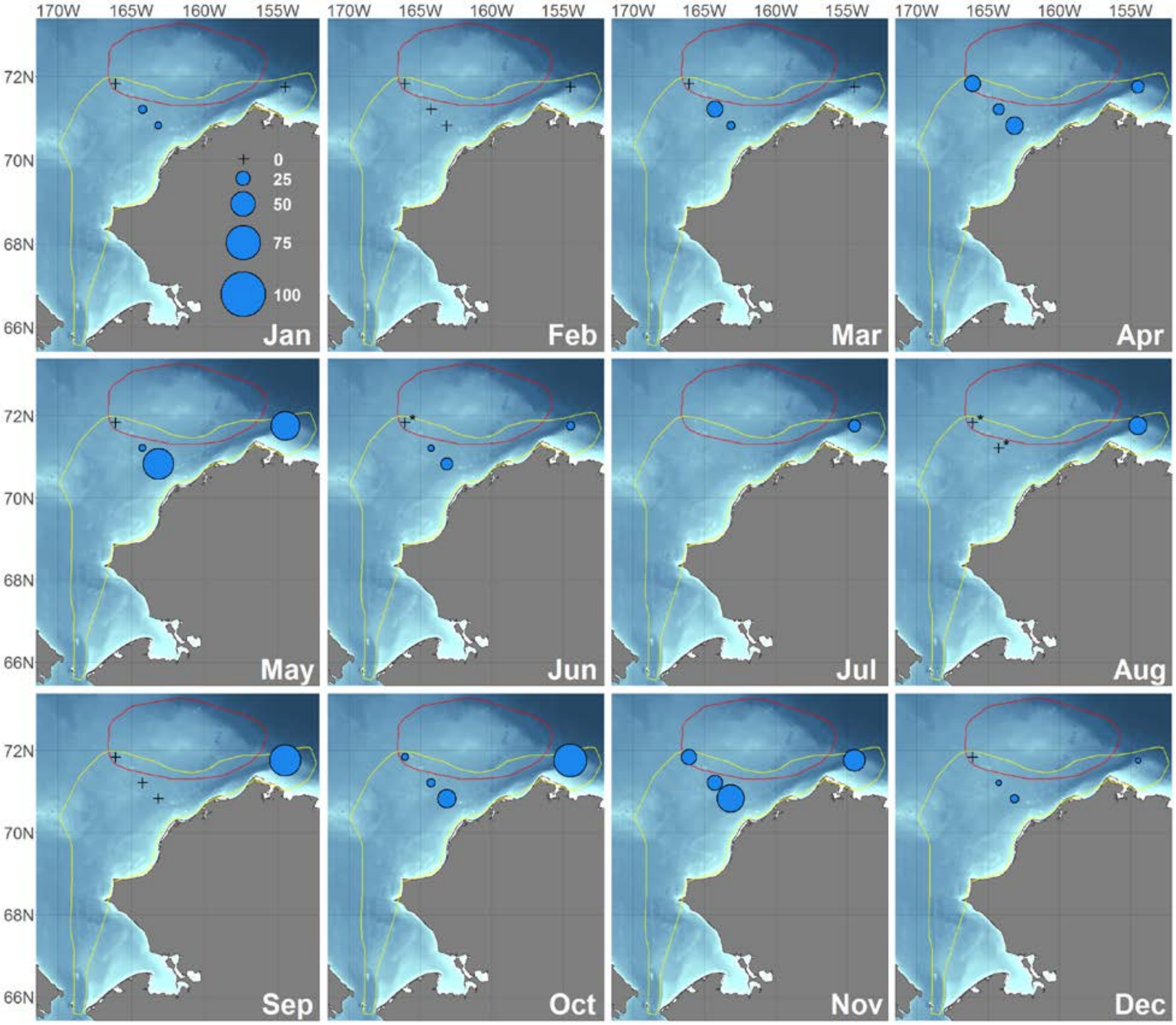

Figure 17. Monthly beluga whale calling distribution, 2011. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.4 for numbers used to generate figure.

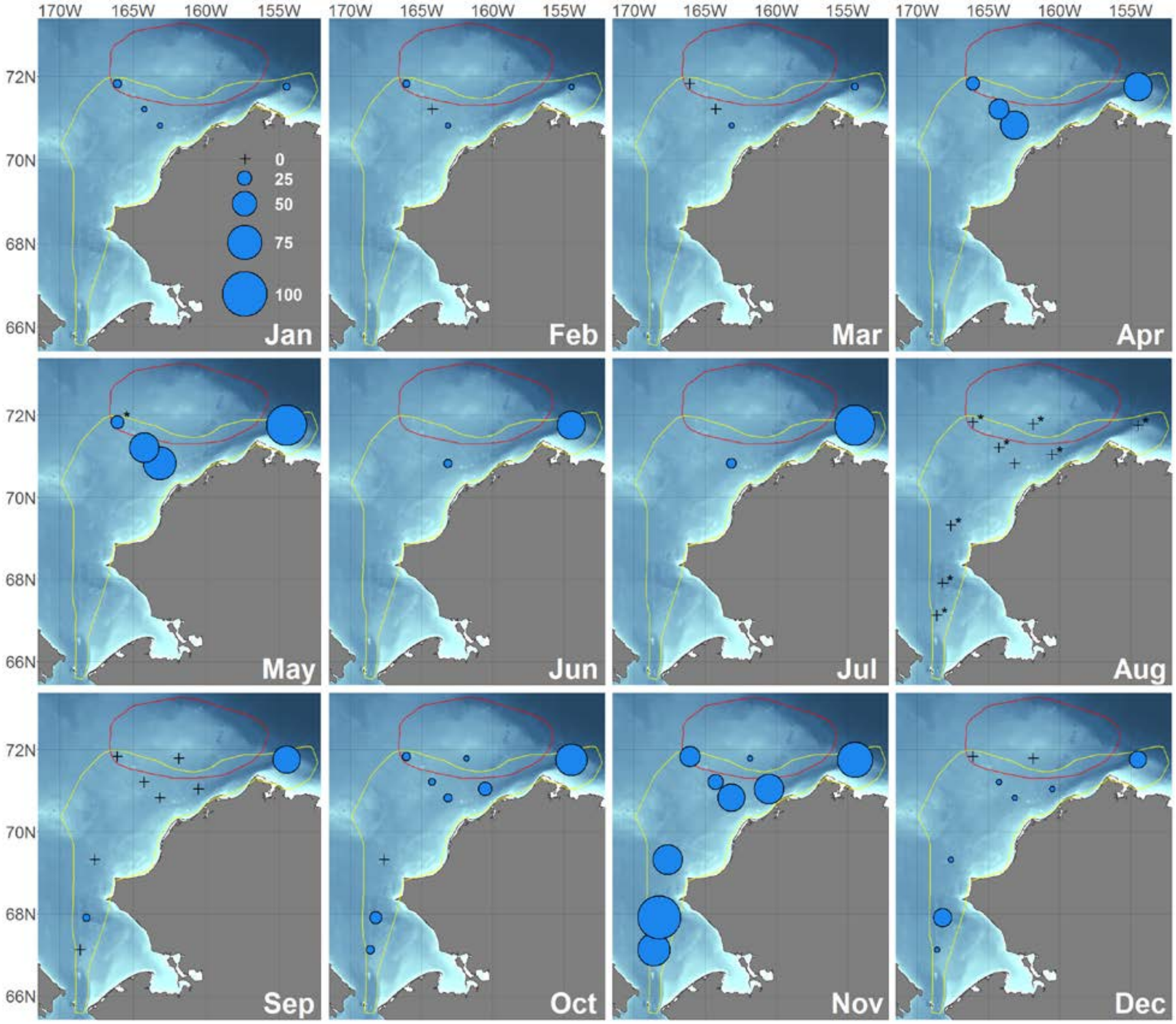

Figure 18. Monthly beluga whale calling distribution, 2012. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.4 for numbers used to generate figure.

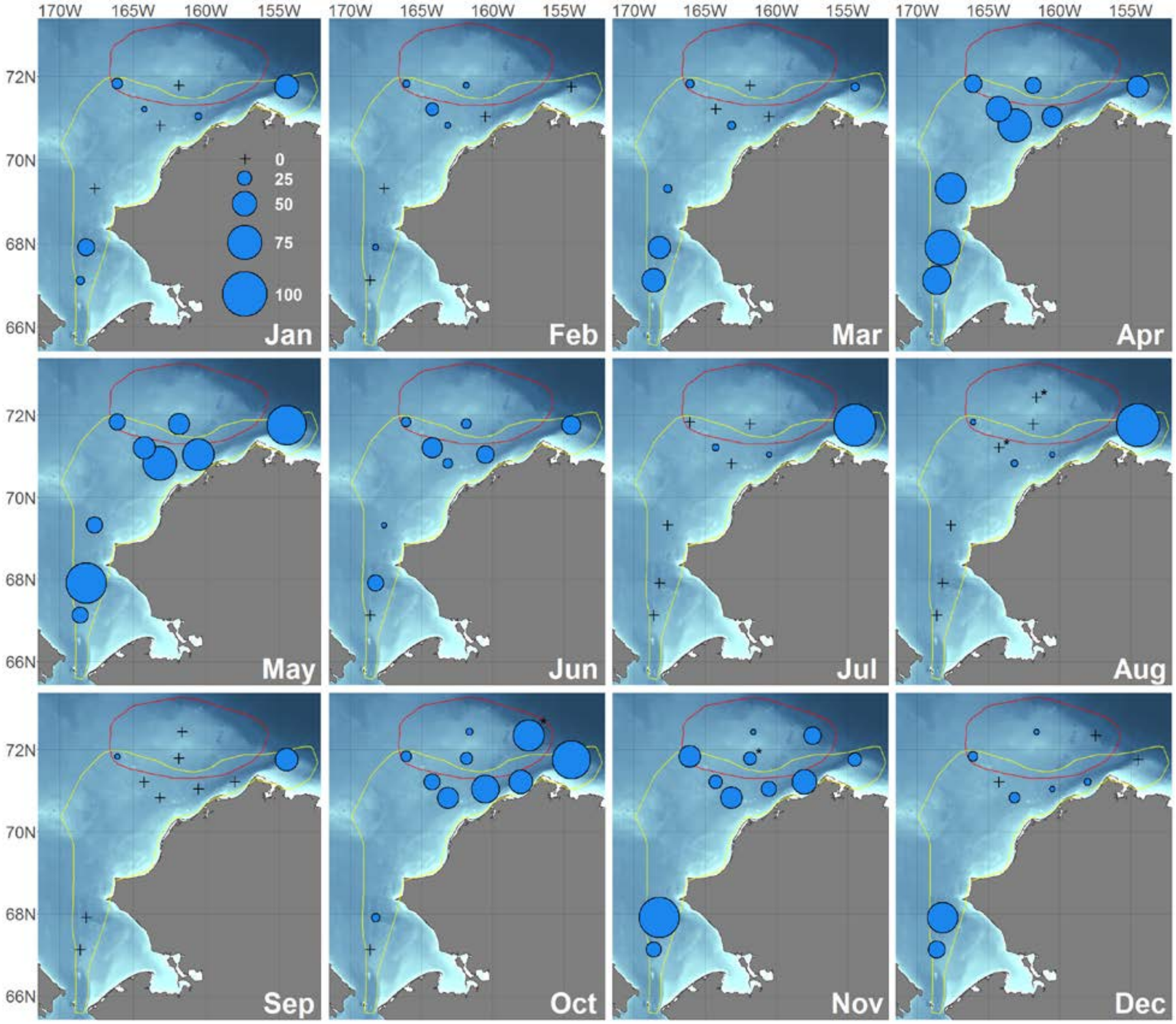

Figure 19. Monthly beluga whale calling distribution, 2013. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.4 for numbers used to generate figure.

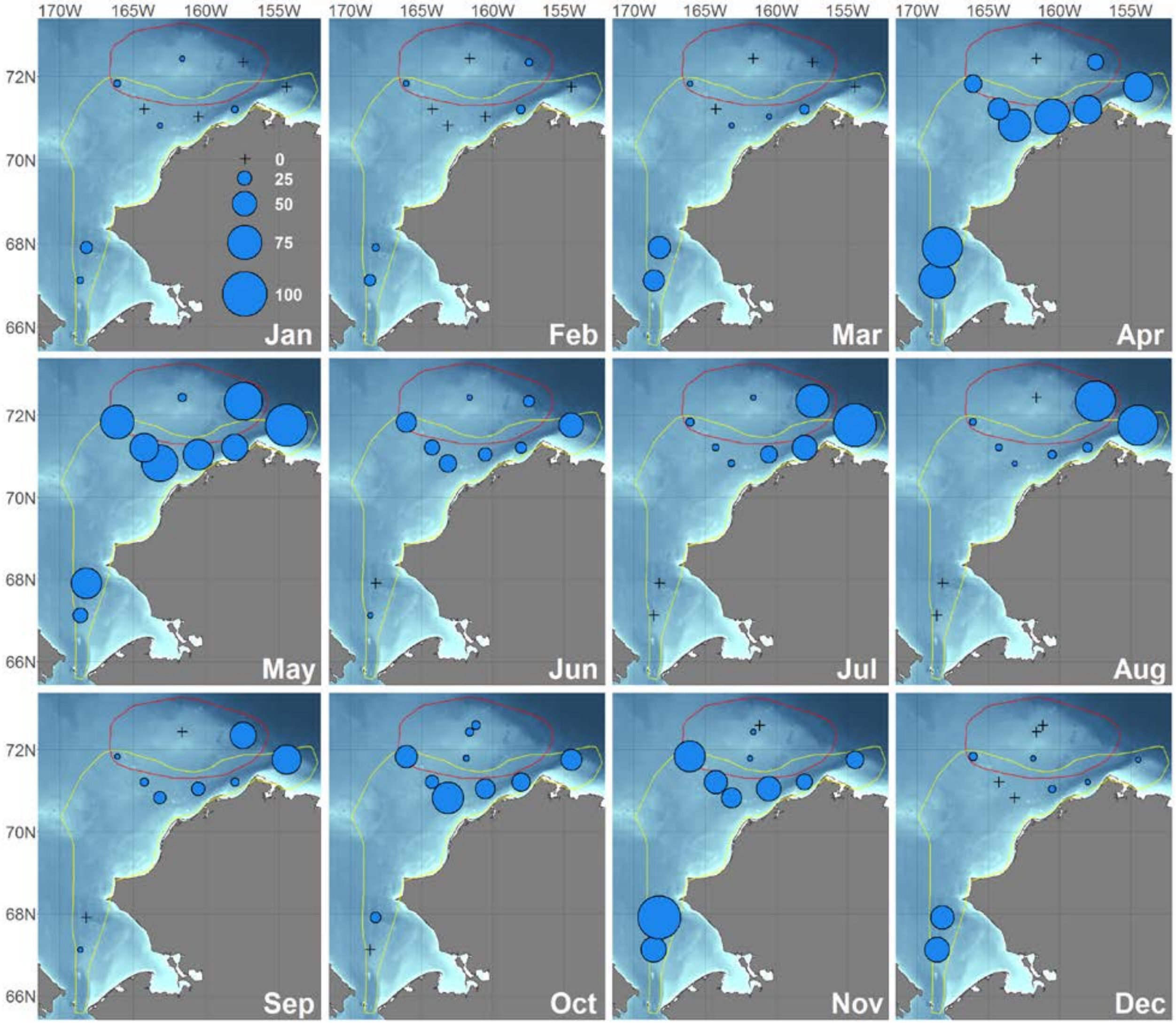

Figure 20. Monthly beluga whale calling distribution, 2014. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.4 for numbers used to generate figure.

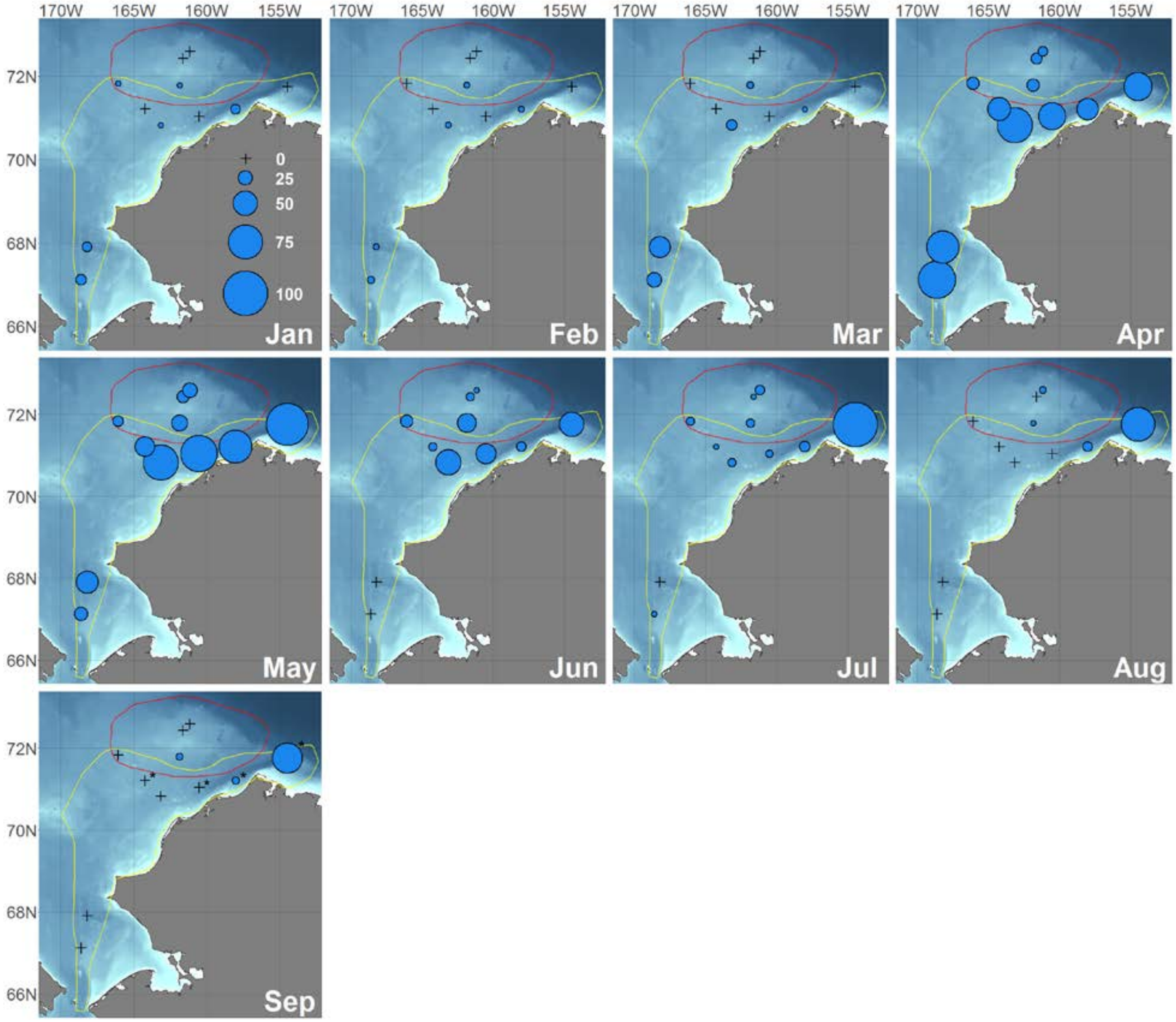

Figure 21. Monthly beluga whale calling distribution, 2015. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.4 for numbers used to generate figure.

Bearded seals

Bearded seal calling activity was nearly ubiquitous at all CHAOZ-X moorings sites for all years where data were available (Figures 22-28; Table 2). Multiple weeks of saturated (i.e., 100% of all ten-minute time intervals per day had calling detected) calling activity were present for each location and year. Among the mooring sites, the western (IC3) and shoal (WT2) sites had the greatest proportion of days with calls as well as days with peak calling, followed closely by the two sites on the northeastern flank of the shoal (HS1 and HS2), with the slope site (HS3) having the lowest proportions of both days with calling and peak calling (Table 9). Peak calling for all sites occurred on slightly more than half of the days with calling activity present (Table 9). Calls were detected during all months for all moorings, with the exception of the HS2 site on the northeastern flank of the shoal and the slope site (HS3), had no calling in August-September and August-November, respectively (Table 10). The moorings sites with the highest monthly averages followed this trend as well, with the slope site (HS3) having consistently lower levels of calling activity than the other sites (Table 10). For all sites, calling was lowest in July-August, increased between September through January, and was present on all days of the month for all years from February through June (Table 10).

Table 9. Total bearded seal calling activity, 2010-2015, for all CHAOZ-X mooring locations. Number of days with recordings (Eff), number of days with calling activity (#), number of days with calling activity > 50% (#pk), percent of days with calling activity (#), number of days with calling activity > 50% (#pk), percent of days with calling activity (%), percent of days with calling activity > 50% (%pk).

Mooring	Eff	#	# pk	%	% pk
IC3	1647	1079	651	66	40
WT2	788	571	330	72	42
HS1	747	473	242	63	32
HS2	348	193	99	55	28
HS3	327	156	76	48	23

Table 10. Average monthly bearded seal calling activity, 2010-2015, for all CHAOZ-X mooring locations. Number of days with calling activity (#), number of days with recordings (Eff), percent of days with calling activity per month (%).

Month	IC3			WT2			HS1			HS2			HS3		
	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%
Jan	136	155	**88**	59	62	**95**	56	62	**90**	26	31	**84**	14	31	**45**
Feb	126	141	**89**	56	56	**100**	56	56	**100**	28	28	**100**	21	28	**75**
Mar	149	155	**96**	62	62	**100**	62	62	**100**	31	31	**100**	25	31	**81**
Apr	150	150	**100**	60	60	**100**	60	60	**100**	29	30	**97**	29	30	**97**
May	138	138	**100**	62	62	**100**	62	62	**100**	31	31	**100**	31	31	**100**
Jun	95	98	**97**	60	60	**100**	60	60	**100**	30	30	**100**	29	30	**97**
Jul	4	93	**4**	3	62	**5**	13	62	**21**	6	31	**19**	2	31	**6**
Aug	8	99	**8**	4	63	**6**	1	64	**2**	0	31	**0**	0	31	**0**
Sep	55	158	**35**	19	77	**25**	14	76	**18**	0	16	**0**	0	20	**0**
Oct	60	155	**39**	66	88	**75**	27	61	**44**	6	28	**21**	0	3	**0**
Nov	45	150	**30**	62	74	**84**	22	60	**37**	1	30	**3**	0	30	**0**
Dec	113	155	**73**	58	62	**94**	40	62	**65**	5	31	**16**	5	31	**16**

Table 11. Key timing events for bearded seal calling activity. Underlined dates are recorder limited. Ice start and end dates were obtained from satellite-derived ice concentration data. *These dates were obtained by estimating the dates for the main pulses in Figure 22. Note this is the only species where the key timing events are listed for deployment (and not calendar) year.

Year	Mooring	Calling Dates		Main Pulse* Dates		Peak Calling Dates		Ice Start Date	Ice End Date
		Start	End	Start	End	Start	End		
2010-11	IC3	10/1/2010	6/8/2011	3/2/2011	6/8/2011	12/28/2010	6/8/2011	10/31/2010	7/5/2011
2011-12	IC3	8/30/2011	5/14/2012	11/22/2011	5/14/2012	11/26/2011	5/14/2012	11/22/2011	7/27/2012
2012-13	IC3	8/28/2012	7/2/2013	11/10/2012	7/2/2013	12/2/2012	7/1/2013	11/3/2012	7/21/2013
	WT2	9/11/2012	7/5/2013	9/29/2012	7/5/2013	11/21/2012	6/25/2013	10/31/2012	8/11/2013
2013-14	IC3	9/24/2013	7/5/2014	12/11/2013	7/1/2014	12/19/2013	7/1/2014	10/26/2013	7/30/2014
	WT2	8/9/2013	11/14/2013	-	-	10/22/2013	10/22/2013	10/24/2013	8/10/2014
	HS1	9/12/2013	7/29/2014	12/11/2014	7/10/2014	12/31/2013	6/28/2014	10/22/2013	8/15/2014
	HS3	12/20/2013	7/9/2014	3/18/2014	6/29/2014	3/29/2014	6/28/2015	10/23/2013	8/7/2014
2014-15	IC3	11/22/2014	6/28/2015	12/13/2014	6/28/2015	12/23/2014	6/24/2015	11/3/2014	6/30/2015
	WT2	10/6/2014	6/30/2015	10/28/2014	6/30/2015	12/4/2014	6/29/2015	10/31/2014	7/17/2015
	HS1	9/24/2014	7/8/2015	11/11/2014	7/8/2015	1/11/2015	7/5/2015	10/23/2014	7/16/2015
	HS2	10/4/2014	7/6/2015	1/1/2015	7/6/2015	2/3/2015	7/5/2015	10/22/2014	8/2/2015
	HS3	-	-	-	-	-	-	10/19/2014	-
2015-16	IC3	8/2/2015	-	-	-	-	-	11/12/2015	-
	WT2	8/12/2015	-	-	-	-	-	11/7/2015	-
	HS1	8/21/2015	-	-	-	-	-	11/5/2015	-
	HS2	-	-	-	-	-	-	10/27/2015	-

Unlike the spring/fall pulses in calling activity seen for bowhead and beluga whales, the main pulse of calling activity for bearded seals was overwinter (i.e., pulse was Oct-June). With few exceptions, the start of each period of calling typically ramped up from low to high levels over a variable period of time. In some cases (e.g., IC3 in 2011) a smaller pulse of calling activity was seen before the main pulse. Because of the variation in calling activity during this ramp-up period, it was difficult to precisely define the edges of the main pulses. The date ranges listed in Table 11 for these main pulses, therefore, should be considered rough estimates. In general, there was no evident interannual or inter-site trend among years for the start of the main pulse other than the shoal site (WT2) having an earlier start date for the main pulse than the other locations. Likewise, there were no clear trends among years or mooring locations for the start date of peak calling (days with >50% calling activity). Conversely, the end of the calling activity period ended abruptly, with very little difference among the end of all calling, the main pulse of calling, and peak calling (Figure 22; Table 11). When not recorder limited, the ending date of the main pulse occurred between the end of June and the beginning of July.

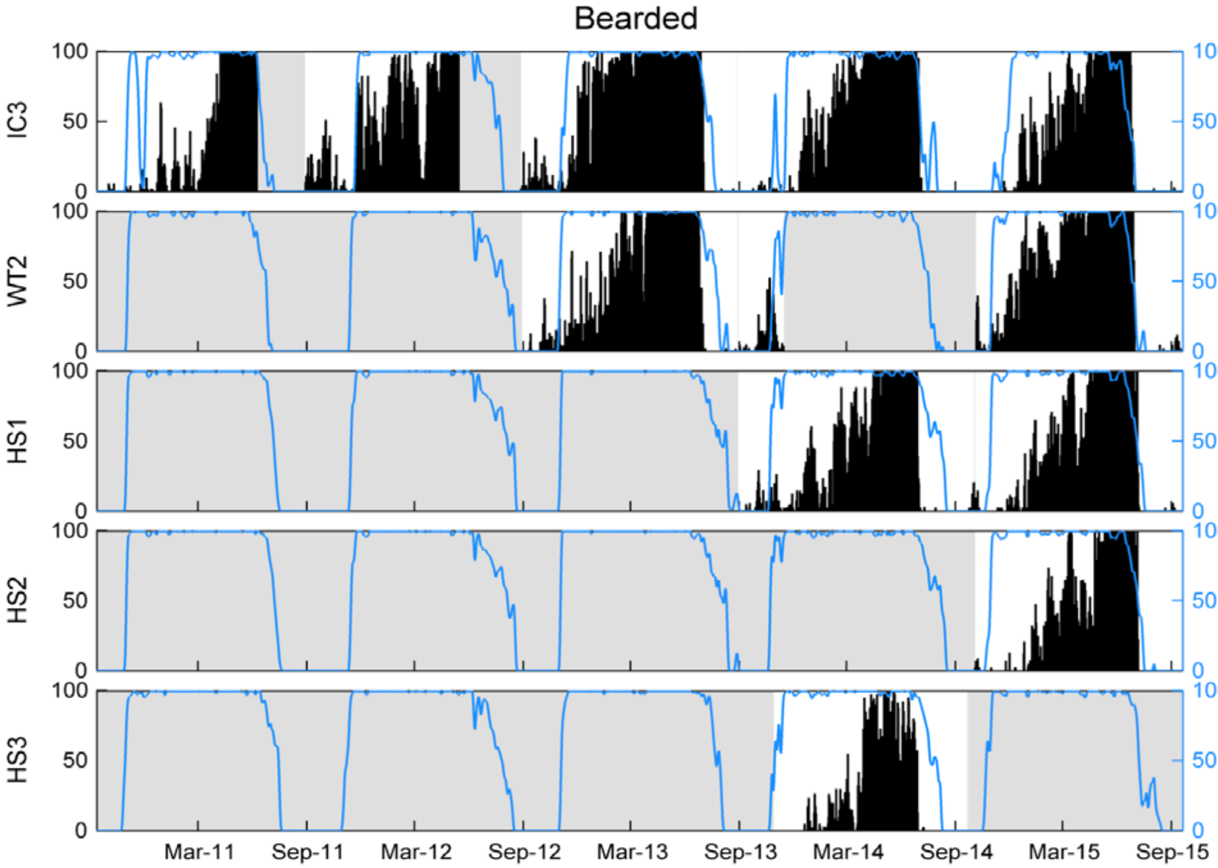

Figure 22. Bearded seal calling activity (presented as the percentage of ten-minute time intervals with calls) for the five CHAOZ-X locations (see Figure 3A), 2012-2015. Blue line indicates percent ice cover (zero-phase, three-day moving average). Gray shading indicates no data.

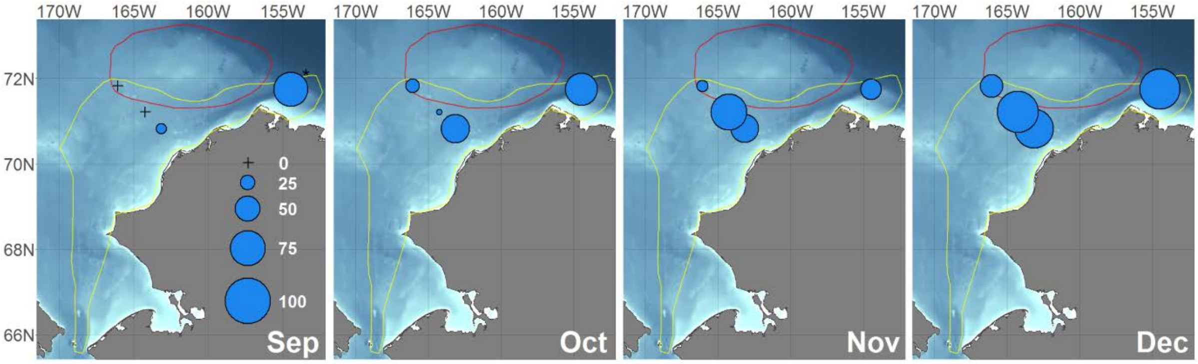

Figure 23. Monthly bearded seal calling distribution, 2010. Graduated scale in the September panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.5 for numbers used to generate figure.

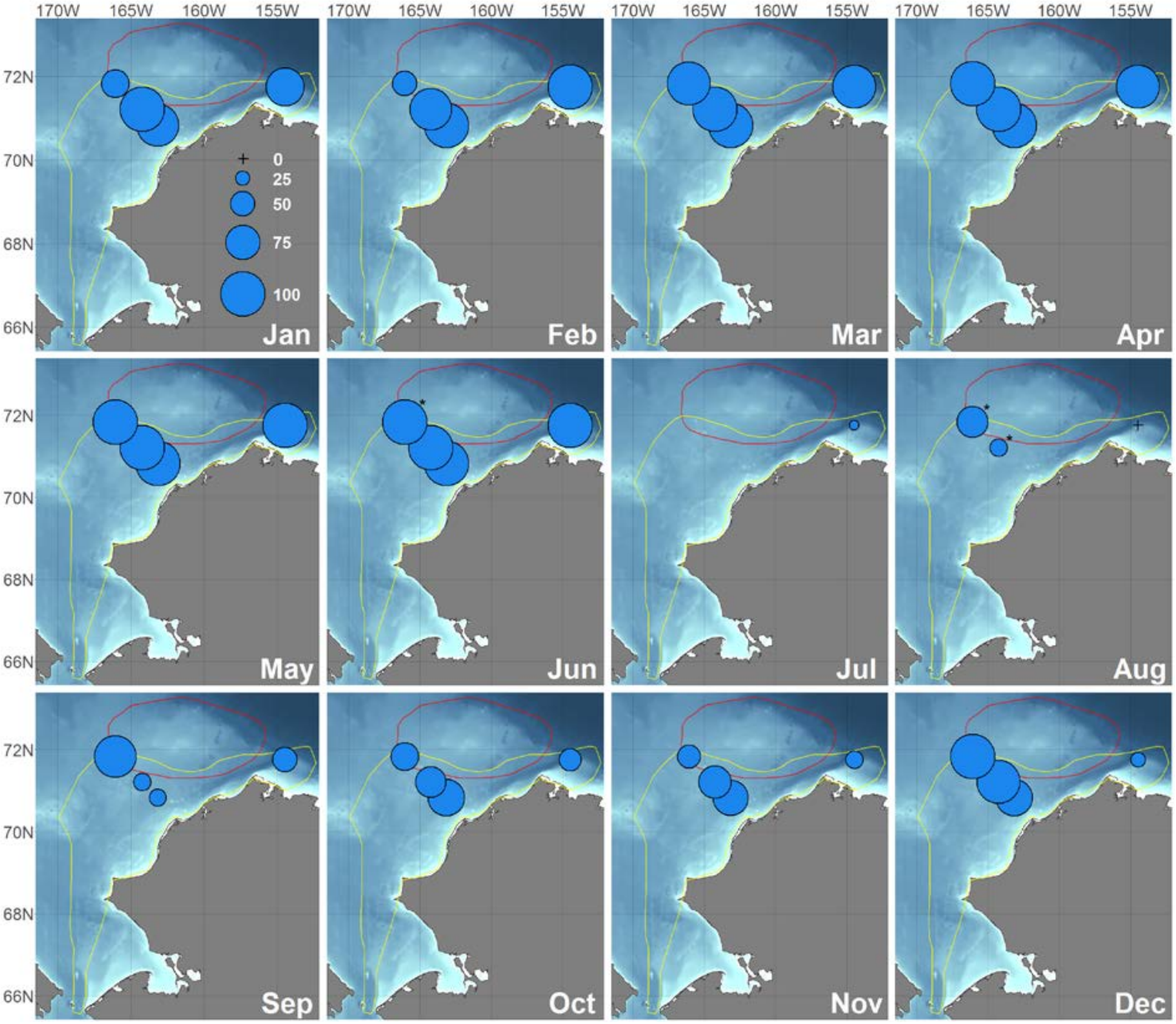

Figure 24. Monthly bearded seal calling distribution, 2011. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.5 for numbers used to generate figure.

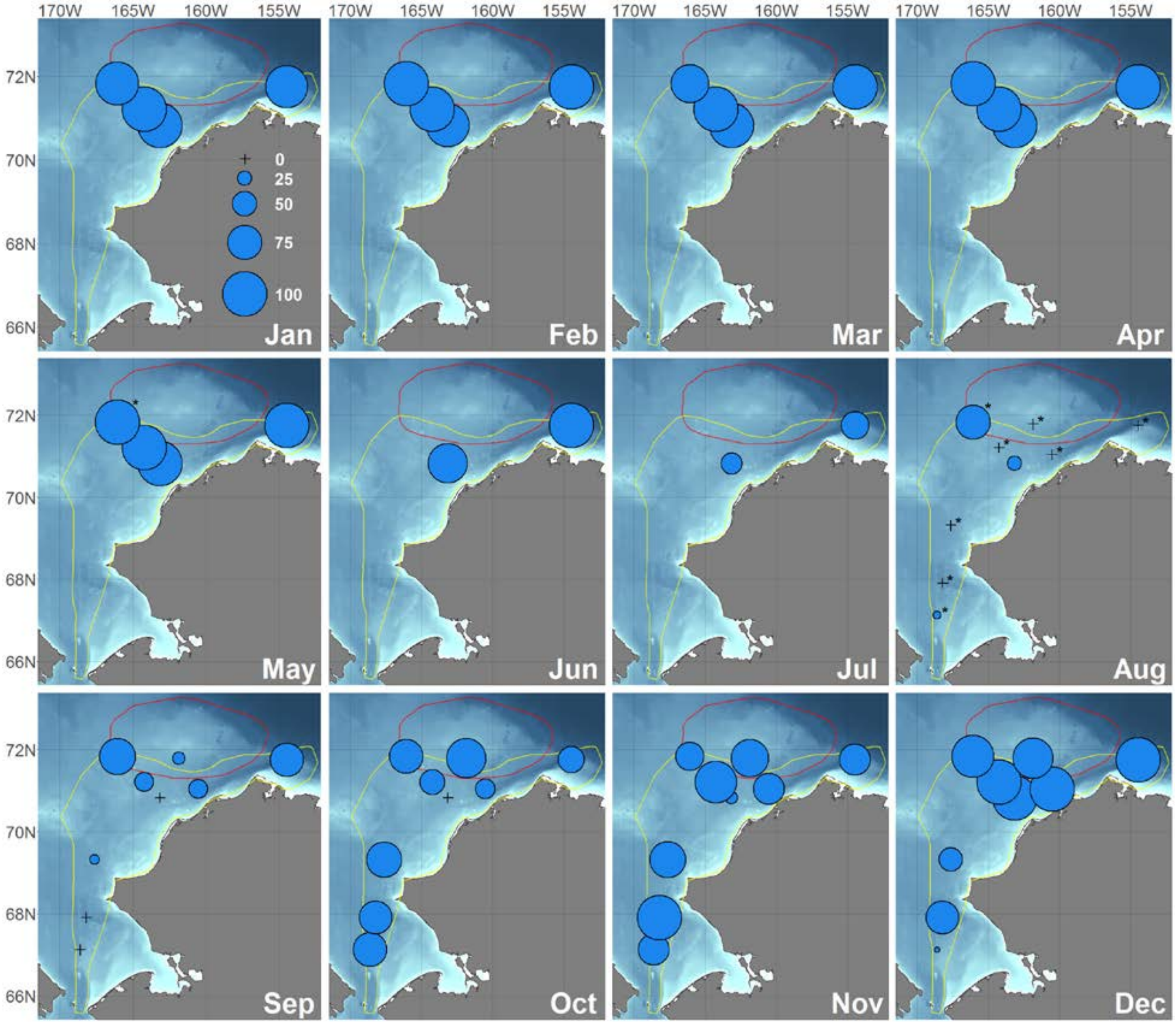

Figure 25. Monthly bearded seal calling distribution, 2012. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.5 for numbers used to generate figure.

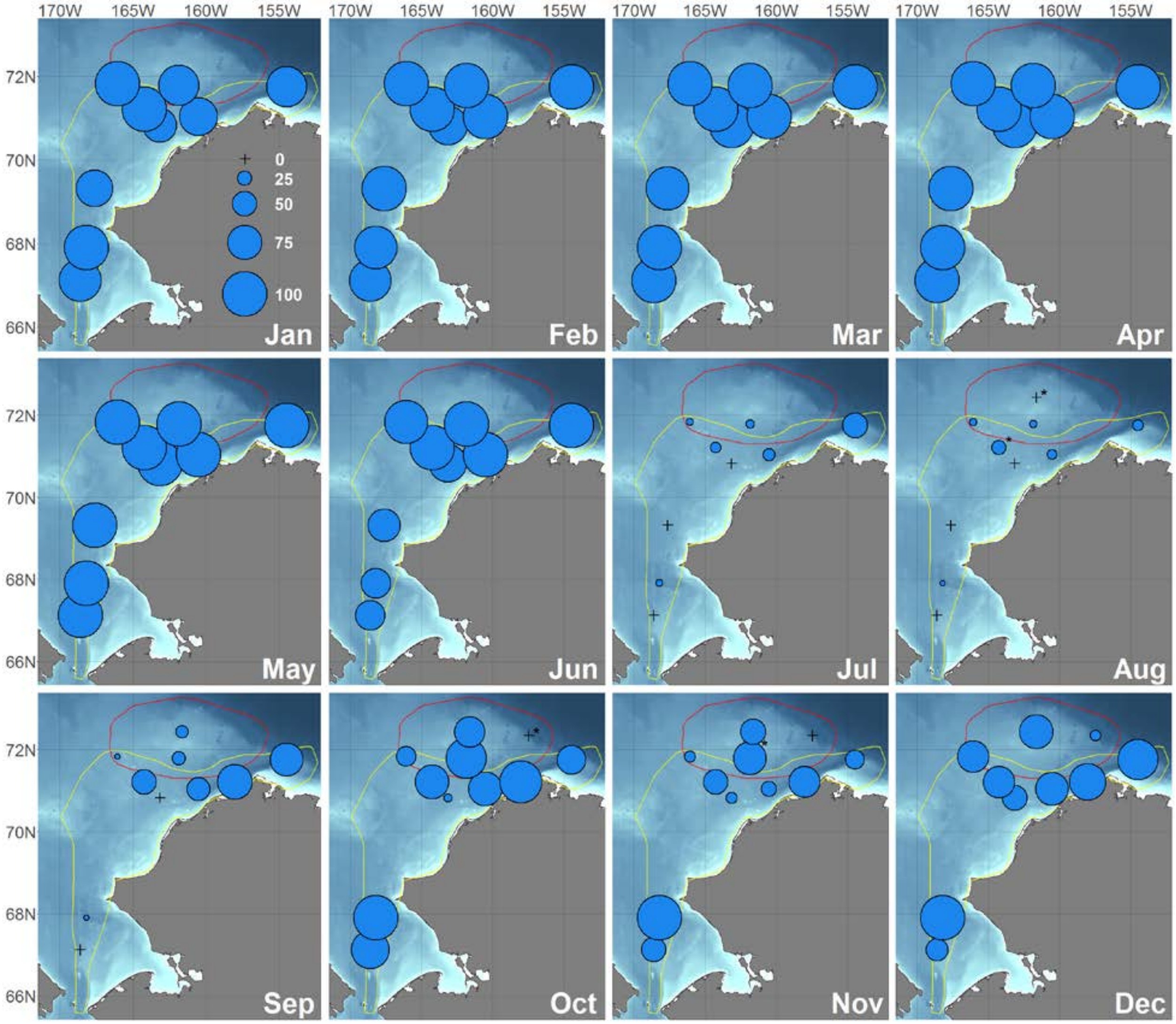

Figure 26. Monthly bearded seal calling distribution, 2013. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.5 for numbers used to generate figure.

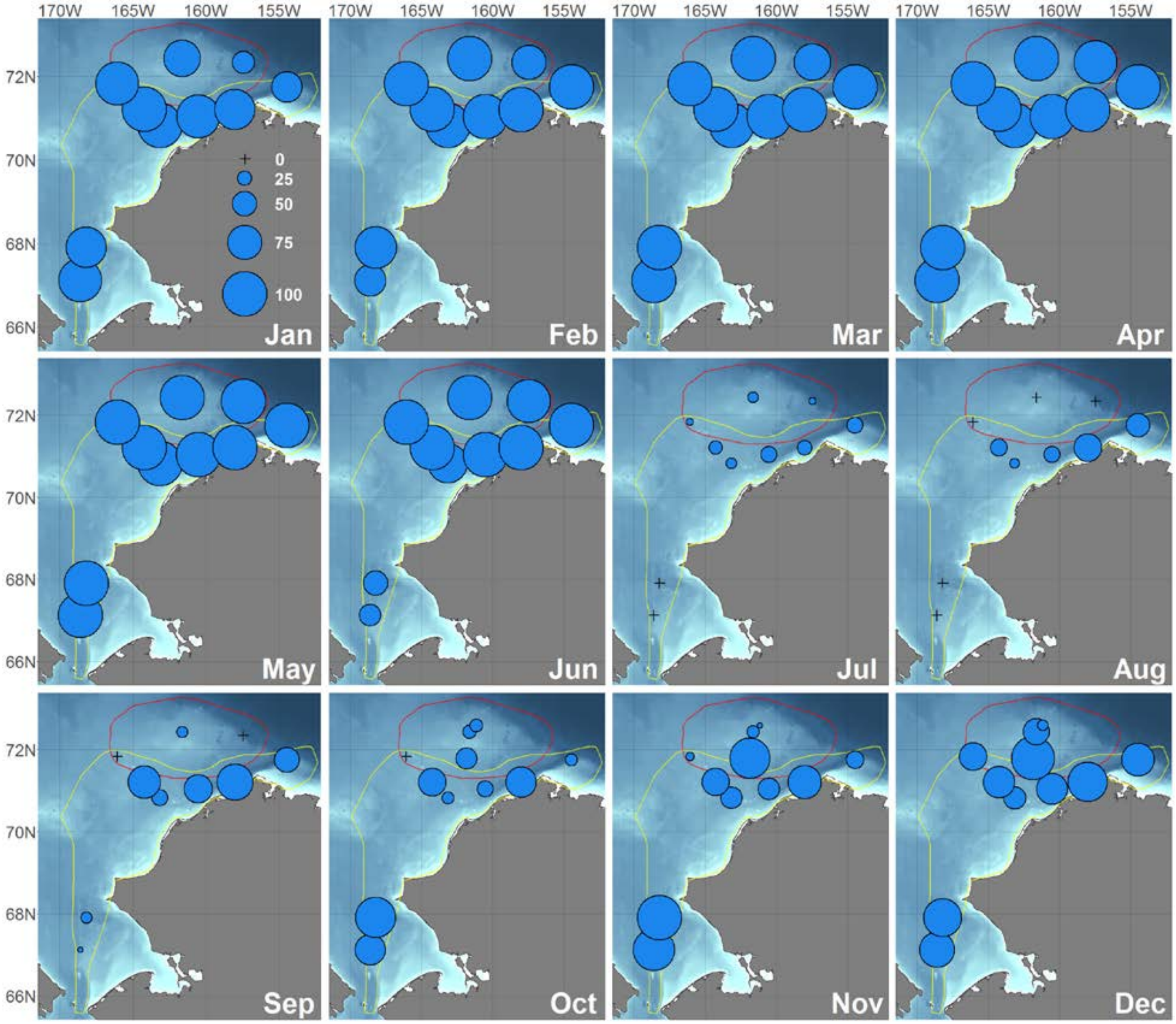

Figure 27. Monthly bearded seal calling distribution, 2014. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.5 for numbers used to generate figure.

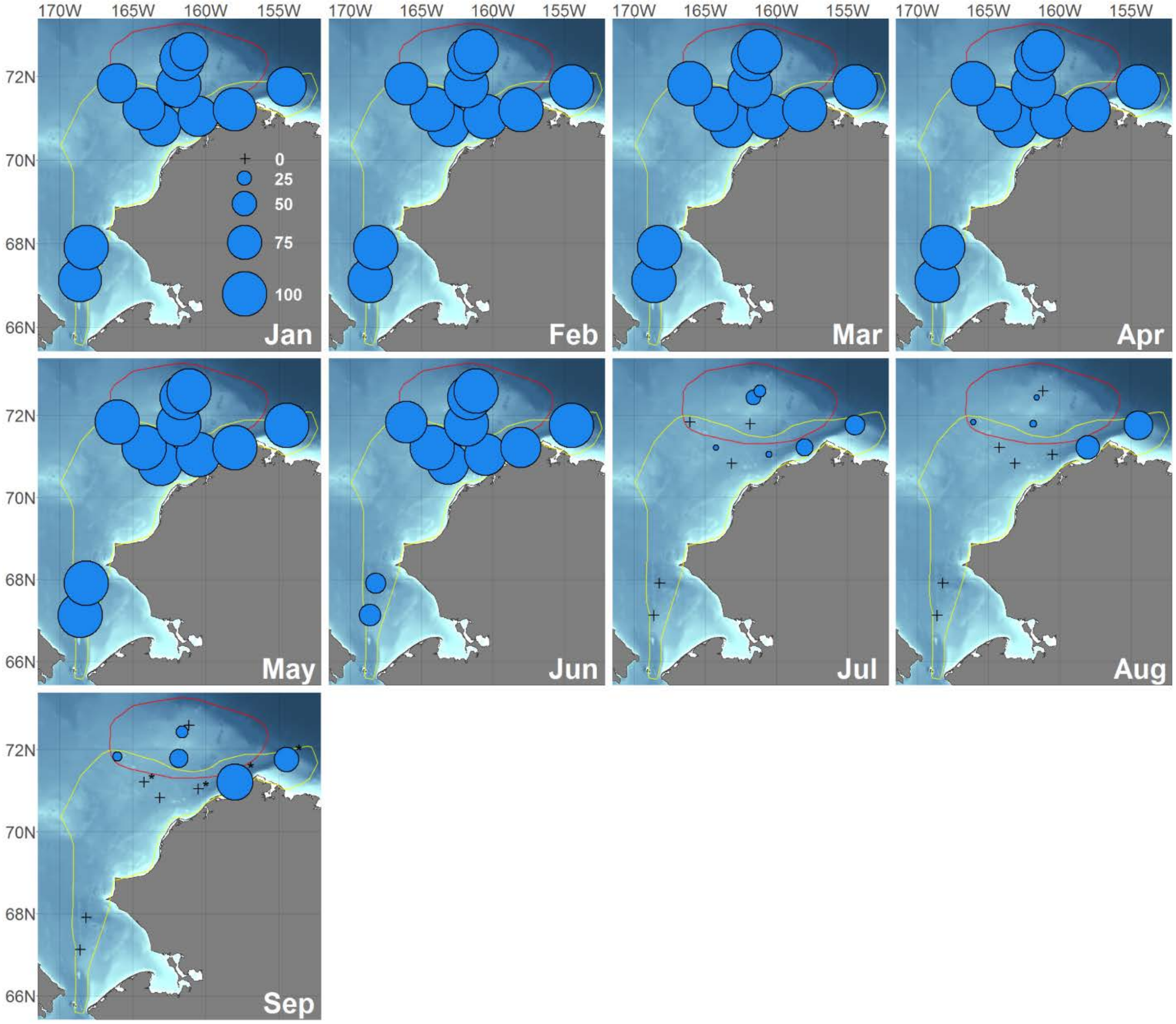

Figure 28. Monthly bearded seal calling distribution, 2015. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.5 for numbers used to generate figure.

Walrus

Walrus calling activity was detected on all CHAOZ-X study area mooring for all years where data were available (Figures 29-35; Table 12), with the exception of the slope site (HS3). Among the mooring sites with calls detected, calling activity decreased with distance away from the shoal site, HS1, with the western site (IC3) having the lowest proportion of days with calls (Table 12). Peak calling activity followed this same trend, with 60-70% of days with calls at all shoal sites (HS1 and HS2, and WT2) being peak calling days, while the western site (IC3) had only 21% of those days with peak calling (Table 12).

The months with calling activity varied among mooring sites, with the western site (IC3) and the shoal site (HS1) having walrus calling activity detected in all months (Figures 29-35;

Table 13). The WT2 and HS2 shoal sites were similar, with calling detected from June through December at HS2, and from June through November plus February at WT2. Again, no calls were detected at the slope site HS3. July was the month with the highest consistent presence of walrus among all CHAOZ-X mooring sites with detections. For the three mooring sites on or closest to the shoal (HS1, HS2, WT2), the main months with consistent calling activity were June through October. This time period was also true for the western site, IC3, but calling activity was also present with fairly similar levels of sustained calling from December through April.

Table 12. Total walrus calling activity, 2010-2015, for all CHAOZ-X mooring locations. Number of days with recordings (Eff), number of days with calling activity (#), number of days with calling activity > 50% (#pk), percent of days with calling activity (%), percent of days with calling activity > 50% (%pk).

Mooring	Eff	#	# pk	%	% pk
IC3	1647	434	93	26	6
WT2	788	268	196	34	25
HS1	747	315	193	42	26
HS2	348	109	77	31	22
HS3	329	0	0	0	0

Table 13. Average monthly walrus calling activity, 2010-2015, for all CHAOZ-X mooring locations. Number of days with calling activity (#), number of days with recordings (Eff), percent of days with calling activity per month (%).

Month	IC3			WT2			HS1			HS2			HS3		
	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%
Jan	26	155	**17**	0	62	**0**	5	62	**8**	0	31	**0**	0	31	**0**
Feb	50	141	**35**	0	56	**0**	2	56	**4**	0	28	**0**	0	28	**0**
Mar	40	155	**26**	1	62	**2**	3	62	**5**	0	31	**0**	0	31	**0**
Apr	23	150	**15**	0	60	**0**	5	60	**8**	0	30	**0**	0	30	**0**
May	11	138	**8**	0	62	**0**	10	62	**16**	0	31	**0**	0	31	**0**
Jun	42	98	**43**	39	60	**65**	34	60	**57**	18	30	**60**	0	30	**0**
Jul	71	93	**76**	62	62	**100**	62	62	**100**	30	31	**97**	0	31	**0**
Aug	34	99	**34**	62	63	**98**	64	64	**100**	31	31	**100**	0	31	**0**
Sep	58	158	**37**	70	77	**91**	73	76	**96**	15	16	**94**	0	22	**0**
Oct	35	155	**23**	30	88	**34**	32	61	**52**	12	28	**43**	0	3	**0**
Nov	12	150	**8**	4	74	**5**	12	60	**20**	2	30	**7**	0	30	**0**
Dec	32	155	**21**	0	62	**0**	13	62	**21**	1	31	**3**	0	31	**0**

Table 14. Key timing events for walrus calling activity. Underlined dates are recorder limited. Ice start and end dates were obtained from satellite-derived ice concentration data. *These dates were obtained by estimating the dates for the main pulses in Figure 29.

Year	Mooring	Calling		Peak Calling		Summer Pulse* Dates		Winter Pulse* Dates		Ice End Date	Ice Start Date
		Start	End	Start	End	Start	End	Start	End		
2010	IC3	10-Sep	31-Dec	12-Dec	12-Dec	10-Sep	10-Oct	3-Dec-10	22-Apr-11	16-Jul	31-Oct
2011	IC3	1-Jan	23-Dec	28-Jan	29-Sep	29-Aug	10-Oct	25-Nov-11	10-May-12	5-Jul	22-Nov
2012	IC3	9-Jan	2-Oct	16-Feb	29-Sep	28-Aug	2-Oct	9-Jan-13	21-May-13	27-Jul	3-Nov
	WT2	30-Aug	12-Oct	30-Aug	6-Oct	30-Aug	12-Oct	14-Mar-13	14-Mar-13	17-Aug	31-Oct
2013	IC3	9-Jan	16-Dec	8-Feb	11-Oct	26-Jun	24-Nov	14-Jan-13	20-Feb-14	21-Jul	26-Oct
	WT2	14-Mar	13-Nov	17-Jun	11-Oct	13-Jun	18-Oct	-	-	11-Aug	24-Oct
	HS1	30-Aug	17-Dec	30-Aug	3-Oct	30-Aug	30-Oct	13-Nov-13	17-Dec-13	30-Aug	22-Oct
	HS3	-	-	-	-	-	-	-	-	3-Aug	23-Oct
2014	IC3	14-Jan	24-Dec	23-Jun	5-Aug	2-Jun	9-Oct	8-Dec-14	17-Mar-15	30-Jul	3-Nov
	WT2	6-Oct	27-Nov	7-Oct	8-Oct	6-Oct	9-Oct	-	-	10-Aug	31-Oct
	HS1	11-Feb	19-Dec	21-Jun	9-Oct	18-Jun	18-Oct	6-Nov-14	7-May-15	15-Aug	23-Oct
	HS2	5-Oct	19-Dec	-	-	5-Oct	18-Oct	5-Nov-14	19-Dec-14	15-Aug	22-Oct
	HS3	-	-	-	-	-	-	-	-	7-Aug	19-Oct
2015	IC3	12-Mar	1-Sep	24-Jun	24-Aug	9-Jun	1-Sep	-	-	30-Jun	12-Nov
	WT2	1-Jun	17-Sep	10-Jun	17-Sep	10-Jun	17-Sep	-	-	17-Jul	7-Nov
	HS1	2-Jan	16-Sep	20-Jun	16-Sep	11-Jun	16-Sep	-	-	16-Jul	5-Nov
	HS2	12-Jun	16-Sep	18-Jun	16-Sep	12-Jun	16-Sep	-	-	2-Aug	27-Oct

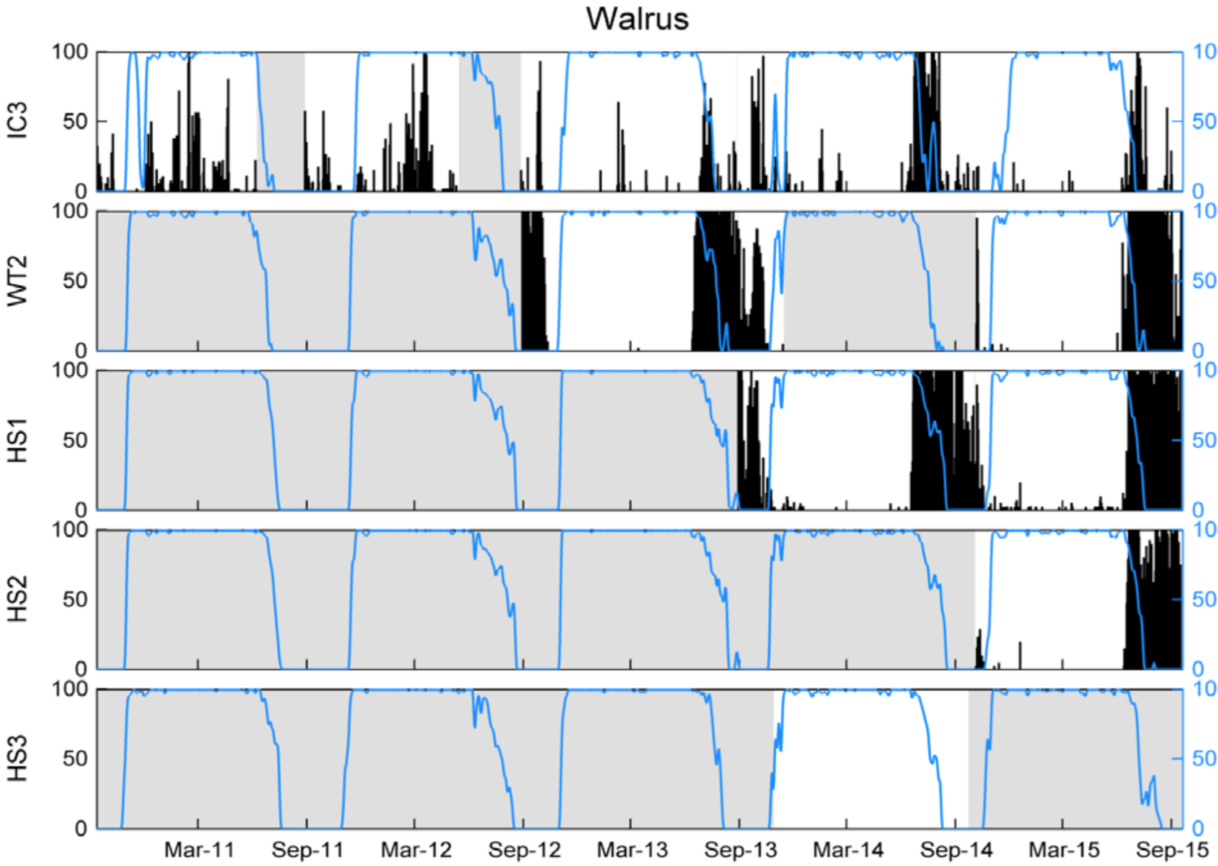

Figure 29. Walrus calling activity (presented as the percentage of ten-minute time intervals with calls) for the five CHAOZ-X locations (see Figure 3A), 2012-2015. Blue line indicates percent ice cover (zero-phase, three-day moving average). Gray shading indicates no data.

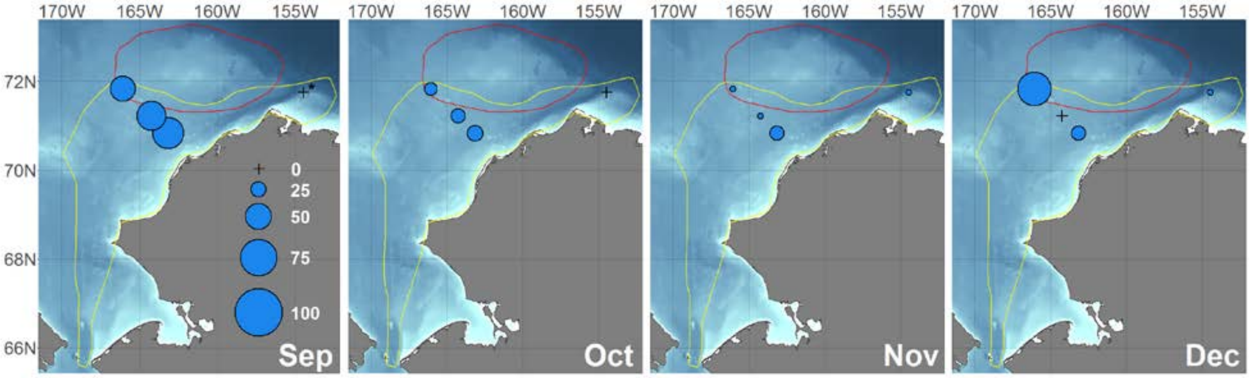

Figure 30. Monthly walrus calling distribution, 2010. Graduated scale in the September panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.6 for numbers used to generate figure.

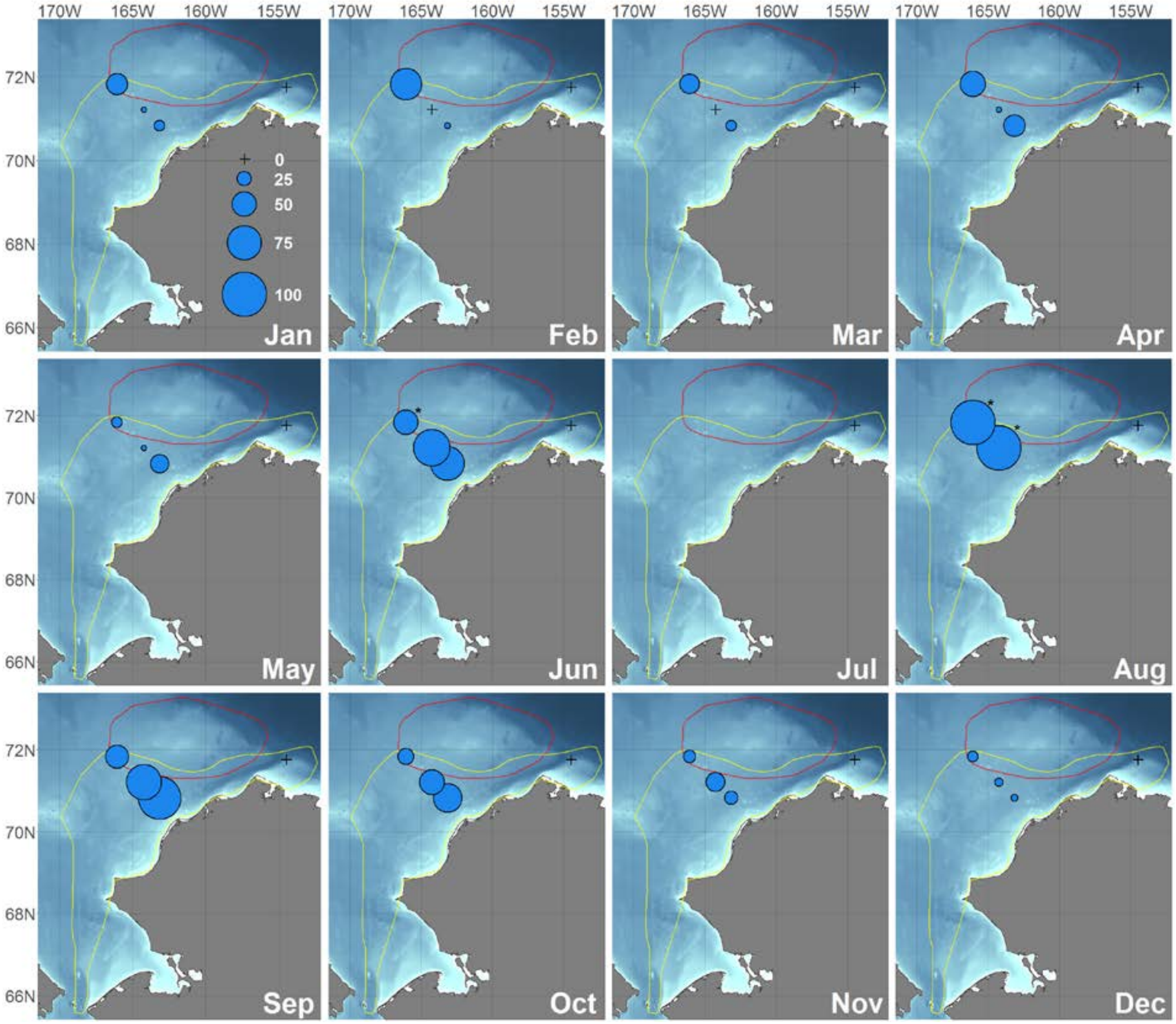

Figure 31. Monthly walrus calling distribution, 2011. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.6 for numbers used to generate figure.

Walrus had two periods with calling activity - summer and winter (Figures 29-35; Table 14). In general, the summer pulse of calling had higher calling activity levels sustained for longer periods of time than the winter pulse. In fact, winter calling for all shoal sites (i.e., HS1, HS2, and WT2) could not be described as a pulse - it was either a steady trickle of days with low detections or practically non-existent. Winter calling at the western site (IC3), in contrast, had high levels of sustained calling activity overwinter, which steadily decreased throughout the five years of recordings. The summer pulse of calling began in June for all moorings and years where data were available. In general the start date varied longitudinally, with the western mooring site (IC3) detecting calling activity earlier than those further east (Figure 29; Table 14). October appeared to be the end of the summer pulse of calling activity, this time with the latest detection of calling activity occurring on HS1 and HS2, the two sites on the northeastern flank of the shoal. Winter pulse dates varied among years and mooring sites with no apparent trends evident (Figure 29; Table 14).

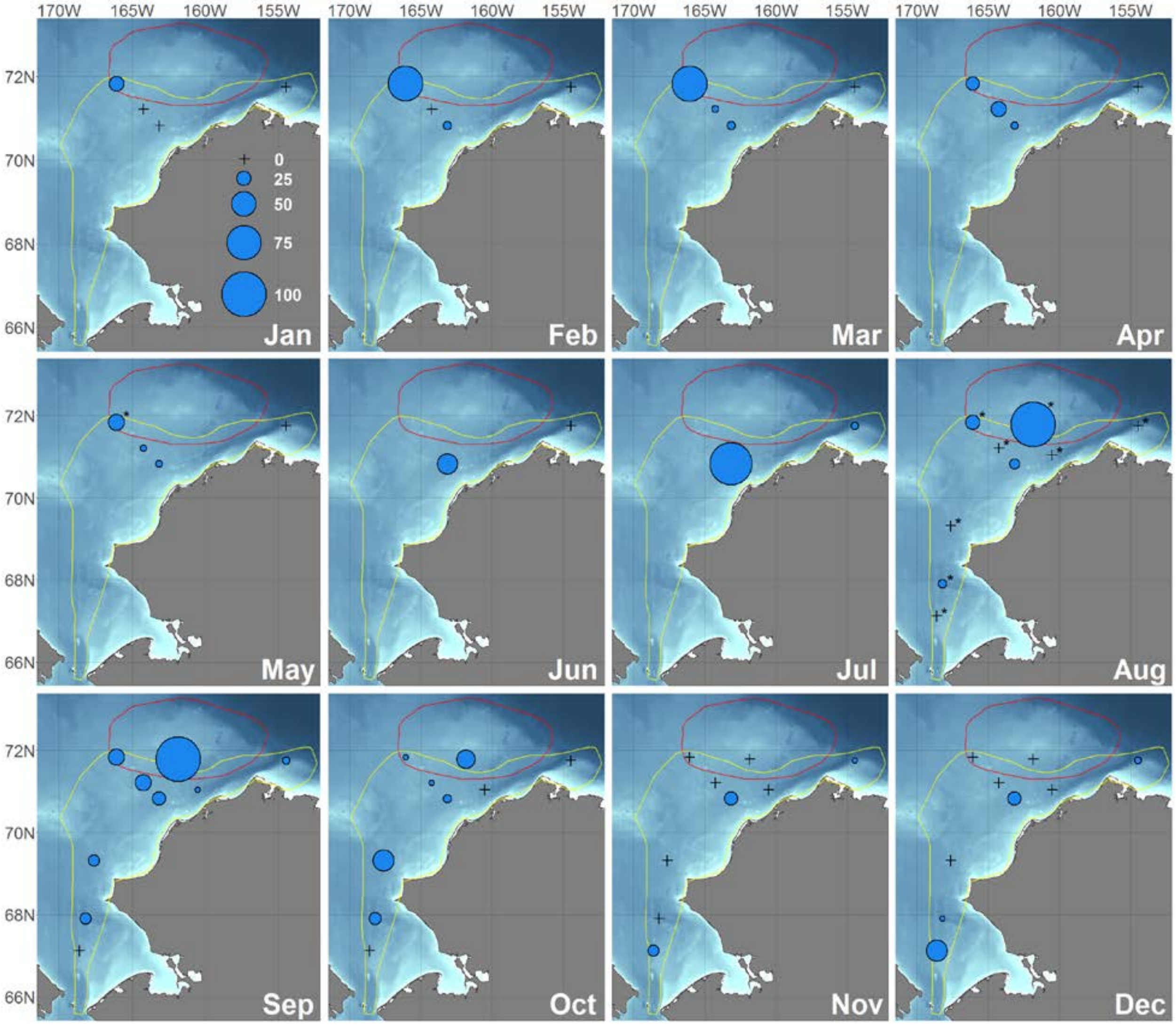

Figure 32. Monthly walrus calling distribution, 2012. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.6 for numbers used to generate figure.

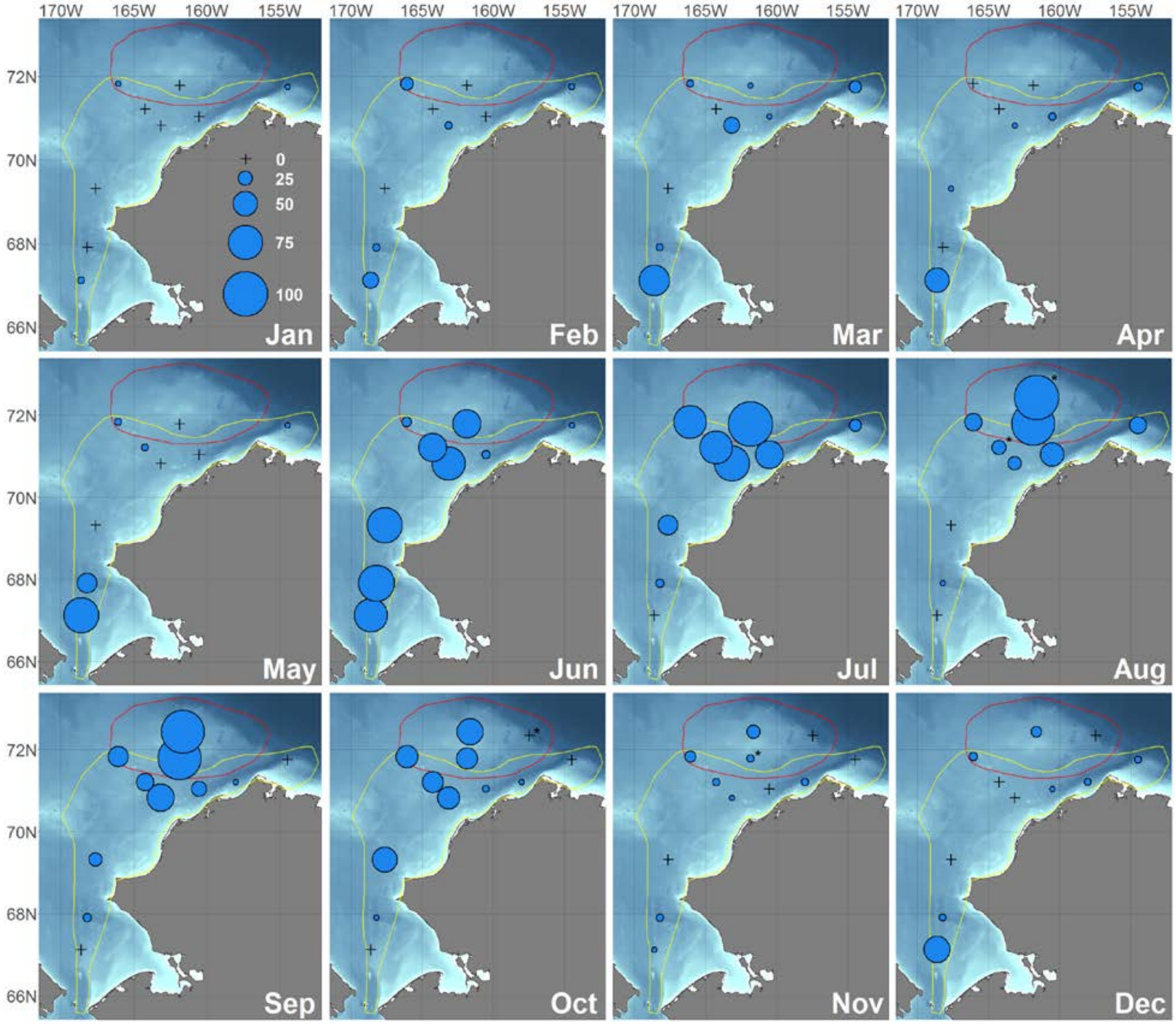

Figure 33. Monthly walrus calling distribution, 2013. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.6 for numbers used to generate figure.

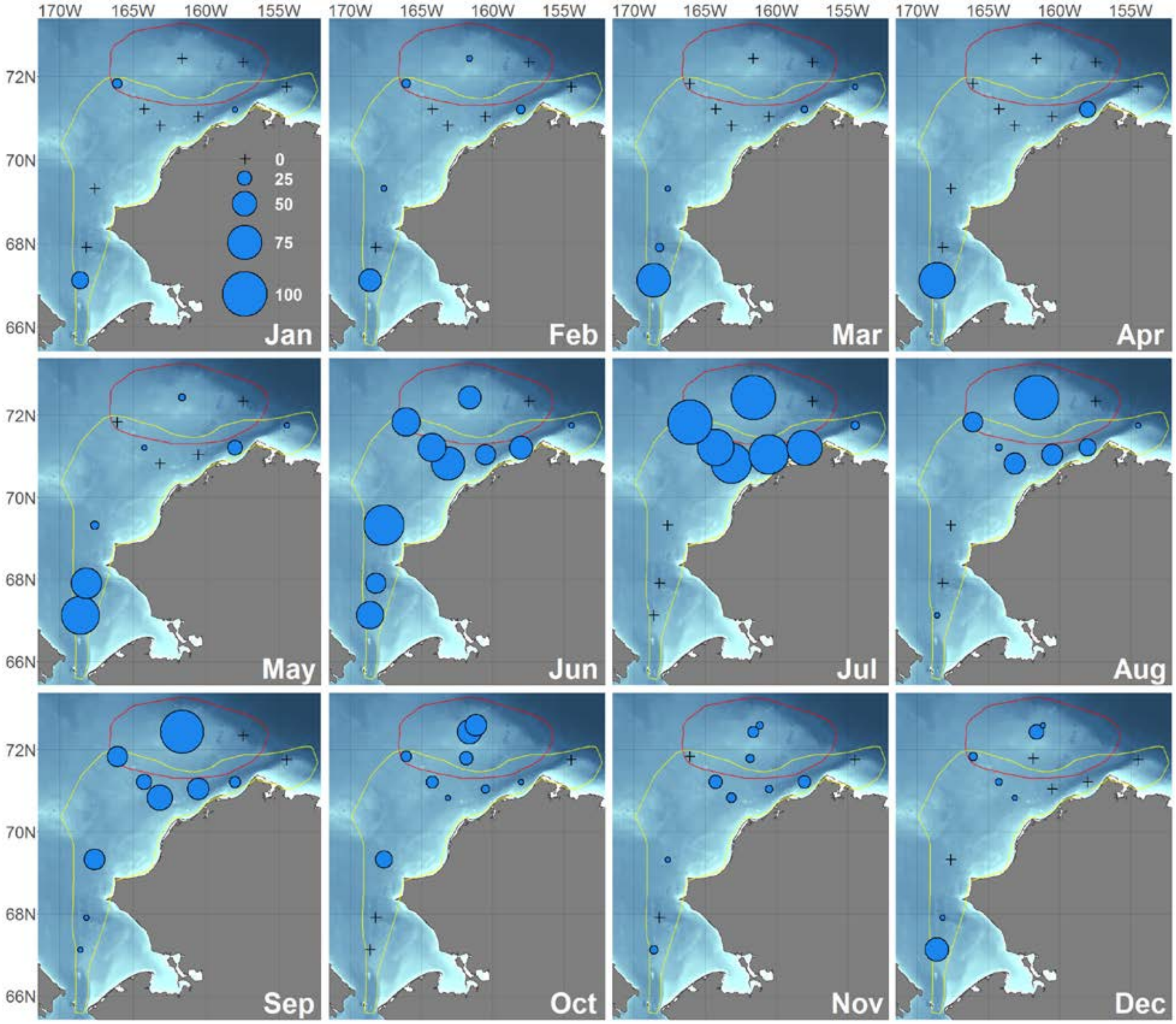

Figure 34. Monthly walrus calling distribution, 2014. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.6 for numbers used to generate figure.

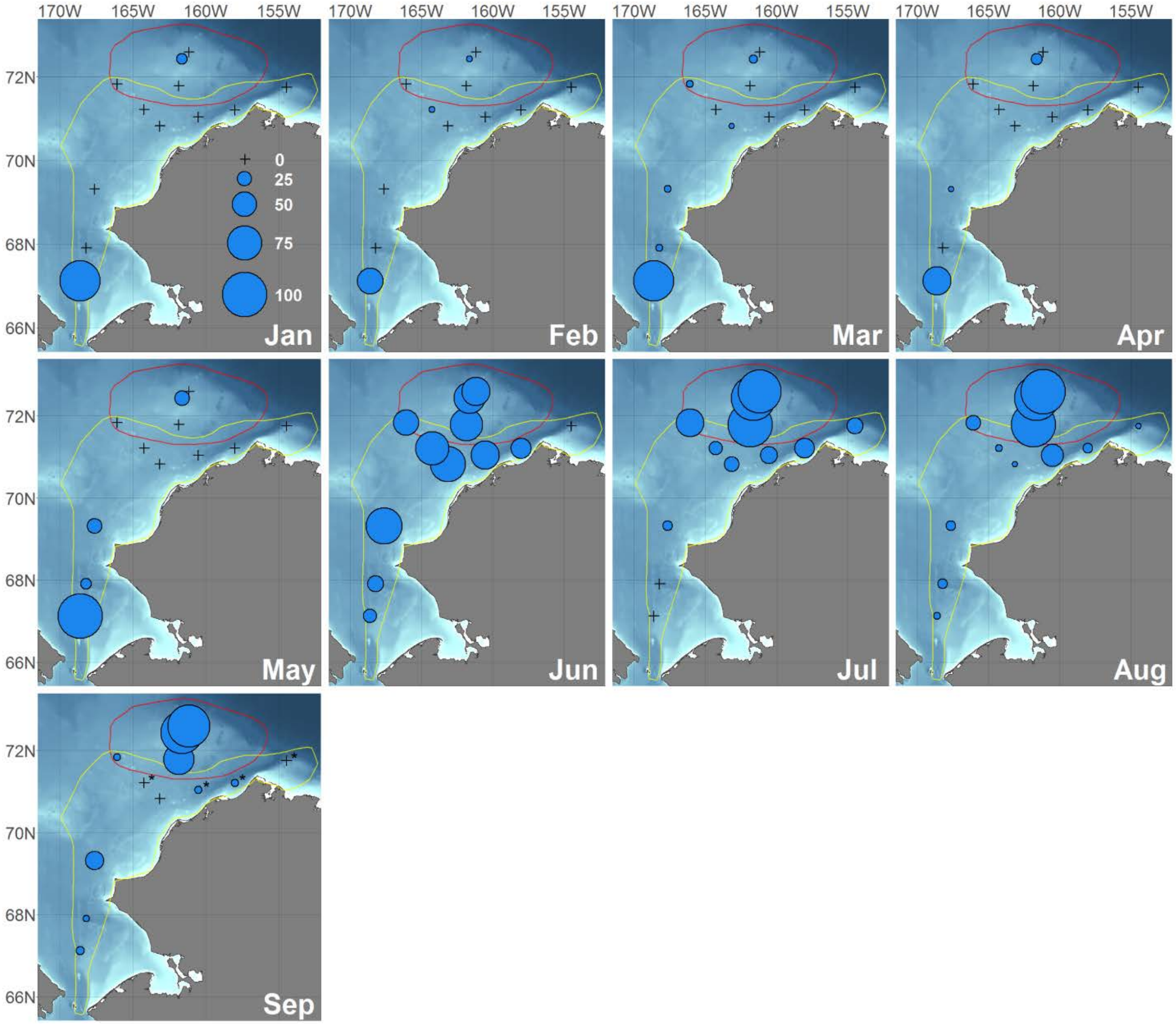

Figure 35. Monthly walrus calling distribution, 2015. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.6 for numbers used to generate figure.

Gray whales

Calling activity for gray whales was minimal in the CHAOZ-X study area, occurring on just three days (Figure 36; Table 15). These days were divided between the western (IC3) and shoal (HS1) sites, and occurred on 25 August 2014 and 16 July 2015 at IC3 and 15 July 2014 on HS1 (Table 16). Because of the sparsity of gray whale calling activity, the maps of their calling distributions from 2010 to 2015 will be included only in Appendix E (Appendix E.1-E.6) and will not be reproduced here.

Table 15. Total gray whale calling activity, 2010-2015, for all CHAOZ-X mooring locations. Number of days with recordings (Eff), number of days with calling activity (#), number of days with calling activity > 50% (#pk), percent of days with calling activity > 50% (%pk).

Mooring	Eff	#	# pk	%	% pk
IC3	1647	2	0	<1	0
WT2	788	0	0	0	0
HS1	747	1	0	<1	0
HS2	348	0	0	0	0
HS3	329	0	0	0	0

Table 16. Average monthly gray whale calling activity, 2010-2015, for all CHAOZ-X mooring locations. Number of days with calling activity (#), number of days with recordings (Eff), percent of days with calling activity per month (%).

Month	IC3			WT2			HS1			HS2			HS3		
	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**
Jan	0	155	**0**	0	62	**0**	0	62	**0**	0	31	**0**	0	31	**0**
Feb	0	141	**0**	0	56	**0**	0	56	**0**	0	28	**0**	0	28	**0**
Mar	0	155	**0**	0	62	**0**	0	62	**0**	0	31	**0**	0	31	**0**
Apr	0	150	**0**	0	60	**0**	0	60	**0**	0	30	**0**	0	30	**0**
May	0	138	**0**	0	62	**0**	0	62	**0**	0	31	**0**	0	31	**0**
Jun	0	98	**0**	0	60	**0**	0	60	**0**	0	30	**0**	0	30	**0**
Jul	1	93	**1**	0	62	**0**	1	62	**2**	0	31	**0**	0	31	**0**
Aug	1	99	**1**	0	63	**0**	0	64	**0**	0	31	**0**	0	31	**0**
Sep	0	158	**0**	0	77	**0**	0	76	**0**	0	16	**0**	0	22	**0**
Oct	0	155	**0**	0	88	**0**	0	61	**0**	0	28	**0**	0	3	**0**
Nov	0	150	**0**	0	74	**0**	0	60	**0**	0	30	**0**	0	30	**0**
Dec	0	155	**0**	0	62	**0**	0	62	**0**	0	31	**0**	0	31	**0**

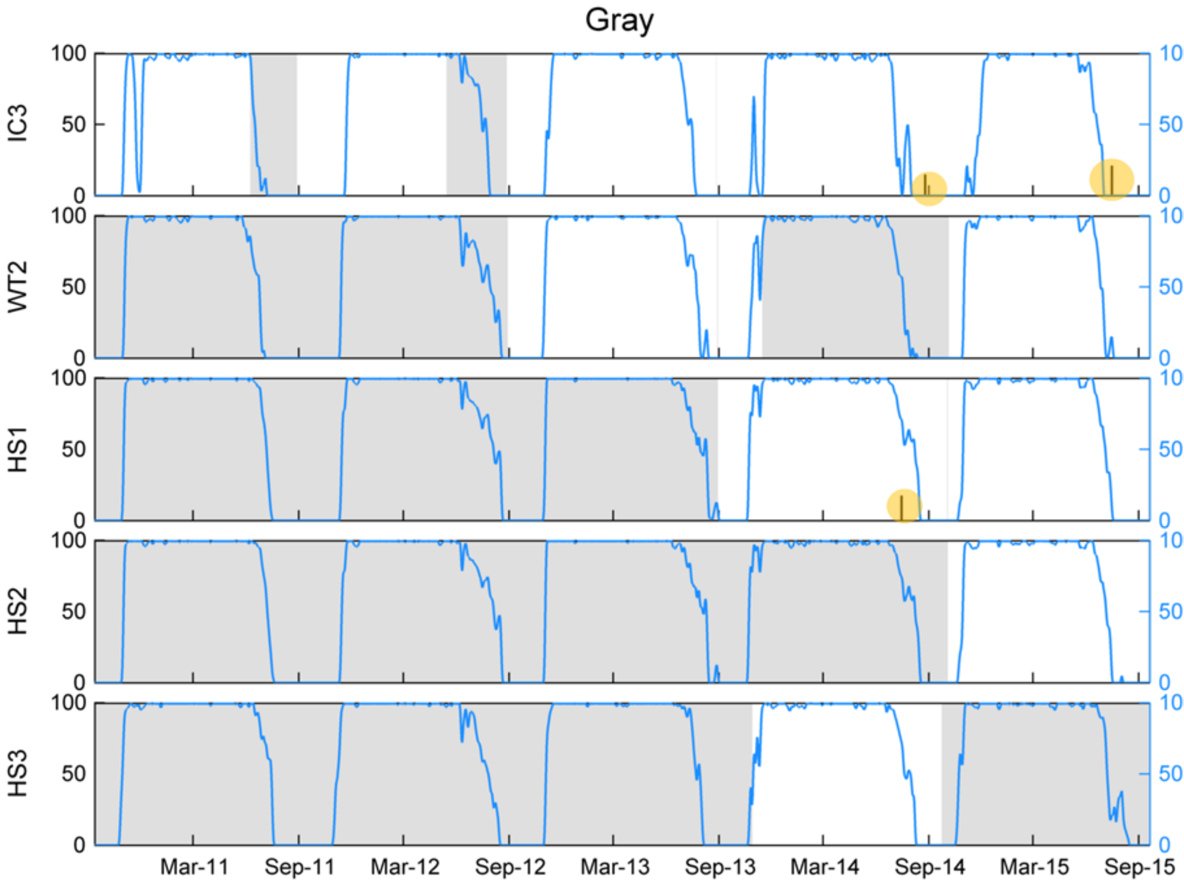

Figure 36. Gray whale calling activity (presented as the percentage of ten-minute time intervals with calls) for the five CHAOZ-X locations (see Figure 3A), 2012-2015. Blue line indicates percent ice cover (zero-phase, three-day moving average). Gray shading indicates no data. Yellow ovals highlight days with calling activity

Other species

The rest of the species analyzed had little to no calling activity detected in the CHAOZ-X study area, either in calling activity levels per day or in number of days with calling activity. Their long-term seasonal distribution plots as well as their monthly spatial distribution plots can be found in Appendix D and E as indicated below. All daily calling activity levels can also be found in the supplemental excel file: PNGresltsforGAM_10minCallRslts.xlsx (file provided separately to BOEM; will be available publicly on the National Center for Environmental Information (NCEI)). Of these species, ribbon seals had the highest number of days with calling activity with 35 days, which still amounts to <1% of all days analyzed (Figure 37; Table 17; and Appendix E.7 - E.12). Approximately half of these days were from the slope (HS3) mooring site, followed by the western site (IC3), with only eight days between the shoal sites, HS1 and WT2 (Table 17). At the slope site (HS3), ribbon seal calling activity was found from April through

November, with the highest percentages in July and August[10] (Table 18). Calling was concentrated in October-November for the other three sites (Table 18).

Humpback whales (Appendix D.1; and Appendix E.13-E.18) were detected on only one day on one mooring (IC3), on 18 August 2014. Humpback whale calling activity was at 10% on this day. Killer whales (Appendix D.2; and Appendix E.19 - E.24) were detected on five days total in a variety of years, months, and mooring locations: 10 September 2012 at IC3; 28 April and 11 June 2013[11] as well as 30 July 2015 at WT2; and 12 August 2015 at HS1. Most of these days had 2.5% or less of ten-minute time intervals with calls detected. The exception was 28 April 2013 at WT2, which had a calling activity level of ~7%.

Table 17. Total ribbon seal calling activity, 2010-2015, for all CHAOZ-X mooring locations. Number of days with recordings (Eff), number of days with calling activity (#), number of days with calling activity > 50% (#pk), percent of days with calling activity (%), percent of days with calling activity > 50% (%pk).

Mooring	Eff	#	# pk	%	% pk
IC3	1647	10	0	1	0
WT2	788	6	0	1	0
HS1	747	2	0	0	0
HS2	348	0	0	0	0
HS3	327	17	0	5	0

Table 18. Average monthly ribbon seal calling activity, 2010-2015, for all CHAOZ-X mooring locations. Number of days with calling activity (#), number of days with recordings (Eff), percent of days with calling activity per month (%).

Month	IC3			WT2			HS1			HS2			HS3		
	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**
Jan	0	155	**0**	0	62	**0**	0	62	**0**	0	31	**0**	0	31	**0**
Feb	0	141	**0**	0	56	**0**	0	56	**0**	0	28	**0**	0	28	**0**
Mar	0	155	**0**	0	62	**0**	0	62	**0**	0	31	**0**	0	31	**0**
Apr	0	150	**0**	0	60	**0**	0	60	**0**	0	30	**0**	2	30	**7**
May	0	138	**0**	0	62	**0**	0	62	**0**	0	31	**0**	2	31	**6**
Jun	0	98	**0**	0	60	**0**	0	60	**0**	0	30	**0**	0	30	**0**
Jul	0	93	**0**	0	62	**0**	0	62	**0**	0	31	**0**	3	31	**10**
Aug	1	99	**1**	0	63	**0**	0	64	**0**	0	31	**0**	5	31	**16**
Sep	0	158	**0**	0	77	**0**	0	76	**0**	0	16	**0**	1	20	**5**
Oct	4	155	**3**	2	88	**2**	2	61	**3**	0	28	**0**	3	3	**100**
Nov	5	150	**3**	4	74	**5**	0	60	**0**	0	30	**0**	1	30	**3**
Dec	0	155	**0**	0	62	**0**	0	62	**0**	0	31	**0**	0	31	**0**

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[10] Although October had 100% days with calls – there were only three days with usable recordings.

[11] The killer whale detections in ice covered months (e.g., April and June) fit all the criteria for marking “yes” for killer whale. However, these detections should be treated with caution, as beluga whales were present in the area at the same time making them difficult to distinguish.

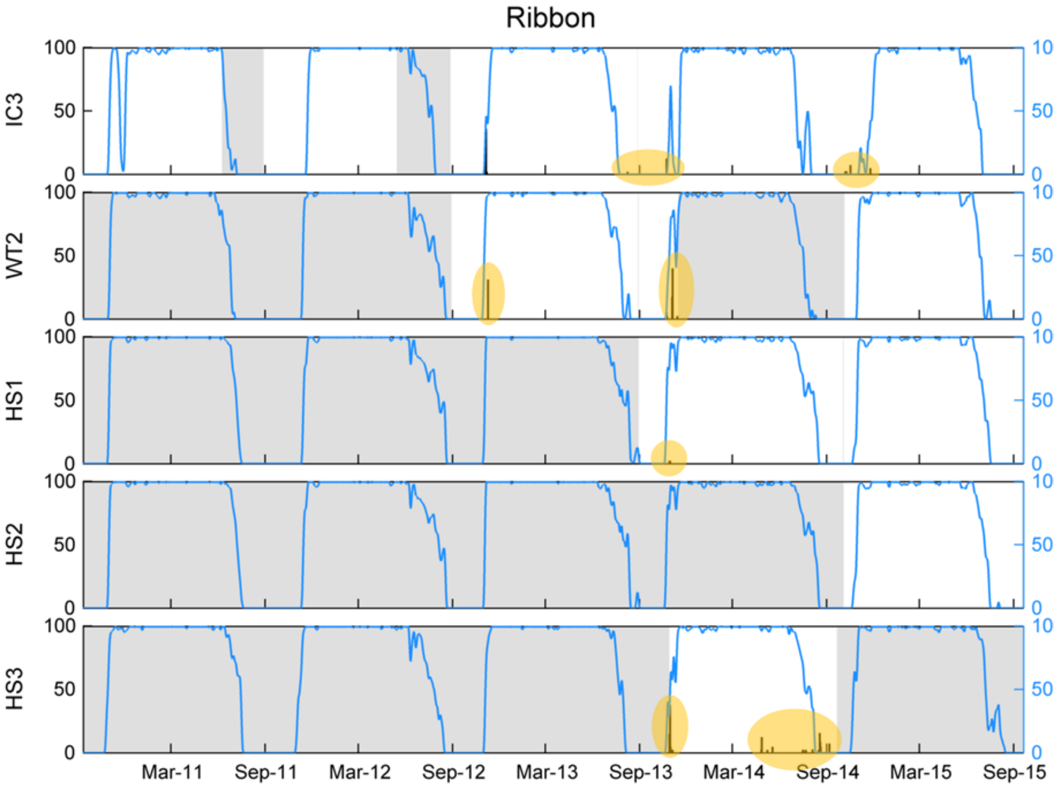

Figure 37. Ribbon seal calling activity (presented as the percentage of ten-minute time intervals with calls) for the five CHAOZ-X locations (see Figure 3A), 2012-2015. Blue line indicates percent ice cover (zero-phase, three-day moving average). Gray shading = no data. Yellow ovals highlight days with calling activity.

A variety of pinniped grunts, yelps, and barks were detected on 8% of all days with recordings, but were not identified to species (Appendix C.11; Appendix D.3). These detections are lumped together as unidentified pinnipeds and most likely include species such as ringed and spotted seals as well as less common calls types from bearded and ribbon seals and walrus. The seasonality (primarily overwinter) of this set of calls aligns most closely with that of bearded seals and so their calling distribution maps are not included in this report. Finally, for all years, there was no calling activity at any CHAOZ-X location for any of the following species: right, fin[12], minke (neither regular nor boing calls detected), and sperm whales.

Note on double knocks:

In the process of analyzing the large data set for the CHAOZ-X and ARCWEST projects, a few sounds caught the attention of our dedicated team of analysts. One sound in particular, a quick double knock, became a point of debate. For years it had been thought to be ‘mooring noise’, created by chain or equipment rattling, and ignored. One analyst, Eric Braen, started to look deeper into this sound and concluded that it seemed likely to be biological, not associated

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[12] Note that only the IC3 mooring from 2010-2012 was analyzed for fin whales. See Section VII.A.1 for details.

with the other quick knocking species (i.e., walrus), and possibly attributed to fish. The rest of the analysis team agreed the evidence was convincing enough to add this sound type to the analysis routine so that seasonality could be determined. Therefore, the more recently analyzed moorings contain results for this sound type. Of these, the double knock was detected on 171 of 2565 days with recordings (~7%). Since this analysis is preliminary and incomplete, further details on seasonality or distribution will not be provided; however, the seasonality of this sound seems to align best with that of beluga whales (Figure 38).

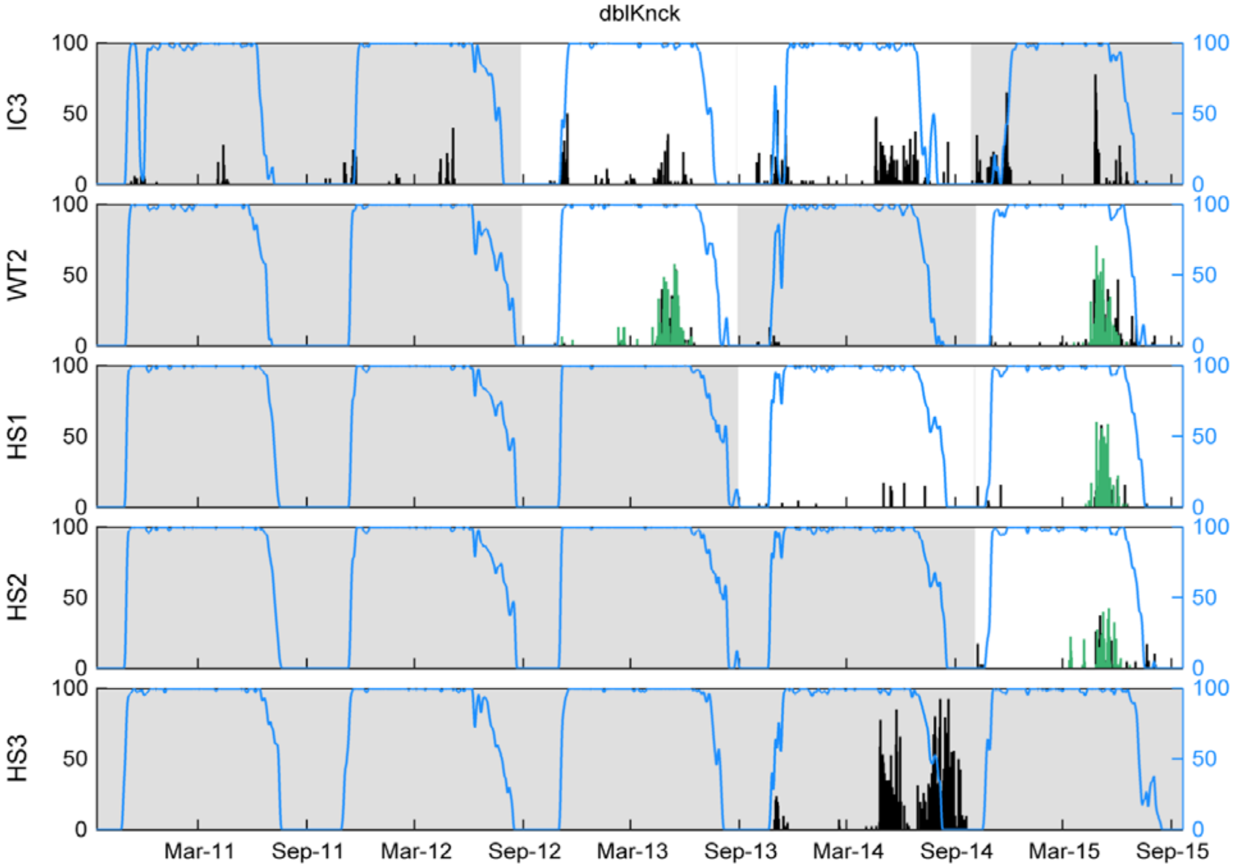

Figure 38. Double knock sound activity (green) overlaid on beluga whale calling activity (presented as the percentage of ten-minute time intervals with calls) for the five CHAOZ-X locations (see Figure 3A), 2010-2015. Blue line indicates percent ice cover (zero-phase, three-day moving average). Gray shading indicates no data or data not yet analyzed.

Environmental and anthropogenic sources

While reviewing the data for marine mammal calling activity, analysts also noted the presence of anthropogenic (seismic airguns and vessel) and environmental (ice) noises. Although not directly related to marine mammal acoustic occurrence, the results for anthropogenic and environmental acoustic detection are included here because they were analyzed and results are presented in a similar manner to those for marine mammals. We use *noise activity* here as the equivalent of *calling activity* for these non-biological sound types.

Seismic airguns

Seismic airgun noise activity was present in all six open water seasons from 2010 to 2015 (Figures 39-45). The open water seasons of 2010, 2011, and 2013 had the highest (saturated) levels of airgun noise activity, with 2013 having the longest sustained period with saturated levels. Among sites, the western site, IC3, had the highest proportion of days with airgun noise activity and peak airgun noise activity; this was closely followed by the shoal sites, WT2 and HS1. The slope site, HS3 had the lowest proportion of days with airgun noise, but the outermost shoal site, HS2, had only one day where airguns were detected (Figures 39-45; Table 19).

Table 19. Total airgun noise activity, 2010-2015, for all CHAOZ-X mooring locations. Number of days with recordings (Eff), number of days with noise activity (#), number of days with noise activity > 50% (#pk), percent of days with noise activity (%) percent of days with noise activity > 50% (%pk).

Mooring	Eff	#	# pk	%	% pk
IC3	1647	113	76	7	5
WT2	788	45	24	6	3
HS1	747	46	29	6	4
HS2	348	1	0	0	0
HS3	329	7	2	2	1

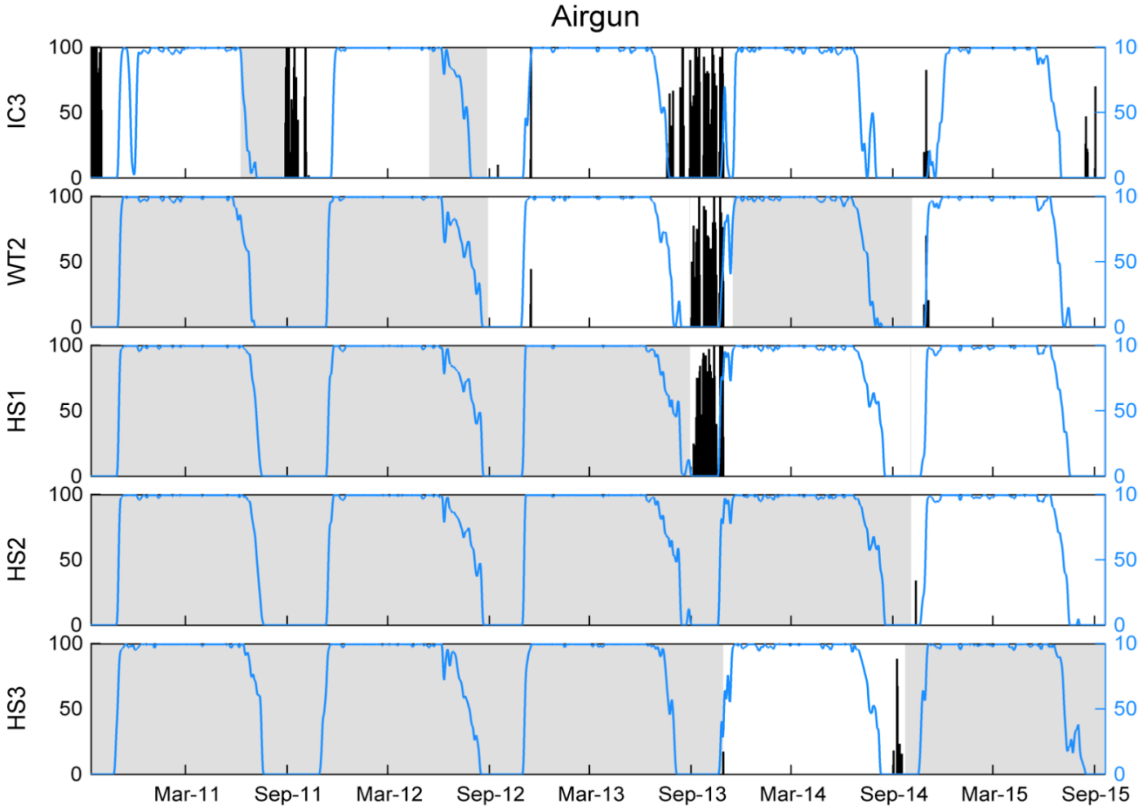

Figure 39. Airgun noise activity (presented as the percentage of ten-minute time intervals with airguns detected) for the five CHAOZ-X locations (see Figure 3A), 2012-2015. Blue line indicates percent ice cover (zero-phase, three-day moving average). Gray shading = no data.

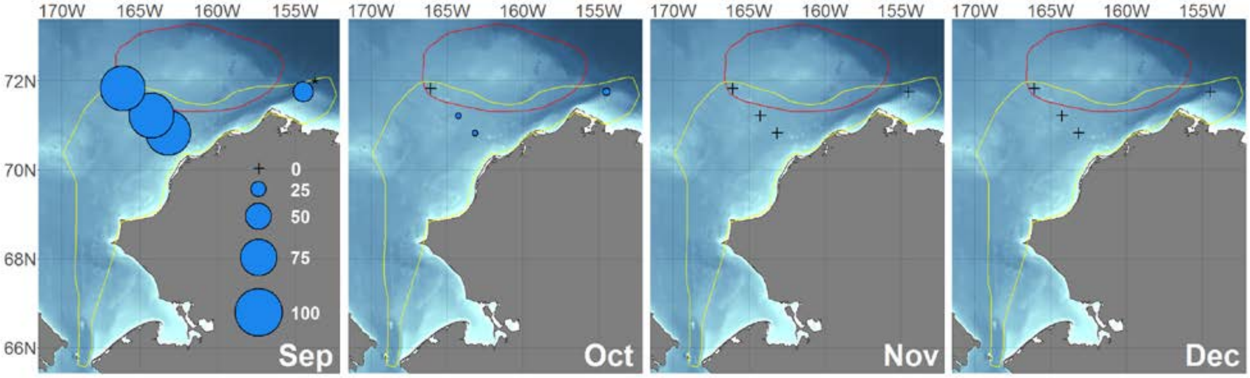

Figure 40. Monthly airgun noise distribution, 2010. Graduated scale in the September panel indicates % days per month with airgun noise. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.14 for umbers used to generate figure.

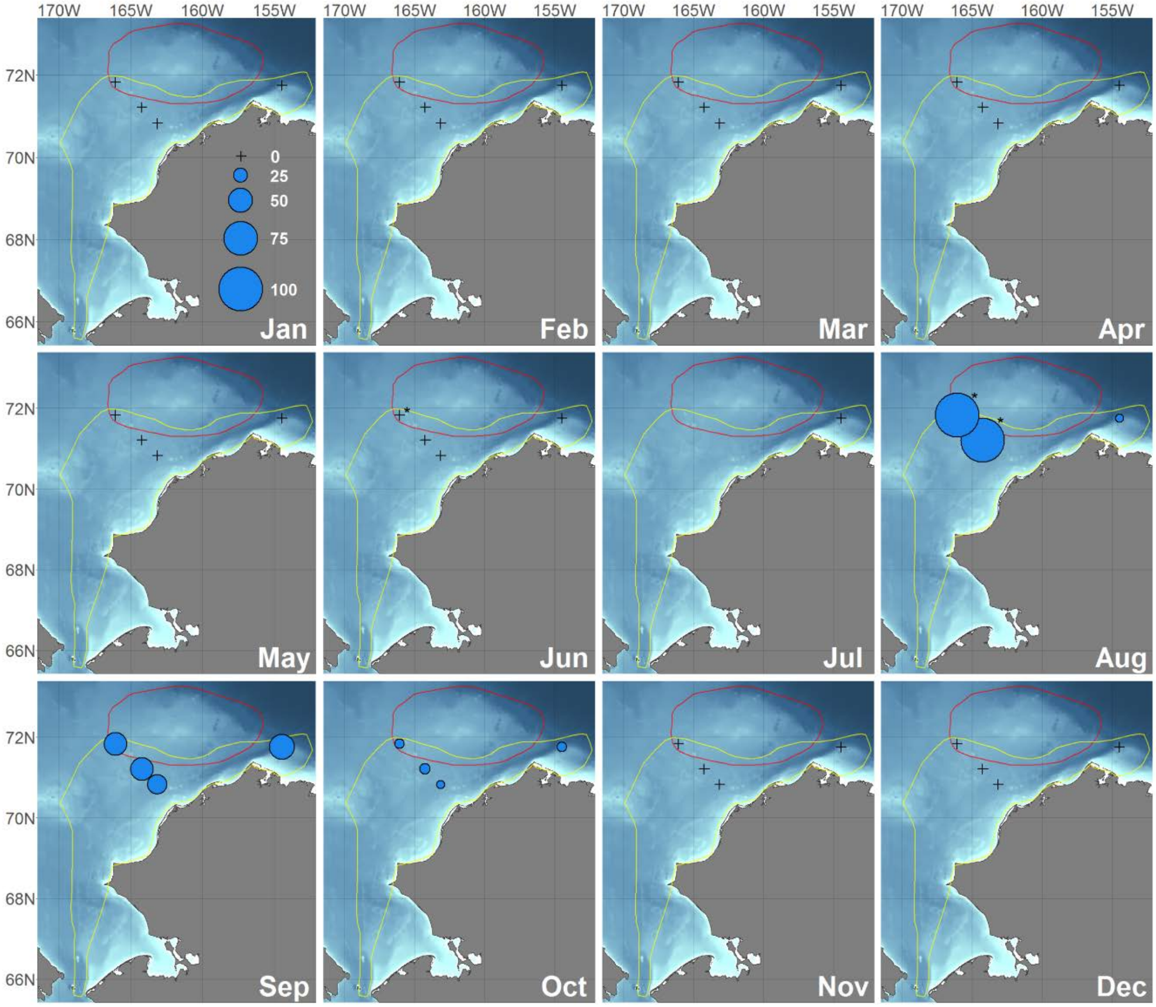

Figure 41. Monthly airgun noise distribution, 2011. Graduated scale in the January panel indicates % days per month with airgun noise. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.14 for numbers used to generate figure.

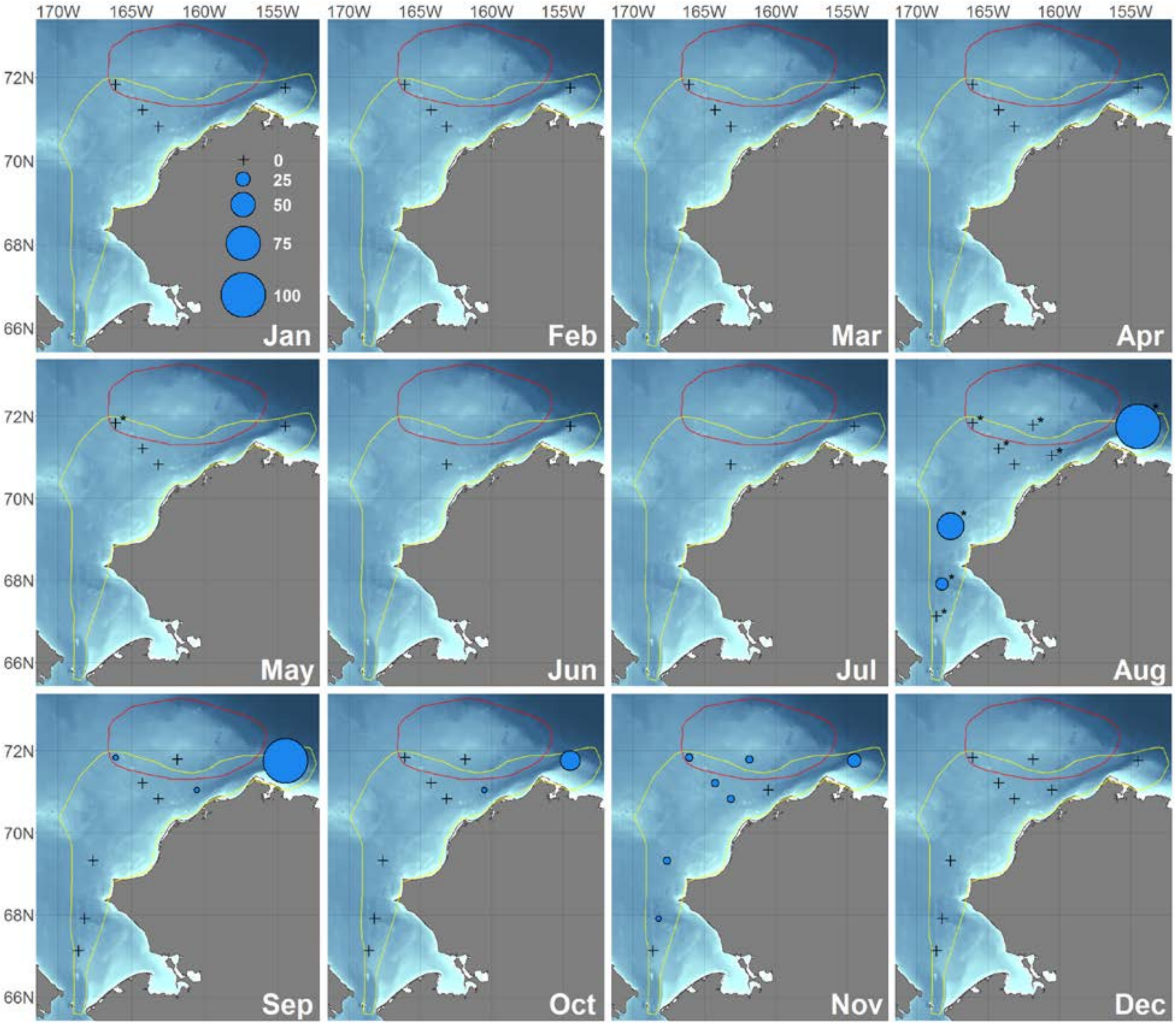

Figure 42. Monthly airgun noise distribution, 2012. Graduated scale in the January panel indicates % days per month with airgun noise. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.14 for numbers used to generate figure.

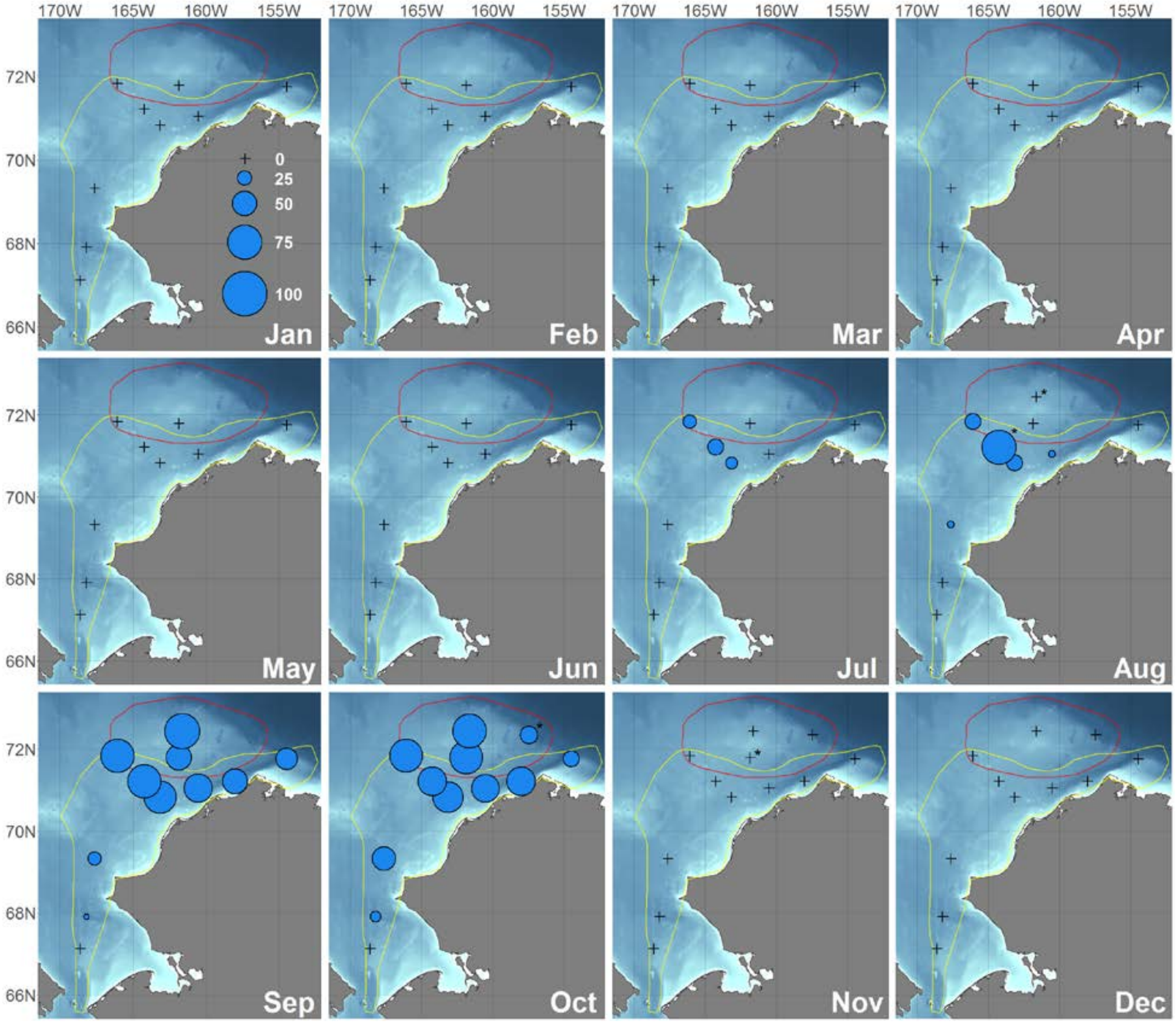

Figure 43. Monthly airgun noise distribution, 2013. Graduated scale in the January panel indicates % days per month with airgun noise. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.14 for numbers used to generate figure.

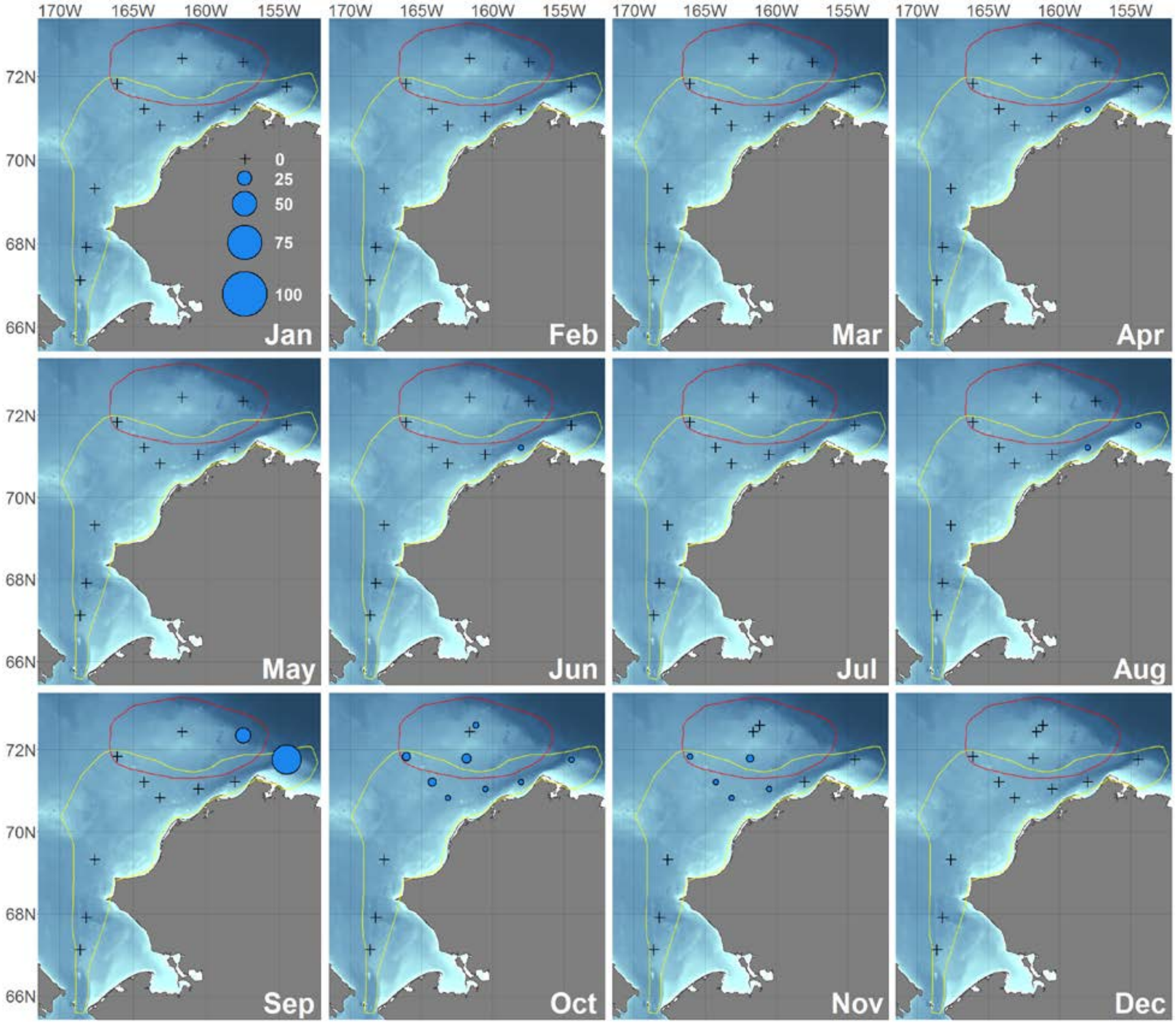

Figure 44. Monthly airgun noise distribution, 2014. Graduated scale in the January panel indicates % days per month with airgun noise. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.14 for numbers used to generate figure.

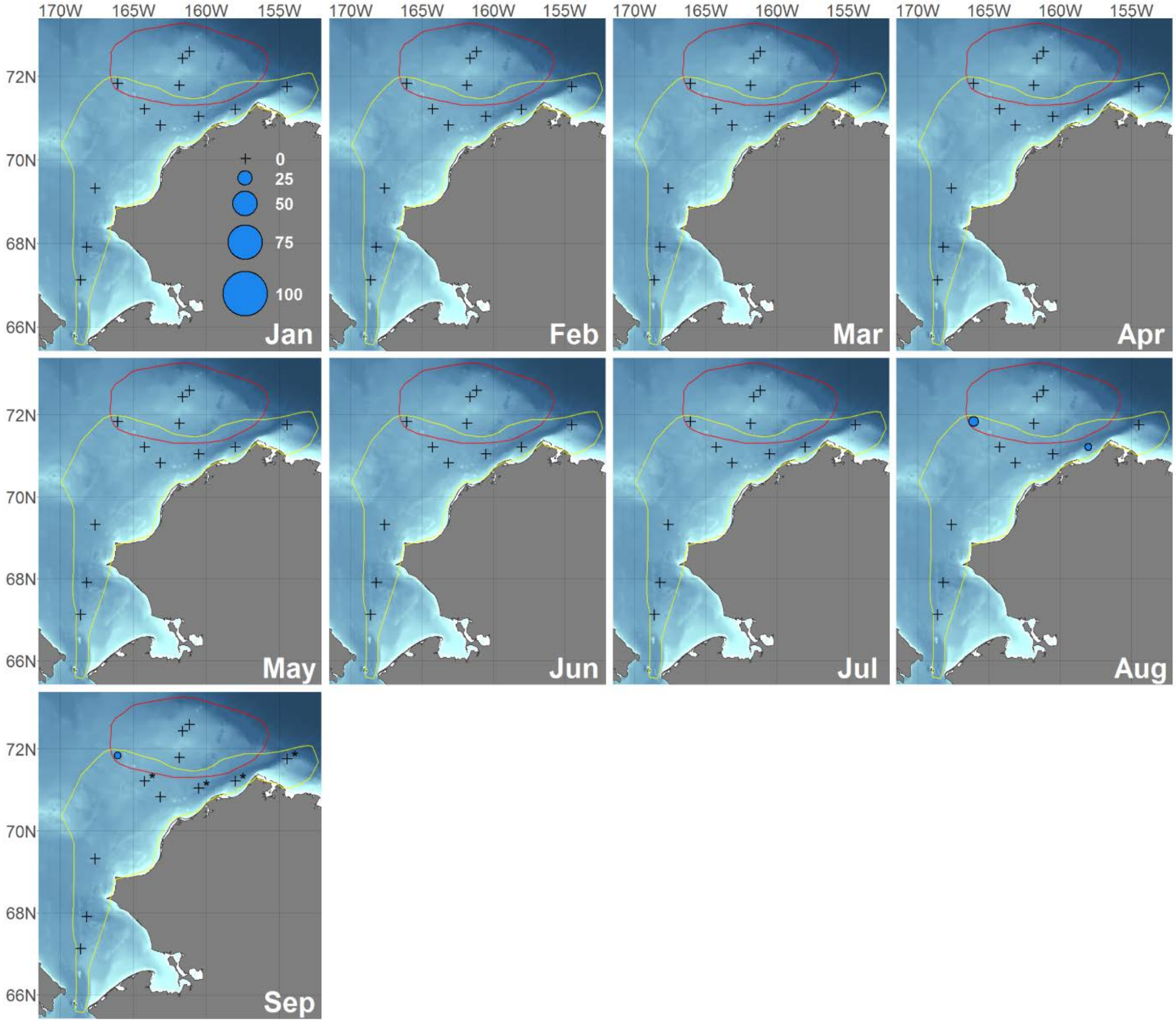

Figure 45. Monthly airgun noise distribution, 2015. Graduated scale in the January panel indicates % days per month with airgun noise. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.14 for numbers used to generate figure.

Vessel noise

Vessel noise was present during all open water seasons from 2010 through 2015 (Figures 46-52); however, the open water seasons of 2012, 2013, and 2015 were the ones with the highest sustained and saturated levels. Vessel noise activity levels among mooring sites varied similarly to those of the airguns (Table 20), with the highest proportion of days with vessels detected found at IC3, WT2, and HS1. Vessels were also detected during the winter periods of 2011-2012, 2013-2014, and 2014-2015 (Figure 46).

Table 20. Total vessel noise activity, 2010-2015, for all CHAOZ-X mooring locations. Number of days with recordings (Eff), number of days with noise activity (#), number of days with noise activity > 50% (#pk), percent of days with noise activity (%),percent of days with noise activity > 50% (%pk).

Mooring	Eff	#	# pk	%	% pk
IC3	1647	100	27	6	2
WT2	788	60	24	8	3
HS1	747	34	15	5	2
HS2	348	6	1	2	0
HS3	329	9	1	3	0

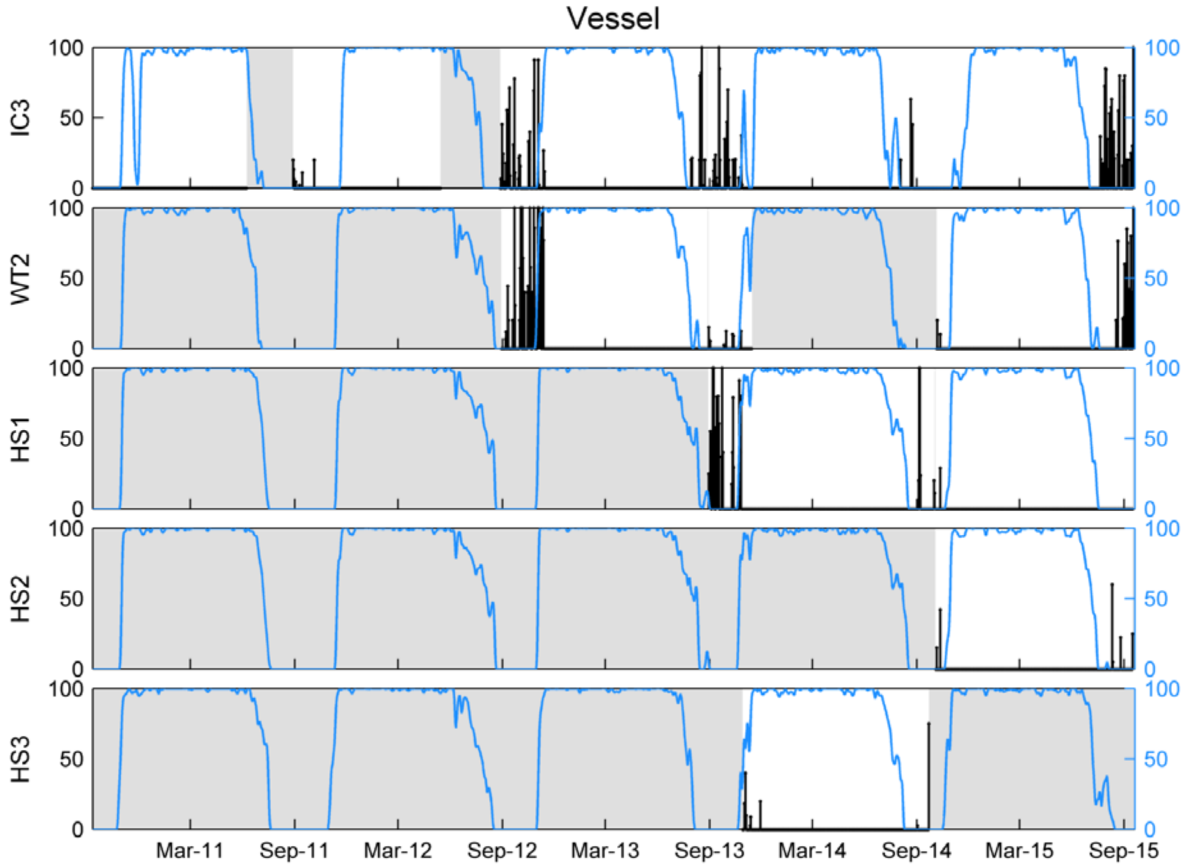

Figure 46. Vessel noise activity (presented as the percentage of ten-minute time intervals with vessels detected) for the five CHAOZ-X locations (see Figure 3A), 2012-2015. Blue line indicates percent ice cover (zero-phase, three-day moving average). Gray shading = no data.

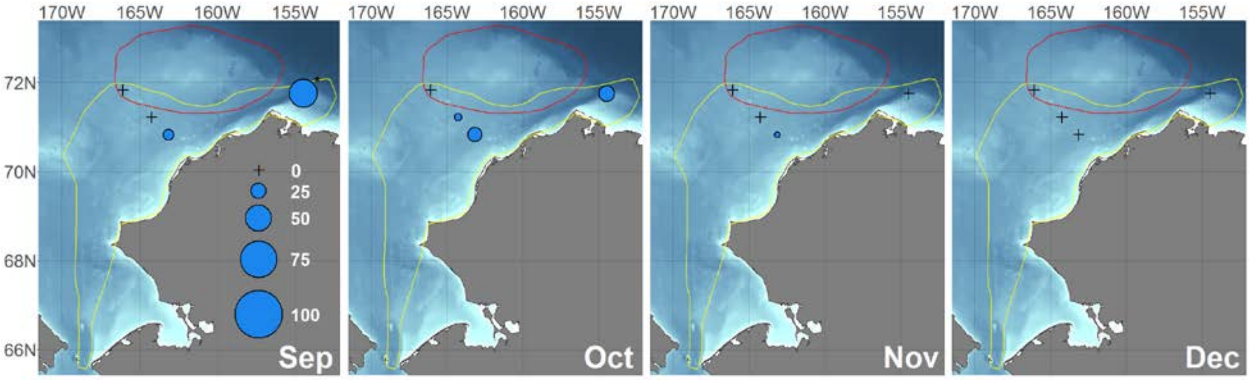

Figure 47. Monthly vessel noise distribution, 2010. Graduated scale in the September panel indicates % days per month with vessel noise. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.13 for numbers used to generate figure.

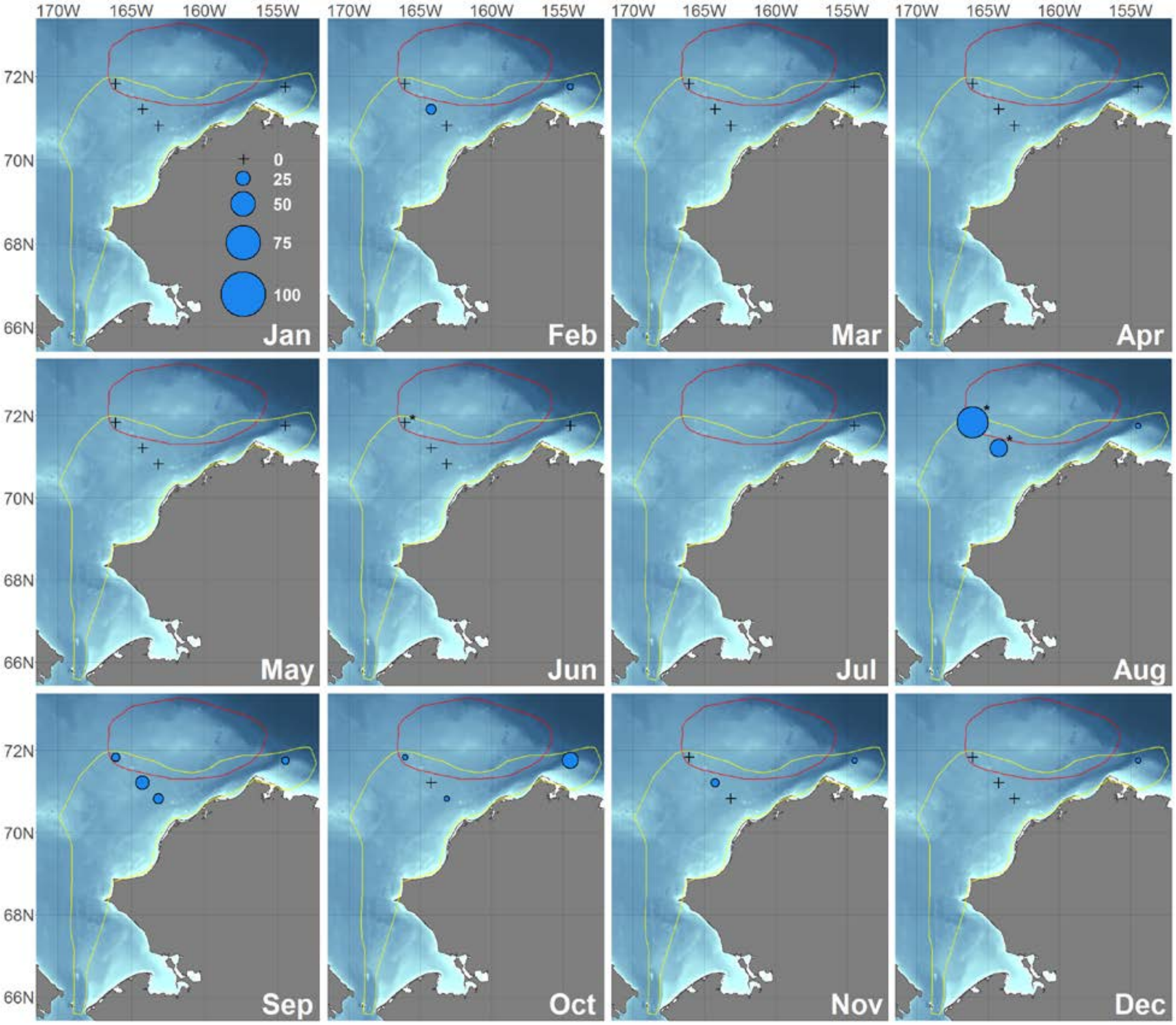

Figure 48. Monthly vessel noise distribution, 2011. Graduated scale in the January panel indicates % days per month with vessel noise. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.13 for numbers used to generate figure.

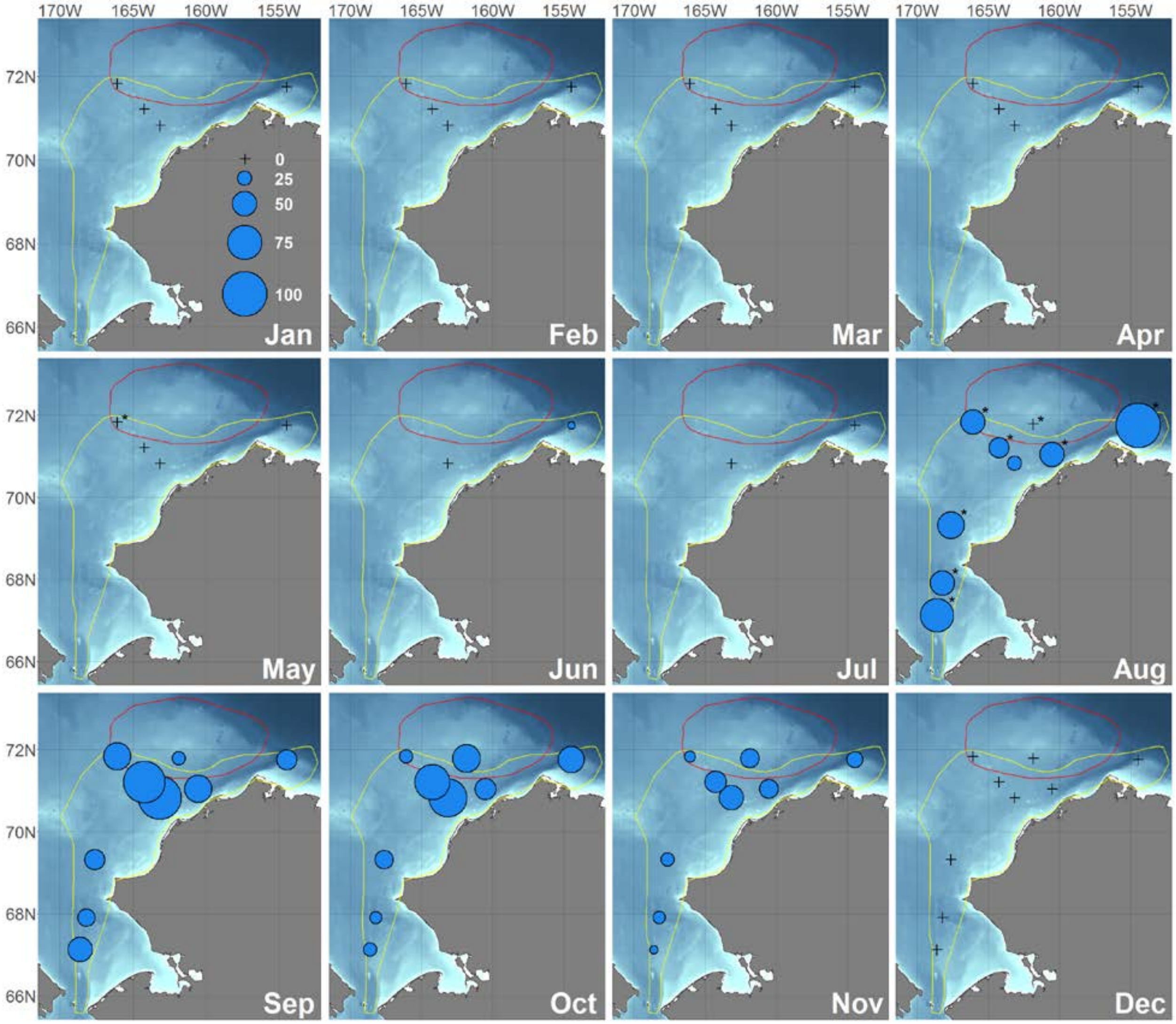

Figure 49. Monthly vessel noise distribution, 2012. Graduated scale in the January panel indicates % days per month with vessel noise. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.13 for numbers used to generate figure.

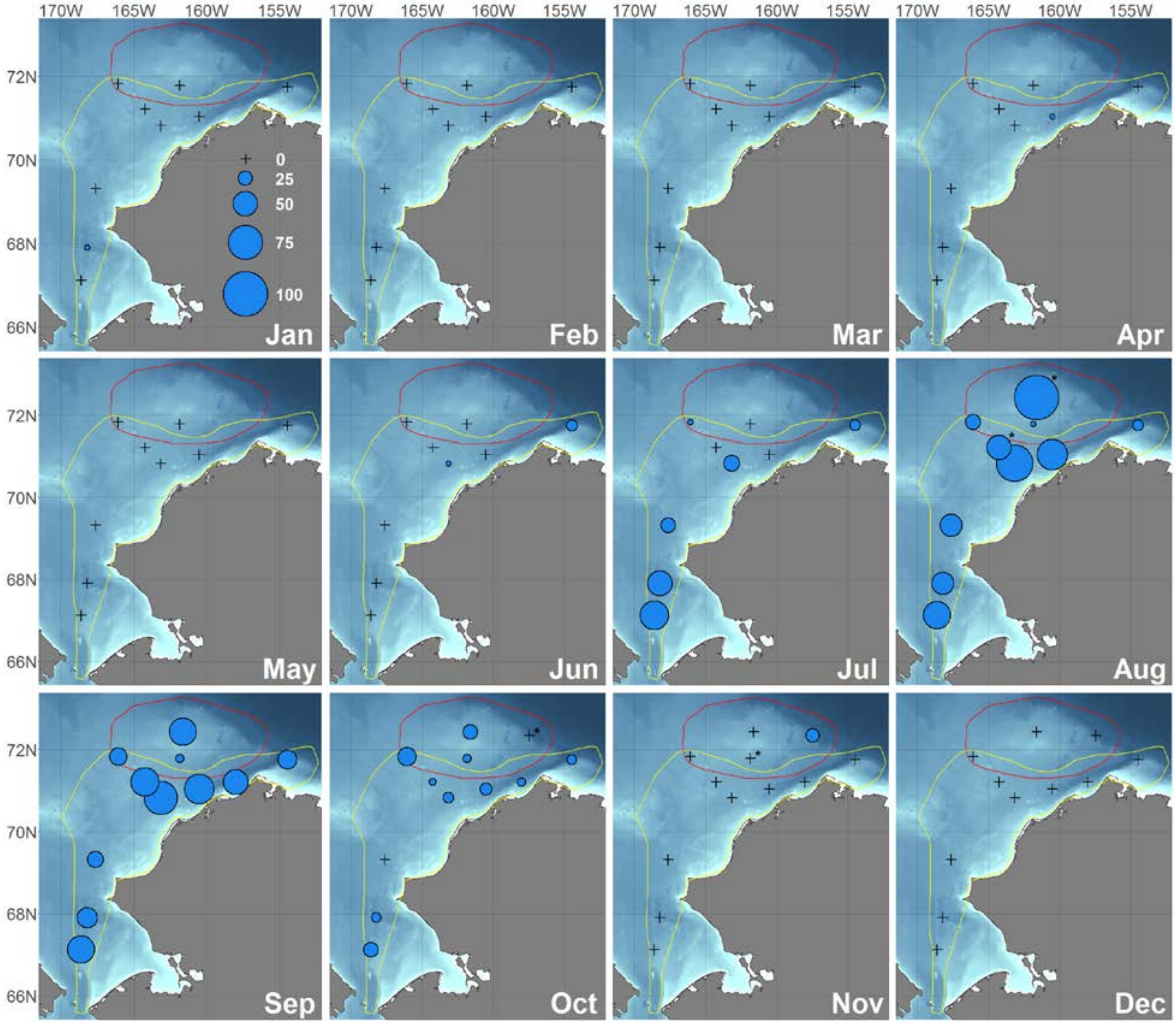

Figure 50. Monthly vessel noise distribution, 2013. Graduated scale in the January panel indicates % days per month with vessel noise. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.13 for numbers used to generate figure.

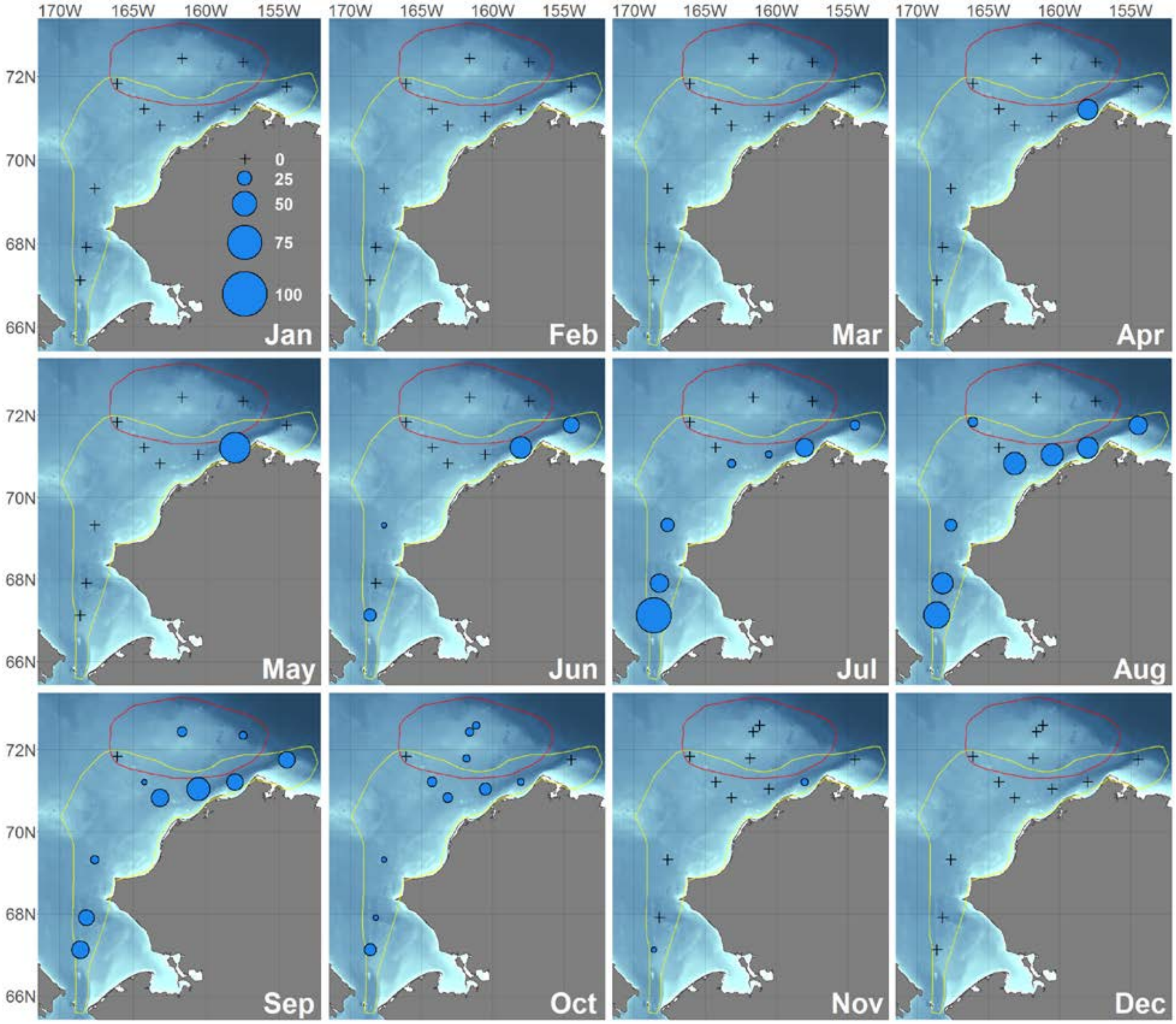

Figure 51. Monthly vessel noise distribution, 2014. Graduated scale in the January panel indicates % days per month with vessel noise. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.13 for numbers used to generate figure.

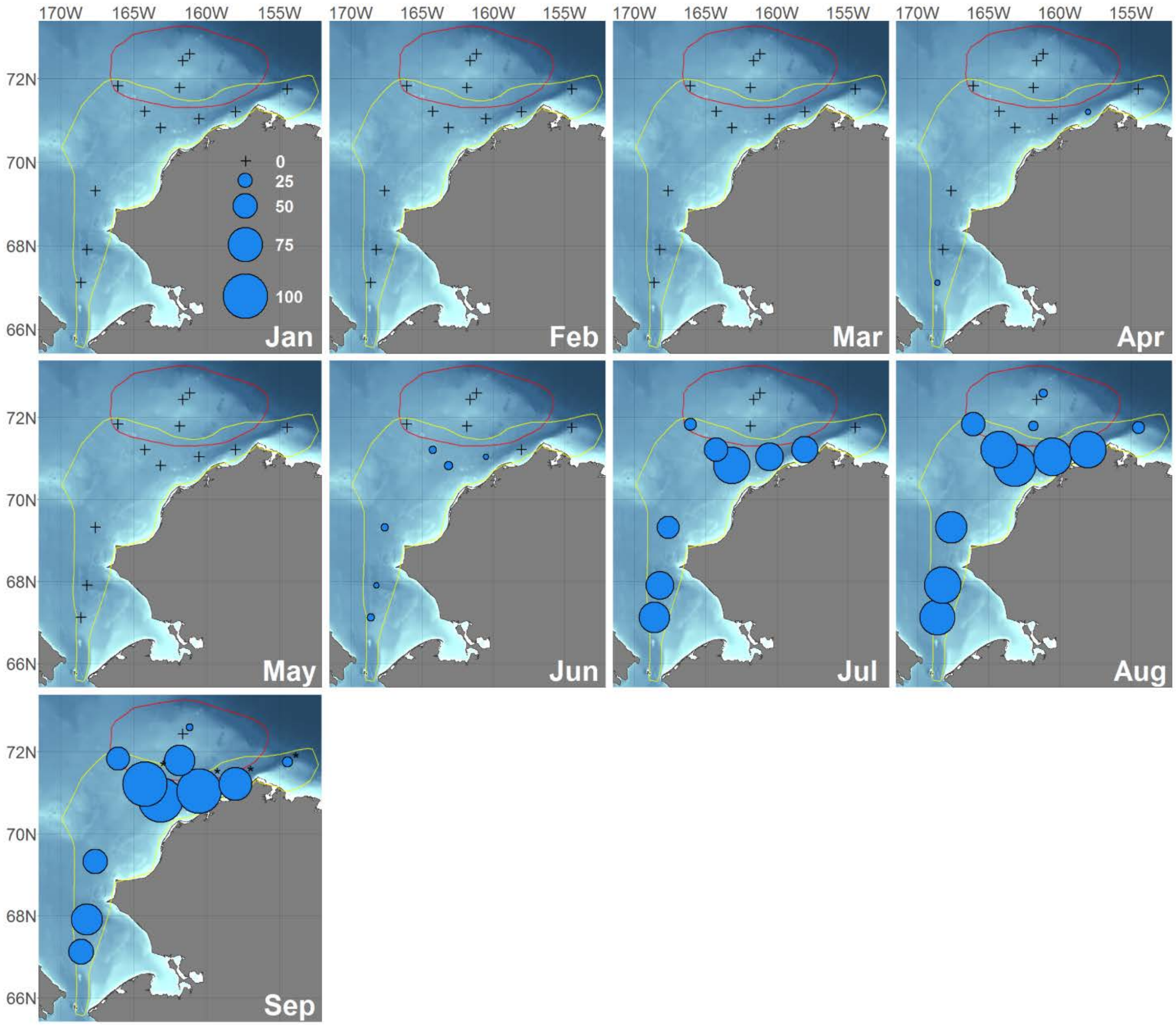

Figure 52. Monthly vessel noise distribution, 2015. Graduated scale in the January panel indicates % days per month with vessel noise. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.13 for numbers used to generate figure.

Ice noise

A substantial source of noise on the year-long recordings was from ice (Figure 53; Table 21), primarily caused by cracking and rubbing (Xie and Farmer 1992). Ice noise was detected during all overwinter periods in all years and at all moorings where data were available (Figure 53). Among sites, the proportion of days with call and peak calling were similar, although the highest for both were found at the shoal site, HS1. In addition, the lower noise activity levels seen during the winters of 2010-11 and 2011-12 were a product of a miscommunication with the analysts to mark ice presence, and should be considered artificially low. A map of ice noise activity can be found in Appendix E.25-E.30.

Table 21. Total ice noise activity, 2010-2015, for all CHAOZ-X mooring locations. Number of days with recordings (Eff), number of days with noise activity (#), number of days with noise activity > 50% (#pk), percent of days with noise activity (%), percent of days with noise activity > 50% (%pk).

Mooring	Eff	#	# pk	%	% pk
IC3	1647	891	289	54	18
WT2	788	494	172	63	22
HS1	747	495	235	66	31
HS2	348	167	43	48	12
HS3	327	226	39	69	12

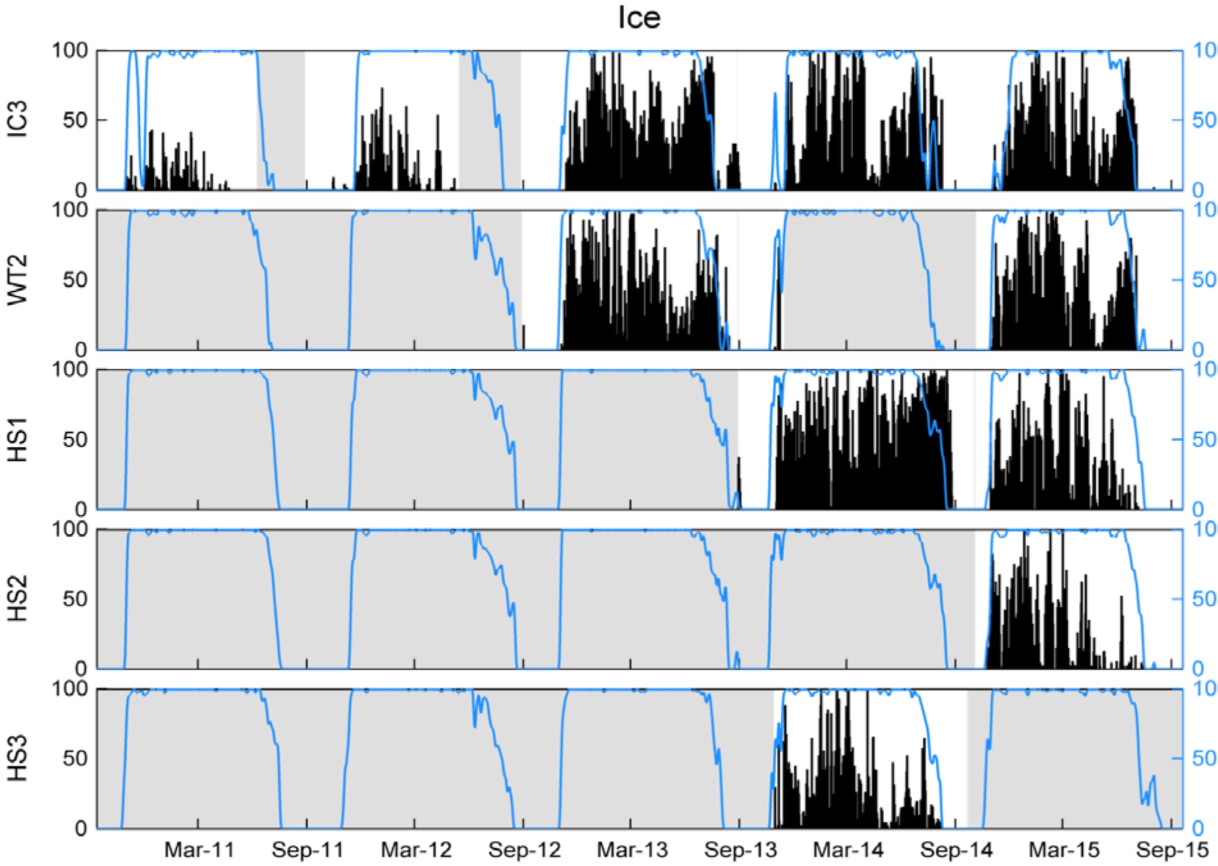

Figure 53. Ice noise activity (presented as the percentage of ten-minute time intervals with ice noise detected) for the five CHAOZ-X locations (see Figure 3A), 2012-2015. Blue line indicates percent ice cover (zero-phase, three-day moving average). Gray shading = no data.

3. *Discussion*

In this section we will discuss the long-term results for each species or signal, and how they relate to current knowledge and literature. Because of the length and detail of the discussion section, key findings for each species or signal will also be presented as concise, bulleted highlights. Please see the Conclusions section (see VII.A.4) for the concise summary.

Bowhead whales

The annual pattern of spring and fall pulses of bowhead whale calling activity described in the results above for the CHAOZ-X study area complement what is currently known about their spatio-temporal distribution in the scientific literature. The bowhead whales detected on the long-term recorders are part of the Bering-Chukchi-Beaufort (BCB) stock that migrate through the Chukchi Sea annually between their wintering grounds in the Bering Sea and their summer feeding grounds in the Canadian Beaufort Sea (see Quakenbush et al. 2010 for an extensive literature review of this migration). In the spring they remain close to shore and use leads in the ice to migrate northward from the northwestern Bering Sea along the Chukotka or Alaskan coasts through the Bering Strait, and then along the Alaskan coast toward their summering grounds in the Beaufort Sea (Braham et al. 1980; Moore and Reeves 1993; Quakenbush et al. 2012). The fall migration is known to diverge once past Point Barrow, AK; some whales head west toward Wrangel Island and others head southwest toward the northern Chukotka coast (Moore and Reeves 1993; Moore and Laidre 2006). In fact, the fall migration pathway in the Chukchi Sea fans out so much that there is no clear pathway; as such, it cannot be a Biologically Important Area (BIA) designated migratory corridor (Clarke et al. 2015a). BIA's are identified as "reproductive areas, feeding areas, migratory corridors, and areas in which small and resident populations are concentrated" (Ferguson et al. 2015). Because the CHAOZ-X study area is offshore, it was expected that the moorings located there would detect a pulse of calling activity associated with the fall migration but would not detect any calling activity associated with the spring migration.

In all years and most locations (all but HS3) the fall pulse of calling activity in the CHAOZ-X study area occurred between August/September and November/December. A distinct end to the fall pulse of calling activity was evident; no calls were detected from January through March, fitting for a population that is currently not believed to overwinter in the Arctic (Braham et al. 1984a). This is consistent with past studies (mainly aerial and some shipboard surveys), which have described the fall migration as beginning in September and continuing through November/December, when the whales pass through Bering Strait (Moore and Reeves 1993). Current data from satellite tagging (Quakenbush et al. 2010) and other passive acoustic studies (Hannay et al. 2013) have indicated a similar time frame. Furthermore, the months with the highest proportion of days with calling activity (Table 4) were September and October at the sites along the northeastern flank of the shoal (HS1 & HS2), October at the shoal site (WT2), and October and November at the western site (IC3), which is consistent with an east-to-west migration. The results for the slope site, HS3, fit with Point Barrow being the point where the migration diverges in the fall. The whales would need to turn sharply at Point Barrow and swim directly offshore for over 100 km to reach HS3; the lack of a fall pulse in calling at HS3 seems to suggest that they do not do this, but rather the population gently fans out once it passes Point Barrow. Finally, when looking more broadly at the calling activity results from the entire Alaskan Chukchi Sea (Figures 8-13), it is clear that the fall pulse of calling seen on the CHAOZ-X moorings is definitely part of the fall migration. With this context, it appears that the fall migration finished earlier at the Hanna Shoal sites, as compared with those moorings closer to shore; this is most evident in the October through December panels of Figure 11 and Figure 12.

The calling activity present during this fall migratory period was typically not steady, but composed of several peaks, the best example occurring during fall 2010 at IC3 (Figure 7), where three distinct peaks or modes were seen. Although not quite as distinctive and/or composed of exactly three peaks, this multi-peak pattern was seen during the fall in most years and at most mooring sites. Hannay et al. (2013) also note the presence of multiple peaks in calling, but did not find the triple-peak to be a consistent feature in their data set. Traditional Ecological Knowledge (TEK) asserts that bowheads are segregated by age class during their fall migration; smaller whales lead the migration, followed by large adults including cow/calf pairs (Braham et al. 1984a)[13]. Recent work by Koski and Miller (2009) using calibrated vertical photography on bowhead whales during their fall migration in the eastern Beaufort Sea, found that small subadults do precede the adults, with cow/calf pairs the last to leave. Ljungblad et al. (1987) also detected three peaks of calling activity in the fall from migrating bowhead whales. While they interpret the three peaks as representing aggregations or pulses of whales passing Barrow, they do not speculate as to the age/sex classes of the pulses. Taken as a whole, these acoustic data suggest that if these pulses do represent temporal separation between age classes, this separation varies interanually as well as spatially. Barrow whalers report that the segregation of migration pulses in the fall is tenuous (Huntington and Quakenbush 2009), which may explain the differences seen here.

A more detailed acoustic analysis of these peaks found in the 2010 and 2014 fall pulses is needed to determine whether there is a difference in call characteristics among them, which would suggest differences in calling among the age/sex classes. Results from this analysis could then be applied to the other years/moorings to determine whether similar, but blurred, patterns exist in those data. We have begun this finer scale analysis with the inclusion of the bowhead whale gunshot call. As shown in Figure 14, this call type occurs near the end of each of the fall migration pulses in calling activity for all years and moorings where data are available. One observed case of gunshot calls being produced during the spring ice census in Barrow was not associated with any visible surface activity (Würsig and Clark 1993), but current recollection of this event is that it was associated with adults and not cow/calf pairs (C. Clark, pers. comm.).

With the exception of the slope site, HS3, the spring pulses in bowhead whale calling activity occurred at much reduced levels and also were not sustained over long periods of time like those present in the fall (Figure 7). As it was expected that most of the spring migration would occur closer to shore in the leads off the shorefast ice, the surprising finding here is that any spring calling was detected at the mooring sites of this CHAOZ-X offshore study area. Although TEK describes another migration path in a lead approximately 75 miles from shore (Huntington and Quakenbush 2009), this is still closer inshore (i.e., approximately even with the WT2 and IC2 mooring sites) than the furthest offshore sites (i.e., HS1, HS2, IC3) where spring calling was detected. It is possible that this offshore lead could have shifted since the mid-nineties when this TEK was collected, but satellite tag (Quakenbush et al. 2013) and passive acoustic data (Clark et al. 1986) have shown that not all whales are confined to the lead system. The HS1-3 mooring sites in the CHAOZ-X study area were located much farther offshore from those of Hannay et al. (2013); their furthest offshore mooring to detect bowhead calling in the spring was PL125, which was roughly located between our IC3 and WT2 sites (Figure 54).

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[13] However, see Huntington and Quakenbush (2009) for description of fall migration being large, then medium, then small whales passing by Barrow.

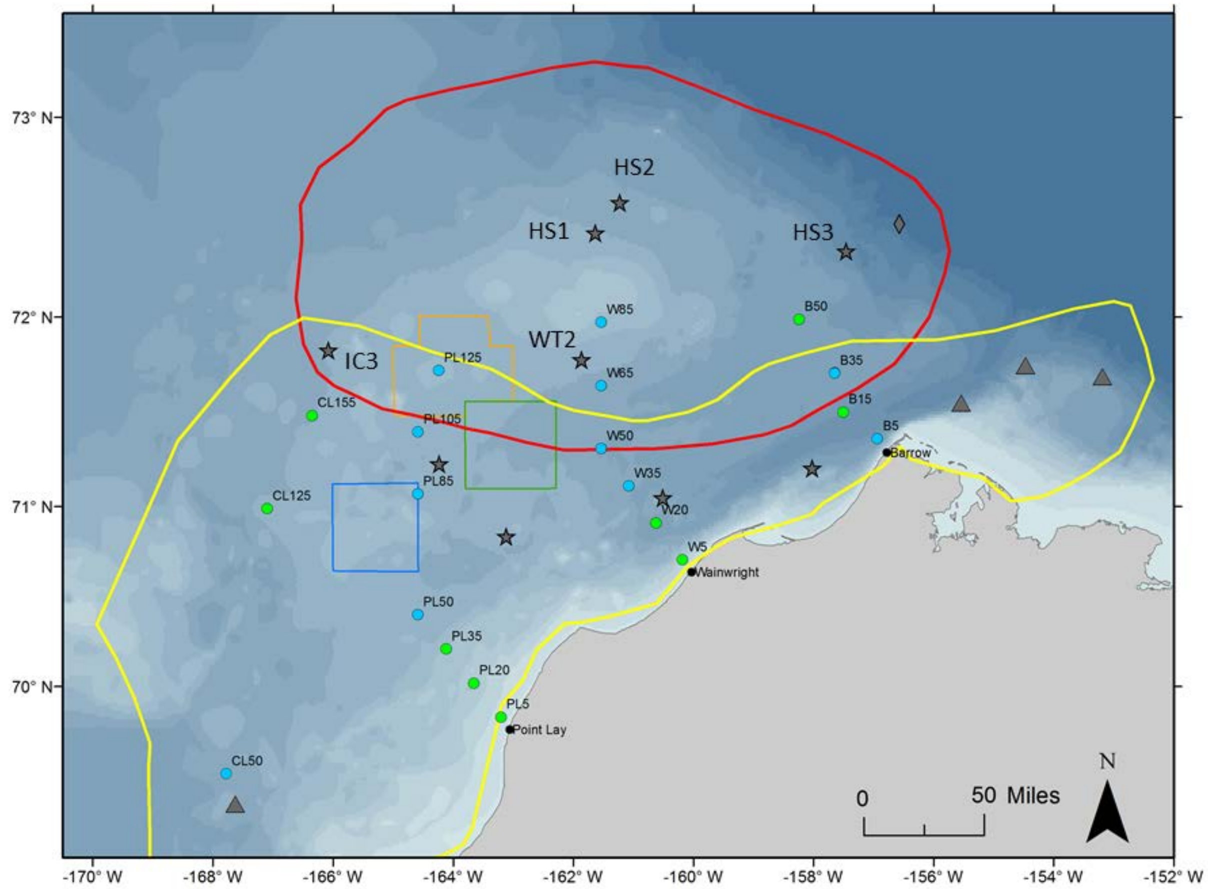

Figure 54. Location of CHAOZ-X passive acoustic moorings (labeled gray symbols) in relation to those deployed by Hannay et al. (2013) and the CSESP study areas. JASCO summer moorings (green circles) recorded generally from August to October, and winter moorings (blue circles) recorded from October to August. Unlabeled gray symbols are passive acoustic moorings from ARCWEST. Red outline delineates CHAOZ-X study area, yellow outline delineates the ARCWEST study area. Colored boxes indicate the former Burger (green), Klondike (blue), and Statoil (orange) lease areas.

It is unknown whether the sustained spring presence of bowhead whales on the slope (HS3) is consistent between years since data exist for only 2014. There are not enough years of data from the shoal sites (HS1-2 and WT2) to determine whether bowheads are present every spring, but the data collected here suggest that this might be the case (Figure 7). For those years/mooring sites with detections, bowhead whale calling activity occurred between April and June. This again agrees with past (Moore and Reeves 1993) and current (Quakenbush et al. 2012; Hannay et al. 2013) literature, as well as from the TEK acquired from centuries of springtime bowhead whale subsistence hunts (Braham et al. 1980). As with the fall migration, it is clear when looking at the broader context of the Alaskan Chukchi Sea (Figures 8-13) that the spring pulse of calling seen on the CHAOZ-X moorings is definitely part of, but on the outskirts of, the spring migration, which mostly occurred along the coastline as expected. Interestingly, however, calling activity arrived at the HS3 site after it was detected along the shore to the east of Barrow, AK, suggesting a possible migration route that either spreads out before, or veers northwest along the slope after, passing by Barrow Canyon (Figure 12).

Although the spring 2013 pulse of calling at WT2 had a clear end, the rest did not. For the spring pulse at HS3 it is difficult to discern whether there are two distinct pulses of spring calling activity or overlap between the spring and fall pulses (Figure 7). In either case, the calling activity gradually decreased until the end of the data was reached. In addition, Hannay et al. (2013) have reported similar decreases in detections after the main pulse of spring calling activity at other locations in the Chukchi Sea.

Calling activity was present at most CHAOZ-X moorings/years during the open water season. The Chukchi Sea is used primarily as a migratory corridor by the BCB stock. It is also identified as a Biologically Important Area (BIA) for reproduction (Clarke et al. 2015a), but this is based on sightings of cow/calf pairs (including neonates) during the spring and fall migrations, and so it still has a migratory context. Whether bowhead whales also use the Chukchi Sea to feed is unclear. Bowhead whales are planktivorous, feeding mainly on copepods and euphausiids, although they can also eat other crustaceans and fish (Lowry 1993; Lowry et al. 2004). They can feed in the water column, at the surface, and epibenthically (Würsig et al. 1989). Recent work by Mocklin et al. (2012) has shown that epibenthic feeding is more prevalent than previously thought. As stated by Clarke et al. (2015a), despite extensive aerial survey effort, very few observations of feeding bowhead whales exist for the northeastern Chukchi Sea to be designated as a BIA for feeding, although they also mention the limitations in identifying feeding behavior during aerial surveys. The area just to the east of Pt. Barrow (Beaufort Sea) is a summer feeding ground for bowheads where a particular set of physical factors including the flow of Alaska Coastal water out of the Chukchi Sea can sometimes concentrate euphausiids and copepods into dense aggregations (Ashjian et al. 2010; Moore et al. 2010; Okkonen et al. 2011). Nevertheless, feeding has been observed in the Chukchi Sea (Lowry and Frost 1984; Ljungblad et al. 1986), and old whaling catch records have shown that bowhead whales historically used the Chukchi Sea in the summer/fall months (Dahlheim et al. 1980). Several authors have also suggested feeding during the spring migration is more common than previously thought (Lowry et al. 2004; Moore and Laidre 2006; Mocklin et al. 2012). Furthermore, recent data from satellite tags have shown that bowhead whales sometimes turn around mid-migration (Quakenbush et al. 2013), and so it is important to note that they most likely are influenced by multiple motivators while in the Chukchi Sea. The factors potentially influencing bowhead distribution will be investigated in Section XI.A.

Finally, as noted in Hannay et al. (2013) it is possible that periods of low calling activity levels are due to low calling rates and not necessarily from low whale presence (Würsig and Clark 1993). However, they counter with the fact that periods with low calling rates also correspond to periods with low numbers of visual observations. From the visual survey and passive acoustic monitoring conducted during our field cruises, it was found that bowhead whales are equally likely to be visually sighted as acoustically detected. Given these cruises occurred outside of the main migratory pulse, the calling detected during the cruises was most likely made by animals at feeding sites and not exclusively by migratory whales. The long-term mooring results presented here agree strongly with those obtained from visual observations, TEK, and satellite tag data, and so we conclude that calling activity is a good proxy for the spatio-temporal distribution of bowhead whales.

Beluga whales

The results for beluga whales, like those for bowhead whales, showed the presence of both spring and fall pulses of calling activity in the CHAOZ-X study area. This, again, agrees with the scientific and TEK information for this species that migrates annually between the Bering Sea and the Arctic (Braham et al. 1984a; Lowry et al. 1985; Moore et al. 2000; Suydam et al. 2001; Suydam 2009; Delarue et al. 2011; Citta et al. 2013; Hauser et al. 2014; Clarke et al. 2015a; Garland et al. 2015a). The story for beluga whales, however, is complicated by the fact that two populations of whales, the eastern Chukchi Sea and eastern Beaufort Sea, are migrating through the study area at overlapping times (Hauser et al. 2014). As summarized in Suydam et al. (2001), these populations were identified based on the areas that they use for calving, molting, and feeding, and confirmed through genetic analysis. The Beaufort Sea population concentrates in the Canadian Beaufort Sea, with core areas near the Mackenzie Delta and in Viscount Melville Sound, while the Eastern Chukchi Sea population concentrates on the continental shelf and slope in the northeastern Chukchi and western Beaufort seas with core areas near Kasegaluk Lagoon and Barrow Canyon (Hauser et al. 2014). After overwintering in the northern Bering/southern Chukchi Seas, both populations begin their migration north to their feeding grounds in the Arctic. It is believed that the Beaufort Sea population begins their spring migration first, starting in March and following leads in the ice until reaching their feeding grounds in the Canadian Beaufort Sea no later than July (Braham et al. 1984a). The smaller Eastern Chukchi Sea population is thought to begin its migration later (D. Hauser, unpublished satellite tag data). They arrive at Kasegaluk Lagoon near Icy Cape, AK by late June – early July, to calve, feed, and molt, and leave by mid- to late July as they spread out to feed further offshore of Kasegaluk Lagoon, near Barrow Canyon, or up to the ice edge (Suydam et al. 2001; Hauser et al. 2014). For both populations, calving and mating occur May-August, although young calves have been seen as early as March and as late as September in the Arctic. Braham et al. (1984a) list Peard Bay (between Barrow and Wainwright) as a prime mating location, but there is no contemporary evidence to support this. In September, the Beaufort Sea population moves west past the Eastern Chukchi Sea population and they hold this west-east positioning for the rest of the fall migration to the Bering Sea (Hauser et al. 2014).

The spring pulse of beluga whale calling activity, with its highest levels occurring from April through June at all sites and years, is consistent with the timing of the spring migration. In addition, where data exist from multiple mooring sites during the same spring period (Table 8), there was a delay of a few days that occurred from west (i.e., IC3 and WT2) to east (i.e., HS1-3), again supporting that this spring pulse in calling activity is indicative of the spring migration. At first glance, these results are puzzling, given the location of the CHAOZ-X moorings offshore, well away from the along-shore lead system. However, this fits with results from other passive acoustic studies (Delarue et al. 2011; Moore et al. 2012; Hannay et al. 2013) that have also found high levels of beluga calling on offshore recorders in the Chukchi Sea in May, and suggests that not all beluga whales are traveling northeast along the inshore lead in the Chukchi Sea at this time of year. In fact, Suydam et al. (2001) have shown with satellite tags that beluga whales do not seem to be limited by high ice concentrations. Fraker (1979) describes extensive leads that develop far offshore (~ 74°N) in the Beaufort Sea, and that a substantial number of beluga whales use these leads in the spring before the pack ice near shore becomes navigable. Beluga whales have been observed swimming within areas with high ice concentrations; the whales were seen transiting between open areas up to 3 km apart (Fraker 1979). Beluga whales have also been seen to break through ice up to 20 cm thick (summarized by Fraker 1979).

Although not discussed, there are satellite ice data in Fraker (1979) that show the presence of leads in the Chukchi Sea (mid-April 1977). Given the rapid rate of climate change in the Arctic (Wang and Overland 2015), it seems likely that these leads are still present, or more extensive, in the present time. The question therefore, is not how the belugas are getting offshore, but rather which population these detections are from, and which route(s) they are taking to get to these offshore sites. Including the full set of Chukchi/Beaufort data (Figures 16-21) provides a bit more context. The March through June panels of Figure 20 suggest that perhaps some belugas are diverging from the inshore lead prior to reaching Point Barrow and some are diverging afterwards. These offshore detections may be from Beaufort Sea animals that have diverged off the easterly migration path along the coastal lead. The offshore detections could also be from Eastern Chukchi Sea animals that are delaying their arrival at Kasegaluk Lagoon by moving offshore to feed first. Again, like the Beaufort Sea population, the Eastern Chukchi Sea population could be branching off at or before Icy Cape, or continuing to Barrow Canyon and looping around offshore. In fact, the only Eastern Chukchi Sea beluga with a functioning satellite tag during its spring migration left the Bering Sea and travelled NW into Russian waters off the Chukotka Peninsula then east toward Barrow Canyon and the ice edge before turning around and heading toward Icy Cape near Kasegaluk Lagoon (see tag #22149; http://www.north-slope.org/assets/images/uploads/2007.jpg[14]). As suggested by Delarue et al. (2011), it would seem logical for the migrating whales to replenish their energy stores before arriving in the lagoon, especially since they may not feed there. The answer probably lies somewhere in the middle: some combination of routes from both populations may be occurring at the same time as is seen during their fall migration (see Hauser et al. 2014). As a final point to consider, the presence of beluga calling activity during winter months at most of the CHAOZ-X mooring locations (Figures 15-21) adds the possibility that a proportion of individuals from either population overwinter offshore. The association between belugas and ice conditions is discussed in detail in Section XI.A.

The presence of calling activity in the summer (primarily in July/August), particularly at the slope site (HS3) are consistent with the July range of the Eastern Chukchi Sea population (Hauser et al. 2014; Figures 19-21). The distance of the CHAOZ-X mooring sites from the core feeding area defined by aerial surveys and satellite tagging (Hauser et al. 2014; Clarke et al. 2015a) supports low whale densities being the cause for the low calling activity levels detected at most of the mooring sites. The slope site, HS3, is located close enough to the July core use area reported by Hauser et al. (2014) to explain its much more consistent and higher levels of calling (Figures 15-21).

Beluga whales are benthic and pelagic feeders (Seaman et al. 1982; Braham et al. 1984a). The diet of the Beaufort Sea population has been said to be primarily Arctic cod, along with other fish, cephalopods, and shrimp (Moore et al. 2000; Hauser et al. 2015). The diet of the Eastern Chukchi Sea population is less well known but is thought to consist of saffron cod, cephalopods, crustaceans, and marine worms (Braham et al. 1984a). Point Lay hunters have reported the stomachs of whales harvested in Kasegaluk Lagoon to contain shrimp, cephalopods, and small fish (Lowry et al. 1985). The most current data are from Quakenbush et al. (2015) who analyzed the stomach contents from both populations. They found that shrimp were the

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[14] Link obtained from http://www.north-slope.org/departments/wildlife-management/co-management-organizations/alaska-beluga-whale-committee/abwc-research-projects/satellite-maps-of-tagged-alaskan-beluga-stocks/1998-2012

predominant prey type of both populations, with the most predominant fish species being saffron cod for the Eastern Chukchi Sea and Arctic cod for the Beaufort Sea, although other studies suggest that even the Eastern Chukchi Sea population feeds on Arctic cod (Stafford et al. 2013; Hauser et al. 2014). Worms and octopus were still more common prey items than fish for the Eastern Chukchi Sea and Beaufort Sea populations, respectively[15].

It is unknown if belugas are feeding at the mooring locations, or vocalizing while passing through the area toward the ice edge. Beluga whales are highly vocal during most behavior states (e.g., during social interactions, or directional swimming/migration), however, studies have shown that beluga whales rely almost entirely on echolocation clicks when foraging (Castellote et al. 2011; Panova et al. 2012; Castellote et al. 2016); although see Stafford et al. (2013) for a summary of evidence to the contrary. Due to sampling rate limitations, the passive acoustic recorders used in this (and the Hannay et al. 2013) study would be unable to detect echolocation clicks, which have peak frequencies between 40-60 kHz (Au et al. 1985). However, the apparent co-occurrence of the double knock call type (on the shoal in the spring) with beluga whale calling activity (Figure 38), and the possibility that it could be attributed to fish, has potential for investigating whether beluga are foraging for fish in the CHAOZ-X study area.

Beluga calling activity in the fall was less prominent than that in the spring. This result follows that of Hannay et al. (2013), and is consistent with aerial survey results (Clarke et al. 2015a), which show beluga whale sightings to be low in numbers, and widely scattered, within the aerial survey limits (i.e., south of 72°N). Although earlier satellite telemetry results (Richard et al. 2001) show avoidance of the Chukchi shelf in this area, recent results from Hauser et al. (2014) show the two populations (and males/females) occupying different shifting areas during the fall, essentially creating a broad distribution across the Chukchi shelf. Past aerial survey data has suggested that the fall migration splits at Point Barrow (Clarke et al. 1993), with one migratory path continuing southwest through the Chukchi Sea and another remaining north of 72°N and heading west. Satellite telemetry data has shown that belugas do travel into the pack ice, and their October range reaches to at least 74°N (see Hauser et al. 2014 and references therein). Belugas were also detected on approximately 30% of all days in October 2008 on a recorder located at 75°N (Moore et al. 2012). The CHAOZ-X data showed the shoal sites, HS1-2 & WT2, to have the least amount of fall calling activity, which suggests the belugas are not passing through that area in large numbers, consistent with aerial survey results (Clarke et al. 2015a). The data from Hauser et al. (2014) do show the slope to be a core area in the fall, so the higher calling activity levels detected at HS3 are expected. The consistently higher calling activity levels detected at the IC3 site, are unexpected based on aerial survey results (Clarke et al. 2015a), but this location appears to be in a core area for female Eastern Chukchi Sea belugas in October based on satellite telemetry results (Hauser et al. 2014).

Multiple peaks of calling are seen in some of the calling pulses. These are the most evident at the IC3 mooring site, and were also seen in the Hannay et al. (2013) data (e.g., their

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[15] It is important to note that the Eastern Chukchi Sea whales analyzed by Quakenbush et al. (2015) were found near Point Lay in June and July, when they are concentrating in Kasegaluk Lagoon for their molt/calving period. Most stomach samples from the Beaufort Sea population were collected during their spring migration, presumably before they have reached their prime feeding grounds. Therefore, these results may not reflect the true composition of the diets in either population. In fact, dive data from Citta et al. (2013) and Hauser et al. (2015) shows that the Eastern Chukchi Sea beluga whales dive to depths of 200-300 m, where the boundary layer between water masses aggregates Arctic cod.

Figure 6, W35). These peaks might be caused by the two populations moving by at different times (Garland et al. 2015a), sex/age segregation (Hauser et al. 2014), or simply because they are stopped by the ice and have to wait until their path is clear again (Fraker 1979). Data from the BOEM-funded CHAOZ and BOWFEST projects have been used to develop call repertoires for the Beaufort Sea (Garland et al. 2015b) and Eastern Chukchi Sea populations. When completed, the two repertoires will be compared and the results applied to the entire data set to hopefully differentiate between the two populations using call characteristics alone.

Bearded seals

Bearded seal calling activity was maintained at such high and sustained levels throughout the ice season in every year and at every CHAOZ-X mooring that, quite frankly, they were considered an annoying source of background noise to the analysts. This ubiquitous calling, however, has resulted in a substantial dataset that can be used to improve our understanding of the spatio-temporal distribution of this species.

At all CHAOZ-X mooring sites and in all years with recordings, calling activity increased from September through January, reaching sustained and saturated levels from February through June, when calling ceased abruptly; July and August had the lowest calling activity levels of the year. Bearded seals give birth to their pups on the ice, between late March through May, and young are weaned within a few weeks (Burns and Eley 1978). Mating and molting occurs after pupping (Burns and Eley 1978). The period with sustained and saturated (100% of all ten-minute recordings per day have detections) calling levels, therefore, coincides with this whelping/mating/molting season. This timing of peak calling activity has been reported in several studies, (i.e., Moore et al. 2012; Hannay et al. 2013; MacIntyre et al. 2013, 2015; Jones et al. 2014; Frouin-Mouy et al. 2016), the latter two of which used data from the CHAOZ and/or BOWFEST studies. It has been well-established that male bearded seals produce long (> 1 min) trills during the mating season (Ray et al. 1969), and that the whelping/mating/molting season occurs from March to late June (Burns and Eley 1978). The abrupt end in calling seen in late June in this and other (i.e., Hannay et al. 2013; MacIntyre et al. 2015) studies may be an artifact of using a binned analysis method, as pointed out by Frouin-Mouy et al. (2016) who counted the number of calls detected and found that this decreased gradually at the end of the mating season. The presence of high levels of calling activity in the CHAOZ-X study area earlier than the whelping season (i.e., in February) is most likely due to pre-mating season male-to-male competition (MacIntyre et al. 2015), as evidenced by the shift in proportion of the use of certain call types throughout the spring (Frouin-Mouy et al. 2016; Jones et al. 2014), and certainly, the ramp up of calling from September through January in this study supports this hypothesis. However, it is also possible, with changing ice conditions in the Arctic, that the detection of calling activity at saturated and sustained levels in February could indicate that the mating season occurs (or is shifting) earlier in the year than visual observations have determined. If so, this is an important documentation of a phenological shift in the behavior of an Arctic species. Cameron et al. (2010) provide a discussion (with references) on geographic differences in the whelping period, the earliest being late February in the Sea of Okhotsk. Further investigation into the composition of call types used during this period (i.e., using the methods of Frouin-Mouy et al. 2016) will help to determine if this is the case.

The data collected for this study also show that bearded seals are present in the offshore areas of the northeastern Chukchi Sea year-round. Again, this is in agreement with the passive acoustic data results presented by Hannay et al. (2013), as well as others (e.g., MacIntyre et al. 2013, 2015; Jones et al. 2014; Frouin-Mouy et al. 2016). Burns (1970), Braham et al. (1977), Burns and Eley (1978), and Allen and Angliss (2013) provide thorough descriptions of the past and current distribution and ecology of bearded seals. Results from over fifty years of vessel and aerial surveys, as well as centuries of information passed down through TEK, have found bearded seals to winter in the northern and central Bering Sea shelf and in the Bering Strait. From late winter to early spring they are dispersed in the broken and drifting pack ice from the Chukchi Sea to the ice edge in the Bering. It is thought that most of the north-bound seals pass through Bering Strait between April and June. Bengtson et al. (2005) found higher densities offshore among the pack ice in May and June. Bearded seals are widely distributed in the summer with some (mostly juveniles) remaining near the coast in the Bering and Chukchi Seas. Most seals head south through the Bering Strait in the fall, ahead of the advancing ice. It has also been reported that bearded seals move slightly offshore in the late-fall/early winter as shore-fast ice forms along the coast (Cameron et al. 2010). This southbound migration is said to be less predictable and noticeable than the northbound leg. Recent satellite tag data has supported these trends, and has shown that the southbound migration does not hug the coast as closely as the northbound migration (Boveng and Cameron 2013).

It is important to note that while these southbound migration trends are presented as ‘the majority of bearded seals’, there are still cases of bearded seals being observed in the winter in the Arctic. For example, Burns and Eley (1978) report that ‘the winter density of bearded seals in the Beaufort Sea is low (about 0.1 animals/mile^2) with animals found in the flaw zone and nearshore pack ice’. Furthermore, visual surveys that are not corrected for haulout behavior could result in a tenfold reduction in density estimates (Bengtson et al. 2005); the fact that acoustic detections are being made means they are underwater and not on the ice. In short, a multitude of passive acoustic recorders distributed throughout the Arctic have all detected the substantial acoustic presence of bearded seals over winter.

Bearded seals spend most of their time associated with the drifting pack ice, rarely hauling out on land (and even avoiding areas with continuous landfast ice). They can, but rarely do, maintain breathing holes, and so avoid areas with high ice concentrations, preferring areas where constantly moving ice helps to keep leads open. However, they also prefer heavier pack ice (70-90% ice cover) than other phocid seals and therefore tend to be distributed further north. Bearded seals tend to prefer areas where water depths are less than 200 m, and are most abundant 20-100 nm from shore (Burns and Frost 1979; Burns 1981a). They are primarily benthic feeders and eat mainly crustaceans, mollusks, cephalopods, worms, and fish. Their ability to forage for a variety of organisms gives them an advantage over the more bivalve-centric walrus when feeding in the same areas (Lowry et al. 1980). However, as sea ice retreats farther away from the continental shelf into deeper waters, benthic foraging opportunities will diminish. The number of days with high levels of calling activity were lower at the slope site, HS3, than at the other CHAOZ-X sites. This lower calling level might be due to HS3, at 163 m depth, being located near the edge of their preferred diving range. This, and other factors determining acoustic presence will be investigated in Section XI.A.

Before the recent changes in sea ice extent, bearded seals spent a majority of their time in the Arctic and subarctic closely associated with the sea ice. This association still holds, but data from aerial surveys, tagging, and passive acoustics show that many individuals now spend their summer in open water. The lack of summer presence of calling activity, however, does not imply absence of animals. As seen since the CHAOZ study (Berchok et al. 2015), and supported by the results from Frouin-Mouy et al. (2016), bearded seal sightings are common during visual surveys in the summer, although acoustic detections are rare (see Section VII.B below for details).

Walrus

One of the biggest surprises of the CHAOZ study (Berchok et al. 2015) was the high level of mid-winter walrus calling activity at the offshore, IC3, mooring site during the ice season in 2010-2011 and 2011-2012. This high level of calling activity did not continue in the subsequent years for the CHAOZ-X study, but instead declined at a steady rate from the winter of 2012 to the winter of 2015 (Figure 29). Only low-levels of calling activity, at or less than the levels seen in winter 2015 at IC3, were seen at the CHAOZ-X shoal sites (HS1-2 and WT2).

Still, the presence of walrus calling activity overwinter in the CHAOZ-X study area is an unexpected result, one that was not reported by any other passive acoustic study. Braham et al. (1984b) report that the population winters on Bering Sea pack ice to the south of St. Lawrence Island (the majority of the population) and in outer Bristol Bay near Round Island, usually around some form of open water (e.g., polynyas). The mating season for walrus occurs mid-winter, between December and March. Their seasonal movements were described by Fay (1982). Walrus time their departure from their wintering sites in the Bering Sea based on ice movements from wind and sea surface currents. They begin dispersing in April, with many moving through the Bering Strait in May where they extend into the northeastern Chukchi Sea. Most reach their summering grounds in July/August. In the past, their southbound migration coincided with the rapid advance of the ice pack in October, which reached Bering Strait by November[16]. This results in a long period, November-April, where walrus should be south of Bering Strait, but this study detected the presence of calling activity in the CHAOZ-X study area; however, historical sightings of walrus off Point Hope from January through April are not uncommon (Fay, 1982). Nonetheless, some form of open water (e.g., polynya, leads) has to be present throughout the time period with this calling activity. Jay et al. (2012) reported large amounts of open water accompanied by high numbers of walrus in the Chukchi Sea in November of 2008-2011, so it is reasonable to assume that some pockets of open water existed overwinter in the years of this study. The MODIS (Moderate Resolution Imaging Spectroradiometer) ice image from mid-March 2012 (Figure 55) provides compelling evidence that cracks forming in the Bering Strait progressed to the CHAOZ-X study area by mid-March, 2012.

It is not unreasonable to assume that the walrus heard overwintering on the offshore recorders are subadults that do not have any reason to expend the energy required to migrate to the breeding ground in the Bering Sea. Indeed, subadults seem ‘the most inclined to wander or to be diverted by irregular ice movements’ (Fay 1982). In addition, young male walrus tend to remain at the periphery of the areas where the adults aggregate in the winter (Fay et al. 1984b). Miller (1975) describes instances of subadult males engaging in reproductive displays and suggests that practice sessions occur; this would explain the presence of calling activity if the

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[16] What has been known about walrus distribution is likely to continue to change as climate change progresses. The passive acoustic data from Hannay et al. (2013) and radio tag data from Jay et al. (2012) suggest that, currently, walrus are moving out of the Chukchi Sea earlier in the season based on the retreat of the ice edge as opposed to the ice advance. Also, Jay et al. (2012) found that walrus are moving to the Chukotka coast prior to heading down through the Bering Strait.

animals are, in fact, subadults. On the other hand, it is possible that, as with bearded seals, a subset of walrus (regardless of age) overwinter in the Chukchi Sea.

Outside of the winter period, the timing of walrus calling activity did correspond to the seasonal movements described above. This summer pulse in calling generally ranged from June through October where data are available (Table 14), and agreed with the findings of Hannay et al. (2013). Summer calling was at the most saturated and sustained levels on the three shoal sites (WT2 and HS1-2), as was expected given the importance of Hanna Shoal as a feeding area for this species (Jay et al. 2012). However, the same authors found that June/July is currently a time period with walrus ranging further north than in the past. Walrus are benthic feeders and prefer to remain in areas where the water depth does not exceed 100 m (Fay 1982). The lack of calling activity at the slope site, HS3, with its depth of 163 m, is therefore unsurprising. Their diet varies spatio-temporally, and they forage opportunistically (Seymour et al. 2014a), but feed primarily on bivalve mollusks (Fay 1982; Jay et al. 2014) and other invertebrates such as worms, snails, and crabs.

Differences in migratory patterns are seen among age/sex classes. Females with calves are the most migratory, and tend to stay with the ice edge as it moves north in the Chukchi Sea. Because of the high energetic demands of nursing (which lasts for approximately two years), it is logical that the females remain ice associated. Adult males are the least migratory, hauling out along the Chukchi coast in the summer. In addition, many thousands of males remain in the Bering Sea for the summer (Fay et al. 1984a). It is unclear why males do not also remain with the ice, but Miller (1976) suggests it is because they do not have any high-energy demands in the summer; they save additional energy by lying closely in groups, and the extra heat generated from neighboring bodies aids with their molt. Their preference for haul out sites that are out of the wind further supports this argument. The molting period is long, happening anywhere from March to October with a peak in July/August (Fay 1982). The time for an individual to molt is also long, taking at least a month to complete; trips into the water will impede the molt as that will cut off circulation to their skin, so the hair follicles cannot regenerate (Fay 1982).

Males may also not need to remain associated with the ice because of their pharyngeal pouches (Fay 1960). These pouches, which can be inflated to aid in flotation during resting periods, were present more often in adult male specimens; fewer female specimens had them, while no juveniles did. He goes on to say that females are neutrally buoyant with just their lungs inflated, while males need the extra buoyancy offered by inflating the pharyngeal pouches. Regardless, it appears that males do have a way to remain in the open water at a low energetic cost. It is important to note, however, that these pharyngeal sacs may not be a long-term solution to diminishing ice haul-outs. When the ice leaves Hanna Shoal early in the season, large aggregations of walrus of all ages and sex classes form enormous haul-outs on land (summarized in Hannay et al. 2013). These combined haul-outs are dangerous for young walrus who can get trampled and killed during stampedes; the resulting calf mortality can have compounding effects on the population (Udevitz et al. 2013). Since females may also be able to rest without hauling out, it is possible that their association with ice is for the benefit of their pups. Another advantage is that they can rest on the ice as it carries them and their pups around to new feeding grounds.

There were still high levels of calling activity detected for most of all three open water seasons (2013-2015) at the three shoal sites, HS1-2 and WT2 (Figure 29). Which walrus are making these calls? If it is assumed that underwater calls are produced by male walrus (Kastelein et al. 2002), it would be expected that the largest levels of calling activity would occur closest to the coast where the males are hauled out. Figure 33, Figure 34 and Figure 35 show that, with the exception of June, the most sustained summer calling is occurring on the shoal and not near the coast; this is in agreement with the findings from Hannay et al. (2013). The lower levels of calling activity near the coast does fit with males not entering the water during the molting period (and perhaps feeding ahead of it in June), but still does not explain the higher levels on the shoal during the peak molting months of July and August. It is possible that it is the females and their young that are producing this high level of calling; they certainly are capable of producing knocks and bells, as shown by Schusterman and Reichmuth (2008). Furthermore, Jay et al. (2012) found that over half the walrus (mostly female) tagged at an onshore haul-out in 2011 made round trips to an area just south of Hanna Shoal, a distance of 200 km. However this does not preclude males also making the trip to the shoal, so at this time a determination on which age/sex classes are included in the calling activity recorded cannot be made.

Calling activity was not detected equally on all CHAOZ-X mooring sites/years or on any of the moorings analyzed by Hannay et al. (2013), which suggests that walrus presence is heterogeneous and highly dependent on local environmental conditions (see Figure 54 for locations of moorings from this and their studies). These factors will be investigated further in Section XI.A.

Figure 55. Ice cover in the northeastern Chukchi Sea. MODIS infrared-band image from mid-March, 2012. The three red dots mark the locations of the offshore (IC3), midshore (IC2), and inshore (IC1) mooring locations. Image recolored to emphasize open water.

Gray whales

Calling was heard in the CHAOZ-X study area on two days in July/August on the IC3 mooring and one day in July on the HS1 mooring. These months fit with the overall sighting rates from aerial surveys, which show an increase in July and August (Clarke and Ferguson 2010). The low level of gray whale calling activity was expected at the CHAOZ-X mooring locations outside of Hanna Shoal (i.e., HS3 and IC3; Table 15). Recent aerial surveys have found that most gray whales remain within approximately 40 km from shore between Point Barrow and Point Lay, AK, as well as 100 km offshore of Wainwright (Clarke and Ferguson 2010; Clarke et al. 2017). The lack of calling activity at Hanna Shoal (i.e., mooring sites HS1-2 and WT2), was also not unexpected, as it again follows the results from recent aerial (Clarke and Ferguson 2010; Clarke et al. 2017) and vessel (Section VII.B.2, this report) surveys, as well as passive acoustic (Hannay et al. 2013) results. Hanna Shoal has ceased to be the prime feeding location it once was (Moore et al. 2000) for this species. Section XI.A will discuss possible reasons for the paucity of gray whales on the shoal.

In contrast with the results presented by Stafford et al. (2007b) who found that gray whale calls were present from October 2003 to May 2004 at a mooring located northeast of Barrow, AK, no gray whale calling activity was present overwinter on any of the CHAOZ-X mooring sites. However, there is an inshore/offshore difference between study areas in this case. Lastly, because there were only a few days where gray whale calling activity was detected, we cannot address timing of their seasonal migrations.

Despite agreement with aerial survey results, it is important to note that the low levels of calling activity detected could also be due to a combination of two factors: a low calling rate, and calling behavior that is context-dependent. Crane and Lashkari (1996), found that gray whales do call along their migration route, but the calling rate is extremely low (mean: 20 hr. between calls). This means, assuming a swim speed of 6 km/hr (Rugh et al. 2001), that there could be ~120 km between calls; the chance that a recorder will be recording when a whale is calling nearby is low. Additionally, although gray whales are presumed to be silent when feeding, (e.g., Ljungblad et al. 1983), the occurrence of additional behaviors such as social or reproductive behaviors may affect calling rates. Data from the joint visual and passive acoustic survey efforts undertaken on the field cruises for this study (see Section VII.B) have shown that the same concentrations of whales in the same area at different times over the course of a single cruise can have vastly different calling rates due to differences in behavior. In short, although feeding was present in both cases (as evidenced by mud plumes), calling was detected only when courtship behavior was also present.

The last confounding factor that may influence both the calling behavior and the detection of those calls is the presence of ambient noise. As mentioned in both Crane and Lashkari (1996) and Hannay et al. (2013), ambient noise can make the low frequency calls of gray whales hard to detect. Furthermore, it is unknown what effect anthropogenic noise, such as that from vessels or airguns, has on the calling behavior of gray whales. Many studies exist (see Moore and Clarke 2002 for summary, as well as Muir et al. 2015 for recent work) that show gray whales react to anthropogenic noise sources by changing their course to avoid it. Only two studies (Dahlheim 1987; Dahlheim and Castellote 2016) have examined the effects of these noise sources on the calling behavior of gray whales. The findings included increased calling rates with playback signals such as boat noise and gray whale calls, but a reduction or cessation of calling altogether when novel sounds (such as oil drilling noise) or killer whale vocalizations were transmitted. It is possible that the presence of the impulsive signals from airguns might have an effect on gray whale calling rates, but whether calling will increase or decrease, and the potential biological consequences of these behavioral disturbances is unknown at this time.

Other species

The northward encroachment of subarctic species into habitats historically occupied solely by Arctic species is a serious concern. Clarke et al. (2013a) suggest their intrusion into the Arctic may be due to either post-whaling population growth, or to climate change extending the open water season. Having the ability to monitor year-round for these species is important as we try to sort out what changes are happening and their subsequent effects on Arctic/subarctic species. For this reason, analysis of the passive acoustic recordings extended to a number of subarctic marine mammal species. Some like fin, killer, minke, and humpback whales and ribbon seals, have been sighted or detected in the Arctic before, and therefore would be expected to have at least some calling activity. We will discuss each of these species below. Other species, such as right and sperm whales, were not expected to be present in the CHAOZ-X study area. Although we did analyze the data for these species, the fact that we did not find any calling activity is expected and therefore no discussion follows.

Ribbon seals

The most common subarctic species detected in the CHAOZ-X study area was the ribbon seal, heard on 35 days among all sites except HS2. More than half these days were found on the slope site, HS3 (Table 17). This predominance at the slope site was expected given what is known about this species. Ribbon seals are deep divers and prefer feeding on the continental shelf slope in the pelagic and demersal zones. They prefer to feed on fish such as pollock and cod (Arctic, Pacific, and saffron), cephalopods such as squid and octopus, and crustaceans. The higher proportion of calling seen at the Chukchi Plateau site (HS3), which was also located at a depth of 163 m, further supports the importance of the slope to this species.

The majority of calling at all sites was centered in October/November. On both the Chukchi Sea shelf (Hannay et al. 2013), and on the Chukchi Plateau (Moore et al. 2012) ribbon seal calling was also detected during October/November. Furthermore, ribbon seal calling activity was additionally detected in August at the western (IC3) and July-September at the slope (HS3) mooring sites. Jones et al. (2014) found ribbon seal calling on their slope site in late September. These results are in agreement with what is known about ribbon seal distribution.

As summarized in Boveng et al. (2013), ribbon seals are strongly associated with sea ice in the Bering and Okhotsk Seas during the whelping/nursing season, which extends from mid-March through June. Molting occurs during the breeding season from late-April/early May to as late as July (Tikhomirov 1961). Ribbon seals do not form dense breeding aggregations, as females tend to be solitary and their breeding locations are within the shifting edge of the pack ice. They do not maintain breathing holes in the winter sea ice, and so prefer areas with ice floes less than 20 m wide and of medium thickness; these areas are never coastal but instead can extend up to 150 km from the southern edge of the ice. Ribbon seals do not remain on the ice until it recedes; after they are finished with their reproductive/molting activities, they leave the ice and spend the rest of the year at sea (Burns 1981b). There they remain highly dispersed during the open-water season, returning to the Bering Sea with the advance of the ice edge (at the CHAOZ-X moorings this was October/November).

Recent satellite tagging efforts have found that about 30% of ribbon seals tagged in the central Bering Sea moved into the Arctic with the ice retreat and, during July-October, spent about 10% of their time there. Most of the tagged seals stayed in the Bering Sea, both on the shelf (including coastal areas) and in the basin, leading Boveng et al. (2013) to suggest that ribbon seals can thrive in a diversity of habitats and environmental conditions outside their ice-obligated activities time period.

For the slope site, however, calling activity was also detected in April and May. This coincides with the reproductive season, when the seals are thought to remain in the Bering Sea. Miksis-Olds and Parks (2011) detected ribbon seals on the Bering Sea shelf, and found that peak calling occurred during the April/May time period. It seems reasonable to assume that ribbon seals that are not participating in reproductive activities may leave the Bering earlier in the season. As these calls are thought to be part of a reproductive/territorial display (Watkins and Ray 1977), it seems likely that the presence of these sounds in the April Chukchi Sea could be indicative of juvenile male practice sessions. However, it is interesting that the ribbon seal downsweep call was detected in the Chukchi Sea prior to their return south to the Bering. If the downsweep is a reproductive/territorial call, it is being produced at the wrong time and place. A more logical scenario is that this call type is used for multiple purposes, as suggested by Jones et al. (2014).

The overall lack of ribbon seal calling activity on our recordings is unsurprising given they disperse widely in open water and most are thought to stay primarily in the Bering Sea. This lack of calling was also reported by other passive acoustic studies near the CHAOZ-X study area over the past decade. In fact, Hannay et al. (2013) found only three ribbon seal detections between July and October over four years of recordings at 10-44 mooring locations per year. Although their overwinter detections of ribbon seals were greater, they were still confined to a small time window of less than ten days in 2008 and only four days in 2009, with none detected in 2007 or 2010. Jones et al. (2014) reported 17 days of callings in 2008, but no others between 2006 and 2009.

Humpback whales

Humpback whales are another subarctic species that is uncommon in the Arctic (Aerts et al. 2013; Clarke et al. 2013a; Berchok et al. 2015; this study - see Section VII.B). The one day of calling detected on the IC3 mooring site in August of 2014 is similar to the two detections reported by Hannay et al. (2013). Their detections were made off Cape Lisburne in August 2010, which again fits with our findings, from the entire eastern Chukchi shelf area, that humpbacks are distributed mainly in the southern Chukchi Sea (Appendix E.13-E.18).

Killer whales

Not much is known about killer whales in the Arctic other than it seems likely they are probably of the transient ecotype. See Clarke et al. (2013a) for references that support this assumption. The transient ecotypes are the mammal eaters, who stalk their prey silently, and so it is unlikely that many calls would be detected in the study area. However, they are typically very noisy just after a kill (Deecke et al. 2005), so perhaps information on their feeding frequency might be able to be obtained from these data with additional analysis on the characteristics of post-meal calling bouts.

Killer whale calling activity was infrequent, occurring on only five days in the CHAOZ-X study area from 2010-2015 and very low levels on those days (Appendix C.9; IC3, HS1-3, WT2). Detections occurred from April through September, which fits with the results from Hannay et al. (2013) who had occasional detections of killer whales in the Point Lay/Cape Lisburne recorders between late July and October annually. In addition, killer whale sightings from shipboard (Aerts et al. 2013; Berchok et al. 2015; this study - see Section VII.B) and aerial surveys (Clarke et al. 2013b) are rare, as are opportunistic sightings (George and Suydam 1998), so it is not just a matter of them being present and not heard, but rather a combination of low presence and low calling activity.

Fin whales

The only mooring in the CHAOZ-X study area that was analyzed for fin whales was that deployed and analyzed for the CHAOZ study (i.e., IC3 2010-11, 2011-12). No calling activity was detected on that mooring, which corresponds with the long-term mooring results from Delarue et al. (2013a) and Hannay et al. (2013), the short-term sonobuoy results (Berchok et al. 2015; Crance et al. 2015; this study Section VII.B), and the long-term mooring results from the extended Chukchi sea study area (Appendix C.12) that all show fin whales distributed more often in the southern Chukchi Sea from Cape Lisburne to Bering Strait.

These limited results agree with what is known about the distribution of this species. Fin whales are a subarctic species that, in Alaskan waters, are common throughout the Gulf of Alaska (Watkins et al. 2000; Stafford et al. 2007a) and Bering Sea shelf (Moore et al. 2002). Historically they ranged in these locations as well as in the Western Chukchi Sea (Mizroch et al. 2009). However, fin whale sightings in the southern Chukchi Sea from aerial surveys conducted since the 1980’s have been rare (Moore et al. 2000; Clarke et al. 2013a). Vessel surveys conducted since 2008 (Aerts et al. 2013) and 2010 (this study, see Section VII.B) have had no sightings of fin whales in the CHAOZ-X study area.

Minke whales

The story for the minke whale mirrors that of the humpback; they are sighted infrequently by visual and vessel surveys (Aerts et al. 2013; Clarke et al. 2013a; this study - see Section VII.B), and passive acoustic detections are rare. There were no days with minke whale calling of any type in the CHAOZ-X study area from 2010-2015. Those minke whales detected by Delarue et al. (2013b) were from a long-term mooring located to the south of the CHAOZ-X study area.

Environmental and anthropogenic sources

Seismic airguns

There were no surprises in the seasonal distribution of seismic airgun noise activity; these activities were confined to the open water season in all years of this study. The airgun activity detected in the 2010 and 2011 open water seasons can be attributed to a variety of seismic exploration by Shell and Statoil in the Chukchi Sea (Blees et al. 2010; Hartin et al. 2011; Reiser et al. 2011). Most seismic work was conducted in the Beaufort Sea in 2012, and there were very low levels of seismic airgun detections in the CHAOZ-X study area, accordingly: three days between September and November at IC3, and two days in November at WT2. These November detections correspond to two of the survey lines conducted by ION Geophysical that extended from the Beaufort into the Chukchi Sea (Beland et al. 2013).

Airguns were detected most persistently during the 2013 open water season, where they were heard on all sites with data (i.e., all but HS2; Figure 39). These detections align well with the extensive seismic survey by TGS in that year, which conducted ~6,000 km of seismic lines from 29 August through 29 October (Figure 56, Cate et al. 2014), and is evident in the spatial distribution map (Figure 43). Shell also conducted 'shallow hazards' and 'ice gouge' seismic surveys from 18 July through 28 September in the Chukchi Sea between Wainwright, and the Burger/Klondike study areas (Reider et al. 2013).

All U.S. Arctic seismic surveys in 2014 occurred in the Beaufort Sea in the Prudhoe Bay and Foggy Island Bay areas (Lomac-MacNair et al. 2014, 2015; Smultea et al. 2014), which explains the lack of airgun activity in the CHAOZ-X study area. However, a few days of airgun activity were detected in October/November 2014 on IC3 and WT2 and in September 2014 at the slope site, HS3. It is possible that the Beaufort activity was detected at HS3 (see September panel of Figure 44), but the October/November detections cannot be attributed to U.S. permitted activities in the Alaska region at this time (i.e., listed on the website http://www.nmfs.noaa.gov/pr/permits/incidental/oilgas.htm). The same was true for 2015, with seismic activities occurring again in the Beaufort Sea (Cate et al. 2015, and others including SAExploration, Inc. and BP Exploration (Alaska)), but a brief period with detections in the CHAOZ-X study areas (i.e., five days in August/September 2015 at IC3, Appendix C.14, Figures 39-45), that cannot be attributed to known permitted activities.

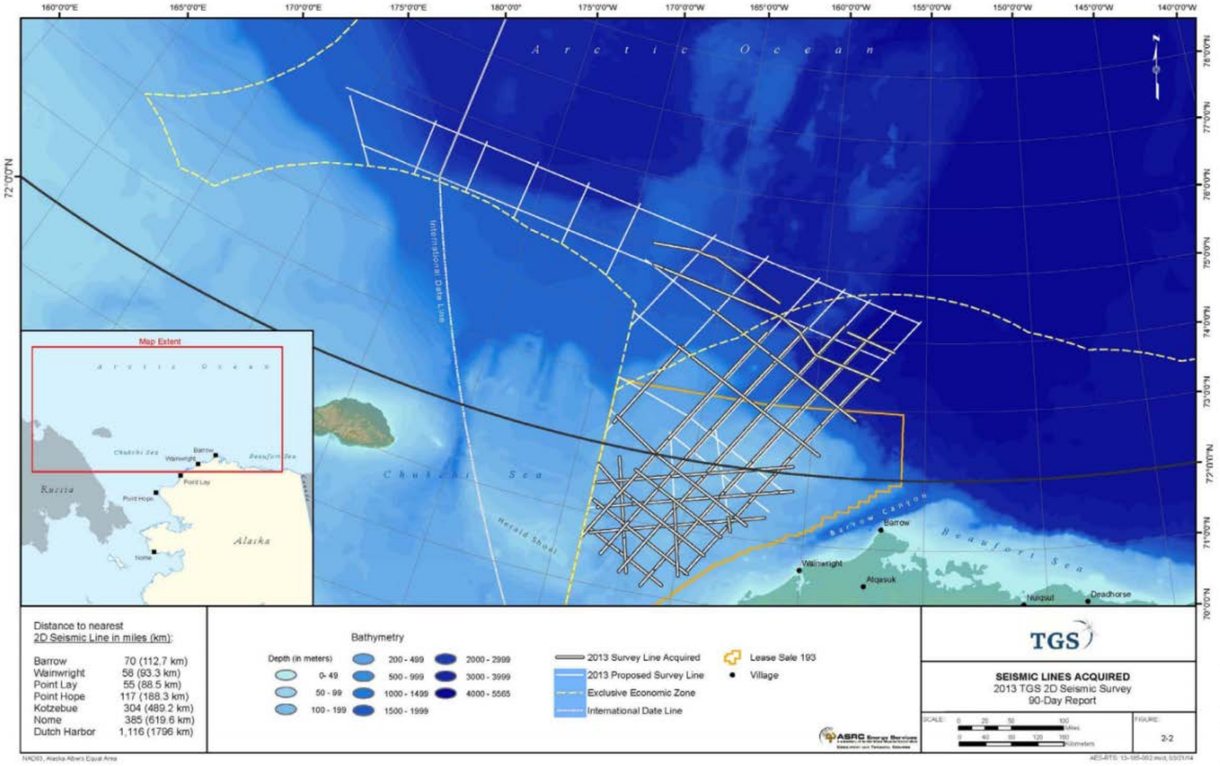

Figure 56. Survey lines acquired during TGS seismic survey August-October, 2013 (Figure from Cate et al. 2014, Figure 2-2).

Vessel noise

The majority of vessel noise was detected during the open water period. The highest and most sustained levels of vessel noise activity occurred in 2012, 2013, and 2015, and primarily at the IC3 and WT2 sites (Figures 46-52), although high levels were present on the shoal in 2013 (site HS1). The 2013 vessel activity is most likely related to the TGS seismic survey mentioned above (Cate et al. 2014). The vessel activity detected in 2012 and 2015 can be explained by Shell's exploratory drilling activities in the Beaufort (Bisson et al. 2013) and Chukchi (Ireland et al. 2016) Seas that required the presence of many support vessels. In addition, this vessel noise presence aligned with the field seasons of scientific studies such as CHAOZ and CSESP (Hopcroft and Day 2013; Berchok et al. 2015), and many others, conducted in the Chukchi Sea.

Ice Noise

A very good summary of the characteristics of ambient noise from ice is provided in Urick (1983). Ice conditions, wind speed, snow cover, and air temperature are all factors that contribute to different qualities of the ice noise. For example, impulsive sounds are prominent during periods of cooling air temperature, while the noise has more of a Gaussian distribution during periods of warming air temperatures. Wind and currents can move the ice – causing collisions and sliding of the ice, which can be impulsive or very tonal (e.g., Xie and Farmer 1992). These tonal sounds may sometimes contain enough frequency modulation to be confused with bowhead and beluga whales unless care is taken to examine the sound within its full context – and by listening closely to the nuances in its character. Wind can also generate sound, even under full ice cover, through the pelting of ice granules on the ice surface. Taking the CHAOZ-X award for most obvious result - ice noise was present when ice was present (Figure 53). As mentioned in the results, the lower ice noise presence seen in the overwinter periods between 2010 and 2012 is due to this noise not being flagged by the analysts, not that it was not there. Further discussion of ice noise can be found in Section IX below.

4. Conclusions

Generally, the seasonal and spatial distributions of sounds from the five main Arctic marine mammal species (bowhead, beluga, and gray whales, walrus, and bearded seals), the five subarctic species (fin, killer, humpback, and minke whales, and ribbon seals), anthropogenic sources (airguns and vessel), and environmental (ice) sources in the CHAOZ-X study area were in good agreement with those from aerial and vessel surveys, satellite tagging efforts, and other passive acoustic studies, as well as the natural history of these species obtained from TEK. These results show that long-term passive acoustic monitoring is an excellent tool for monitoring the presence of these marine mammals and sound sources both spatially and temporally over large geographic regions in the Arctic. In some cases, the results deviated from our current understanding. This could be because of actual changes in distribution, or because passive acoustics are allowing data to be collected at different times and locations, and/or from more or different individuals than past visual survey and satellite tagging efforts. Because of the rapid changes happening in the Arctic, it is important to collect information from all data streams. Maintaining this broad-scale, and near-decade long, set of time series will help provide the best available science to managers responsible for mitigating the impacts of climate change in the U.S. Arctic. Because a lot of details were provided for each species/sound source in the discussion above, a summary of the key findings for each species/sound source in the CHAOZ-X study area is provided as bullet points below (with blue text highlighting interesting or unexpected findings).

Bowhead whales: Bowhead whale calling activity trends well with survey/tagging/TEK results; they are a highly vocal species, producing sounds that can propagate far. Calling activity was present during spring and fall migrations and during the summer (open water period), but not during the winter.

- Fall migration was detected August/September to November/December in all years and locations, except on the slope site, and was timed from east to west, confirming their use of the offshore region during fall migration.
- Lack of a fall pulse in calling at the slope site, HS3, supports migration gently fanning out once past Pt. Barrow.
  - *Fall calling activity was multimodal*, supporting TEK of age/sex class segregation during migration.
  - *Gunshot calling occurs near the end of each peak* in fall calling activity for all moorings in all years.
- Bowheads currently leave the Chukchi Sea in winter - no calling activity was present from January to March.
- *The spring migration does not appear to be contained entirely in the nearshore lead.*
  - Spring calling activity was detected offshore in the CHAOZ-X study area.
  - At Hanna Shoal and the western part of the study area, calling activity was shorter in duration and at lower levels in the spring than during fall.
  - *High levels of spring calling were detected at the slope site,* between April and June, 2014.
- Calling activity was present between the spring and fall pulses of calling, blurring the boundaries between them.

Beluga whales: Two populations can pass through CHAOZ-X study area. Belugas are loquacious, but this is offset by the fact that their sounds do not transmit far (i.e., several km maximum). Calling activity was present in times/areas within the range documented by visual and tagging studies, but it was also present outside of this range as well. Belugas were detected in all four seasons.

- Fall calling activity is generally low compared to the spring.
  - *Highest levels of fall calling were seen at IC3, consistent with satellite tagging but not aerial survey results.*
- *Presence of calling activity overwinter* at most CHAOZ-X mooring locations and years suggests some beluga overwinter offshore, but still over the shelf.
- Spring calling activity was highest from April through June at all sites and years, and was timed from west to east.
  - Highest levels were seen on the slope.
  - *Spring calling activity was far from nearshore lead*, supporting the view that belugas are not limited by high ice concentrations.
  - It is uncertain which population of belugas (Eastern Chukchi or Beaufort) are the source of this offshore calling, and which routes are being taken to get there.
  - *Multimodal calling was evident* - this could be different populations, age/sex class segregation, and/or ice impeding migration.

  - *Double-knock sound* (on the shoal in the spring) occurs simultaneously with beluga whale calling activity; we are currently investigating whether it could be from fish.
- Summer calling was present, especially at the slope site, consistent with the July range of Eastern Chukchi Sea population.

Bearded seals: Bearded seal calling is loud and ubiquitous, but it is also associated with the mating season. So this is one species where lack of calling activity does not mean lack of presence. However, this is also a species where acoustic results offer a different perspective on their seasonal distribution. Calling activity does not have a spring and fall migration component, but rather has sustained levels building up to and throughout the ice season. Summer calling activity is also present.

- Fall-through-spring calling activity is present on every mooring in every year, providing evidence *bearded seals are present in the Chukchi year-round* instead of overwintering in the Bering.
  - Calling activity increased from September through January, reached sustained and saturated levels from February through June, corresponding with the whelping/mating/molting season.
  - Calling ceased abruptly in June, but this could be an artifact of binned analysis; another study that counted individual calls report a gradual decrease in calling activity.
  - Lowest calling activity levels were in July and August.
- The lowest levels and number of days with calling activity were on the slope site, HS3, possibly due to its depth (163 m) being near the edge of their preferred diving depth range and/or a change in the benthic community (prey resources).
  - Saturated and sustained levels are still present at this site.

Walrus: Walrus have high rates of calling activity which can be used as a proxy for presence. A winter and summer pulse of calling was seen in every CHAOZ-X location except on the slope.

- *Overwinter calling detected* at all shoal and western mooring sites.
  - *Highest and most sustained winter levels were at the western mooring site* (IC3).
  - *Levels steadily decreased from 2010 through 2015.*
  - Sporadic and low levels of calling activity occurred on the shoal sites.
- Summer pulse in calling ranged from June through October.
  - *Most saturated and sustained summer levels were on the shoal sites*.
- Lack of calling on slope was unsurprising given its depth (163 m) and their preference for water <100 m deep.

Gray whales: Gray whales call infrequently during migration, and it is uncertain whether they call while feeding; primarily they call during social/reproductive activities. This makes them a poor candidate for passive acoustic monitoring, especially with subsampled analyses that can miss critical detections. However, the low detections in the CHAOZ-X study area fit with aerial survey results that show the majority of sightings within 50 km of shore.

- Although Hanna Shoal was a prime gray whale feeding area in the past, *there was only one day with detections on any of the mooring sites on the shoal* for the entire study. This

could also be a reflection of a change in available prey resources either at this site (depletion) or regionally at other locations (enhancement).
- The three days with detections in the CHAOZ-X study area were in the summer. *No detections were made overwinter.*

Subarctic species: Few detections of subarctic species were made in the CHAOZ-X study area. This was expected, based on aerial survey results.

- *Ribbon seals were the most commonly detected subarctic species* in the CHAOZ-X study area (35 days).
    - *Over half of all detection days were from the slope site,* consistent with their preference for feeding on the continental slope.
    - Main calling centered in October/November at all sites.
    - Calling was from July-September on the slope site as well as April/May; because calling is outside the spatial and temporal range for breeding season, this suggests the downsweep call is used for multiple purposes.
- *Humpback whale* calling occurred on only one day (August 2014, IC3).
- *Killer whale* calling occurred on only five days (April-September).
- *Fin, minke, right, and sperm whales* were not detected; however, only IC3 (2010-2012) was analyzed for fin whales.

Non-Biological sounds: Airgun, vessel and ice noise were also included in the analysis and results were consistent with what is known about these sources.

- *Airguns* were heard during all open water seasons.
    - Most ubiquitous during 2013 when several seismic surveys were underway in the Chukchi Sea.
    - There were a few cases of airguns being detected that could not be attributed to a permitted activity.
- *Vessels* were also detected during open water seasons.
    - Highest and most ubiquitous levels occurred during 2012 and 2015 at the western and shoal locations, corresponding to the multi-vessel effort associated with the Shell exploratory drilling operations.
- *Ice noise* is present overwinter.

5. *Recommendations*

Long-term, year-round, monitoring of marine mammal populations is essential for understanding their distribution and behavioral ecology, particularly in the U.S. Arctic where the environment is undergoing rapid modification as a result of climate change. Continuing to challenge what is currently known about marine mammal distribution in this area is vital, as assumptions - based on data obtained before the dramatic changes in sea ice extent were seen - may be outdated. Data from this project may indicate emerging phenological shifts in particular species such as bearded seals. Passive acoustic monitoring provides an excellent platform for monitoring marine mammals year-round, especially given the inaccessibility of the area for the majority of the year. Not only can we monitor year-round, we can (with careful placement of recorders) cover a large geographic region, allowing large-scale migration and movement patterns to be documented for the majority of marine mammal species present in the Arctic. The ability to cover large areas provides an improved understanding of both the mean patterns and the variance around the mean (e.g., whether or not some animals overwinter in place, or to what extent alternative migration pathways are used). Furthermore, the cost of supplies for turning around our recorders is inexpensive, making continued maintenance of this very valuable long-term dataset quite cost effective. Even if funds are not available for analysis at the current time, there is always the chance they will be in the future. Passive acoustic data do not have an expiration date; the more passive acoustic data that are available the better that trends can be identified. Therefore, our strongest recommendation is to continue to fund deployments and retrievals of these recorders, as well as facilitating vessel sharing (e.g., using funded NSF ship days on the USCG Icebreaker Healy or collaboration with investigators in Japan, China, and Korea who now have annual research cruises to the Chukchi Sea) to keep sea time costs at an equally reasonable level. Additionally, including these data in future Status Reviews will help better guide management efforts. For example, although it is noted that bearded seals do overwinter in the Chukchi Sea (Cameron et al. 2010), the winter passive acoustic results here showed strong bearded calling activity overwinter. These results should be included in future Status Reviews to emphasize their overwinter use of the northeastern Chukchi Seas.

One thing that was apparent during analyses of this data set, is that not much is known about the current ecology of these species in their wintering grounds in the Bering Sea. Recorders that have been deployed for the BOEM-funded ARCWEST project during our transits between Nome and Dutch Harbor, AK have collected a robust data set that can be analyzed to obtain more information from this area and season. From funding obtained through the International Fund for Animal Welfare, Marine Mammal Commission, and the National Fish and Wildlife Federation, much of these data have been analyzed over the past two years for the presence of North Pacific right, bowhead, humpback, gray, and minke whales, walrus, vessels and airguns[17]. We recommend making analysis of the higher frequency (i.e., bearded and ribbon seals, beluga, and killer whales) and lower frequency (i.e., fin and blue whales) species from this data set a priority so that better inferences can be made for the migratory patterns of these species.

We have developed a method for manually analyzing these acoustic data fully, and in as short a time period as possible. This effort is still time-consuming, but necessary, given the poor performance of auto-detection algorithms with the chaos[18] of Arctic species sounds present in the Chukchi Sea. With the inevitable encroachment of subarctic species, the auto-detection problem becomes increasingly more difficult. Still, if auto-detectors can be developed that perform reasonably well, passive acoustic analyses will become orders of magnitude less expensive. These auto-detectors are also of critical importance for passive acoustic monitoring from other platforms such as auto-detection buoys (see Section X.A) and autonomous gliders. For these reasons we recommend further funding of auto-detection techniques and equally important – comparison of these results with data sets fully reviewed by experienced analysts. We will continue to collaborate with M. Baumgartner (LFDCS, WHOI), C. Clark (Cornell Bioacoustics Research Program, see Section X.A below), and X. Mouy (JASCO Applied Sciences) to further develop our auto-detectors.

The development of smaller, low power instruments to pair with autonomous vehicles (e.g., wave glider, sail drone, etc.) presents an important avenue for future research. Future

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[17] Final reports have been written for the IFAW (Wright 2015) and MMC (Wright 2017) projects.

[18] Providing inspiration to the naming of the CHAOZ project!

surveys of the Chukchi will likely include passive acoustic data collected from both Eulerian (moorings) and Lagrangian (AV) platforms. Researchers will need spatial and temporal analytical techniques to merge both types of data.

Great strides in the use of passive acoustics to determine the relative abundance of marine mammals have been made in the past several years. We recommend that these techniques be made a priority so that more information can be obtained from these archival passive acoustic recordings.

Finally, as mentioned in the conclusions above, there are interesting results from this study that should be examined further, namely, the multiple peaks seen in the bowhead and beluga whale migrations, the timing of the bowhead gunshot call type within the main bowhead calling peaks, and the association of the double-knock sound (and its possible attribution to fish) with beluga whales. For the latter, a set of moorings deployed in 2017 will be collocated with active fish echosounders, which will provide additional information to direct that investigation. The AFSC also has Arctic and saffron cod in captivity and passive acoustic recorders have been placed in the tanks and await analysis. In addition, equipping the passive acoustic moorings with CPOD echolocation loggers would allow us to detect echolocation clicks of foraging belugas. Although these instruments are currently unable to last a full year on a duty cycle, further advancements in their development may eventually allow for year-round recording. This would not only increase beluga whale detectability, but also enhance our knowledge of beluga habitat use.

B. Shipboard Observations (Lines: IC, WT, HS, BX, BC)

1. Methods

Sonobuoys

During the 2013-2015 CHAOZ-X field survey cruises, sonobuoys were deployed every three hours to obtain an evenly sampled cross-survey census of marine mammal calling. However, when in areas of high whale density, or when trying to localize on a calling species of interest, multiple sonobuoys were deployed more frequently to obtain near-continuous recording.

A sonobuoy is a free-floating, expendable, short-term passive acoustic listening device that transmits signals in real time via VHF radio waves to a receiver on a vessel or aircraft (Rone et al. 2012). The hydrophone is suspended down from the surface float at a programmable depth. Given that the minimum programmable deployment depth (61 m) of the sonobuoy exceeds that of the shallow Chukchi Sea shelf (~40 m), modifications were made to each and every sonobuoy by tying up sections of the sonobuoy housing to prevent the main wire spool from deploying (Figure 57). These modifications, which do not impact the signal transmission, resulted in a deployment depth of approximately 24 m, placing the hydrophone array at approximately 22 m, or mid-water column. This is below the surface mixed layer, which tends to be less than 20 m (although there are often mixing events that increase the depth of this layer). Additional modifications involved replacement of the 9V display battery so that the sonobuoys could be programmed prior to deployment.

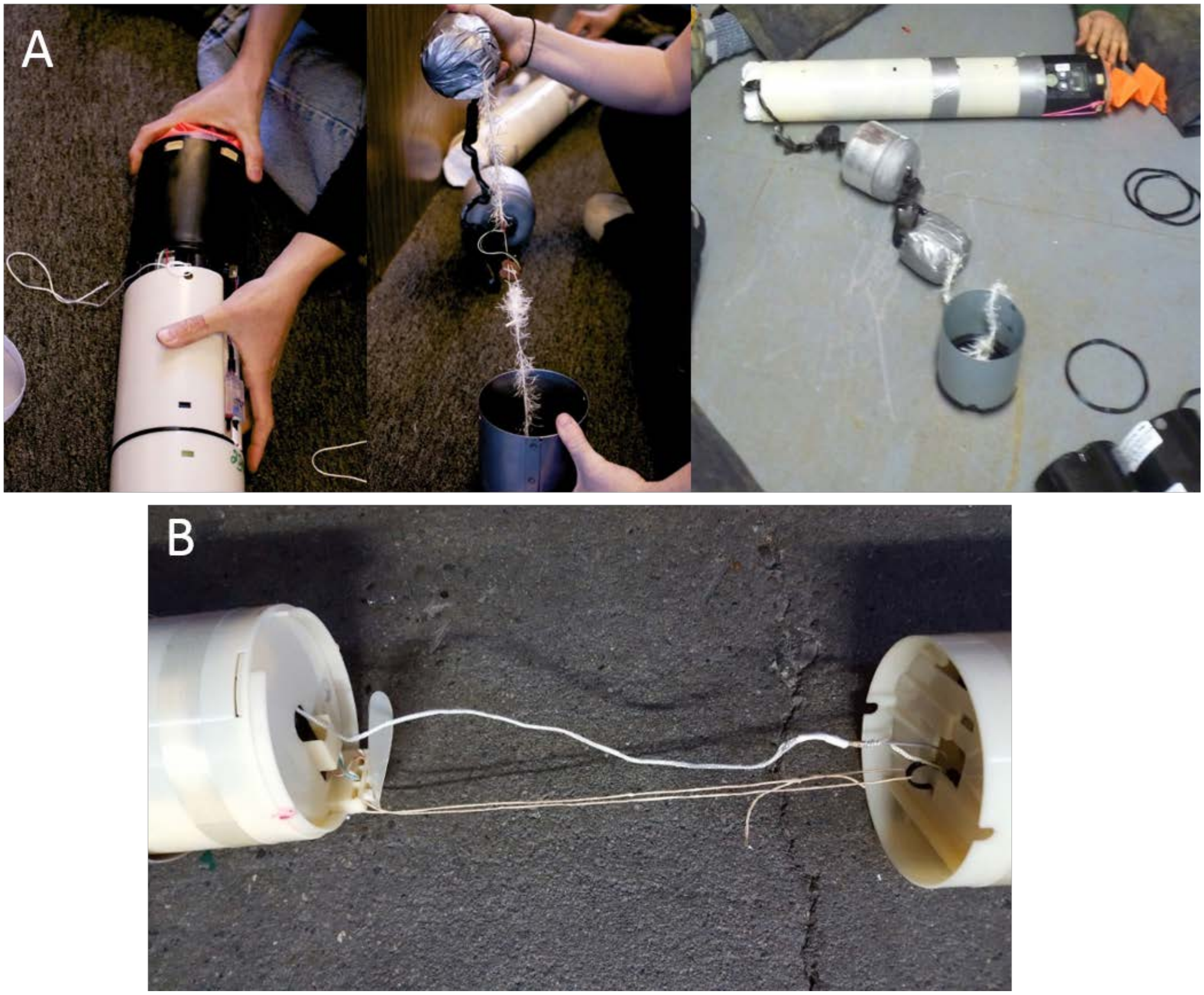

Figure 57. Modifications of a 77C (SPW) sonobuoy(A) (top row, left to right): tying up the top housing; taping up the bottom array of sensors; a 77C sonobuoy fully modified. Modifications of a 53 f (USS) sonobuoy to shorten deployment depth by tying the main spool housing to the top float to prevent cable from unspooling (B).

Two types of sonobuoys were used over the four field seasons: 77C and 53F. The 77C sonobuoys were all manufactured by Sparton (SPW), and 53F sonobuoys were manufactured by either SPW or Undersea Sensor Systems Inc. (USS). 53F sonobuoys have either omnidirectional or DiFAR (Directional Frequency Analysis and Recording) capabilities, and the 77C sonobuoys were DiFAR only. If two or more DiFAR sonobuoys are deployed, cross-fixes can be obtained on a calling animal to determine its location.

In DiFAR mode, the lower limit of the frequency response curve for the 53F sonobuoys had a flat frequency response (±3 dB) from 0.6 to ~2 kHz, with a low-frequency roll-off of 6 dB per octave from 10 to 600 Hz and 18 dB/octave below 10 Hz. On the upper end, a sharp roll-off of 35 dB/octave is present. The DiFAR-only 77C sonobuoys had a similar frequency response with a flat frequency response (±3 dB) from 0.8 to 2.5 kHz, the same low-frequency roll-offs, and a high-frequency roll-off of 25 dB/octave. In Calibrated Omni mode, the 53F sonobuoy had a flat frequency response from 3.5-25 kHz, with a 5 dB/octave roll off from 5 Hz to 3.5 kHz, increasing to 9 dB/octave below 5 Hz and above 25 kHz. The majority of sonobuoys were deployed in DiFAR mode, but occasionally sonobuoys were deployed in Calibrated Omni mode to obtain the full frequency bandwidth when it was not important to get a bearing to the calling animal.

A single mast holding both an omnidirectional Morad VHF 156HD antenna, and a directional Yagi YA 150-9-5 antenna was attached to the highest possible location on the vessel (i.e., crow's nest) with the directional antenna facing astern (Figure 59). The Yagi was used primarily during transit when the sonobuoy was guaranteed to be behind the vessel, and the omnidirectional antenna was used for simultaneously monitoring multiple sonobuoys, or when other shipboard scientific operations caused the sonobuoy to not be directly behind the vessel.

The signals received by the shipboard antennas were pre-amplified (15dB; PV160VDA, Advanced Receiver Research, Burlington, VT), before being sent via cabling to the sonobuoy monitoring station (Figure 58a) located in the bridge[19] of the vessel. A switch located in the bridge next to the acoustic station was used to alternate between antennas depending on the direction of travel. The preamplified signal was then inputted in up to three G39WSBe WinRadio sonobuoy receivers (freq. range: 136.0–173.5 MHz, freq. response: 5 Hz–25 kHz [±1 dB]; WiNRADiO Communications, Oakleigh, Australia), then inputted into a MOTU Ultralite mk3 (Cambridge, MA) multichannel external soundcard. The soundcard digitized the signal at a sampling rate of 48 kHz, and was connected to a laptop computer where the recordings were monitored in real-time using ISHMAEL (Mellinger 2001) software. Source levels of received signals were not calculated, as the recording system was not calibrated. Directional bearing information of the calls was obtained using DiFAR demultiplexing software and a custom MATLAB interface[20]. Accuracy of detection localization (estimated from sonobuoy bearing location and actual whale location) was approximately 3-5 km for distant signals (i.e., tens of kilometers away), to 1-2 km for nearby signals with good signal to noise ratio, although this varied due to sonobuoy drift, whale movement, etc. A Global Positioning System (GPS) feed into the computer provided the ship's position, updated every minute, as well as the sonobuoy deployment location, and time. A custom tracking and plotting program implemented in MATLAB (designed by C. Berchok, Figure 58b) allowed for real-time plotting of the vessel and sonobuoy locations, as well as bearing and location coordinates of calling marine mammals. Directional bearing information was calibrated using the ship as a sound source. All data were simultaneously recorded to an external hard drive.

It is important to note the difference between the in-air reception range (sonobuoy to antenna) and underwater sound propagation range (animal to sonobuoy). In-air reception range was approximately 15-25 km for the omnidirectional and 20-30 km for the Yagi antennas, dependent on sea state conditions, age of the sonobuoy, height of the receiving antenna, and sonobuoy transmission frequency. The average underwater detection range of baleen whale calls on the sonobuoy was estimated at 15-30 km for this study area and time of year, based on localizations of calling animals and their corresponding visual sightings. The detection range for higher-frequency species, such as beluga, is much smaller (i.e., 2-10 km). This decreased detection range may be one reason for the fewer acoustic detections of beluga, killer whales, and ribbon seals. Under the best conditions, with an average cruising speed of 9 kts, the 30 km radius

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[19] This arrangement allowed the acoustic technician to interact with the Captain and Visual Observation Team, and to make simultaneous visual and acoustic observations when possible.

[20] Greeneridge Sciences, Inc., Santa Barbara, CA and Whale Acoustics, www.whaleacoustics.com

around the deployed sonobuoy could be monitored for up to an hour and a half. When the next sonobuoy was deployed three hours later, its 30 km detection radius would just touch that of the previous one. So although there are temporal gaps in the sonobuoy coverage at times, the spatial coverage was near-complete, at least for low- and mid-frequency species. All species were identified using the same acoustic cues and parameters as those listed in Section VII.A above.

Figure 58. Sonobuoy monitoring station (A). Custom designed DiFAR tracking and monitoring program (B).

Figure 59. Omnidirectional and Yagi antenna placement (A) in relation to the R/V *Aquila* and (B) in relation to each other on the crow's nest.

Visual surveys

Vessel surveys were conducted in the Gulf of Alaska, Bering, Chukchi, and Beaufort Seas during the summers of 2013-2016. Visual operations were conducted to document the presence and distribution of all marine mammals encountered throughout the survey when transiting to mooring locations and sampling stations. Given the remote location and paucity of survey effort in a large portion of the areas, any information on distribution would provide an invaluable contribution to existing scientific knowledge.

Shipboard visual survey methods were conducted during daylight hours, or as long as weather and light conditions would allow. On effort status was defined as a visibility greater than 4 km and Beaufort sea state ≤ 5. Visual operations were considered ‘on effort’ when at least one scientist was 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. Depending on the year, a rotating team of two to five scientists collected sighting data using standard line-transect methods during on-effort status. Operations began at 08:00 and ceased at 22:00, or as long as conditions would allow. A full observation period lasted 60 minutes (30 minutes in each position) and was followed by a 30 min rest period. One observer was stationed on the ship’s bridge wing. The observer used 25x ‘big-eye’ binoculars (Figure 60) with reticles to scan from 90° port to 90° starboard. The data recorder was positioned on the bridge and surveyed the trackline with 7x50 binoculars while scanning through the viewing area of the primary observer. When a sighting was detected, the primary observer conveyed to the recorder the horizontal angle and number of reticles from the horizon to the initial sighting. Additional information collected was sighting cue, course and speed, species identity, and best, low, and high estimates of group size. The computer programs *Mysticetus* (2013, www.mysticetus.com) and *WinCruz* (2014, 2015) (https://swfsc.noaa.gov/uploadedFiles/Divisions/PRD/WinCruz.pdf) were used to record all sighting and environmental data (e.g., cloud cover, wind speed and direction, and sea conditions).

Under unacceptable weather conditions (visibility less than 4 km and/or sea state 6 or greater), surveying continued in an off-effort status. When weather deteriorated (visibility ≤ 1 km and/or taking spray over the bow), off-effort watches were conducted on the bridge by one observer/recorder. Off-effort watches were conducted mainly to monitor weather changes and to notify the team when conditions improved as well as to record off-effort sightings.

Figure 60. Marine mammal observer using 25x "big-eye" binoculars.

2. Results

A summary of the combined visual and passive acoustic effort during the 2010-2016 CHAOZ-X field surveys is shown in Figure 61, Table 22, and Table 23. Because funds from NOAA/OAR (with supplemental funds from ARCWEST) were available to conduct a fourth field season in 2016, and as sampling occurred in the CHAOZ-X study area, results from this year will be included in the report. In addition, although CHAOZ-X results were from 2013-2016, the plots below and the discussion will also present detections from the entire survey area as well as the CHAOZ 2010-2012 field seasons for a comprehensive analysis. For full survey coverage results, which include the visual and acoustic effort undertaken on the transit legs through the Bering Sea, please see Appendix F.

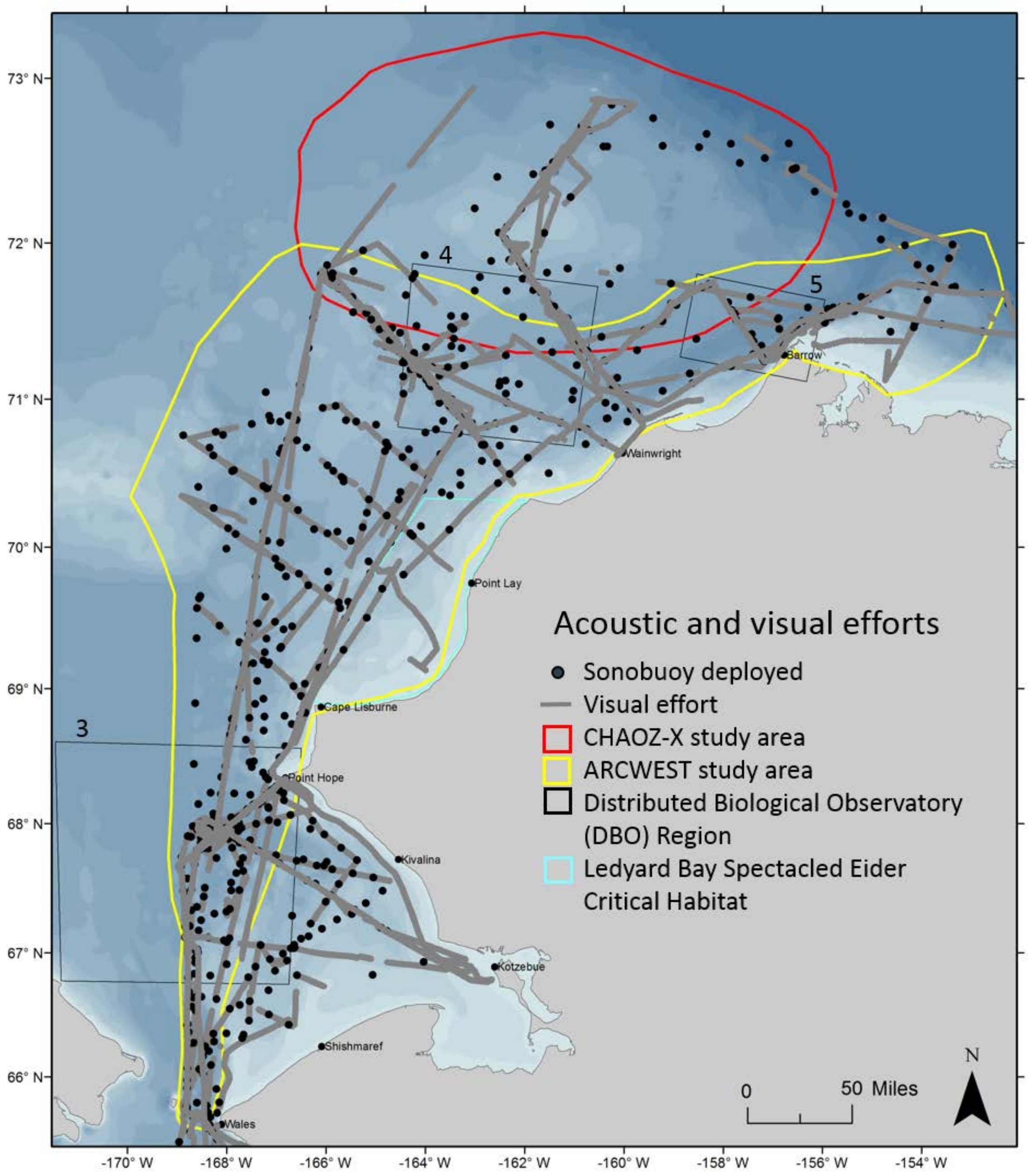


Figure 61. Summary of combined visual and acoustic effort, 2010-2016. Gray lines = visual effort, black dot = successful sonobuoy deployment.

Table 22. Total number of sonobuoys deployed per year in the CHAOZ-X study area, the number of successful deployments (sonobuoy functioned properly), and the success rate, 2013-2016.

Year	Total # deployed	# successful deployments	Success rate
2013	23	21	0.913
2014	39	32	0.821
2015	17	13	0.765
2016	15	13	0.867
TOTAL	**94**	**79**	**0.841**

Table 23. Summary of visual trackline effort for CHAOZ-X (bolded), ARCWEST, and all waters, 2013-2016.

Year	ARCWEST		CHAOZ-X		All waters (includes Bering Sea)	
	Km	Nm	**Km**	**Nm**	Km	Nm
2013	1,561	843	**274**	**148**	2,552	1,378
2014	1,290	697	**338**	**183**	2,511	1,356
2015	680	367	**103**	**56**	1,162	627
2016	1,196	646	**216**	**117**	2,282	1,232
Total	***4,727***	***2,553***	***931***	***504***	***8,507***	***4,593***

A total of 79 sonobuoys were successfully deployed in the CHAOZ-X study area from 2013 through 2015. The total number of sonobuoys deployed per year, the number of successful deployments (sonobuoy functioned properly), and their success rate is shown in Table 22, and sonobuoy deployment locations and species detected are presented in Table 24 and Figures 62-66. For a complete listing of each sonobuoy deployment and species detected, see Supplemental material. In total, three cetacean species (bowhead, gray, and beluga whales), and three pinniped species (walrus, bearded, and ribbon seal) were acoustically detected in the study area (Figures 62-66; Table 24).

Table 24. Total number of successful sonobuoys (total number deployed) and number of times species were acoustically detected per year in the CHAOZ-X study area, 2013-2016.

Year	Total buoys	# Bowhead	# Gray	# Walrus	# Bearded	# Beluga	# Ribbon
2013	21 (23)	2	1	7	1	0	0
2014	32 (39)	14	0	9	10	4	1
2015	13 (17)	0	0	3	2	0	0
2016	13 (15)	0	0	3	4	0	0
TOTAL	**79 (94)**	**16**	**1**	**22**	**17**	**4**	**1**
(% of buoys)		**20%**	**1%**	**28%**	**22%**	**5%**	**1%**

Over the four year study, a total of 504 nm (931 km) of on-effort trackline was surveyed in the CHAOZ-X study area, and a total of 4,593 nm (8,507 km) for all waters (Arctic and Bering Sea) combined (Figure 61; Table 23). One cetacean species (bowhead whale), one confirmed pinniped species (walrus), and polar bears (*Ursus maritimus*) were visually sighted within the study area (Figures 62-65; Table 25).

The most commonly sighted and/or acoustically detected species were walrus, bowhead whales, and bearded seals (Figures 62-66). Walrus were present in the study area in all survey years, with almost all sightings and acoustic detections in the western half of the study area (Figure 62). In 2013, there was a large concentration of walrus sightings off Hanna Shoal. Bowhead whales were seen or acoustically detected in three years, 2010, 2013, and 2014, throughout the study area (Figure 63, diamonds). Although there were only two visual sightings of bowheads, there were sixteen separate acoustic detections, most of which occurred in 2014. There were no acoustic detections or visual sightings in 2015 or 2016. Gunshot calls (produced by bowheads) were detected on only one buoy (2016; Figure 63, stars), suggesting that this is not the most common call type for this species at this time of year. Belugas were only acoustically detected in 2014, in the northeastern portion of the study area along the slope (Figure 64, diamonds); there were no visual detections of belugas during the surveys. Only one sonobuoy detected gray whales in the southern portion of the study area (2013; Figure 65); no gray whales were visually sighted in the CHAOZ-X study area.

Bearded seals were acoustically detected in all four CHAOZ-X years (2013-2016), with most detections near Hanna Shoal (Figure 66, triangles). Ribbon seals were acoustically detected on only one sonobuoy in 2014 in the northeastern portion of the study area near the slope (Figure 66, star). Although bearded and ribbon seals can be acoustically identified to species, visual sightings of all seals were categorized as unidentified due to the difficulty identifying animals in the water. Unidentified seals are most likely bearded, spotted and ringed seals (Figure 66, circles). Four polar bears were sighted in 2013 and one in 2016. Bear sightings within the study area from both years occurred near Hanna Shoal (Figure 64, triangles). Harbor and Dall's porpoise, as well as subarctic species like fin, humpback, killer, and minke whales, were not detected in the study area.

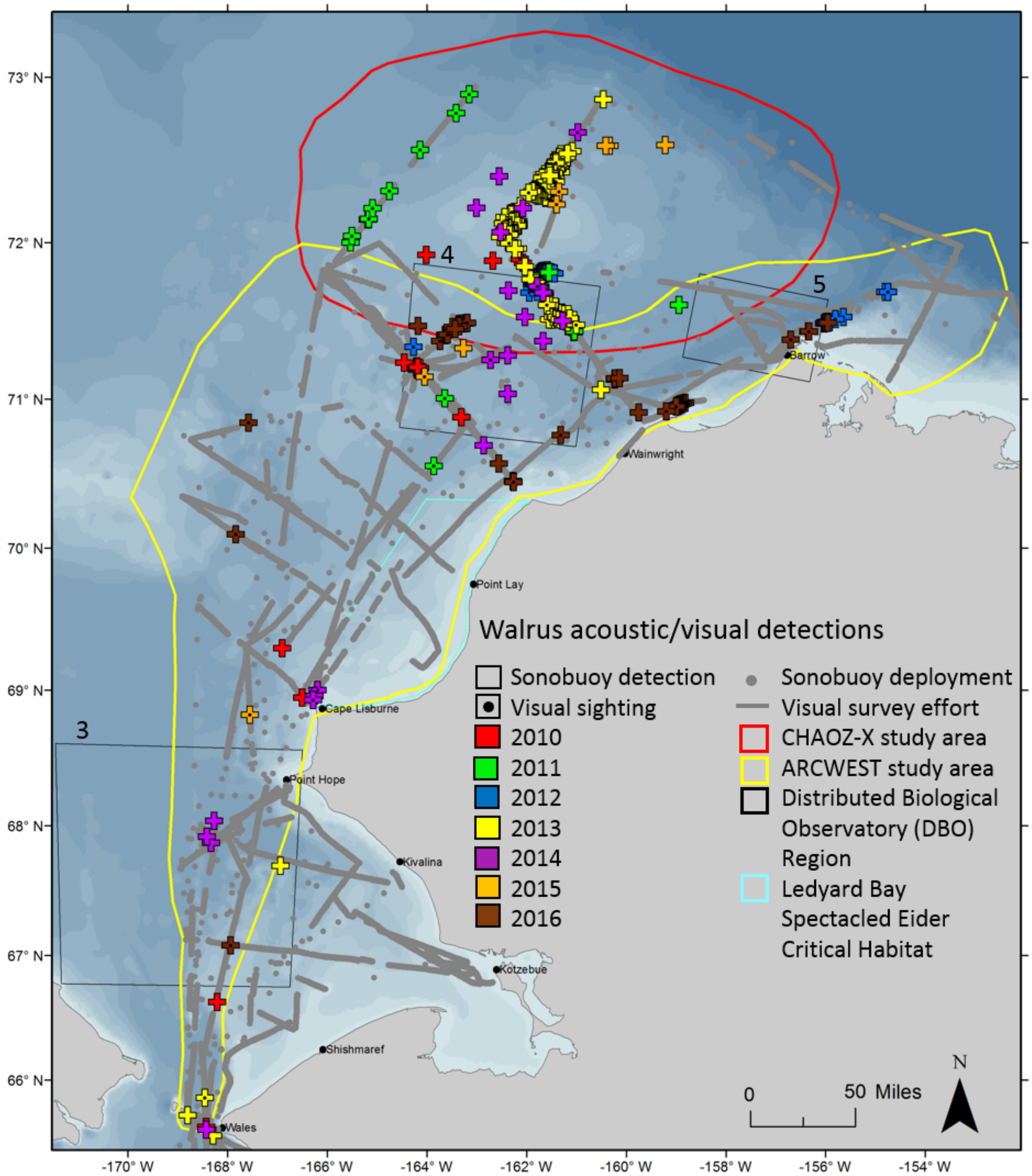


Figure 62. Walrus acoustic and visual detections during all surveys, 2010-2016.

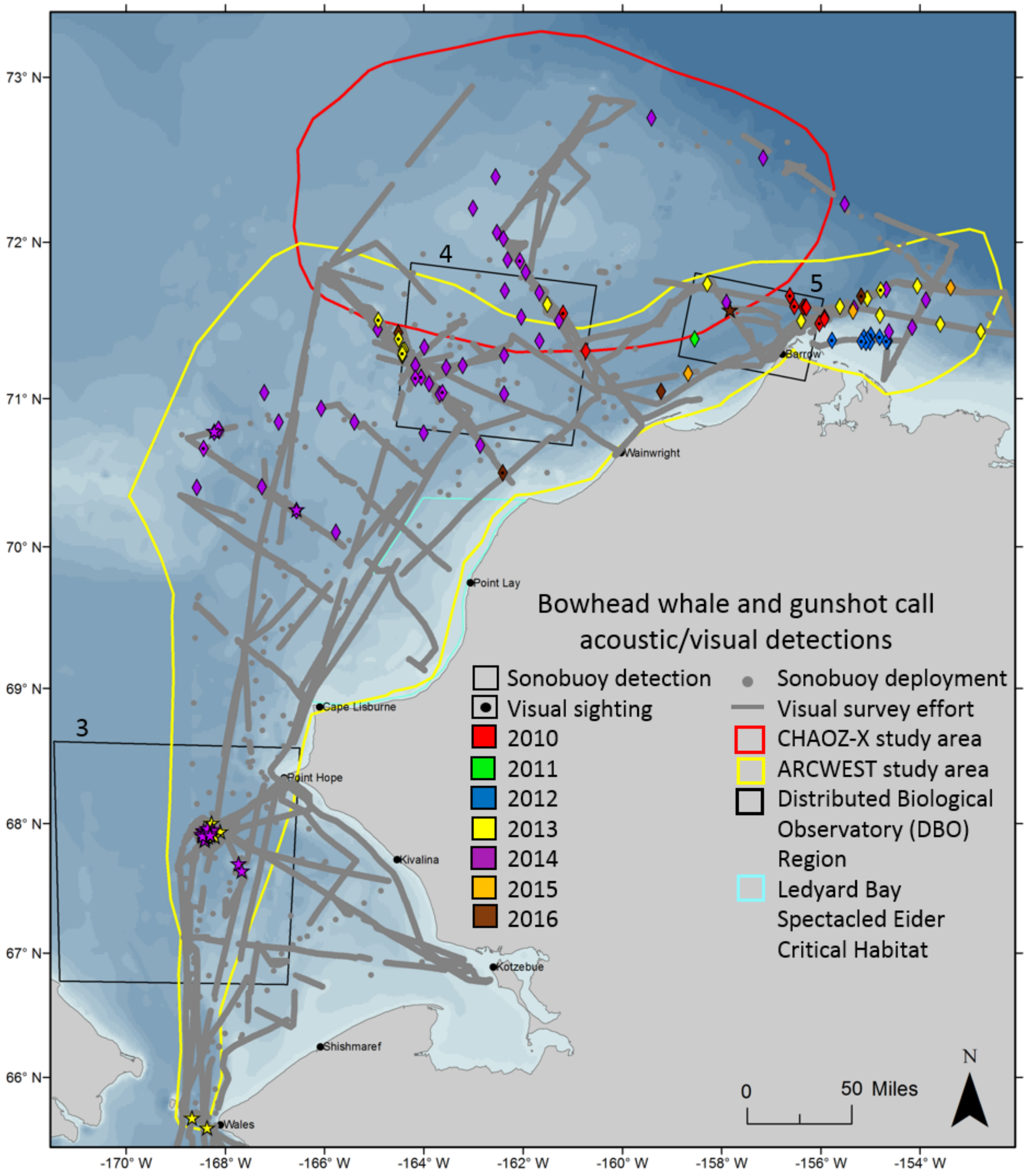


Figure 63. Bowhead whale acoustic and visual detections during all surveys, 2010-2016.

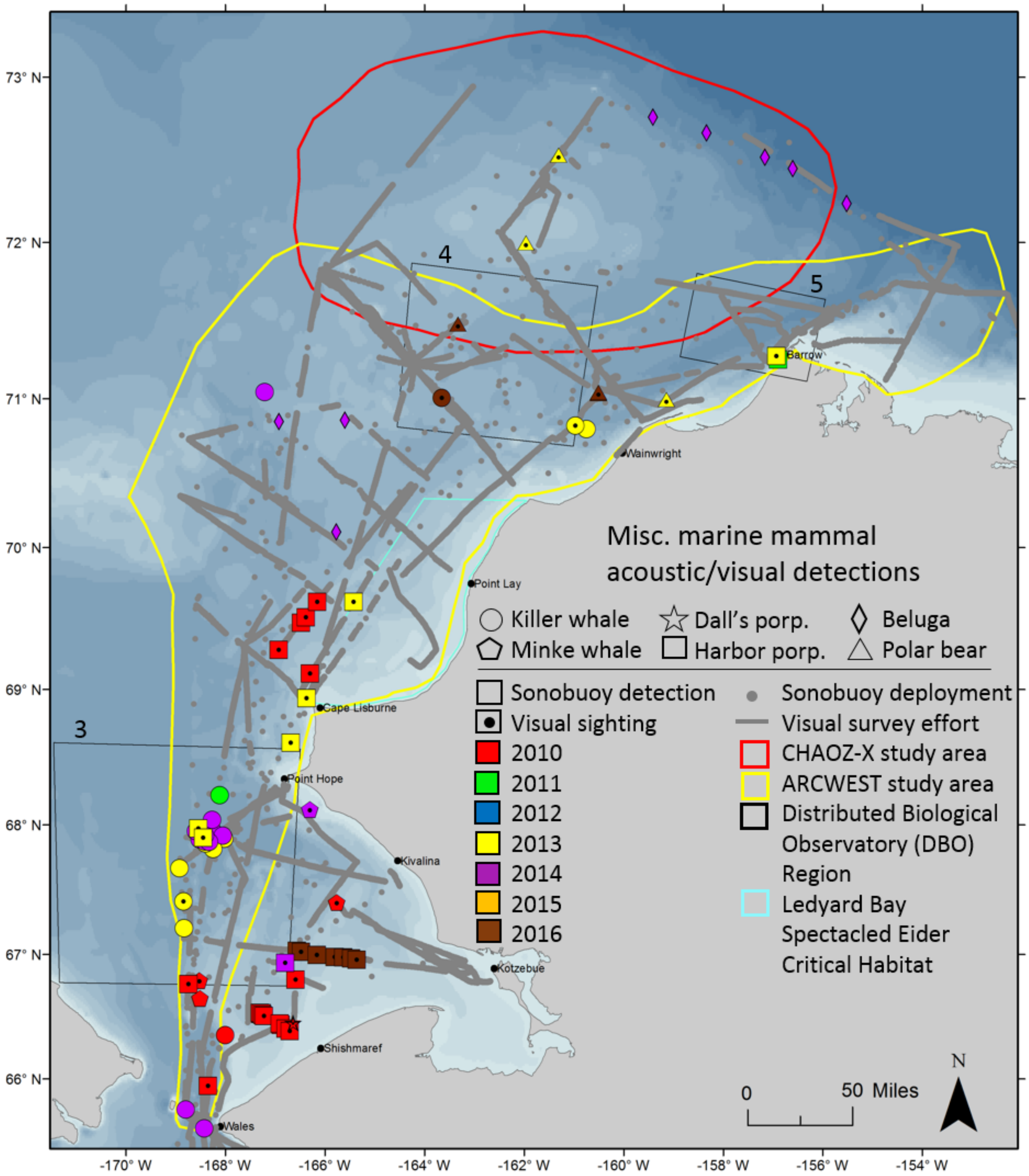


Figure 64. Acoustic and visual detections of miscellaneous marine mammals during all surveys, 2010-2016. Killer whale = circle; minke whale = pentagon; Dall's porpoise = star; harbor porpoise = square; beluga whale = diamond; polar bear = triangle.

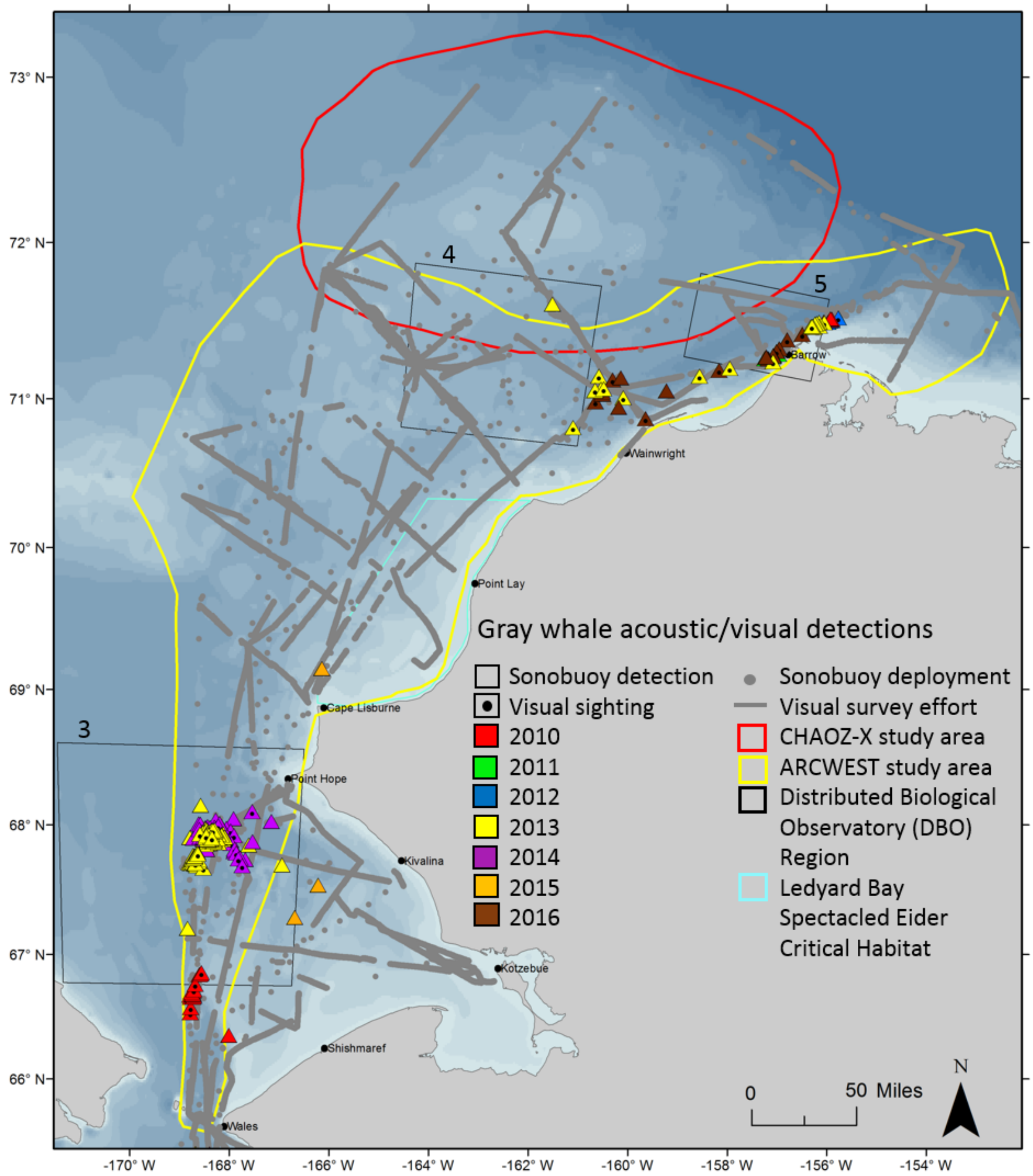


Figure 65. Gray whale acoustic and visual detections during all surveys, 2010-2016.

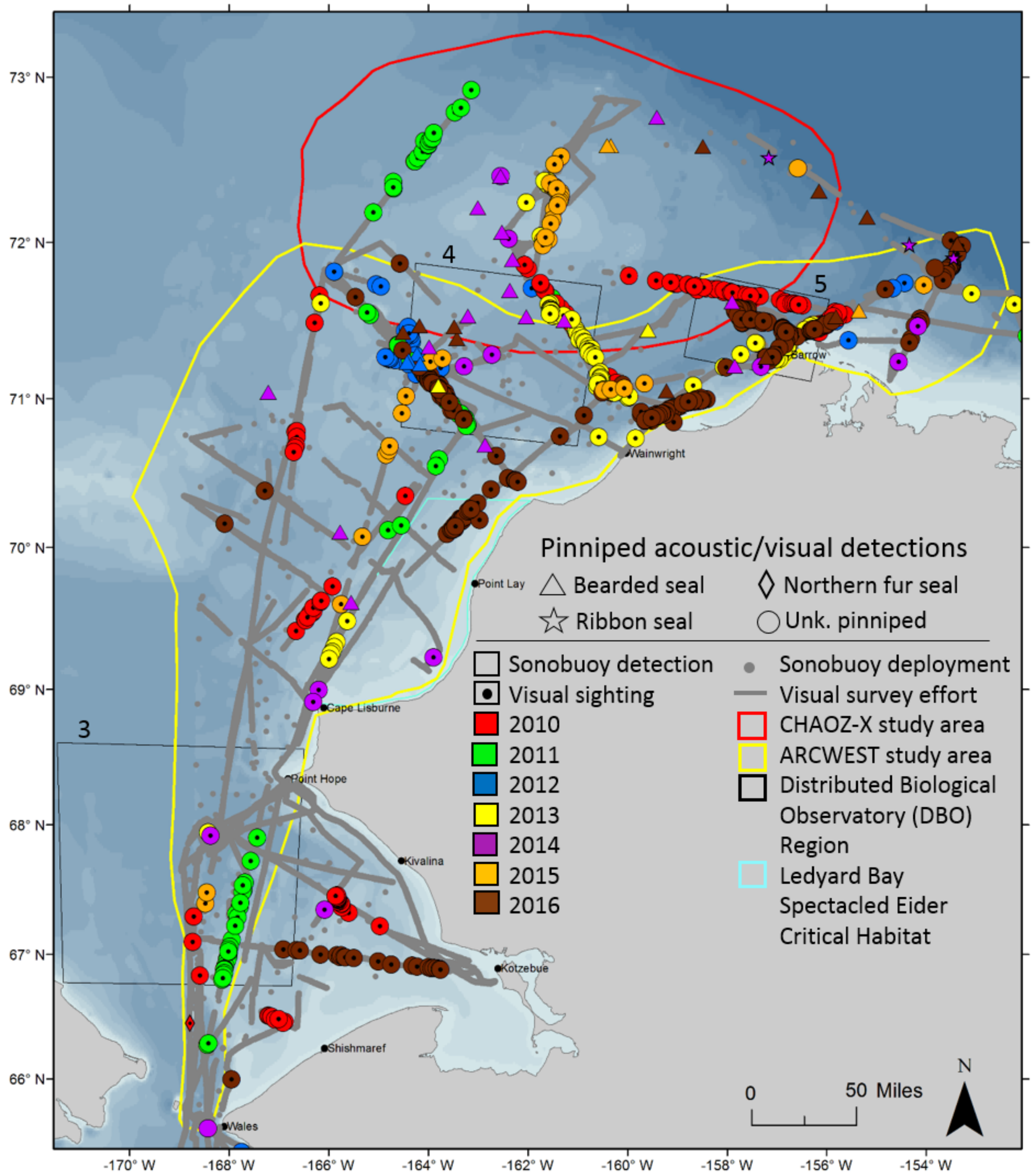


Figure 66. Acoustic and visual detections of all pinnipeds during all surveys, 2010-2016. Bearded seal = triangle; ribbon seal = star; northern fur seal = diamond; unknown pinniped = circle.

Table 25. Summary of sightings (number of individuals) for CHAOZ-X (bolded), ARCWEST, and all waters (includes Bering Sea) 2013-2016. *Gray whales = In 2013-2014, several days of dedicated tagging operations were conducted in a high gray whale density area near Pt. Hope and King Island. Therefore, these numbers likely reflect a substantial number of duplicate sightings and should be considered artificially high. A large portion of the unidentified large whales were in these same areas. All sightings were plotted to keep track of animals in the area prior to and during small boat operations.

	ARCWEST					**CHAOZ-X**					All waters				
	2013	2014	2015	2016	Total	**2013**	**2014**	**2015**	**2016**	**Total**	2013	2014	2015	2016	*Grand Total*
Bowhead whale	6(8)	6(13)	0	3(3)	15(24)	**1(1)**	**1(1)**	**0**	**0**	**2(2)**	6(8)	7(14)	0	3(3)	*16(25)*
Dall's porpoise	0	0	0	0	0	**0**	**0**	**0**	**0**	**0**	16(66)	0	1(3)	0	*17(69)*
Fin whale	0	0	0	0	0	**0**	**0**	**0**	**0**	**0**	21(28)	0	0	3(3)	*24(31)*
Gray whale*	141(288)	123(189)	0	18(43)	282(520)	**0**	**0**	**0**	**0**	**0**	159(308)	204(308)	0	18(43)	*381(659)*
Harbor porpoise	6(7)	0	0	0	6(7)	**0**	**0**	**0**	**0**	**0**	12(16)	1(2)	2(2)	7(8)	*22(28)*
Humpback whale	1(1)	1(2)	0	0	2(3)	**0**	**0**	**0**	**0**	**0**	74(116)	6(7)	5(10)	13(15)	*98(148)*
Killer whale	2(15)	0	0	1(4)	3(19)	**0**	**0**	**0**	**0**	**0**	7(54)	3(14)	1(2)	2(5)	*13(75)*
Minke whale	0	0	0	0	0	**0**	**0**	**0**	**0**	**0**	1(1)	1(1)	1(1)	3(5)	*6(8)*
Northern fur seal	0	0	0	0	0	**0**	**0**	**0**	**0**	**0**	17(19)	5(6)	4(7)	11(16)	*37(48)*
Polar bear	1(1)	0	0	4(4)	5(5)	**2(4)**	**0**	**0**	**1(1)**	**3(5)**	3(5)	0	0	4(4)	*7(9)*
Sea otter	0	0	0	0	0	**0**	**0**	**0**	**0**	**0**	19(723)	0	0	0	*19(723)*
Steller sea lion	0	0	0	0	0	**0**	**0**	**0**	**0**	**0**	4(24)	0	0	0	*4(24)*
Walrus	1(3)	4(6)	2(3)	35(1194)	42(1206)	**185(1793)**	**2(4)**	**2(3)**	**12(882)**	**201(2682)**	187(1797)	6(10)	4(6)	35(1194)	*232(3007)*
Unid seal	72(81)	9(9)	16(16)	217(311)	314(417)	**35(41)**	**1(1)**	**27(27)**	**18(22)**	**81(91)**	135(156)	17(19)	45(45)	296(419)	*493(639)*

3. *Discussion*

The four research cruises conducted for this study (2013-2016) took place in August, September and October; the sonobuoy and visual survey results therefore represent just a snapshot of marine mammal distributions for one season in the study area. However, the primary benefit of the short-term survey data is the extensive spatial coverage they are able to achieve. These nicely complement the long-term, but point-sampled, data collected by the passive acoustic recorder moorings. In this section we will discuss results from the short-term marine mammal data that were collected during the four survey cruises and how they tie in with the long-term passive acoustic recorder results. We will not repeat information already contained in the discussion for the long-term moorings (Section VII.A.3), and instead will refer the reader back to that section when needed.

Walrus

There was good consistency between the visual and acoustic results for walrus detections in the northeastern Chukchi Sea, and also between the shipboard surveys and long-term mooring results (see Section VII.A.2). This supports the statement by Hannay et al. (2013) that walrus calling activity can serve as a proxy for walrus presence in the northeastern Chukchi Sea. Several of the acoustic detections were made in rough seas or at night, when visual operations had ceased, indicating that passive acoustic monitoring is a nice complement to traditional visual surveys because it provides information on calling animals in a variety of unworkable visual survey conditions. Most sightings/detections occurred offshore between Icy Cape and Wainwright, near Hanna Shoal in the western half of the study area. Again, these results are consistent with what is currently known about walrus distribution (Jay et al. 2012). Walrus distributions were generally consistent among all years, although this may be a result of the tracklines and lack of deviation from those lines. The distribution of walrus as determined from ASAMM (Aerial Survey of Arctic Marine Mammals) aerial survey data correlated nicely with the shipboard observations of this study. Although widely distributed throughout the Chukchi Sea, walrus were consistently seen in high numbers every year near Hanna Shoal from August to October (e.g., Clarke et al. 2017). Walrus are associated with sea ice in July and early August, then move near Hanna Shoal and coastal haul-outs near Pt. Lay in late August and September (Clarke et al. 2015b). However, the highest concentrations of walrus recorded during aerial surveys occurred outside the study area at their land-based haul outs. Extremely large haul outs near Point Lay have become more common in recent years, and can reach numbers in excess of 30,000 individuals (Clarke et al. 2015b, 2017).

Bowhead whales

There were comparable visual and acoustic results for bowhead whales, which suggests that their calls are a good proxy for presence, at least during this early fall time period. Clark et al. (1986) present results from multiple studies conducted during the spring ice survey off Barrow, AK that also suggest that comparable results are obtained from visual and acoustic survey methods when the visual observers had an unimpeded view of the area. Bowhead whale sightings and detections were mainly concentrated outside the CHAOZ-X study area near Barrow, AK, as is expected from numerous studies (e.g., Moore et al. 2000; Shelden and Mocklin 2013; Clarke et al. 2016). Aerial survey data from the same time period showed only scattered sightings of bowheads in the study area in September and October; most of the sightings are to the east of Barrow Canyon (Clarke et al. 2017). However, this is in contrast with the long-term recorder results, which show bowhead whale calling activity in September at almost all of the CHAOZ-X moorings (Section VII.A.2).

There were a few acoustic detections and one visual sighting in 2013 (late August/early September) in the southern portion of the study area, suggesting that they were just beginning their fall migration south during this time period. However, in 2014 there were numerous acoustic detections and visual sightings in the study area, predominantly along the Wainwright line. The field survey happened later in the year in 2014, with the majority of the Chukchi work occurring in October. This may account for the increase in bowhead visual and acoustic detections compared to other years. There were no visual or acoustic detections in 2015 or 2016, despite the majority of the work occurring in early to mid-September. There was only one acoustic detection of a gunshot call in 2016. Based on the long-term results (Figure 10) which show that the gunshot calling occurs near the end of the major seasonal pulses of regular bowhead calling activity, and near the end of the open water season, it would not be expected that gunshot calls would be frequently detected during the field seasons. Indeed, only one sonobuoy detected gunshot calls, in the eastern portion of the study area.

Beluga whales

Belugas were never visually sighted during any of the four field seasons, and were only acoustically detected in 2014 on four sonobuoys in the northeastern portion of the study area, close to the slope. This is consistent with the long-term recorder results, in which belugas were acoustically detected in August/September at only the slope site, HS3 (Section VII.A.2). Given that satellite tagging results (Hauser et al. 2014) and combined passive acoustic/aerial data (Stafford et al. 2013) show that the Barrow Canyon area is a core area for beluga whales in August-October for beluga whales, it was expected that belugas would have been more frequently detected or sighted during the field surveys; however, they were only detected in 2014, when the field season occurred later in the year (October) and extended out over the slope. Aerial survey data (summarized in Clarke et al. 2015a) have found beluga whale sightings to be infrequent and widely distributed throughout the Chukchi Sea in the fall, with a sharp decline in sightings by September/October. This assumption is also supported by long-term passive acoustic recorder results from Hannay et al. (2013) and those from this study (Figure 15). Clarke et al. (2015a) suggest that the beluga whales are north of our study area as they migrate west in the fall. This northern path of their fall migration is supported by the acoustic detections presented here; all acoustic detections of belugas were far north along the slope. These may represent those animals who follow the slope west to Russian waters before continuing south to the Bering Sea. This is further supported by data from Moore et al. (2012) that showed a few detections of beluga whale calling activity in October and November on a recorder located far north on the Chukchi Plateau.

It is important to note that the satellite tagging results from Hauser et al. (2014) showing the core use area near Barrow Canyon were from 40 Beaufort Sea whales and 24 Eastern Chukchi Sea whales out of a total estimated population size of ~40,000 and 4,000 whales, respectively. Therefore, the data are not necessarily contradictory; all methods support the assumption that low numbers of animals are present in the Chukchi Sea in August and September. It is expected that these low densities would result in low sighting and detection rates during our surveys. Hannay et al. (2013), suggested that the lack of call detections in their data reflected a possible reduction in calling for the purpose of predator (i.e., killer whale) avoidance. Although these data cannot be used to link calling activity to whale presence, the low numbers of call detections and lack of visual sightings during our four years of field surveys suggest that the low levels of calling activity, for this highly vocal species, correspond to low beluga whale densities in that area. However, given that four sonobuoys in the study area had beluga whale detections, the results also suggest that passive acoustics may be a slightly better method of detection for this species, rather than visual surveys.

Gray whales

Gray whales were more often detected visually than acoustically in August/September, albeit outside the study area, a finding that supports the low calling rate reported by Crane and Lashkari (1996) for migrating gray whales. There were no visual sightings of gray whales in the CHAOZ-X study area, and only one acoustic detection. In the northeastern Chukchi/western Beaufort Seas, most sightings/detections occurred close to shore, in areas deemed to be gray whale Biologically Important Areas (BIAs) for feeding and reproduction for the summer and fall (Clarke et al. 2015a). Thus, the lack of sightings or acoustic detections within the CHAOZ-X study area is expected based on the defined BIAs. Only one offshore acoustic detection of a gray whale occurred, near the southern edge of the study area, close to Hanna Shoal. This area used to have high concentrations of feeding gray whales in the 1980s, but aerial surveys flown there since then have found very few whales (Clarke and Ferguson 2010), most of which occur in July and early August, before these field surveys took place (Clarke et al. 2017). This is also consistent with the long-term recorder data, in which gray whales were detected, albeit rarely, in the CHAOZ-X study area in late July and August (Section VII.A.2). Low levels of acoustic detections of gray whales have also been reported for the Hanna Shoal area by Hannay et al. (2013).

Gray whales are presumed to be silent when feeding (e.g., Ljungblad et al. 1983). Although reports exist of sounds being recorded in the presence of feeding gray whales (e.g., Moore and Ljungblad 1984), it is likely there were other behaviors occurring in addition to the feeding, such as social or reproductive behavior (S. Moore, pers. comm.). This was also observed during the 2013 field survey, in which gray whales that were feeding near Point Hope (evidenced by extensive mud plumes) were predominantly silent, while gray whales that were exhibiting presumed reproductive behavior - in the same area, with the same presence of mud plumes - were very vocal.

If the lack of calling while feeding holds true for gray whales, given that the Chukchi is a known feeding ground, it is expected that the vocal activity of gray whales would be low. The other two areas of high gray whale concentrations were encountered outside the study area in the southern Chukchi Sea off Point Hope and just north of Bering Strait. These areas are well known gray whale hotspots (Moore et al. 2003; Bluhm et al. 2007) and as such, are also designated as a BIA for gray whale feeding (Clarke et al. 2015a).

Bearded seals

Bearded seals were acoustically detected in all four years; however, with the exception of 2014, there were very few detections each year. This is consistent with the long-term results presented in Section VII.A.2, which had only sporadic detections in August and increasing calling activity in September. These also correspond with the results reported by Hannay et al.

(2013) on their long-term recorders, who reported an abrupt decrease in detections from the end of June to late August. The authors suggested that this decrease was due to a lack of calling and not an absence of animals, which is supported by the visual and acoustic data presented here. The breeding season for bearded seals ends in late June/early July. Since most of the acoustic detections in that time frame are highly vocal males producing long trills, it is not unexpected that the end of the breeding season results in a decrease in calling activity, and by extension, a decrease in acoustic detectability. Additionally, there are quite a few unidentified seals in the study area; it is highly likely that many of those sightings are bearded seals, suggesting that bearded seals may still remain in the area in late summer, but not vocalize as often. This is supported by ASAMM aerial survey data, which report consistent, albeit low, numbers of bearded seals in the study area during their summer surveys (e.g., Clarke et al. 2015b, 2017).

Small ice seals

As mentioned above, there are numerous unidentified pinniped sightings in the study area; it is likely some of these are the small ice seal species (spotted, ringed, ribbon). However, due to the difficulty in positively identifying these species when in the water, they were all categorized as ‘unidentified’. Small ice seals are difficult to sight during aerial surveys at altitudes flown by ASAMM and therefore, those records are saved as ‘unidentified pinnipeds’. Although difficult to distinguish visually, we were able to acoustically identify ribbon seals. Only one acoustic detection of a ribbon seal occurred in the study area (2014). Ribbon seals, like bearded seals, make distinctive, stereotyped calls that are easily identified. However, as mentioned with analysis of the long-term recorder data, all Arctic pinnipeds make a variety of sounds in the snort/bark/yelp/etc. category that are often difficult to distinguish. As the original objectives of this project did not focus on ice seals, we just flagged any instances of this ambiguous calling as ‘unidentified pinniped’. A combination of visual and acoustic survey methods should be used to help distinguish between the various species of ice seals in order to obtain a more accurate idea of distribution in the Chukchi Sea in the August - October time period.

Other species

Humpback and minke whales

Humpback and minke whales were not detected or sighted in the CHAOZ-X study area during the survey cruises. Most of the detections/sightings occurred to the south of Cape Lisburne, which fits with the long-term mooring data and the very few to zero detections at the mooring locations farther north. As mentioned previously (Section VII.A.2, ASAMM aerial survey efforts have also determined that humpback and minke whales occur infrequently offshore in the northern Chukchi Sea. Indeed, neither species was visually sighted during aerial surveys in the study area during any year of the CHAOZ-X surveys (Clarke et al. 2014, 2015b, 2017). However, they are opportunistic feeders, just like fin whales, and are currently well positioned to penetrate into the Biologically Important feeding Areas of bowhead and gray whales, if conditions continue to change.

Killer whales

No killer whales were sighted in the CHAOZ-X study area in any year of the surveys; all sightings were located farther south, in approximately the same areas as the concentrations of gray whales (Figure 64). As discussed in Section VII.A.3above, these killer whales are most likely the transient ecotype, which eat marine mammals such as gray whales. The transient ecotype tend to be more quiet than the other ecotypes (Deecke et al. 2005), likely as a means of reducing auditory cues to potential prey. Furthermore, they were found to be silent when chasing or hunting gray whales (Ljungblad and Moore 1983). While the possibility that killer whales are present but not vocalizing cannot be eliminated, the lack of sightings/detections during the four years of survey cruises supports the long-term recorder findings that killer whales are rare offshore in the northern Chukchi Sea.

Fin whales

The lack of detections of fin whales in the study area in the northern Chukchi Sea are consistent with results presented by other passive acoustic studies (Delarue et al. 2013a; Hannay et al. 2013), and from the results obtained from our long-term recorder data (Section VII.A.2). All sightings and detections were located in the southern Chukchi Sea, well outside the study area. Therefore, detections of fin whale calling activity at the CHAOZ-X mooring locations were not expected (Section VII.A.3). Although there were no sightings or detections in the study area, the number of sightings or detections in the northern Chukchi Sea shelf in recent years has slowly been increasing (Clarke et al. 2013b). This evidence of increased presence of fin whales in the Arctic is most likely due to increased use of passive acoustics to monitor for this species, as this monitoring began only recently (i.e., since the mid-late 2000's). Additionally, fin whale calls are very low frequency, and can travel potentially great distances. This makes them ideal candidates for passive acoustic monitoring, as their calls can often be heard at greater distances than they can be visually seen from a vessel. Although it is not unreasonable to assume that there are increasing numbers of fin whales present in the Chukchi Sea, more long-term data are needed in more locations to determine if such a trend exists.

The acoustic detection of fin whale calling activity so far to the east (off Barrow Canyon) in 2012 during the CHAOZ study, suggests the possibility that this species may be encroaching on more northeasterly territories (Crance et al. 2015). This could be a result of post-whaling recovery, a response to the changing climate and ecosystem (Clarke et al. 2013a; Crance et al. 2015), or it could simply be due to the increase in passive acoustic monitoring. In any case, a greater presence of this species in the northeastern Chukchi could have potentially devastating impacts on the ecosystem (Moore and Huntington 2008). Fin whales are opportunistic feeders, capable of thriving on zooplankton as well as fish (Mizroch et al. 1984; Perry et al. 1999; Flinn et al. 2002). The impact of this increased resource competition on feeding specialists such as bowhead whales could be substantial (Perry et al. 1999), particularly in this area where the zooplankton community is moderated by sea ice and temperature (Questel et al. 2013).

Harbor and Dall's Porpoise

These small odontocete whale species were not sighted in the study area during any year of the surveys. Furthermore, the only sounds produced by porpoise are echolocation clicks that are too high to be detected on our sonobuoys or long-term recorders. Both species of porpoise are also difficult animals to identify during aerial surveys (at the altitudes typically flown in the Arctic) due to their small size; vessel surveys are therefore a good method for collecting information on their distribution in this area. It has been suggested that harbor porpoise are undergoing a range expansion and being seen more frequently in the Chukchi Sea (Aerts et al. 2012); more data should be collected so that these trends can be better identified.

Polar bears

Three sightings of polar bears were reported in the study area, two in 2013 and one in 2016. These all occurred near Hanna Shoal in the middle of the study area. The low number of sightings corresponds with the 2012-2015 ASAMM aerial survey data, which reported only four sightings of a polar bear in the CHAOZ-X study area in four years: three in 2012, and one in 2015. However, in 2016 there were six separate polar bear sightings from aerial surveys in the study area (Clarke et al. 2017). Although ice was encountered during all four survey years, 2016 had a larger amount than previous years, and as such had a larger number of ice seals hauled out on ice floes. This may explain the larger number of aerial survey polar bear sightings in 2016. Polar bears are not known to make any underwater sounds that can be detected on passive acoustic recordings.

4. Conclusions

Shipboard visual and passive acoustic surveys conducted while the ship is underway provide an inexpensive way to leverage on the sea time needed to service the long-term moorings and conduct the biophysical sampling stations. The cruise track needed to complete this mooring/sampling work is extensive, covering a wide spatial area at an important time of the year for many marine mammal species. The results of these four years of shipboard surveys have shown that the offshore northeastern Chukchi Sea is an important area for resident species in the August-October time period, including bowhead, walrus, and bearded seals. Although there was some interannual variability in detection locations, all three of these species were detected visually or acoustically during the surveys. Although not detected in the CHAOZ-X study area, subarctic species (e.g., fin, humpback, minke, and killer whales) were seen on the eastern Chukchi shelf during the surveys. Clarke et al. (2013) suggest there may be an increase in these cetaceans within this region, which could be either a result of post-commercial whaling recovery and seasonal changes, a response to climate change, or both.

The combination of visual and acoustic surveys is essential to maximize the detection potential for marine mammals. Either method alone runs the risk of missed detections and underestimating the importance of an area to a particular species. For example, harbor and Dall’s porpoise vocalizations are very high frequency, and therefore undetectable on sonobuoys due to sampling rate restrictions. On the other hand, fin whale calls are very low in frequency, and very loud; as a result, they have the potential to travel larger distances, and are therefore theoretically easier to detect acoustically. More generally, visual methods are restricted to good sea conditions, visibility, and daylight hours, while acoustic methods are limited to just the animals that are making calls. By combining visual and acoustic surveys, we can obtain a more complete picture of marine mammal distribution within the study area. In addition, having this combination of methods on the same survey cruise allows comparisons to be made *in situ*. We have found that bowhead whales, fin whales, humpback whales, and walrus are equally likely (or for beluga and killer whales – equally unlikely) to be sighted or detected during the August-October time period of these cruises. For gray whales, bearded seals, minke whales, and the two porpoise species, however, call detections cannot be used as a proxy for presence of these species at this time of the year. It is important to note that the season over which these statements are valid must be defined so that the data are not misinterpreted during other times of the year.

In addition to the benefits listed above, having dedicated visual observers working concurrently with passive acoustics allows for focal follows to be conducted. These focal follows are crucial for several reasons. First, they allow for cross-validation of each method. They also are very important for attributing call types to species and to certain behaviors for those species, adding to their known calling repertoire. Finally, they play a critical role in creating a database of call counts for each species, which is necessary for eventually being able to estimate their relative abundance. Information obtained on these call repertoires and call counts could then be applied to the data collected from our long-term recorders, providing not only year-round seasonal distribution of the various species, but year-round seasonal distribution of their behaviors, and, eventually, accurate estimates of their year-round relative abundance.

5. Recommendations

While out at sea, we make every attempt to have a dedicated visual observation team working concurrently with someone using sonobuoys for real-time passive acoustic monitoring. In the event that we do not have a dedicated field season in the upcoming years, it is important that we ensure at least one visual observer and one passive acoustic technician are included in any opportunistic field surveys we may conduct. This ensures that we take full advantage of any opportunity to conduct combined visual/acoustic surveys, increase our knowledge of the calling repertoires of each marine mammal species, and increase the sample size of our database of call counts. Furthermore, the bearing information from the DiFAR sonobuoys will allow, with multiple sonobuoys deployed, the localization of calling animals. This then allows us to obtain estimates of call detectability that are necessary for future calculations of relative abundance.

VIII. BIOPHYSICAL PATTERNS AND TRENDS (OBJECTIVES 1, 2)

A. *Moored Observations (Moorings: C3/IC3, C6/WT2, C7/HS1, C8/HS2, HS3, C9)*

1. Methods

Mooring Sites and Instrument Configuration Moorings (C6, C7, C8 and C9)

In 2013 and 2014, mooring deployments were planned at C6, C7, C8 and C9 (Figure 2). In 2013, however, year-long biophysical moorings were deployed at only two sites (C6 and C7) - equipment failures prevented the deployment of moorings at C8 and a government shutdown prevented the deployment of C9 (Figure 2, Table 26). In 2014 moorings were deployed at all four sites - C6, C7, C8 and C9. In 2015, the mooring planned at C9 in 2013 was deployed. To avoid ice keels, the top of each shelf mooring was only ~10 m off the bottom (or ~30 m below the surface). Mooring designs were identical for each year (Table 26) and the instruments that successfully collected data are listed in Table 27. Several instruments failed and a number collected data for only part of the deployment period.

Data were collected at least hourly, and all instruments were calibrated prior to deployment. The physical and chemical data were processed according to manufacturers' specifications. All current time series were low-pass filtered with a 35-hour, cosine-squared, tapered Lanczos filter to remove tidal and higher-frequency variability, and re-sampled at 6-hour intervals. CTDs (including Niskin bottles) were conducted following or preceding mooring recoveries and deployments to provide quality control of the data collected by some of the instruments on the moorings (e.g., temperature, salinity, Photosynthetically Active Radiation [PAR], dissolved oxygen, chlorophyll fluorescence, and nitrate).

Table 26. Summary of mooring locations and measurements taken for the CHAOZ-X study 2013-2016. All moorings were taut-wire moorings, measuring temperature (T; SEACAT, RCM-9), conductivity from which salinity (S; SEACATS, RCM-9) is derived, currents (RCM-9, acoustic Doppler current profiler [ADCP]) and chlorophyll fluorescence (Wetlabs Eco Flourometer). Nitrate concentrations were measured using Atlantic ISUS or SUNA. Oxygen was measured using Aanderaa Oxygen Optode 3835 and turbidity was also measured on the RCM-9. The ASL IPS-5 instrument acoustically measures ice keel depth.

Year	Site	Mooring ID	Long. (W)	Lat. (N)	Instruments Used
2013	C6	13CKP-6A	161° 52.470'	71 46.621 N	QSP-2300, ISUS, 600 KHz ADCP, SBE-16, ECO-Fluor.
		13CKIP-6A	161° 51.607'	71 46.436 N	RCM9, IPS-5
		13CKT-6A	161 52.912 W	71 46.320 N	TAPS-6NG
	C7	13CKP-7A	161° 36.249'	72 25.453 N	600 KHz ADCP, SBE-16 , ECO-Fluor., SUNA
	C8	13CKP-8A	Not deployed – equipment failure		
	C9	13CKP-9A	Not deployed (delayed until 2015)		
2014	C6	14CKP-6A	161° 52.74'	71 46.60 N	SBE-16, ECO-Fluor., ISUS, QSP-2300, 300 KHz ADCP
		14CKIP-6A	161° 51.86'	71 46.45 N	RCM9, IPS-5
		14CKT-6A	Not deployed		
	C7	14CKP-7A	161° 37.240'	72 25.475 N	QSP-2300, RDI 600 KHz ADCP, SBE-16, ISUS, ECO-Fluor.
	C8	14CKP-8A	161° 12.31'	72 34.98 N	300 KHz ADCP, ECO-Fluor., SBE-37
		14CKIP-8A	161° 12.89'	72 35.18 N	RCM9, IPS-5
		14CKT-8A	161 13.56 W	72 34.98 N	TAPS-6NG
	C9	14CKP-9A	156° 33.922'	72 27.473 N	2 RCM9s, RCM11, 75 KHz ADCP, SBE-37
2015	C9	15CKP-9A	156° 32.977'	72 28.011 N	RCM11, 2 RCM9s, 75 KHz ADCP, SBE-37

Table 27. The data collected at each site, each year. X indicates at least some data were collected, F indicates that the instrument failed completely and no data were collected. Blank indicates that no instrument was deployed. Two types of nutrient sensors were deployed – the ISUS and the SUNA.

Site	Year	Temp	Sal	Chl	O_2	Turb	PAR	Nut	Ice	RCM	ADCP
C6	2013	X	X	X	X	X	X	ISUS	X	X	X
	2014	X	X	F			X	ISUS	X	X	X
C7	2013	X	X	X			X	ISUS		F	X
	2014	X	X	X			F			X	F
C8	2014	X	X	X	X	X	X	ISUS	F	X	X
C9	2014	X F X	X X							X 300 m F 600 m X 950 m	X
	2015	X X X	X X							X 300 m X 600 m X 950 m	X

Nitrate sensors

Note that the nitrate sensors from ARCWEST are included in this discussion. Nitrate time series are derived from optical sensors purchased from Satlantic (In Situ Ultraviolet Spectroscopy [ISUS] or Submersible Ultraviolet Nitrate Analyzer [SUNA]). These sensors are accurate to ~2 µM, and do not have internal standards. The data were calibrated against reference field samples that were collected while the sensor was deployed. The calibrations included both an offset and drift correction. After these adjustments, several time series (2013: C5 and C6; 2014: C5) had periods with negative values, and a secondary offset or drift correction was applied.

Ice Profilers

Ice-draft time-series data were collected from upward-looking IPS5 sonar ice profilers (ASL Environmental Sciences) during year-long deployments in the Chukchi Sea. The devices were mounted near the ocean floor, and used a high-frequency 420 kHz transducer with a narrow, 1.8° beam width. These instruments ping the under-surface of ice and waves measuring the travel time. These data, together with temperature and pressure data, are used to calculate the ice draft. Five instruments were deployed each year (Table 27). Raw data were extracted from compact flash cards using IPS5extract™, and data were processed using the IPS Processing Toolbox™, both proprietary MATLAB tools developed by the manufacturer. Range and sensor data were trimmed to exclude pre- and post-deployment data, and early- and late-season waves. NCEP 6-hourly mean sea-level pressure data were used to remove atmospheric pressure. Tilt corrections were applied using sensor tilt and magnitude data. Range null targets were recovered from amplitude data. Range data were de-spiked in 2 passes: for 1-2 point, and 3-4 point outliers. Further linear interpolation was applied to obvious outliers of up to 10 data points. Daily ice-draft data were averaged from 1-second preliminary ice draft starting at time 00:00:00 UTC each day. Statistics (e.g., means, medians, standard deviations) were calculated within the MATLAB environment. These daily ice draft data include ice cover and exclude waves and ice-free data segments.

Satellite remote sensing and ice data

Sea-ice data used in this project were version-2 Bootstrap algorithm files described by Comiso (2007). Bootstrap data from 1978 through 2015 files were obtained from the National Snow and Ice Center (http://nsidc.org/data/docs/daac/nsidc0079_bootstrap_seaice.gd.html). The version-2 Bootstrap algorithm was enhanced by comparison with the Advanced Microwave Scanning Radiometer – Earth Observing System (AMSR-E) data. Note that the AMSR-E satellite was launched in May 2002 and failed in October 2011. For the years presented in this report, data were derived from the Special Sensor Microwave Imager/Sounder (SSMI/S) flown on F17.

Bootstrap files were not yet available for 2016; for that year we use the near-real-time NSIDC 0081 files (Maslanik and Stroeve 1999). These files are derived using the SSMI/S instrument aboard the DMSP F17 and F18 satellites. Both data-sets are on the 25km Polar stereographic grid. The time series of percent areal coverage were calculated in ~50 km x ~50 km box around each of the mooring sites.

Winds

Wind velocity was obtained from the North American Regional Reanalysis (NARR), which was introduced as an extension to the National Centers for Environmental Prediction Reanalysis 2 (NCEPR2) for the North American Region using the high resolution NCEP Eta model (~32 km grid size compared to NCEPR2's 2.5° grid) and includes additional assimilated parameters to improve the reanalysis product (Mesinger et al. 2006). Model estimates of winds were at 3 hourly intervals for NARR. Data were binned and averaged into 6 hourly intervals.

Satellite-tracked drifters

The satellite-tracked drifters were funded as part of ARCWEST, but are included here because they provide insight in flow patterns near Hanna Shoal. Twelve, satellite-tracked drifters were deployed in 2013 and an additional 12 in 2015, in the Chukchi Sea (Table 28). These complement the 12 drifters that were deployed in 2012. The original plan was to deploy in 2014, but the cruise was very late that year and the drifters would have been caught in ice within 4-6 weeks. It was decided it would be more cost effective to deploy in 2015, when drifters could be deployed earlier, providing a longer observation period. The drogues were "holey socks" centered at a depth of ~30 m, which was below the summer mixed layer depth. Each drifter was instrumented with a temperature sensor at the bottom of a float (i.e., just below the sea surface). At these high latitudes, more than 14 position-fixes per day were obtained from Argos, until the drifter was caught in the ice in the fall after which time the fixes became erratic. Once the data were received from Argos, spurious data were deleted from the time series. Data collected after the drogue was lost or entered into ice (determined from maps of ice extent) were noted.

Table 28. The identifying number of the drifter, the latitude and longitude where it was deployed, and the date it was deployed.

Argos Drifter	Latitude (°N)	Longitude (°W)	Date Deployed
122534	67.768	168.591	23-Aug-13
122535	71.508	164.911	27-Aug-13
122536	71.307	164.503	3-Sep-13
122538	71.045	160.482	28-Aug-13
122539	71.209	164.244	27-Aug-13
122540	69.301	167.623	25-Aug-13
122541	70.803	162.962	27-Aug-13
128951	70.855	163.234	4-Sep-13
128952	66.572	168.47	9-Aug-13
128953	71	165.403	27-Aug-13
128954	67.582	168.441	12-Aug-13
128955	69.998	167.058	23-Aug-13
136859	71.076	163.864	10-Jul-15
136860	71.077	164.829	11-Jul-15
136861	71.084	164.314	18-Jul-15
136862	71.074	164.35	11-Jul-15
136863	69.491	165.316	12-Aug-15
136864	68.199	167.314	11-Aug-15
136865	66.793	168.154	11-Aug-15
136866	69.294	164.599	12-Aug-15
136867	67.485	168.281	9-Jul-15
136868	66.032	168.361	9-Jul-15
136869	71.082	163.823	18-Jul-15
136870	71.083	164.845	18-Jul-15

Zooplankton Volume Backscatter Estimates Derived From ADCP Measurements

Estimates of zooplankton volume backscatter (Sv) were also derived from the upward looking, Teledyne RDI Workhorse Sentinel Acoustic Doppler Current Profilers (ADCP) at each mooring site (Table 27). Note that the frequency of the instruments changed in 2014. Previous to this, all sites had 600 KHz instruments. Beginning in 2014 there was a mix of 75, 300, and 600 kHz instruments. Measurements of echo counts from each bin and time point were used to estimate volume backscatter.

MATLAB™ (R2012b) was used to process all data. The ADCP echo intensities (counts) were converted to Sv according to Gostiaux and Van Haren's (2010) modified version of the commonly used Deines (1999) sonar equation:

$$Sv = C + 10\log10((Tx+273.16)R2) - LDBM - PDBW + 2\alpha R + 10\log10(10KcE/10 - 10KcEr/10),$$

where C is a transducer/system noise constant provided by the manufacturer (-139.3 dB for the Workhorse Sentinel), Tx (°C) is the variable temperature at the transducers, LDBM is the 10log10 (transmit pulse length constant in meters), PDBW is the 10log10 (variable transmit power in Watts), α (dB/m) is the sound absorption coefficient of seawater, R (m) is the slant range along the beam to the scatterers, E (counts) is the echo intensity, Er (counts) is the reference noise level determined from the lowest echo intensity value over the whole water column during the entire deployment period, and Kc (dB/count) is the conversion factor provided by the manufacturer to convert ADCP counts to dB. Sv was calculated separately for each beam, then the average of all beams was computed in the linear domain before being converted back to log units.

Wavelet analysis (Torrence and Compo 1998) was applied to standardized ADCP data ([x – mean]/standard deviation) to examine the dominant modes of temporal variation and to determine strength of these modes across the observation period. Software to accomplish the analyses was written in Python using information at https://github.com/aaren/wavelets as a resource. Wavelet transforms are similar to Fourier transforms in that they convert information in the time domain into the frequency domain. They are particularly informative when a signal is non-stationary, which is the case with our data. The orthogonal basis functions used here were sine and cosines. The rapid ascent and descent of zooplankton during diel vertical migration result in a "square" shaped migration. In addition, the length of time zooplankters remain in the upper water column also varies (see below).

2. *Results*

Time Series of Physical and Chemical Data from Biophysical Moorings

Except for the ADCPs (which measure throughout the water column) and ice profiler (which measures keel depth), all measurements were in the bottom 10 meters of the water column. Sites C7 and C8 were to the north of Hanna Shoal and C6 was to the east. All three sites were on the shelf. Site C9 was at the continental shelf break. The mean currents (including moorings which were part of ARCWEST) reveal the flow pattern in the vicinity of Hanna Shoal (Figure 67). The flow on the north site of Hanna Shoal (C7 and C8) was weaker than expected, while the flow to the south of Hanna Shoal (C2) was strong. Flow at C6 was stronger than at C7 and C8, but weaker than at C2. The strongest flow was at C9. Data from this mooring (C9) revealed a new current - the Chukchi Slope Current, which flows westward from Barrow Canyon at least as far west as the mouth of Harold Canyon, as evidenced by satellite-tracked drifter trajectories (see Figure 74).

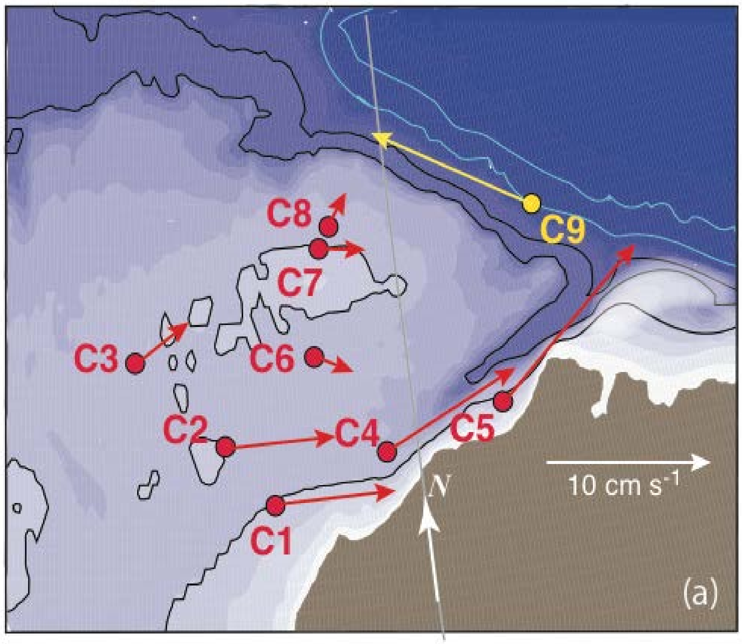


Figure 67. Locations of the 9 moorings that have been deployed as part of three BOEM programs (CHAOZ, CHAOZ-X and ARCWEST). Relative annual mean bottom velocity at each shelf mooring site (C1-C8) and at 48 m at C9 (yellow indicates the slope mooring).

The three moorings sites on the Chukchi shelf (C6, C7, and C8) had the weakest mean flow of the 9 moorings (Figure 67) with mean flow of 2.4 cm s^{-1} (2-year average) at C6, 2.8 cm s^{-1} (1-year average) at C7 and 2.1 cm s^{-1} (1-year average) at C8. In addition, these moorings had the weakest maximum daily average currents and reversals were common (Figures 68-73). Interestingly, the single year of current data at C8 was not highly significantly ($p=0.05$) correlated with the currents at any of the other mooring sites (C1-C7), while the currents at C7 were weakly correlated with C5 ($p=0.05$) and better correlated with those at C6 ($p=0.01$). The correlations among the currents measured at the other sites (C1, C2, C3, C5 and C6) were significant ($p<<0.01$).

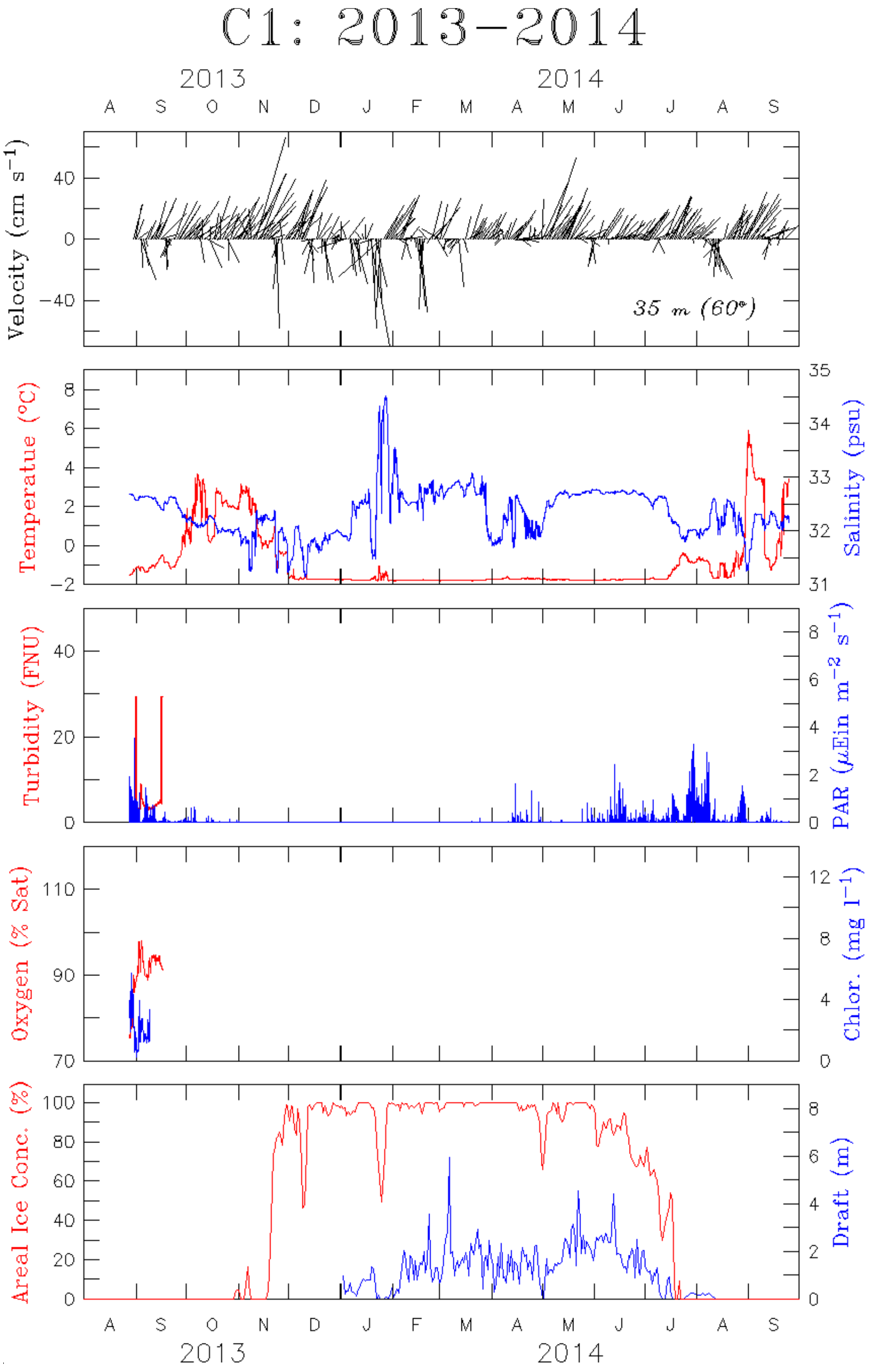


Figure 68. Times series from the inshore mooring (C1) on the Icy Cape line for 2013-2014. From top panel to bottom panel: near bottom currents (low pass filtered and rotated 60°); near bottom temperature and salinity; turbidity and PAR; dissolved oxygen and chlorophyll fluorescence; and daily median depth of ice keels and percent areal ice cover in 25 km x 25 km box around the mooring site.

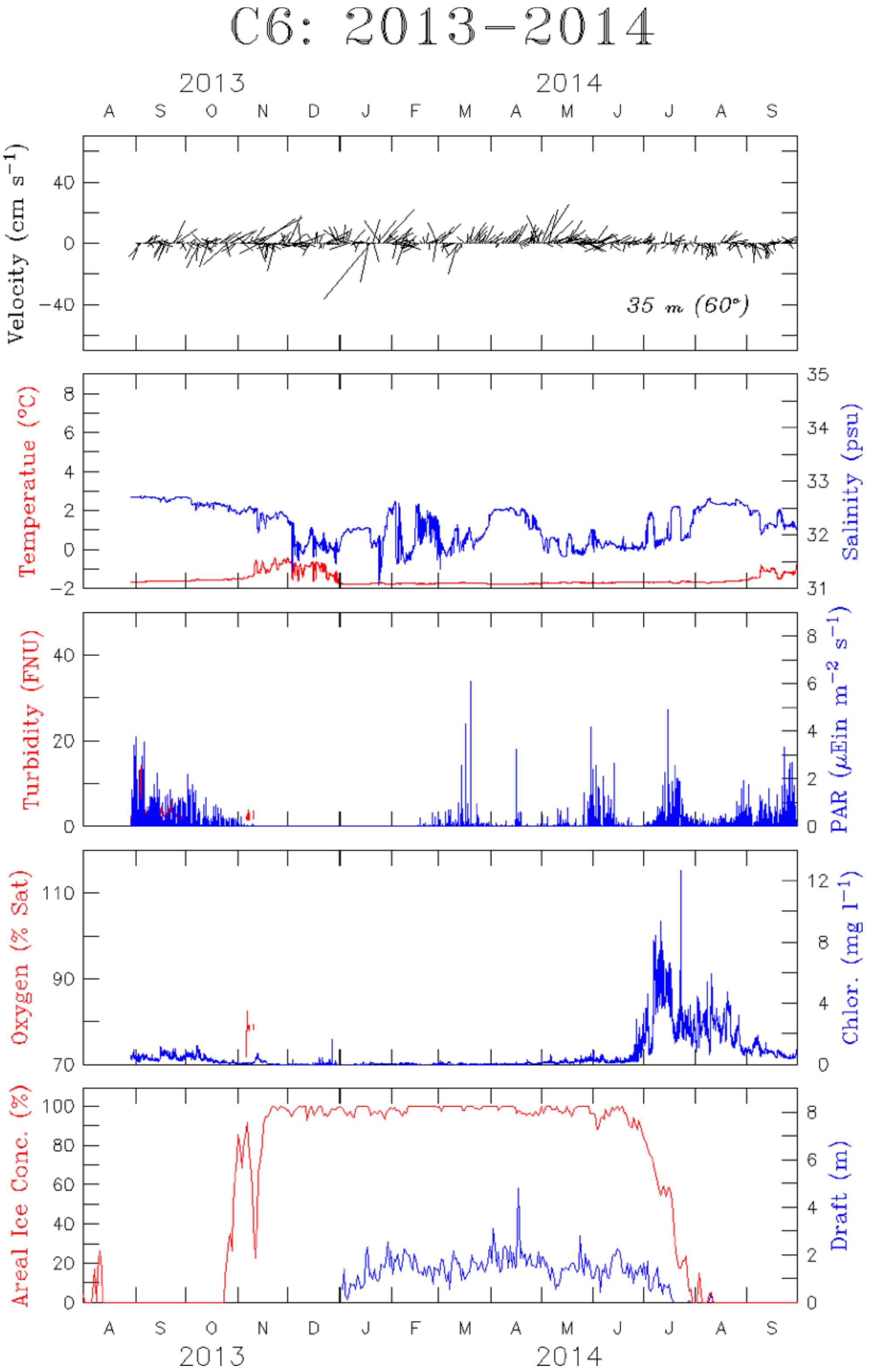


Figure 69. Times series from C6 for 2013-2014. From top panel to bottom panel: near bottom currents (low pass filtered and rotated 60°); near bottom temperature and salinity; PAR; chlorophyll fluorescence; and daily median depth of ice keels and percent areal ice cover in 25 km x 25 km box around the mooring site.

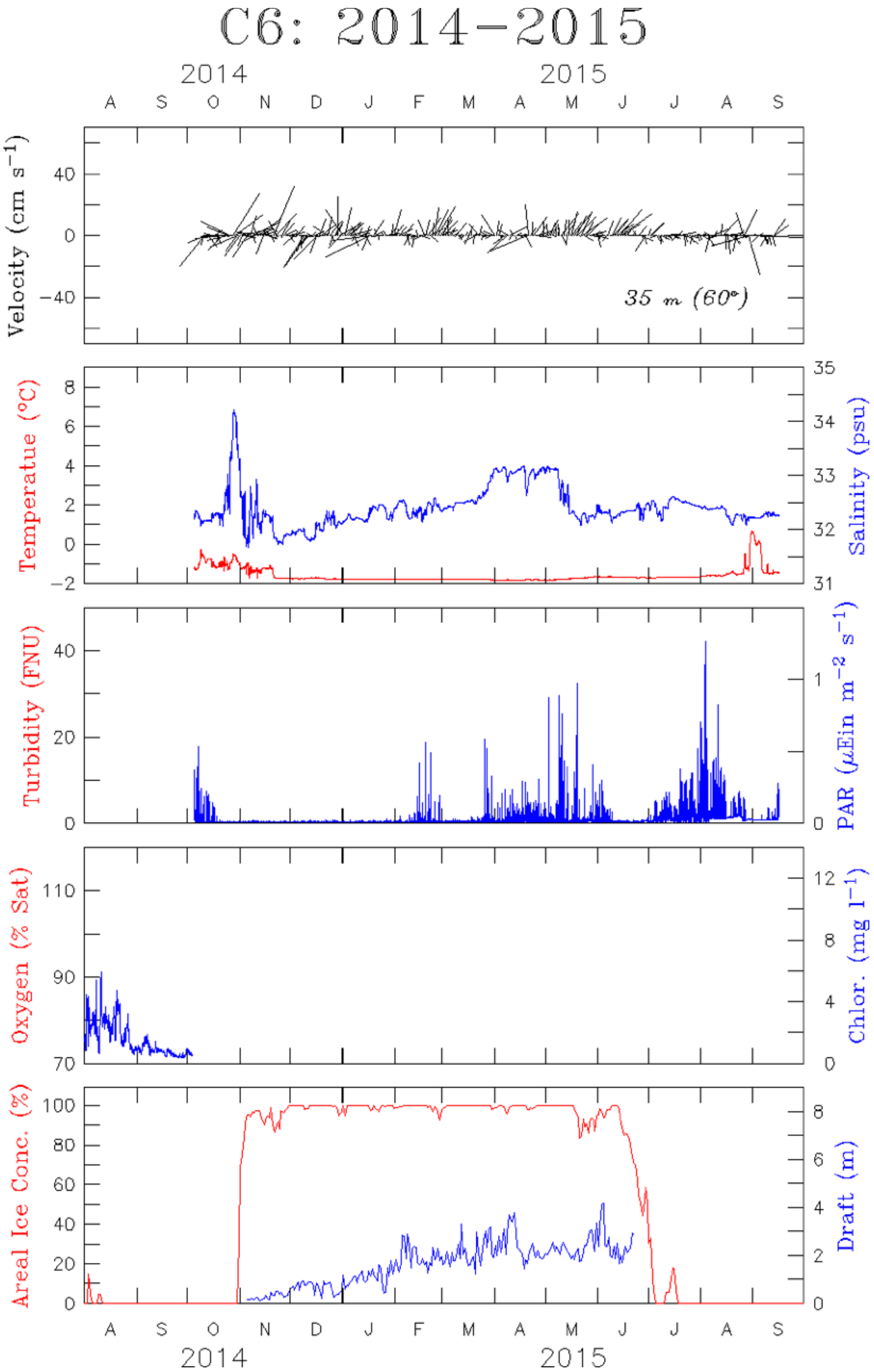


Figure 70. Times series from C6 for 2014-2015. From top panel to bottom panel: near bottom currents (low pass filtered and rotated 60°); near bottom temperature and salinity; PAR; chlorophyll fluorescence; and daily median depth of ice keels and percent areal ice cover in 25 km x 25 km box around the mooring site.

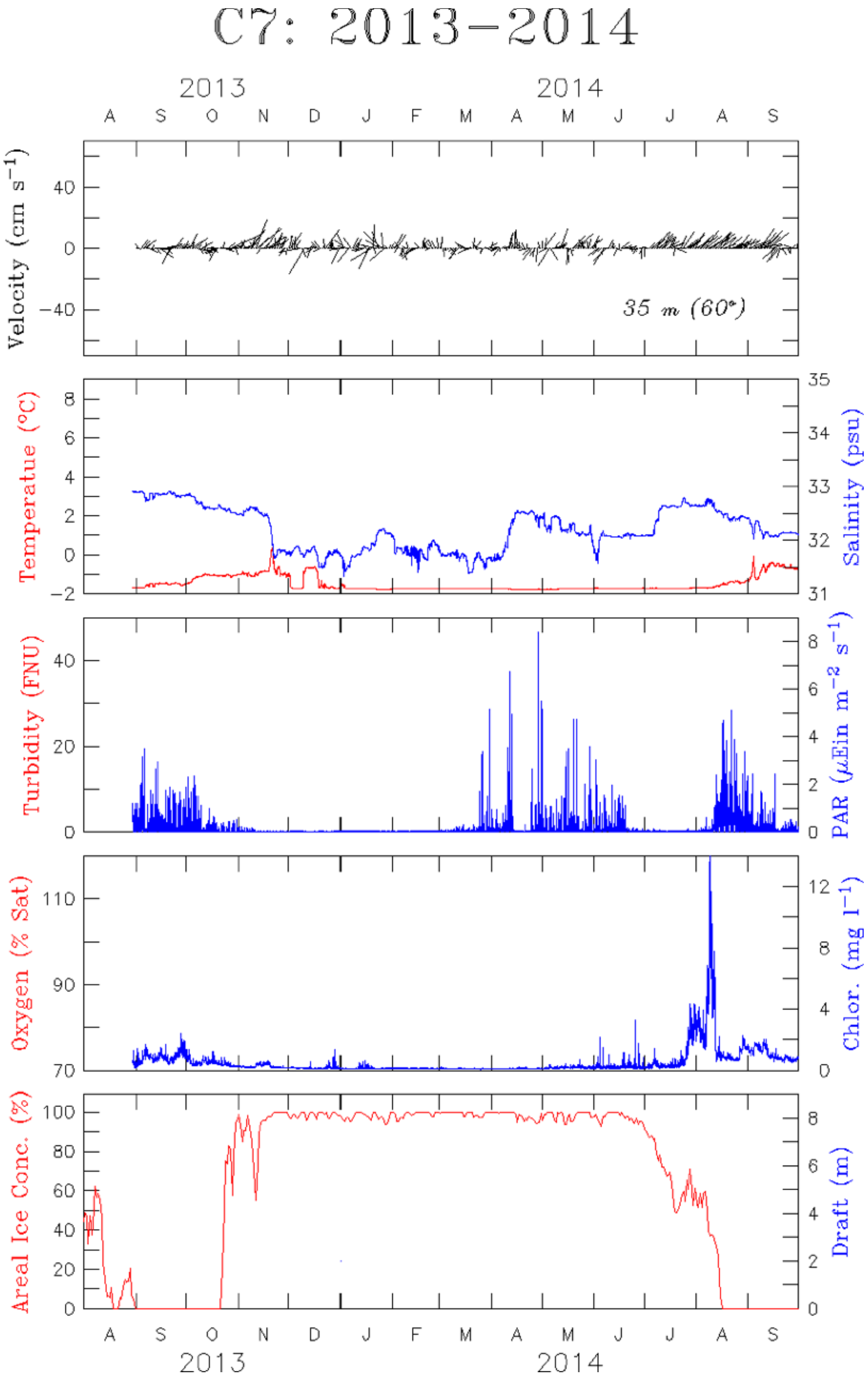


Figure 71. Times series from C7 for 2013-2014. From top panel to bottom panel: near bottom currents (low pass filtered and rotated 60°); near bottom temperature and salinity; PAR; chlorophyll fluorescence; and percent areal ice cover in 25 km x 25 km box around the mooring site.

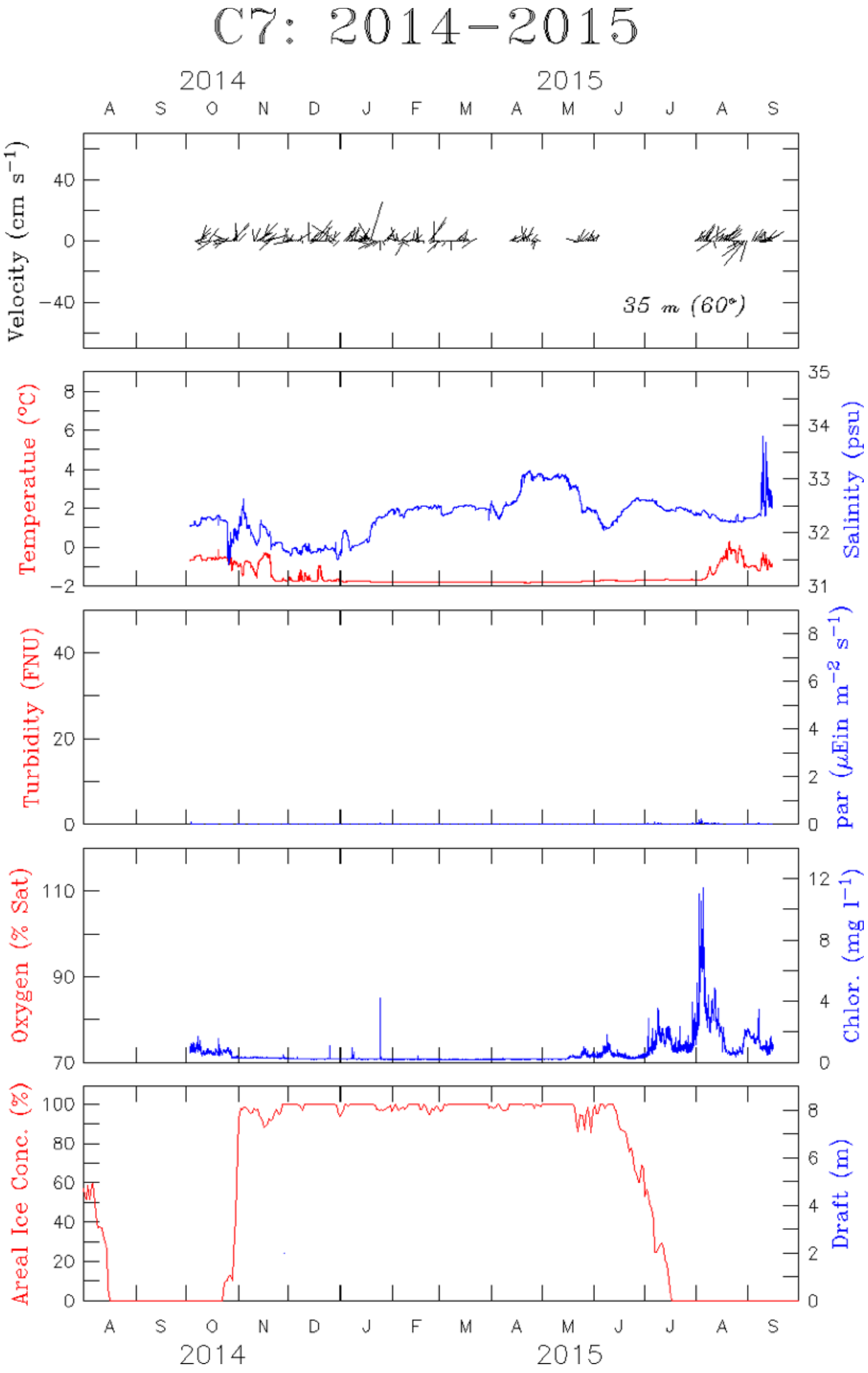


Figure 72. Times series from C7 for 2014-2015. From top panel to bottom panel: near bottom currents (low pass filtered and rotated 60°); near bottom temperature and salinity; chlorophyll fluorescence; percent areal ice cover in 25 km x 25 km box around the mooring site. The gaps in the velocity record was a result of a malfunction of the RCM 9.

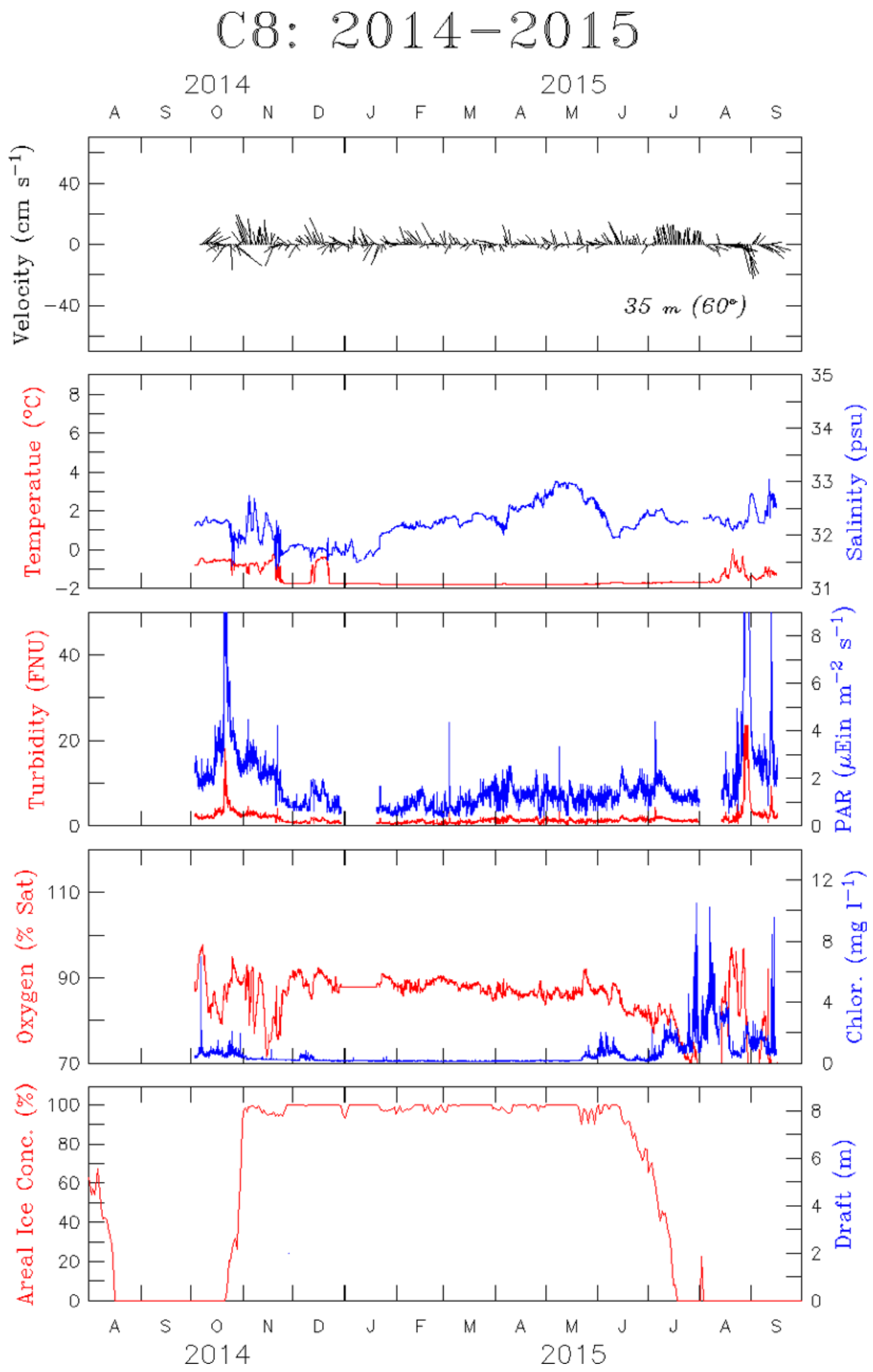


Figure 73. Times series from C8 for 2014-2015. From top panel to bottom panel: near bottom currents (low pass filtered and rotated 60°); near bottom temperature and salinity; turbidity and PAR; chlorophyll fluorescence and percent oxygen; and percent areal ice cover in 25 km x 25 km box around the mooring site.

Bottom currents were generally eastward. Daily net speeds were < 35 cm s^{-1}. The low-pass filtered time series were variable, with reversals lasting typically 2-4 days. The variability in currents was forced by winds. Vertically, the currents were well correlated (typically $r > 0.7$; $p<<0.01$).

Bottom temperature ranged from approximately -1.8 to < 1 °C, with maximum temperatures occurring in late August or September. Salinity ranged from <31 to ~34.5. The variability in salinity was the result of different water types (e.g., Alaska coastal water, Atlantic Water, Bering Sea water, etc.), the melting of sea ice and deep mixing of the resulting melt water, and the freezing of surface waters and resulting brine rejection.

Light levels at the bottom began to increase in April or May while the region was still covered in ice. This may be due to an increase in the number of open leads or the melting of snow from the top of the ice, which would decrease the albedo. Typically, measureable light reached the bottom from May through September.

Chlorophyll from the “spring” phytoplankton bloom was evident in each time series, typically occurring in late July or August. In the Arctic the spring plankton bloom likely occurs immediately under and within the ice. Then as the ice melts, the epontic algae, often pennate diatoms are released into the water and sink to the bottom where our fluorometer was located. The first bloom may consume near-surface nutrients, however if it doesn’t, or if mixing delivers nutrients from below the pycnocline, then a second phytoplankton bloom may occur.

Associated with the increase in primary production is an increase of percent oxygen saturation (e.g., Figure 73), suggesting that primary production continued at depth and that the production of oxygen exceeds consumption by bacteria decomposing organic matter or that advection continually replenishes oxygen (~40 m).

Sea ice arrives in early to mid-November, increasing quickly to near 100% areal coverage and declines precipitously in late May or June.

Satellite-tracked drifters

Mean flow patterns:

The Chukchi Sea consists of a broad shallow shelf (Figure 2), which is incised by two major canyons at the slope – Barrow Canyon in the east and Herald Canyon in the west. Bathymetry plays an important role in directing the mean flow patterns. Trajectories from the 39 satellite-tracked drifters (includes drifters deployed during the CHAOZ study in 2011 and 2012) provided information on flow patterns during the ice-free season, primarily June–October (Figure 74). The drogue depth of these drifters was ~30 m, which in the summer months is usually below the surface mixed layer, so these trajectories represent near bottom flow. The trajectories showed a general flow pattern: northward flow through Bering Strait; a separation south of ~68°N, with some drifters continuing northward into the Central Channel and the remainder transiting westward toward Herald Canyon; a split (~71°N) in Central Channel with most of the drifters moving eastward toward the coast and a few in 2015 continuing northward to circulate clockwise around Hanna Shoal; strong flow northeastward along the Alaskan coast (~71–74°N); and well defined northwestward flow along the Chukchi Slope from Barrow Canyon toward Herald Canyon.

The average velocities measured at the current meters revealed a similar pattern (Figure 67). Note that data from all the moorings deployed as part of the three BOEM-funded projects (CHAOZ, CHAOZ-X and ARCWEST) are combined in this map. Strongest shelf flow is evident in the vicinity of Barrow Canyon (C4 and C5) with eastward flow along the Icy Cape transect (C1, C2, and C3). The newly identified Chukchi Slope Current (Corlett and Pickart 2017) is evident at C9. The weakest flow, largely eastward, is evident north of Hanna Shoal (C7 and C8) and southeast of Hanna Shoal (C6).

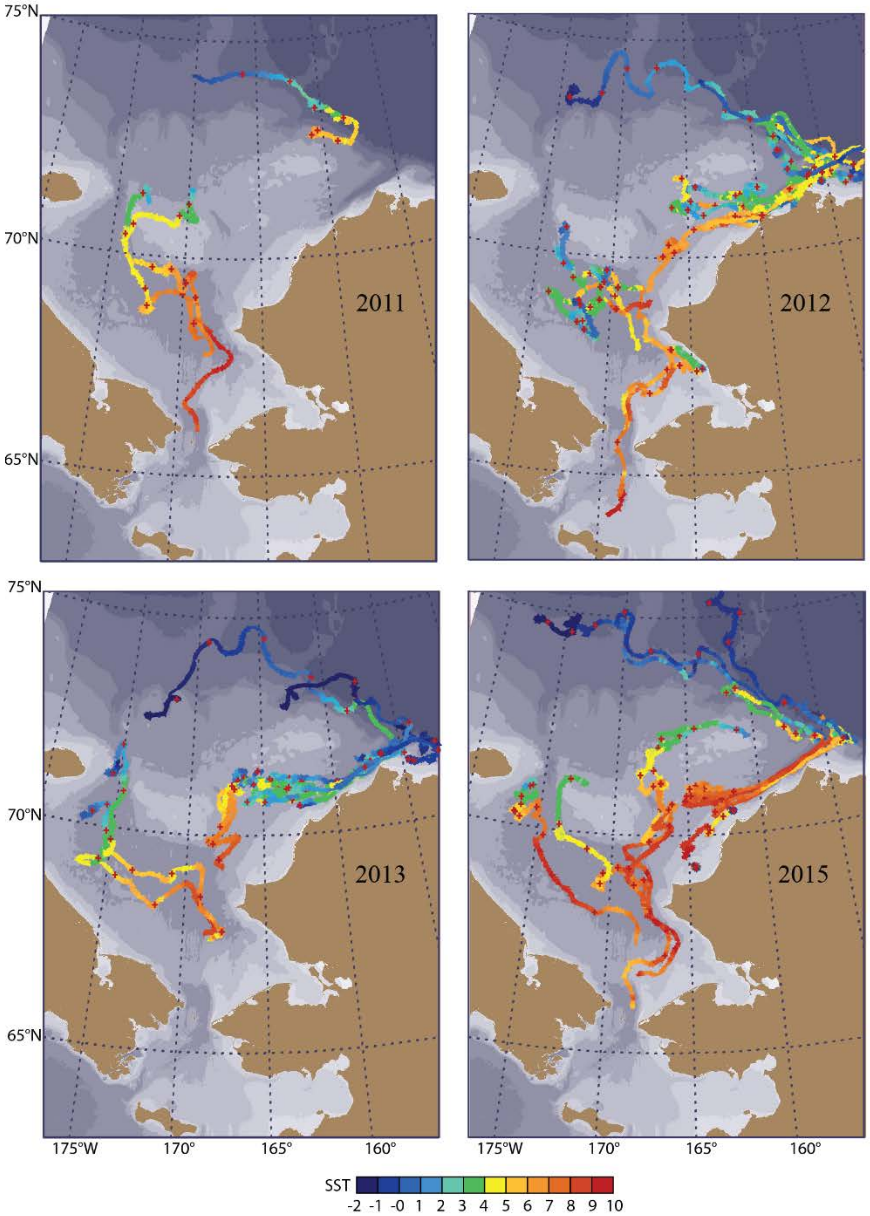


Figure 74. Drifter trajectories (drogue depth ~30 m) for four years. The drifters are color coded by sea surface temperature (scale [°C] is at the bottom). The length of time between red crosses on trajectories is five days. In 2011, 2012, and 2013 drifters were deployed in August, while in 2015 drifters were deployed primarily in July. The circles indicate deployment location.

Time series of nutrients and salinity from biophysical moorings

Nitrate concentrations in bottom waters of the Chukchi Sea are modulated by both physical (e.g., advection, mixing, and brine rejection) and biological (e.g., assimilation, nitrification) processes that vary in space and time. All of the time series (Figures 75-76) show nitrate drawdown in August-November related to primary production, but the appearance of this signal in bottom waters may be the result of several mechanisms, including *in situ* production and mixing. During ice retreat, large amounts of ice-associated algae sink to the bottom. When bottom PAR is sufficient to support production, *in situ* growth near the bottom can occur and result in the drawdown of nitrate, nitrite, and ammonium and increase in oxygen percent saturation. A second mechanism is mixing. In summer, a two-layer system forms, and nitrate is depleted in the upper water column. The breakdown of this two-layer system, which usually occurs as a result of the late summer/early fall storms, mixes nitrate-depleted water (and fresher water) to the bottom. So the overall timing and extent of nutrient drawdown in bottom waters is related to the timing of ice retreat, storm events, and advection.

In the time series (Figures 75-76), nitrate replenishment usually commenced with the arrival of ice (not shown) and a thoroughly mixed water column. Often, but not always, pulses or periods of higher nitrate were associated with increases in salinity. These increases in salt were related to advection of different water masses passing the mooring, or salt rejection during ice formation. There were also periods when nitrate increased despite level or decreasing salinity (e.g., June and July), and this may be an indication of nitrification.

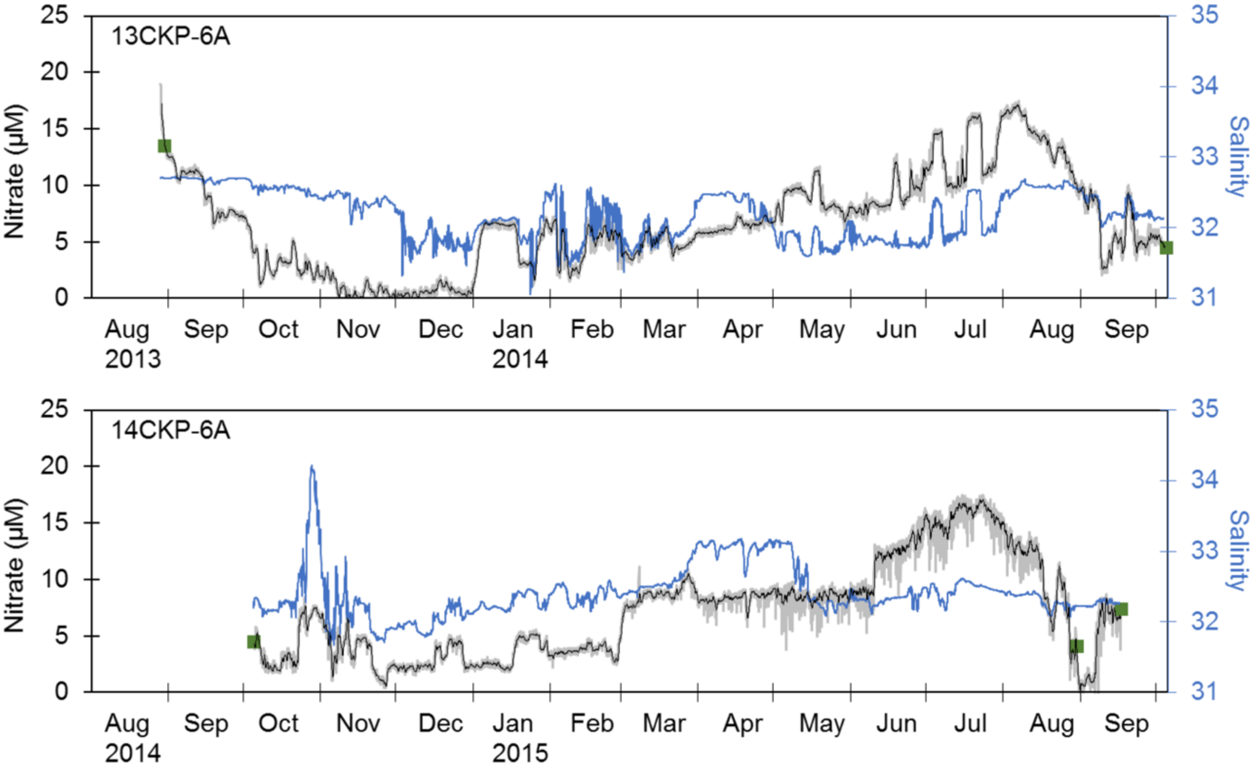


Figure 75. Time series of nitrate (black, gray) and salinity (blue) at mooring C6 from 2013-2014 (top) and 2014-2015 (bottom). Salinity data are identical to data shown in Figure 69 and Figure 70, Nitrate data include hourly data (gray) overlaid with a 12-hour running mean (black). Nitrate samples collected in the field were used to calibrate the data (green squares).

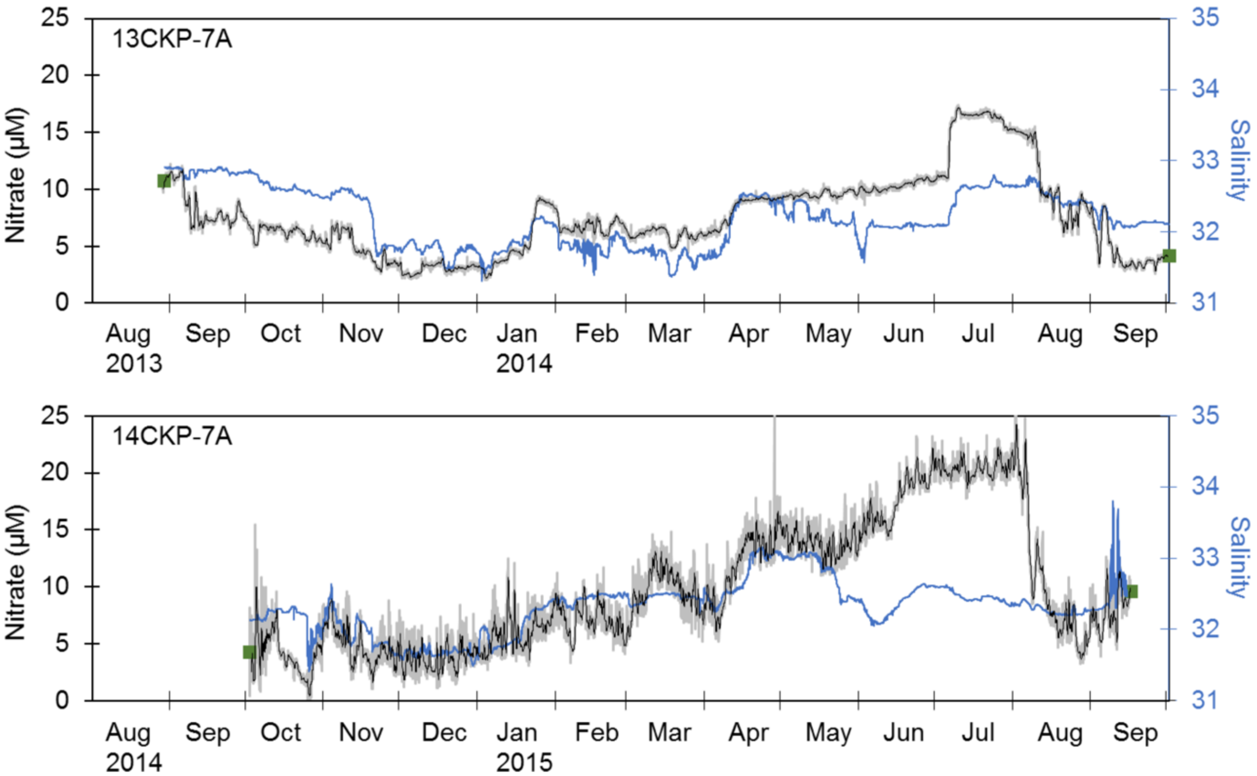


Figure 76. Time series of nitrate (black, gray) and salinity (blue) at mooring C7 from 2013-2014 (top) and 2014-2015 (bottom). Salinity data are identical to data shown in Figure 71 and Figure 72. Nitrate data includes hourly data (gray) overlaid with a 12-hour running mean (black). Nitrate samples collected in the field were used to calibrate the data (green squares).

Time series of ice keel depths

A comparison between the 15-day running average of the median keel depth at the different mooring sites is shown in Figure 77. In 2015, the steady deepening of ice keels in November- January is evident. Both years showed considerable spatial variability in keel depth over the winter and spring months.

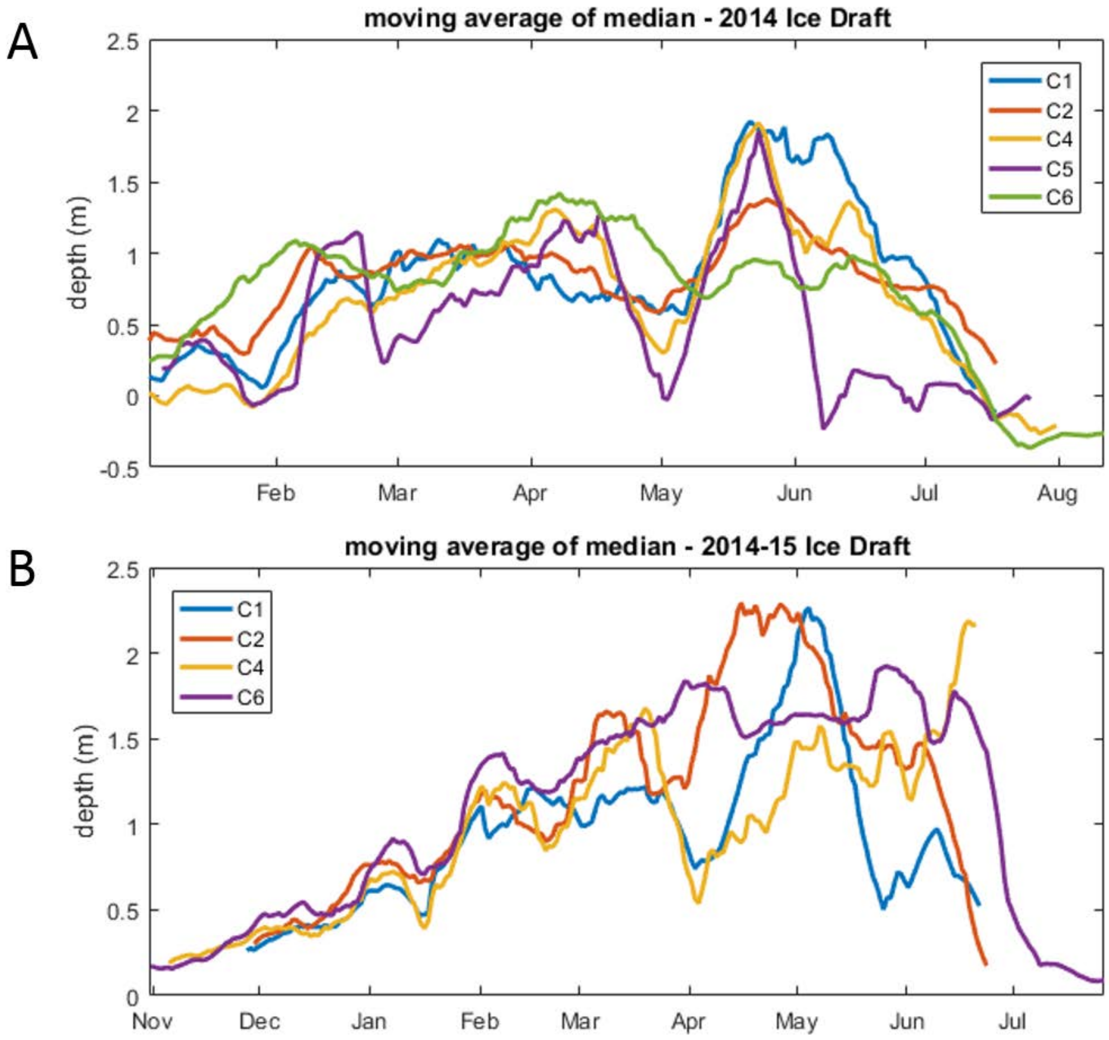


Figure 77. Time series of daily median ice keel draft in A) 2014 (from the 2013-2014 dataset) at five mooring sites and in B) 2014-2015 at four mooring sites.

Maximum depth of the ice keels was greater in 2015 than in 2014 (Figures 78-79). At both C1 and C4 (collected as part of ARCWEST and shown here for comparison) there were ice keels that reached a depth of almost 30 m in May and April, respectively. The greatest variability occurred at C5 (also collected as part of ARCWEST). In contrast, C6, especially in 2014, had the least variability. Keel depths of >20 m were common every year at all locations. Periods when the ice draft was <1 m were common at C1, C4 and C5 – the coastal moorings where polynyas often occurred. In contrast, C2 and C6 farther from the coast rarely showed periods of thin ice in the winter.

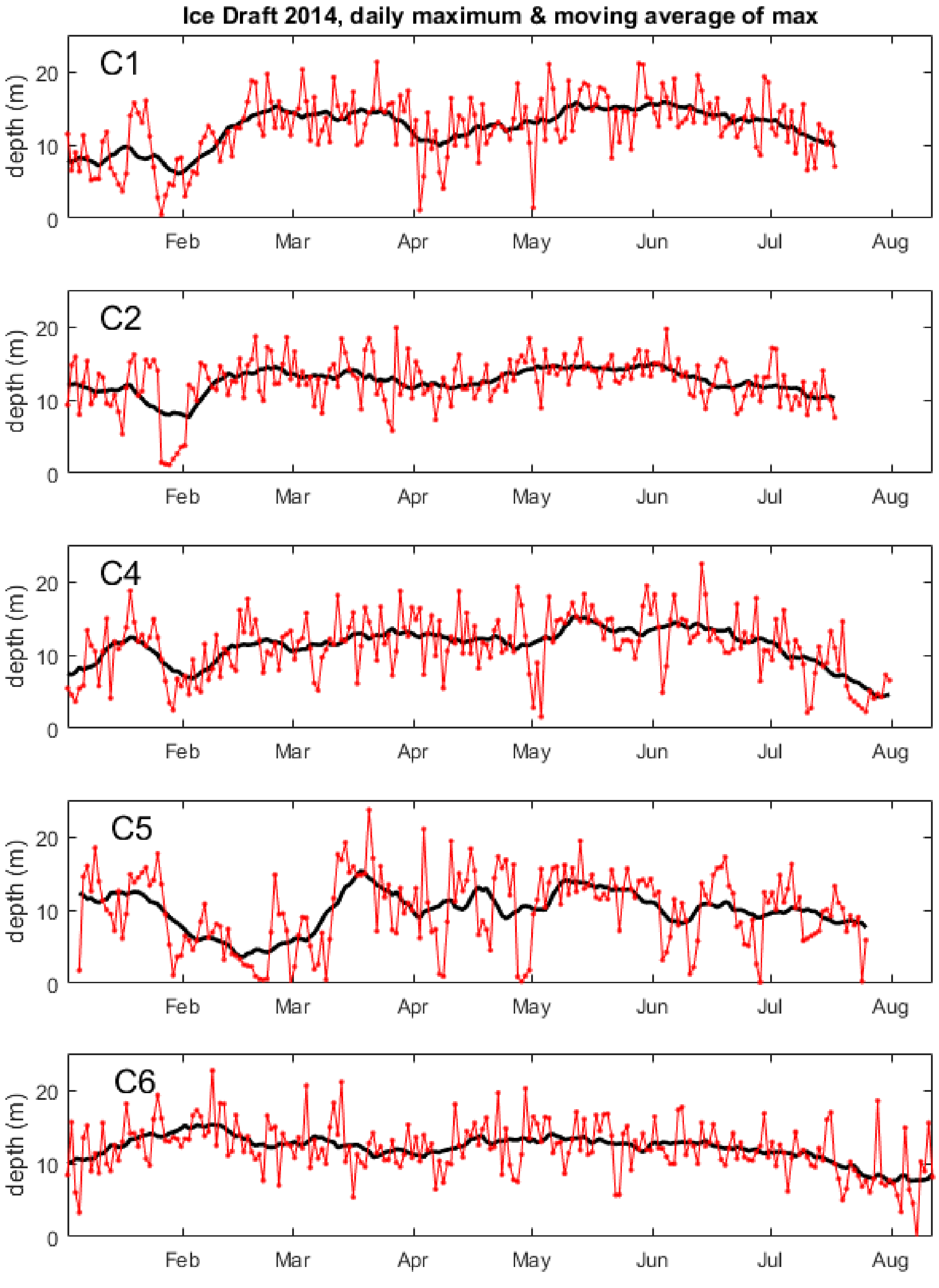


Figure 78. Time series of the daily maximum ice keel draft in 2014 (from the 2013-2014 dataset) at each mooring site. The 15-day running average is shown.

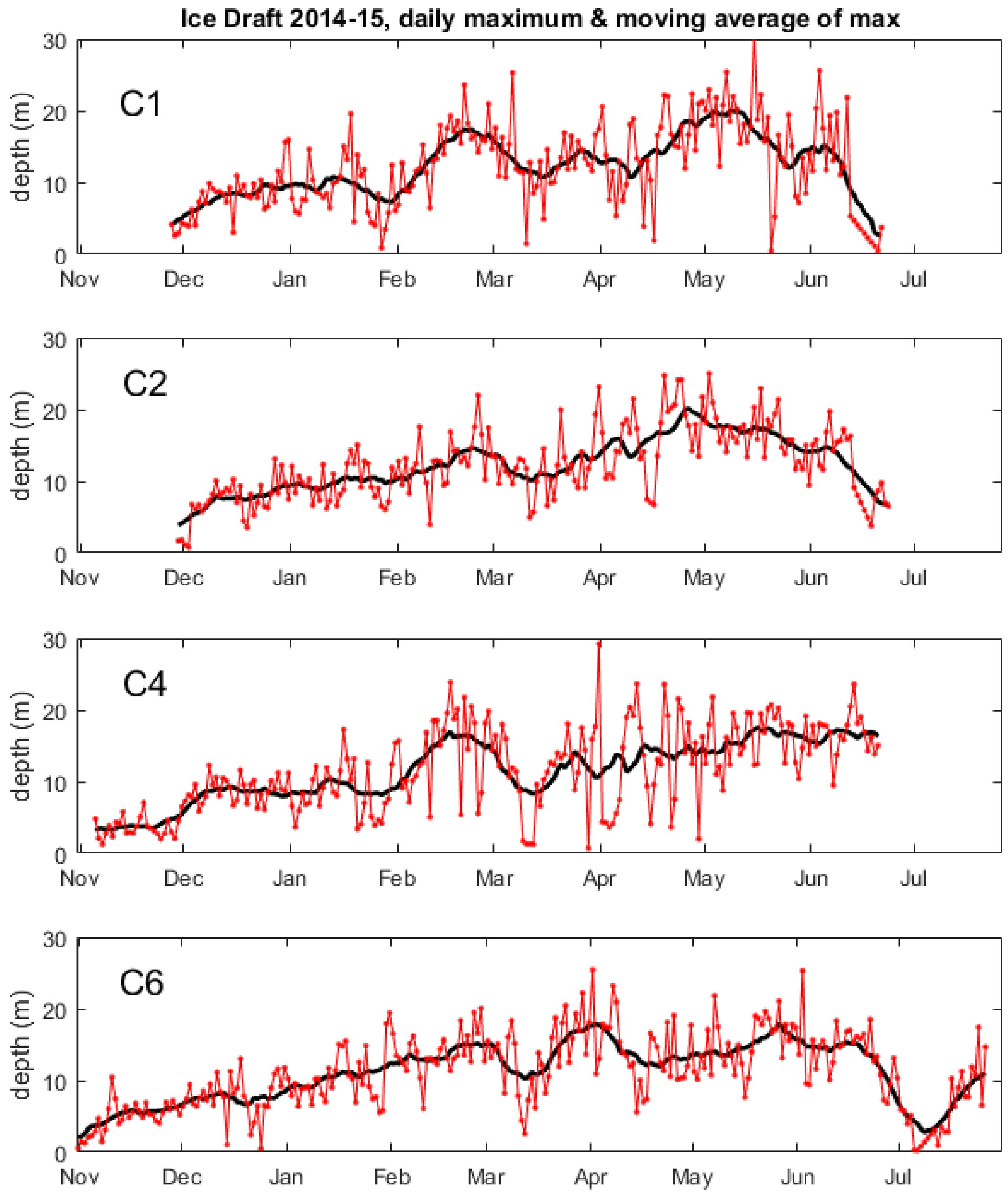


Figure 79. Time series of the daily maximum ice keel draft in 2014-2015 at each mooring site. The 15-day running average is shown.

Time series of currents at C9

In contrast to the relatively weak currents on the shelf, flow at C9 on the slope was stronger. During both deployments at C9 (Figures 80-81), there was evidence of the westward flowing Chukchi Slope Current (Corlett and Pickart 2017), which is also evident in the satellite-tracked drifter trajectories (Figure 74). The slope current extends from the surface to ~300 m depth and it is stronger during the summer months than during the winter. Below 300 m the flow weakens and in 2015-2016, there was a well-defined eastward flow at 377 and 672 m. Over the two years, mean flow (0.2 cm s^{-1}) at ~900 m does not differ significantly ($p<0.1$) from 0 cm s^{-1}.

Temperature and salinity at 300 m were consistent with Atlantic water. The drifter trajectories (Figure 74) provide evidence that this slope current extends along the slope as far west as Herald Canyon.

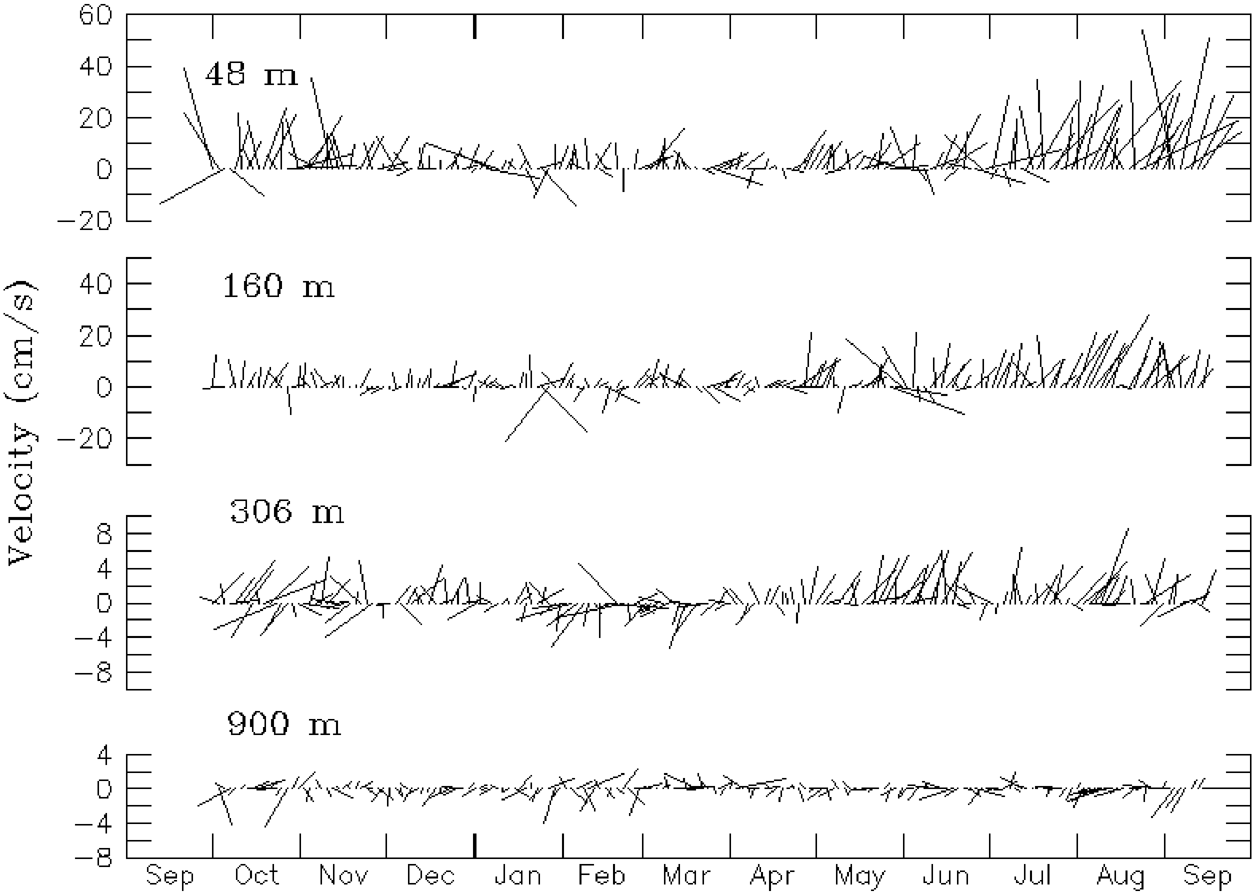


Figure 80. Low-pass filtered velocity (daily) data from selected depths at C9 in 2014-2015. The vectors were rotated -80° (upward is approximately westward). Note the bottom two time series have different scale from the top two times series.

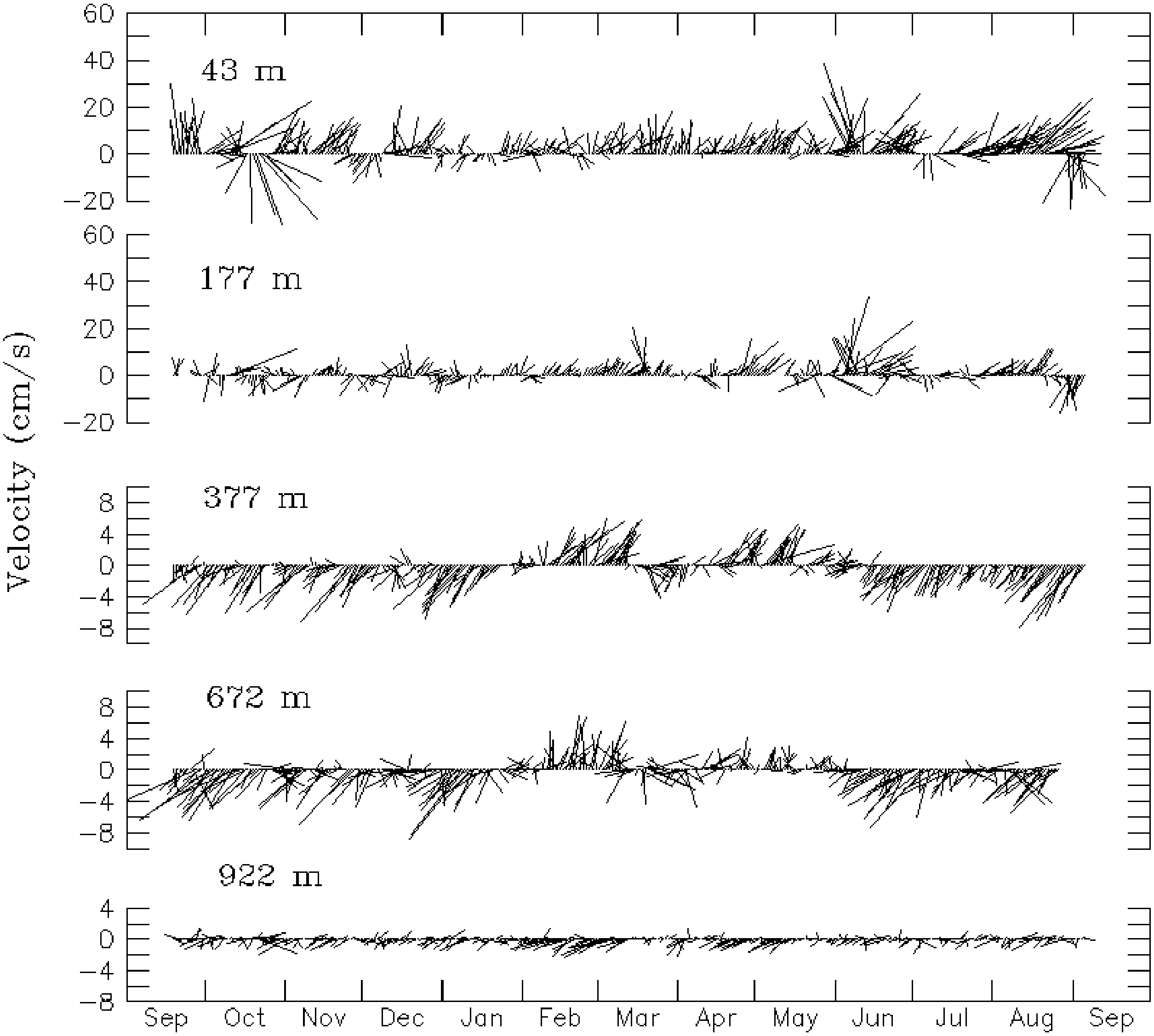


Figure 81. Low-pass filtered velocity (daily) data from selected depths at C9 in 2015-2016. The vectors were rotated -80° (upward is approximately westward). Note the bottom three time series have different scale from the top two times series.

Zooplankton Volume Backscatter Estimated From Multi-Frequency Acoustic Measurements (TAPS6-NG)

We were successful in updating the controller board to allow the instrument to sample the entire year. The new controller board is more reliable, easier to program, and has more storage capacity than the old board. However, we continued to have issues with the system that prevented successful application of this technology. In particular, the signal-to-noise ratio of the system was not optimal for this region and most of the time we could not distinguish between noise and zooplankton backscatter.

3. Discussion

The Arctic has changed markedly in the last decade, entering a new phase sometimes referred to as the “new normal” - thinner ice, earlier ice retreat in spring and late ice arrival in the fall, warmer ocean temperatures during summer, and changes in weather patterns (Wood et al. 2015). In addition, the northward transport of water through Bering Strait has increased during the last decade. These physical changes will continue to have profound impacts on this ecosystem. Long-term observations are necessary to quantify the changes in the ocean. In this report we focus our attention on Hanna Shoal and brief comparisons between conditions over the shoal and general patterns over the Chukchi Sea shelf. In our companion report for ARCWEST we explain in depth the patterns we observed over the entire shelf during the 3 study years (2013 - 2015).

Time Series of Physical and Chemical Data from Biophysical Moorings

Study of the Hanna Shoal region was relatively more difficult that the rest of the shelf, due to persistence of sea ice late in the season. Thus the data collected with moored instruments takes on increased importance in this region.

The currents measured at the mooring sites and the satellite-tracked drifters provided insight into the flow patterns over the eastern Chukchi Shelf. The flow around the north side of Hanna Shoal (C7 and C8) was weaker than expected, with stronger flow occurring south of the shoal. The flow at C6 was markedly weaker than that which occurs at Icy Cape as evidenced by the flow at C1, C2 and C3 (Figure 67). A map of the mean flows from a combination of previous work and the observations collected as part of CHAOZ-X and ARCWEST is shown in Figure 67.

In addition to weaker flow around the shoal, the temperatures and salinities at C6, C7 and C8 are much less variable than was observed nearer the coast. Bottom temperatures typically ranged between -2 and 0 °C, while along the coast bottom temperatures at times exceeded 6°C. The cause of this is likely due, at least in part, to advection of warmer Bering and Alaska Coastal Water along the coast, and timing of sea-ice retreat. Ice persists longer at Hanna Shoal, thus limiting local heating.

It is not surprising on such a shallow shelf, that the bottom currents are correlated with local winds. This is particularly true at C6 and C7. While the currents differ between the more coastal areas and the mooring around Hanna Shoal, the export of phytoplankton to the ocean bottom appeared to be similar. Light reaching the seafloor (where our moored instruments resided) began to increase in April or May, presumably with the melting of snow from sea ice and the increased day length and sun angle. The light levels then declined for about a month as epontic algae grew inside and directly beneath the ice in response to increasing light levels. This attenuated the light reaching the bottom. With the breakup and retreat of sea ice, we observed a sharp increase in chlorophyll fluorescence that was associated with increased dissolved oxygen saturation, implying that phytoplankton cells continue to photosynthesize at the sea floor on the shoal and that the rates of oxygen production from photosynthesis exceed rates of respiration by microbes and phytoplankton on the seafloor.

Peak chlorophyll fluorescence values appeared to be similar between the inshore mooring along the Alaska coast (C1, Figure 68) and the offshore moorings over Hanna Shoal (C6, C7, C8; Figures 69-73). Only in one time series were we able to observe something that could be considered a fall event where high levels of phytoplankton sank to the bottom (C8, 2014-2015).

The best time series of oxygen saturation was also from this mooring (C8, 2014-2015). The data from this time series are somewhat different from the data we obtained from the stations transects. In this case oxygen saturation sharply declined during periods of high fluorescence and then increased between the summer and fall maxima in chlorophyll fluorescence.

In sharp contrast to the shelf moorings (C1 - C8) measurements at C9 revealed a strong westward flow at the shelf break. This mooring provided some of the first current meter measurements of the slope flow. While C9 provided point source data for the flow, the drifters revealed its persistence as far west as Herald Canyon (Figure 74). The flow appears to be seasonal, with the strongest flow occurring during the summer months. The two years of data differ – with the flow stronger during 2014-2015 in the near surface and weaker during following year. In addition, during the second mooring deployment (2015-2016) there appeared to be a reversal of flow below 300 m, but comparison between the two deployments was difficult with the failure of the 600 m current meter in 2014-2015. During both years, the flow at the bottom was very weak and the two-year average did not differ significantly from zero ($p<0.1$). In summer of 2016, C9 was deployed for the third year, with more extensive temperature measurements. It is hoped that data from this third deployment will provide greater insight into the slope flow.

The thickness sea ice varied on scales of minutes - monthly. The deepest keels typically occurred in spring. It is not surprising that the deepest keels occurred near the coast where both onshelf flow of multi-year (thick) ice and the rafting of first year ice occurred. However, keels >25 m occurred at all mooring sites.

Performance of the TAPS6--NG was very disappointing. At the time the project was conceived it was difficult to obtain moored multi-frequency instruments suitable for this application. We chose, therefore to use an instrument that had been developed many years earlier, through support of the Office of Naval Research and the National Science Foundation to Drs. D. Van Holliday and Mr. Charles Greenlaw, both experts in the field. Some aspects of this particular design had been updated, however others, such as the controller CPU and coding language had not. Dr. Holliday, passed away in February 2010, before the first CHAOZ field season and Mr. Greenlaw retired from Tracor/BAE Systems however continued to support the TAPS instruments and was involved in our project as a contractor. We developed the ability to produce and calibrate the instruments here in Seattle and produced over 10 instruments that were deployed in the Arctic beginning in 2011. The instruments worked well on the bench and in soak tests in Lake Washington. However once deployed in the field, we soon experienced problems with the controller board; the instruments were not turning on and off as programmed and they ran out of battery power long before the deployment was finished and long before our battery endurance calculations predicted. We then embarked on an effort to redesign the controller board and replace the original CPU with a modern CPU that could be programmed in C (the old CPU was programmed in FORTH). This effort was successful, however by the time this effort was completed, there was only one field season remaining and during that deployment the signal-to-noise ratio for the instruments was not optimal to detect the low biomass of zooplankton in the Chukchi Sea water column.

Zooplankton Volume Backscatter Estimates Derived From ADCP Measurements

When we first examined the temporal patterns in ADCP-derived zooplankton volume backscattering from CHAOZ, we found evidence for diel vertical migration (DVM) in the echograms during the summer. We then looked at the annual data using a technique to measure the power in the diel (24 hr) and semi diel (12 hr) spectral bands. This technique was sometimes, but not always, able to detect statistically significant DVM, particularly if it only occurred during part of the year.

During ARCWEST and CHAOZ-X we repeated the analysis of annual backscatter data from the moored ADCP instruments in both regions. The results below focus on whether or not backscatter over Hanna Shoal different from that over the broader shelf, typified by data from site C2 (Table 29). In general we were able to analyze the data at two different depths, one at the surface and one in the bottom layer at a variety of locations.

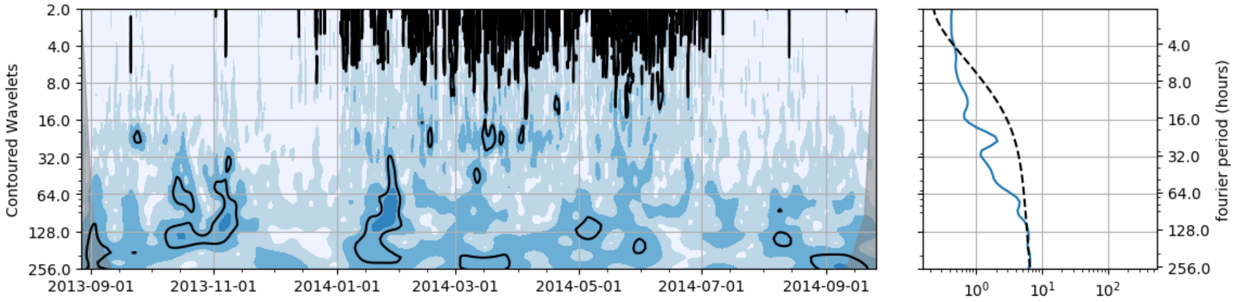
Table 29. Locations of ADCP backscatter (echo count) measurements during 2013 and 2014. This table focuses on a comparison between one station in the ARCWEST region (C2) and available measurements on and around Hanna Shoal (CHAOZ-X region). Water mass indicates the source of water generally found in that region (ACW = Alaska Coastal Water; BSW = Bering Shelf Water).

Mooring	Location	Depths	Project	Water Mass
2013				
C2	Icy Cape (mid shelf)	11, 31	ARCWEST	ACW/BSW
C6	Hanna Shoal (south flank)	11, 31	CHAOZ-X	BSW
C7	Hanna Shoal (north flank)	14, 32	CHAOZ-X	BSW
2014				
C8	Hanna Shoal (north flank)	10, 30	CHAOZ-X	BSW

We were successful making ADCP measurements and estimates of zooplankton backscatter at different sites around Hanna Shoal, however due to difficulty with some of the instruments we could not get measurements from all sites in all years.

There was little evidence for sustained, strong diel vertical migration by zooplankton and nekton scatterers over the shoal or at site C2 (Figures 82-84). However there were periods when DVM was evident in the wavelet analysis. Often times the analysis detected a diel signal when ice was still present over the region. For example in (e.g., Figure 83, Panel C - 2013, C7, 14 m) in the 24-hr band from around the first of February to the first of July.

A) 13CKP_2a_11m



B) 13CKP_2a_31m

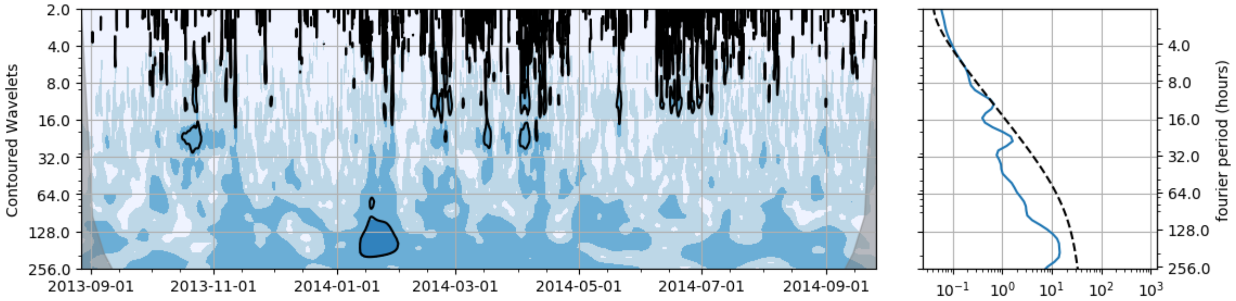
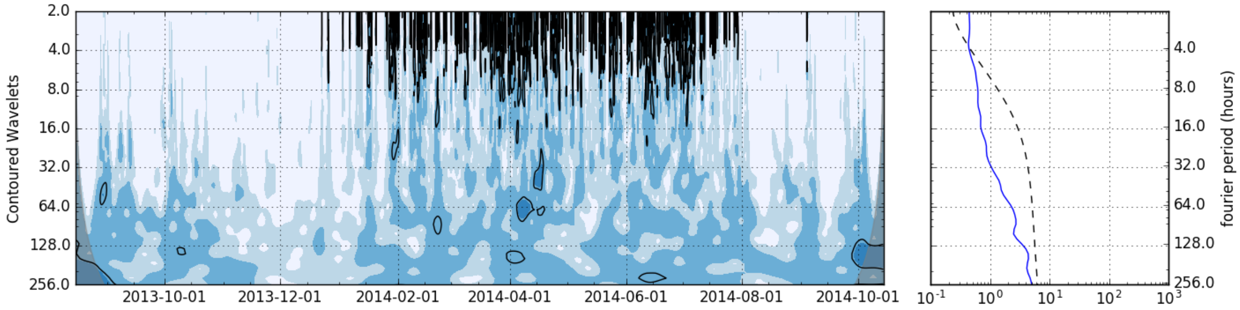
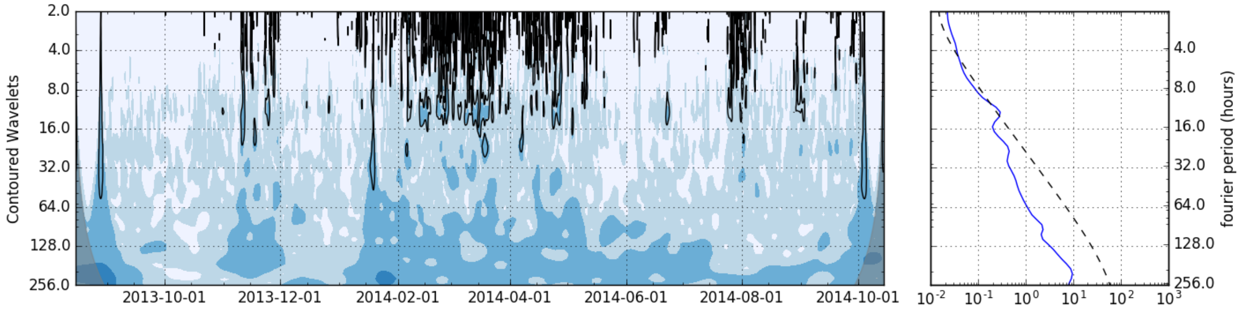


Figure 82. Wavelet analysis of 2013-2014 ADCP data at mooring C2 (middle of Icy Cape line).A) 11 m; B) 31 m. Left plots show contoured wavelet values as a function of date. Right plots show the average magnitude of temporal signal as a function of period. Dotted line is p = 0.05 such that when the peaks on the blue line are to the right of the dotted line, variability in that period is considered to be statistically significant. .

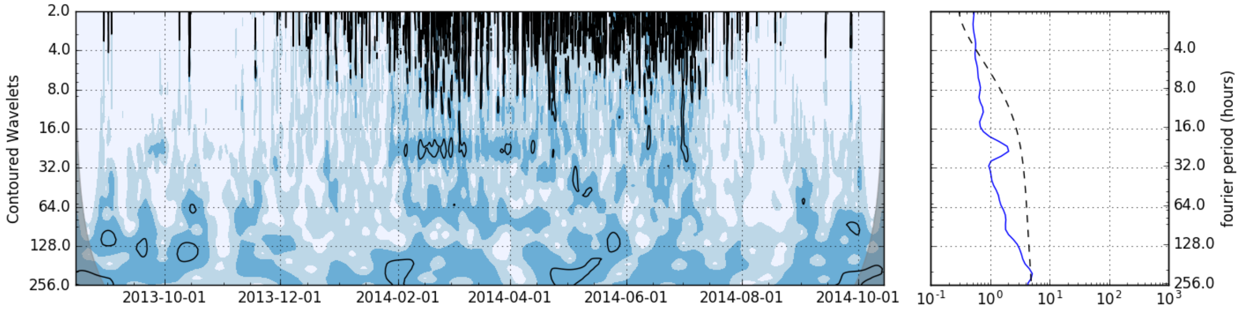
A) 13CKP_6a_11m



B) 13CKP_6a_31 m



C) 13CKP_7a_14m



D) 13CKP_7a_32m

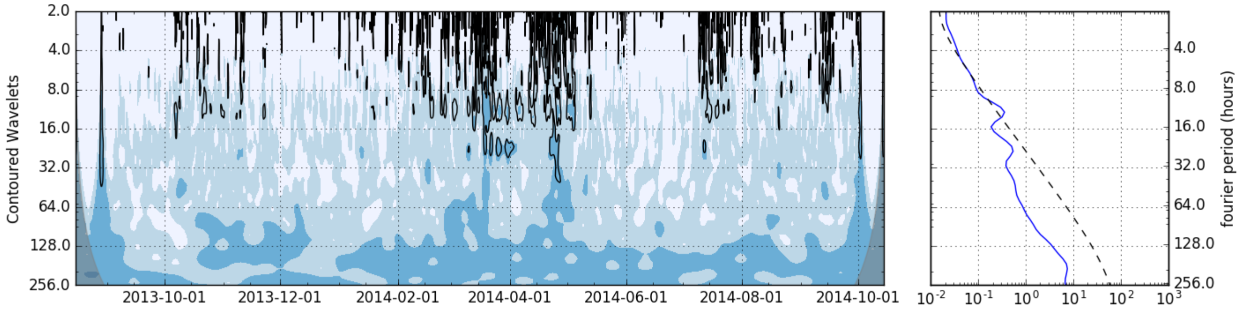
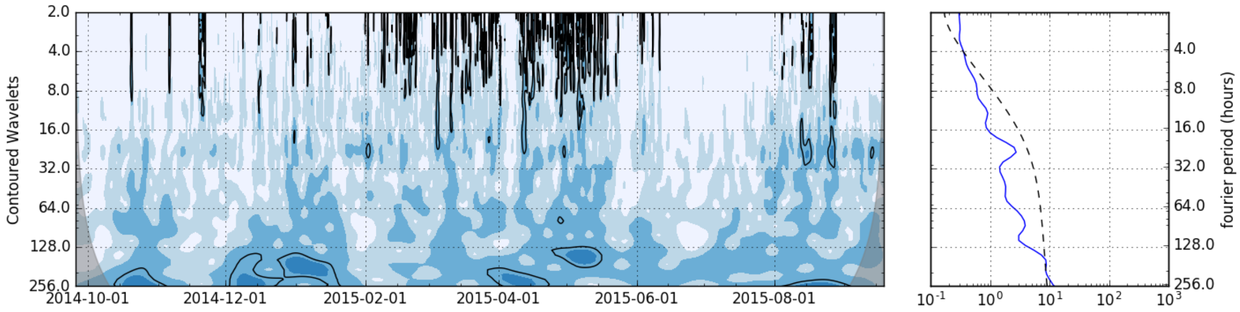


Figure 83. Wavelet analysis of 2013-2014 ADCP data at Mooring C6 (south flank of Hanna Shoal) and Mooring C7 (Northeast flank of Hanna Shoal). A) C6-11 m; B) C6-31 m; C) C7-14 m; D) C7-32 m. Details of plot construction are the same as in the previous figure.

A) 14CKP_8a_10m



B) 14CKP_8a_30 m

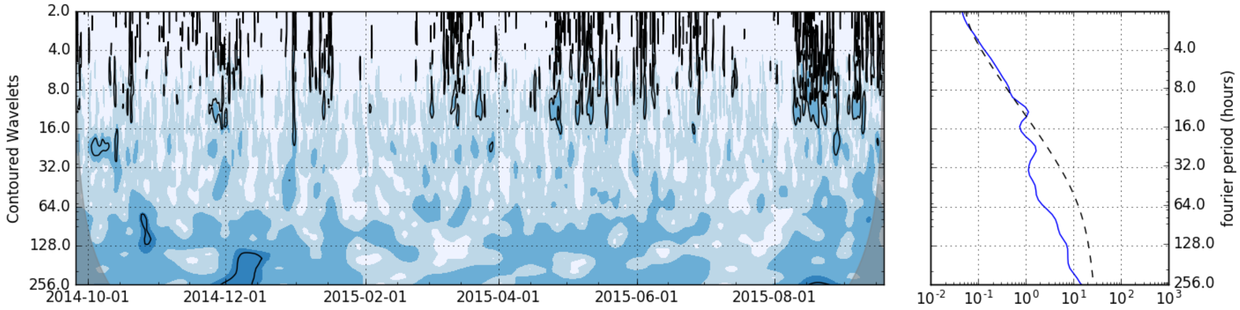


Figure 84. Wavelet analysis of 2014 - 2015 ADCP data at mooring C8 (northeast flank of Hanna Shoal). A) 10 m; B) 30 m. Details of plot construction are the same as in the previous figure.

4. Conclusions

- The Chukchi shelf is characterized as an inflow shelf for the Arctic (Carmack and Wassmann 2006), with ~1 Sverdrup of Pacific water entering the Arctic through Bering Strait (Woodgate et al. 2012). Approximately, 40% of this water flows over the US portion of the shelf and exits to the Arctic basin through Barrow Canyon, with most of this flow occurring south of Hanna Shoal.
- The currents in the vicinity of Hanna Shoal are significantly ($p<0.01$) correlated with winds.
- Ice is a primary forcing mechanism on this shelf. Ice typically appears sometime in November and disappears in July. The biggest ice keels appear in spring (often exceeding 20 m).
- During spring, melting sea ice results in export of large quantities of ice algae to the bottom (Martini et al. 2016). This pulse of organic matter supports the benthic communities that dominate this shelf.
- After the export to the bottom, oxygen concentrations increase, often exceeding 100% saturation for short periods in summer. Decreasing light in late summer results in a decrease in chlorophyll fluorescence and oxygen concentrations.
- By the end of summer, nitrate concentrations are usually low in the bottom layer of the ocean. Nitrate increases during the winter, often in phase with increases in salinity. The increases in nitrate during the fall and winter are not monotonic, but vary as different

water masses are advected past the moorings. By late spring, the nitrate supply is usually replenished near the sea floor.

This system is dominated by high seasonal and interannual variability and changing conditions. Moore et al. (2016) developed the Arctic Marine Pulses conceptual model which identifies the importance of these pulses to this ecosystem - late spring brings the increased river runoff and the retreat of sea ice and all the concomitant factors (e.g., warming, the “pulse” of productivity exported to the seafloor, increased transport through Bering Strait), while fall brings the return of sea ice, cooling, reduction in light, and retreat of many species southward.

5. Recommendations

As ice disappears in fall and spring, the wave heights in the open water become greater (ice dampens wave heights), which will have a profound impact on coastal communities (via erosion, flooding, etc.). The wave height data collected by these moorings will provide a range of wave heights to expect as ice disappears. Additionally, as weather patterns change, the strength of the transport along the Alaskan coast will also change. This Bering Water is an important source of heat, salt and nutrients to the entire Arctic. Increases in the flux of heat will in turn impact the timing of freeze up, and may well exacerbate the increase of open water storms during the fall and spring. It is therefore critical that we continue to moor physical and biological instrumentation in close proximity to better conduct interdisciplinary studies in this period of rapid environmental change to better predict the effects of these changes on the ecosystem. Biophysical moorings have been deployed each year since 2010 on the Icy Cape line (inshore, midshore, and offshore), thus it is essential that we maintain this now, long-term dataset. The measurements of currents provide an estimate of transport along the Alaskan coast in the Chukchi Sea. These, combined with measurements of temperature, salinity, chlorophyll fluorescence, nutrients and PAR will provide indices to better understand how the ecosystem is changing, especially under ice cover.

One of the questions that needs to be addressed in regard to the nutrient budget is whether the nutrients on the southern and middle shelf are replenished primarily by advection or if local nitrification plays a role. Observations show great horizontal variability in many lower trophic level parameters (e.g., temperature, salinity, nutrients, primary production, etc.). One of the important questions is what occurs under the ice and in the water column not just for the short time that ships collect data, but also in fall-early spring period. New technology (e.g., wave gliders, Saildrones) can play an important role in both mapping and better understanding the small scale mechanisms that influence the spatial patterns and what occurs under the ice.

Since the project inception over 7 years ago, a new, low-power, wide band, commercial echosounder has been developed for application on moorings. It has been used to successfully examine fish backscatter in the Gulf of Alaska by the AFSC’s midwater fish assessment group (De Robertis et al. 2017). The instrument will be deployed in the Arctic in 2017 as part of the NPRB-BOEM-NOAA-UAF sponsored Arctic Integrated Ecosystem Research Program. This instrument and techniques developed at the AFSC to discriminate fish from euphausiids in acoustic data (Ressler et al. 2012; Smith et al. 2013) show great promise for remote determination of the temporal and spatial distribution of euphausiids in the Arctic. Integrated ecosystem research needs to continue, but to understand mechanisms, regional scale modeling is a crucial partner with observations.

B. Shipboard Observations *(Lines: IC, WT, HS, BX, BC)*

1. Methods

Hydrography-- Physical and Chemical Variables

Hydrographic data were collected during cruises in 2013, 2014 and 2015 (Table 30). The primary design of the hydrographic survey was to collect temperature, salinity, chlorophyll fluorescence, oxygen and PAR using a Sea-Bird SBE 911plus platform and to collect samples of oxygen, chlorophyll, nutrients (nitrate, phosphate, silicate, nitrite and ammonium), and salinity at alternate stations (see Figure 2 for station locations). In addition, CTD casts were collected at the moorings sites and other sites when time permitted. The primary purpose of the salinity and oxygen samples was to calibrate the instruments on the CTD. In addition, CTD casts were made following or preceding mooring recoveries and deployments; these measurements were used for quality control of the data collected by instruments on the moorings.

In 2013-2015, sampling was done with a Sea-Bird SBE 911plus system with dual temperature and salinity sensors, and oxygen (SBE-49) sensors, a photosynthetically active radiation (PAR) sensor (Biospherical Instruments QSP-200 L4S or QSP-2300), and a chlorophyll fluorescence (WET Labs WETStar WS3S) sensor. Nutrients and chlorophyll samples were collected at the surface, at 10-meter intervals, and at the bottom of the cast.

Specifically, samples collected to measure dissolved inorganic nutrients were filtered through 0.45 µm cellulose acetate filters, frozen on board the ship (-40°C), and analyzed at PMEL. Measurements were made on an automated continuous flow analyzer with segmented flow and colorimetric detection. Protocols of Gordon et al. (1994) were used for analysis of phosphate, silicic acid, nitrate and nitrite, and protocols from Mantoura and Woodward (1983) were used for analysis of ammonium. These protocols include calibration of labware, preparation of primary and secondary standards, and corrections for blanks and refractive index.

Chlorophyll-a and phaeopigment concentrations were estimated after extracting the filters for 24 hr extraction in 90% acetone in the dark at – 80°C. We used a Turner Designs TD-700 fluorometer calibrated with pure chlorophyll-a measuring fluorescence before and after acidification. Salinity calibration samples were taken on approximately half the casts and analyzed using a laboratory salinometer at PMEL. Oxygen samples were taken on most casts and titrated using the Winkler method. The number of CTD stations and the number of nutrient and chlorophyll samples collected are shown in Table 30.

Table 30. The number of hydrographic stations occupied in the Chukchi Sea together with the number of nutrient (nitrate, nitrite, ammonium, silicate, phosphate) samples and the number of chlorophyll samples collected and processed.

Dates	CTD	Nutrients	Chlorophyll	Ship
12 Aug-17 Sep 2013	48	247	224	*F/V Aquila*
7 Sep-20 Oct 2014	86	444	425	*F/V Aquila*
6 Aug-4 Sep 2015	127	693	465	*NOAA Ronald H. Brown*
6 Sep-26 Sep 2015	16	74	68	*F/V Aquila*
3 Sep-29 Sep 2016	71	369	423	*F/V Aquila*

Chlorophyll data analysis

Chlorophyll concentrations (mg m^{-3}) from the individual depths were interpolated along each transect to produce section plots of discrete depth chlorophyll-a concentration using the point Kriging algorithm in Surfer v.10 (Golden Software). Threshold values for the subsurface chlorophyll maximum were calculated according to Martini (2016) using the extracted chlorophyll-a concentrations.

Zooplankton Net Data

Zooplankton were collected on each cruise using a multiple-opening and closing 1 m^2 Tucker Sled trawl equipped with sled-like runners at the bottom so that samples could be taken in close proximity to the bottom (Dougherty et al. 2010; Figure 85). Two 505 µm mesh nets were used for most of the tows – one was opened and closed while the sled was on the bottom and the other was used to obtain plankton from the ocean bottom to the surface. A 25 cm net with 150 µm mesh was suspended in the net that profiled the entire water column. Temperature and conductivity measurements of the water column were obtained with a SeaBird FastCAT (SBE 49) mounted on the sled behind the net mouth. Both Tucker nets contained a calibrated General Oceanic flow meter to estimate volume filtered. Net configurations, sampling strategy, and instruments for individual years are described in Table 31.

When two 505 µm nets were used, the bottom net was fished for 2 minutes along the bottom before being closed. At closure, the frame was retrieved at approximately 20 m/min so that the second net sampled the entire water column. Plankton captured by the nets was washed into the cod ends, sieved through identically-sized wire mesh screens and preserved in glass jars with sodium borate-buffered 5% Formalin. Samples were inventoried at the end of the cruise and then sent to the Polish Sorting Center in Szczecin, Poland for processing. Subsampled taxa were enumerated and identified to lowest possible genera and life stage and returned to Seattle for verification. A portion of the returned samples were QA/QC'd for species identification and enumeration. The remainder of the sample was archived at the Polish National Marine Fisheries

Research Institute in Gdynia, Poland and will be archived there for 20 years from the date of sample collection, under an existing Joint Studies Agreement between the U.S. NOAA-Fisheries and the Polish National Marine Fisheries Research Institute. After 20 years the samples will be destroyed. Zooplankton data from this project are stored in the NOAA-Fisheries, AFSC, Recruitment Processes Program relational database, EcoDAT.

Figure 85. 1 M^2 Tucker sled on the icy deck of the R/V *Aquila*. The kneeling scientist has his head in the net mouth. The TAPS-6 (black canister) is mounted on the top bar of the tucker frame and is pointed down into the tow path of the net. The transducer faces point to the right and down in this picture.

Zooplankton Data Analysis

A Welch's two sample t-test was done using R Base package to determine if the yearly means of each zooplankton taxa category of interest were statistically different from each other. Nonparametric multivariate analyses were done using PRIMER-E and R vegan package. Only species that had at least 2% occurrence were included in the analysis. The zooplankton abundances were 4th root transformed so that the less abundant taxa were more equally represented. A Bray-Curtis similarity matrix was calculated for each station and the matrix was used to conduct a cluster analysis with all three years combined (2013 – 2015). The similarity matrix for each station was also used to conduct a cluster analysis for each individual year and to produce a non-metric, multidimensional scaling plot (NMDS).

A generalized additive model (GAM) with a Gaussian distribution was used to determine general patterns of the abundance anomalies for the calanoid copepod *Calanus glacialis*. This was done using the arm and mgcv packages from R. The smoothing parameter estimation method was Generalized Cross-validation (GCV), and model selection was done by balancing deviance explained and the Bayesian Information Criterion (BIC) score to avoid overfitting and preferring parsimony. Six years of zooplankton data (2010-2015) were used to create the model. The abundance anomaly was calculated by subtracting the integrated abundance at a particular station from the mean integrated abundance for all years and dividing by two times the standard deviation of the integrated abundance for all years. There were twenty environmental predictors used as independent variables of which only eight significantly contributed to model performance. Latitude and longitude were kept in the model to retain the spatial component even though they did not contribute significantly to the model. Environmental predictors used were those co-collected with zooplankton tows, except for the surface transport. Surface transport was calculated from u and v wind velocities from the North American Regional Reanalysis (NARR) model output. To improve model performance the abundance anomaly and mean chlorophyll-a were log transformed.

Table 31. Net configuration and sampling strategy for all transect lines except the Barrow Canyon line (BC). On that transect line no along-bottom net tow was attempted.

Year	Large Mesh Nets	Small Mesh Nets
2013	505	153
2014	505	153
2015 NOAA Ship *Ron Brown*	505	153
2016	505	153

2. *Results*

Hydrography -- Physical and Chemical Variables

The Chukchi Sea consists of a broad shallow shelf (Figure 86), which is incised by two major canyons at the slope – Barrow Canyon in the east and Herald Canyon in the west. The flow on the eastern part of the shelf is generally northward and follows bathymetry (Figure 86). Three types of water enter into the Chukchi shelf through Bering Strait: Alaska Coastal Water (ACW), Bering Sea Summer Water (BSSW) and Anadyr Water (AW). In addition, intrusions of Atlantic water (AtlW) from the Arctic Ocean basin onto the shelf can occur either through Barrow Canyon or over the shelf break to the west of Barrow Canyon. Water properties are modified by local processes such as ice formation and melt, and production and remineralization. Thus the physical, chemical, and biological properties over the shelf are the sum total of advective and *in situ* processes. Table 32 summarizes the range of temperature and salinity expected for each water type. Data collected through this program provides insight into the magnitude of transport and flow pathways, and associated fluxes.

Table 32. Temperature and salinity ranges for different water masses in the Chukchi Sea. (From Danielson et al. 2017).

Water Mass	**Temperature (°C)**	**Salinity**
Alaska Coastal Water (ACW)	7 - 12	20 - 32
Winter Water (WW)	-2 - 0	30 - 33.5
Bering Shelf Summer Water (BSSW)	0 - 8	30 - 33.5
Atlantic Water (AtlW)	-2 - 1	33.5 - 35

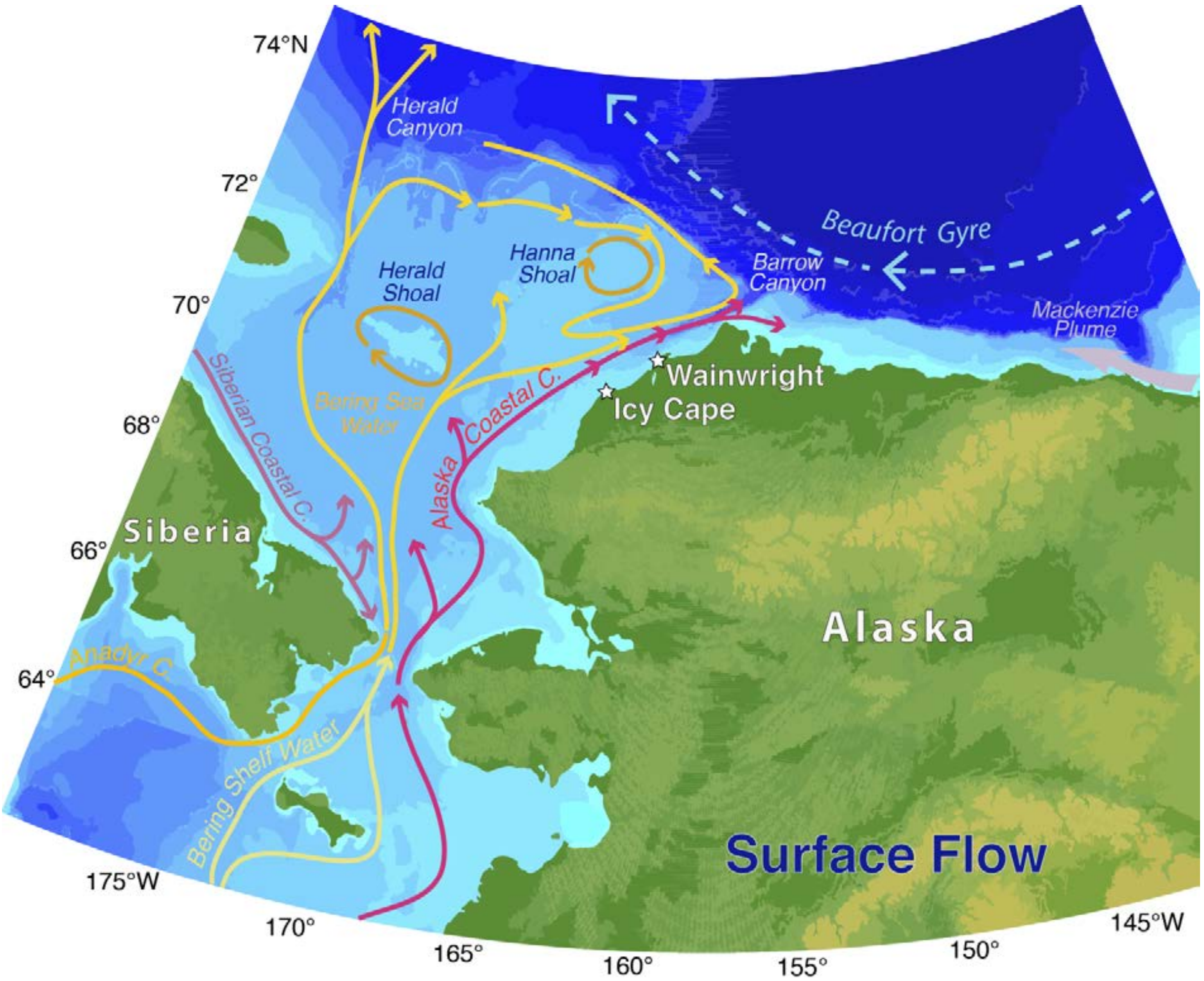


Figure 86. Map of currents over the Chukchi shelf (modified from Wood et al. 2015).

Interannual and spatial variability among hydrographic sections

Two hydrographic lines were occupied (BX and Hanna Shoal), but these lines were not fully occupied each year (Figure 2, Table 33). The Icy Cape, Wainwright, and Barrow Canyon lines were part of the ARCWEST program, but are included in this report to provide additional context for BX and Hanna Shoal lines.

Nitrite is an intermediate compound in several important biological reactions, and concentrations are generally low. While sections of nitrite are shown for completion, these will not be discussed. Note that our hydrographic transects were occupied at very different times in the three years of this project: 2013 – early September; 2014 – late September/early October; and 2015 – mid August.

With a few exceptions surface temperatures were warmer in 2015, and bottom waters were colder and saltier in 2013. Higher salinities in 2013 were generally associated with increased nutrient content in the bottom water. The following sections highlight distinctive features and variability along each hydrographic line.

Table 33. Five primary hydrographic lines (including the Icy Cape, Wainwright and Barrow Canyon lines that were part of the ARCWEST program). X indicates the lines were occupied, P that it was partially occupied and blank that no data were collected along that line.

Hydrographic Lines	2013	2014	2015
BX	X	P	X
Hanna Shoal	X	X	
Icy Cape	P	X	X
Wainwright	X	P	X
Barrow Canyon	X	X	X

<u>Icy Cape</u> (Figures 87-89)

In 2013, the innermost stations could not be sampled. As in all other hydrographic lines presented here, the warmest surface temperatures were observed in 2015. Conditions in 2013 were much different than in the other two years with cooler surface waters that were especially fresh offshore, a strong 2-layer system inshore, bottom waters that were cold, salty, and nutrient-rich, and a subsurface layer with a thin subsurface chlorophyll maximum (SCM) at several stations and supersaturated oxygen content. In 2014, stratification was relatively weak, especially nearshore, and there was relatively high chlorophyll fluorescence throughout the water column in the northwest. In 2015 there was a two-layered system, but to a lesser extent than in 2013. Nitrate was generally depleted in the surface waters in all years and in 2015 it was depleted at depth despite a stratified water column. Ammonium was high in bottom waters in all years.

Wainwright (Figures 90-92)

In 2013, conditions at Wainwright and Icy Cape were similar with a cold, salty and nutrient rich bottom layer, and a layer of supersaturated oxygen just above the SCM. However, unlike Icy Cape, bottom waters at Wainwright were more under saturated in oxygen. A distinctive feature in the 2013 section was an upper layer of unusually fresh water that extended over most of the section. Salinities in this layer were similar to those observed at the offshore stations at Icy Cape in 2013. In 2014, the innermost stations could not be sampled, but many of the same features observed in 2013 were observed offshore including cold bottom water, an SCM, and oxygen supersaturation just above the chlorophyll maximum. However, in 2014, nutrient concentrations were lower, especially nitrate which had concentrations < 5 µM in the bottom layer. In 2015, temperatures were warmer than in 2013, nutrient concentrations remained relatively low compared to 2013, and stratification was weaker at the innermost stations. Although there was an SCM, oxygen concentrations were not > 120% supersaturated as in the previous years.

Barrow Canyon (Figures 93-95)

In 2013, a fresh surface layer extended over most of the transect line. The observation of this layer at Icy Cape, Wainwright and Barrow Canyon suggests extensive ice melt with relatively little mixing in the northeastern Chukchi Sea. In 2013, there was a deep layer of cold, salty and nutrient-rich water that extended across most of the canyon, but in 2014 and 2015, this deep layer was not observed over the southeastern portion of the canyon. The subsurface chlorophyll maximum was observed to extend across the entire transect in 2013, while in 2014 and 2015 it was much more patchily distributed. In 2015 high chlorophyll fluorescence extended to the surface at 2 stations over the southeastern portion of the transect. The size of the subsurface nitrate pool decreased from 2013 to 2015.

BX Line (Figures 96-98)

The BX Line was parallel to and ~80 km from the coast, and the bathymetry along this section was relatively flat. The BX Line connected the end of the Barrow Canyon Line with the Wainwright Line, therefore properties at the NW end of the Barrow Canyon Line were very similar to the NE end of the BX Line. In 2013 and 2015, the pycnocline and nutricline were relatively flat, but in 2014 these isolines dipped to the northeast. Bottom water retained properties of winter water with very cold temperatures and high nutrient concentrations. There was an SCM with oxygen supersaturation generally above the SCM and undersaturated waters below the SCM. These features were especially intense in 2015.

Hanna Shoal Line (Figures 99-100)

The Hanna Shoal Line and outermost portion of the Wainwright Line connected over Hanna Shoal, therefore properties at the NW end of the Wainwright Line were very similar to the SW end of the Hanna Shoal Line. Even though Hanna Shoal was only 30 m in depth, the water column had not mixed and a two-layer structure was retained over the shoal. As observed on the Wainwright Line, there was an SCM with oxygen supersaturation generally above the SCM and under saturated waters below the SCM, and nitrate concentrations were especially low in 2014. The subsurface fluorescence maximum was near bottom over the top of the shoal, but stayed at that depth (~30 m) as the seafloor deepened towards the northeast where nitrate was still >1 µM.

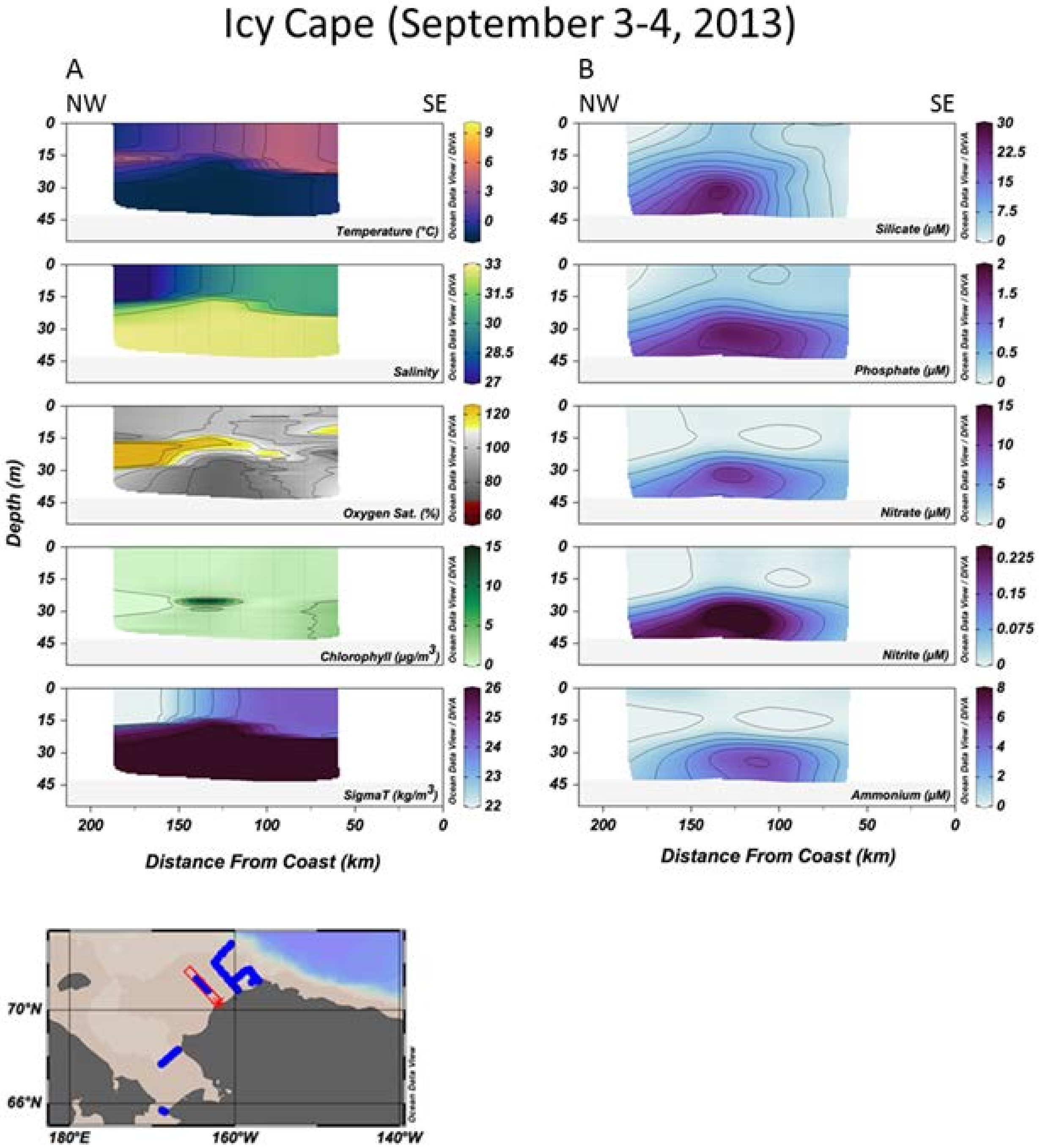


Figure 87. Hydrographic measurements at Icy Cape in September 2013. (A) Temperature, salinity, oxygen (percent saturation), chlorophyll fluorescence and sigma-t. (B) The five nutrients (silicate, phosphate, nitrate, nitrite and ammonium). The coastline is on the right side of each plot. The line occupied is indicated in red in the bottom left panel.

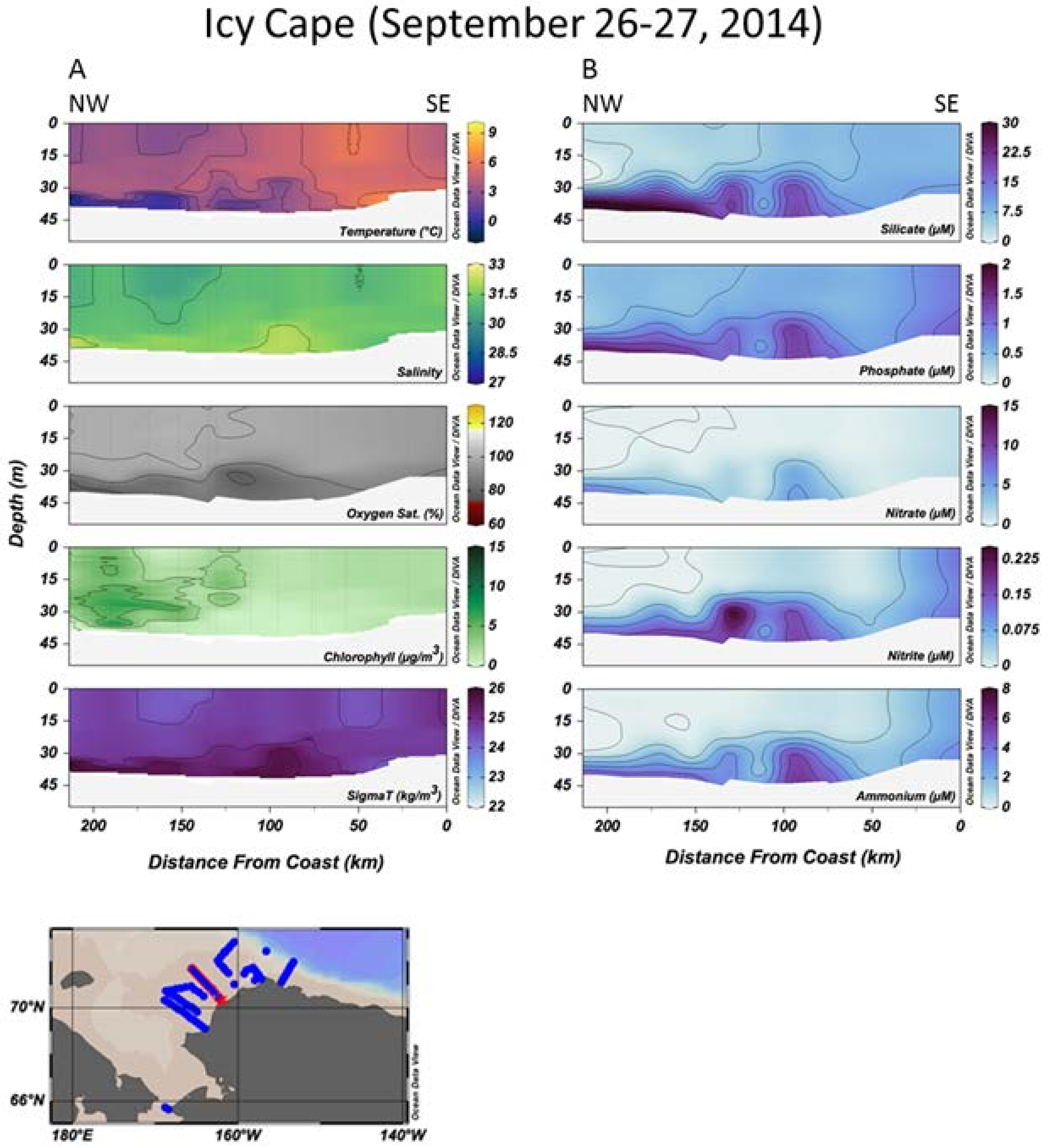


Figure 88. Hydrographic measurements at Icy Cape in September 2014. (A) Temperature, salinity, oxygen (percent saturation), chlorophyll fluorescence and sigma-t. (B) The five nutrients (silicate, phosphate, nitrate, nitrite and ammonium). The coastline is on the right side of each plot. The line occupied is indicated in red in the bottom left panel.

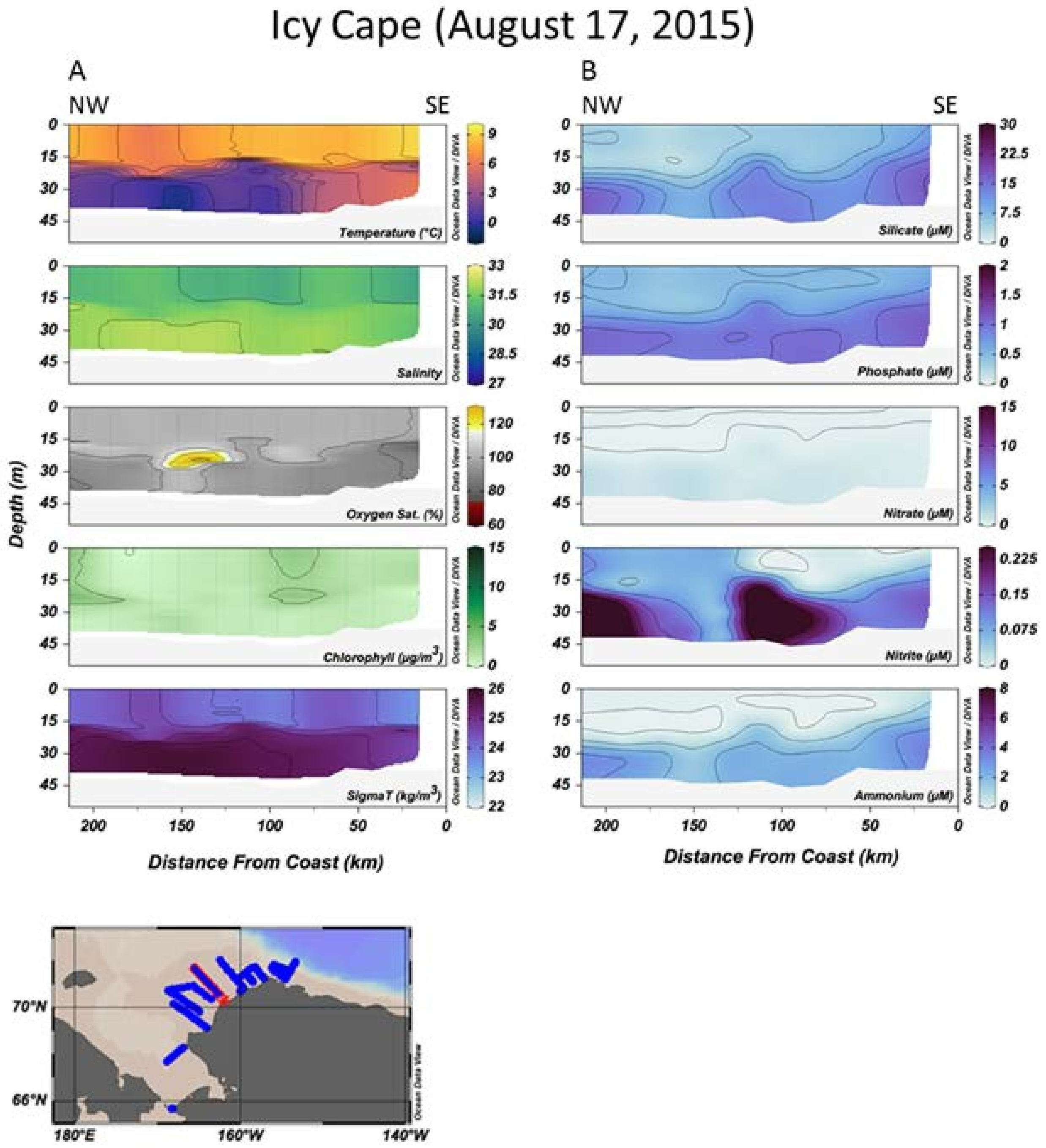


Figure 89. Hydrographic measurements at Icy Cape in August 2015. (A) Temperature, salinity, oxygen (percent saturation), chlorophyll fluorescence and sigma-t. (B) The five nutrients (silicate, phosphate, nitrate, nitrite and ammonium). The coastline is on the right side of each plot. The line occupied is indicated in red in the bottom left panel.

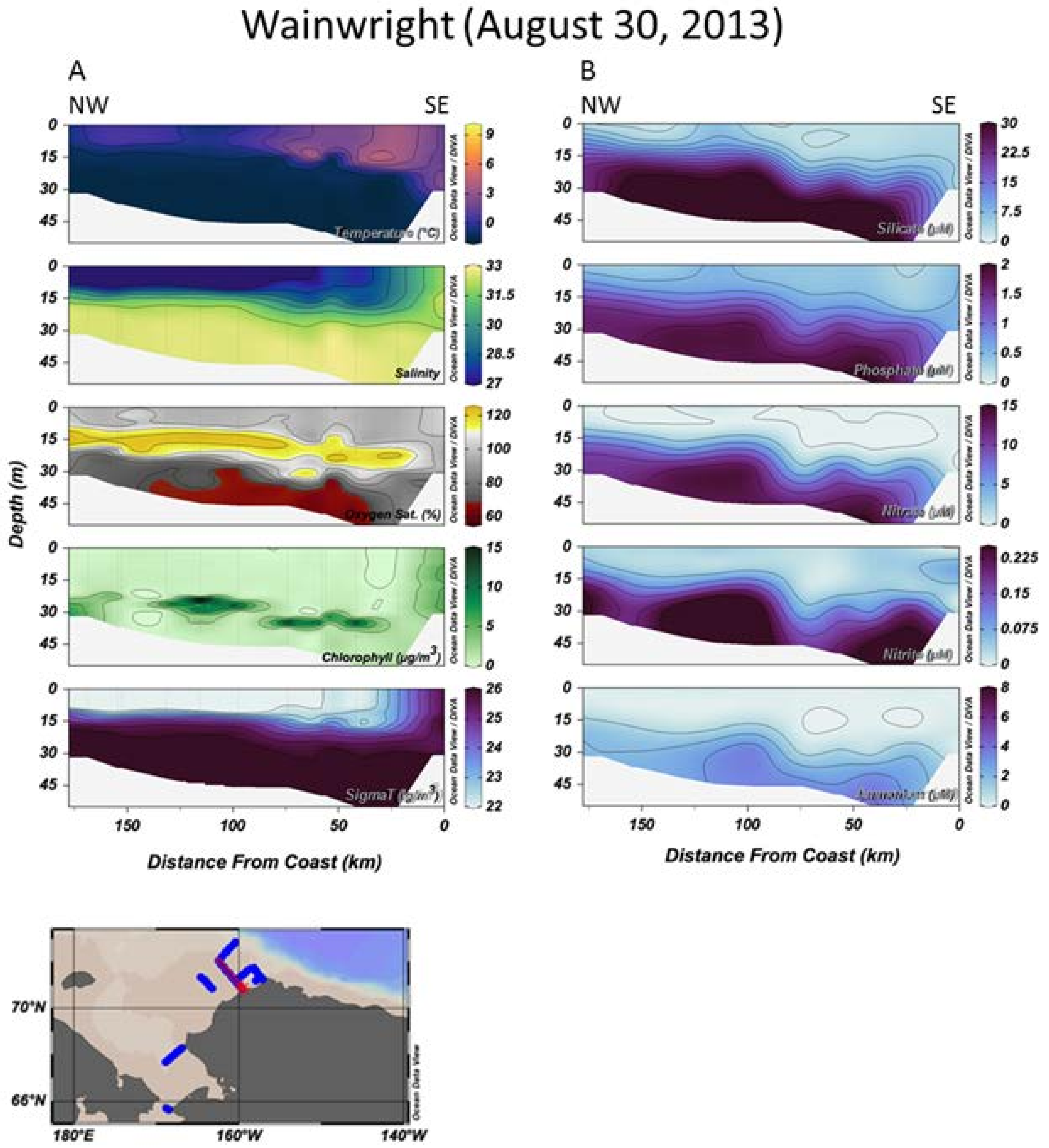


Figure 90. Hydrographic measurements at Wainwright in August 2013. (A) Temperature, salinity, oxygen (percent saturation), chlorophyll fluorescence and sigma-t. (B) The five nutrients (silicate, phosphate, nitrate, nitrite and ammonium). The coastline is on the right side of each plot. The line occupied is indicated in red in the bottom left panel.

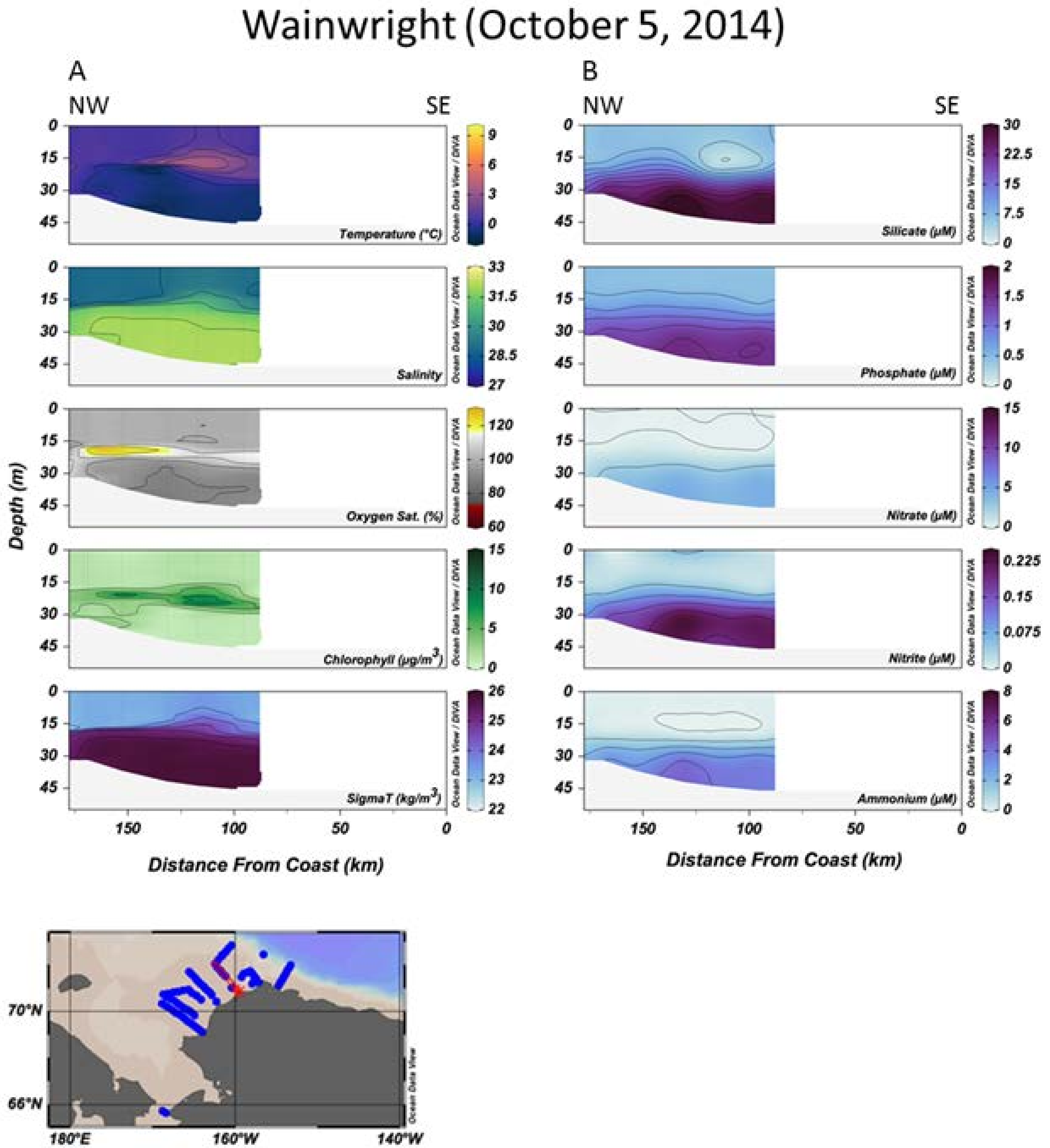


Figure 91. Hydrographic measurements at Wainwright in October 2014. (A) Temperature, salinity, oxygen (percent saturation), chlorophyll fluorescence and sigma-t. (B) The five nutrients (silicate, phosphate, nitrate, nitrite and ammonium). The coastline is on the right side of each plot. The line occupied is indicated in red in the bottom left panel.

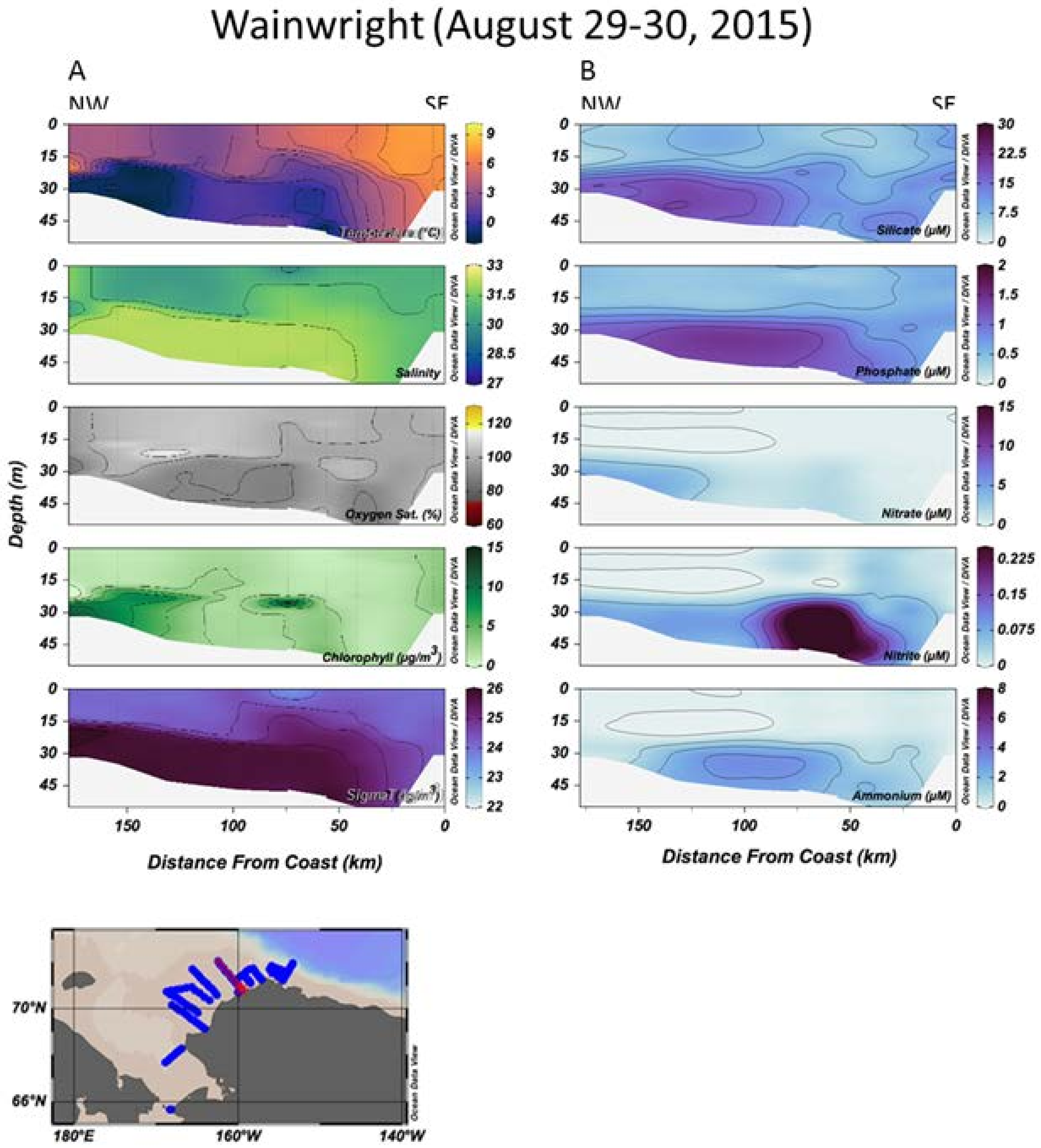


Figure 92. Hydrographic measurements at Wainwright in August 2015. (A) Temperature, salinity, oxygen (percent saturation), chlorophyll fluorescence and sigma-t. (B) The five nutrients (silicate, phosphate, nitrate, nitrite and ammonium). The coastline is on the right side of each plot. The line occupied is indicated in red in the bottom left panel.

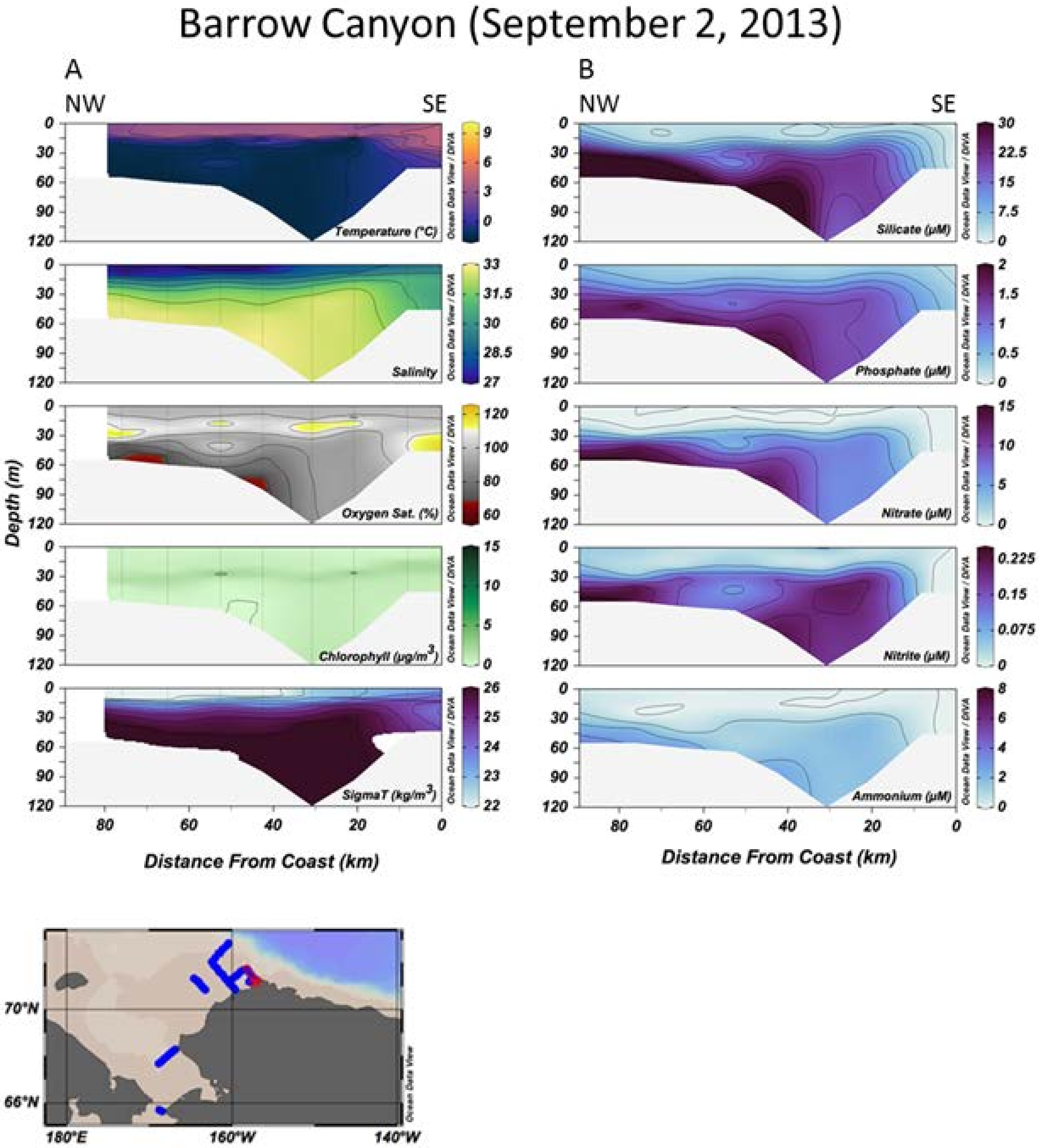


Figure 93. Hydrographic measurements at Barrow Canyon in September 2013. (A) Temperature, salinity, oxygen (percent saturation), chlorophyll fluorescence and sigma-t. (B) The five nutrients (silicate, phosphate, nitrate, nitrite and ammonium). The coastline is on the right side of each plot. The line occupied is indicated in red in the bottom left panel.

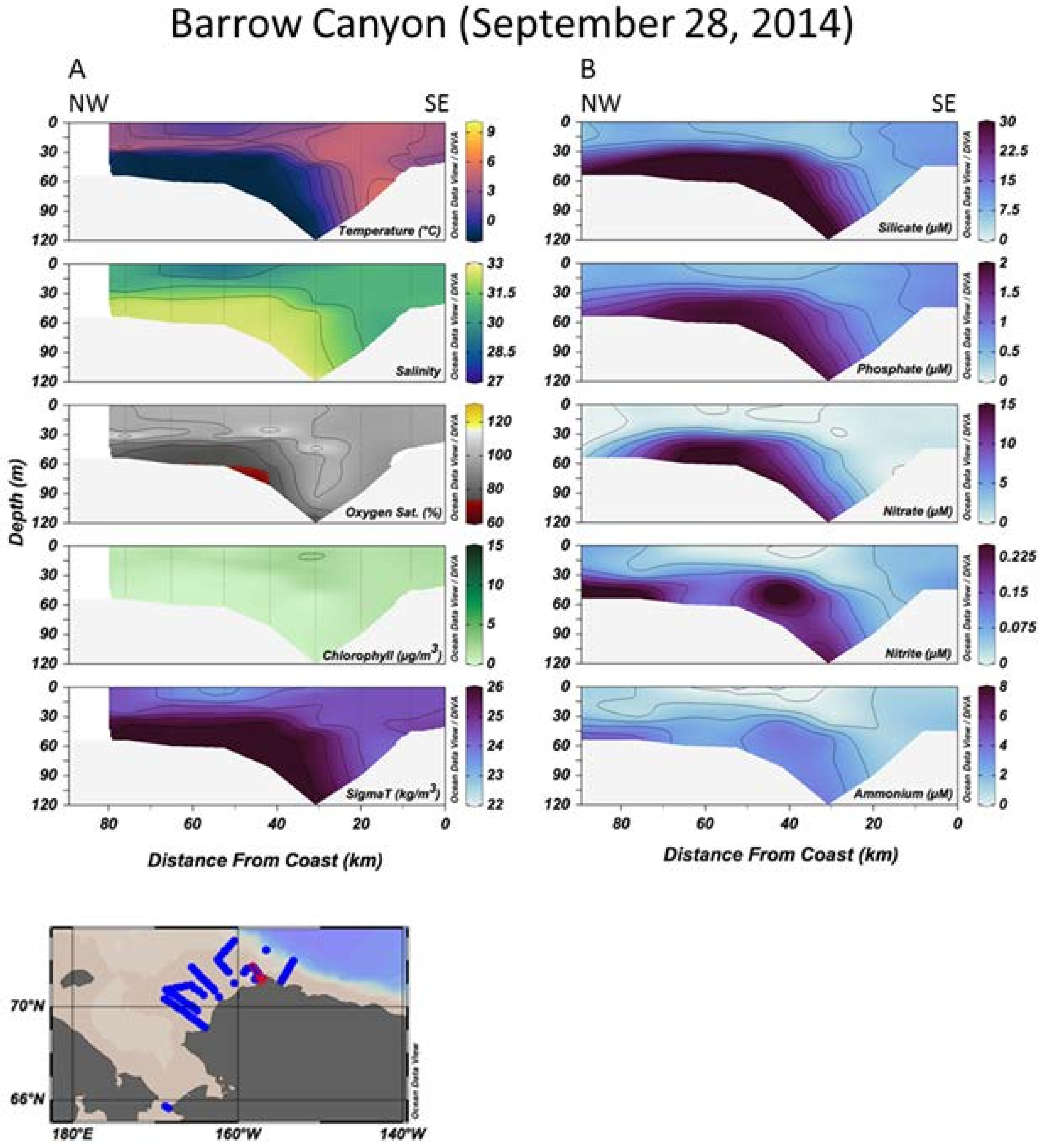


Figure 94. Hydrographic measurements at Barrow Canyon in September 2014. (A) Temperature, salinity, oxygen (percent saturation), chlorophyll fluorescence and sigma-t. (B) The five nutrients (silicate, phosphate, nitrate, nitrite and ammonium). The coastline is on the right side of each plot. The line occupied is indicated in red in the bottom left panel.

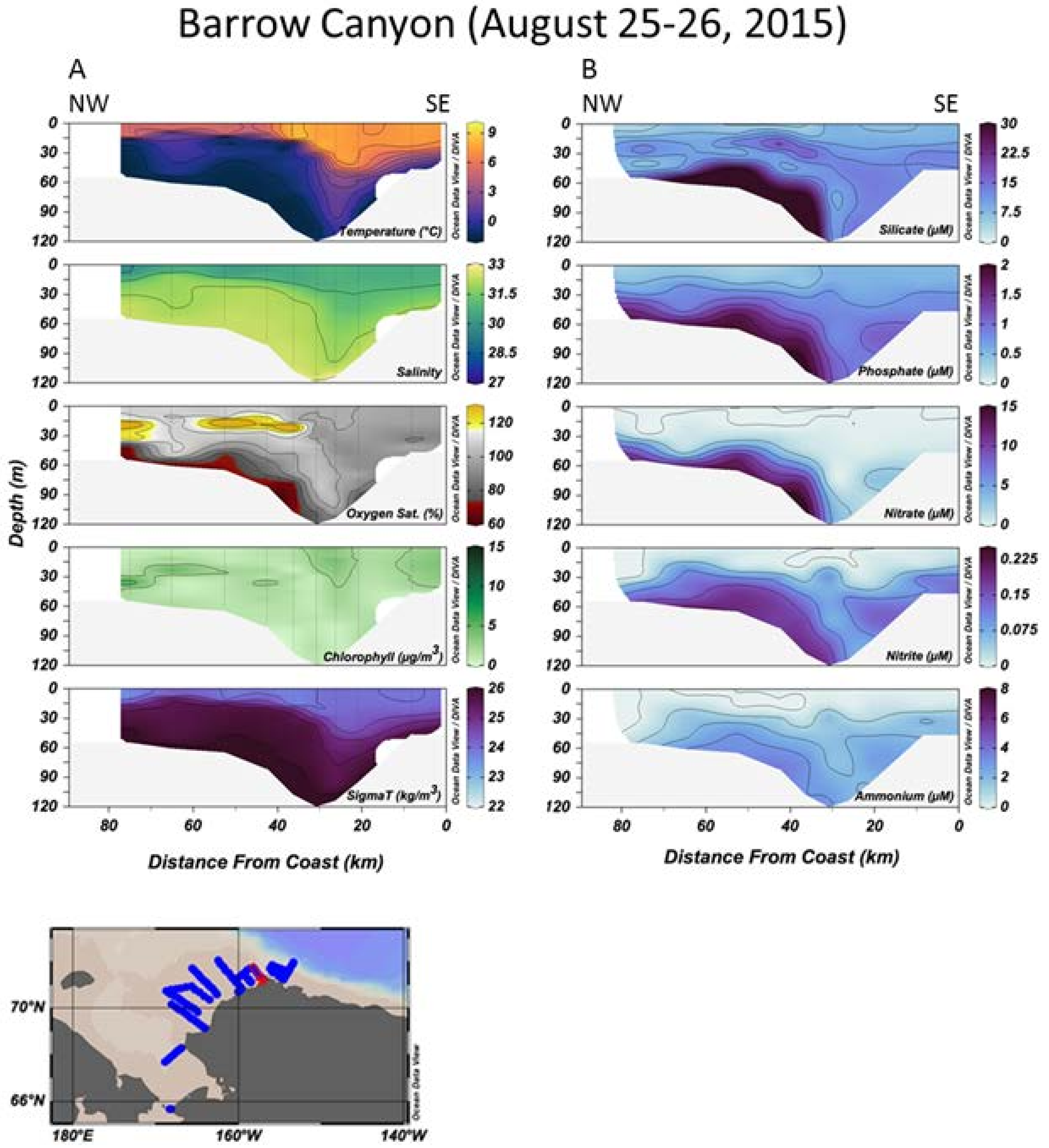


Figure 95. Hydrographic measurements at Barrow Canyon in August 2015. (A) Temperature, salinity, oxygen (percent saturation), chlorophyll fluorescence and sigma-t. (B) The five nutrients (silicate, phosphate, nitrate, nitrite and ammonium). The coastline is on the right side of each plot. The line occupied is indicated in red in the bottom left panel.

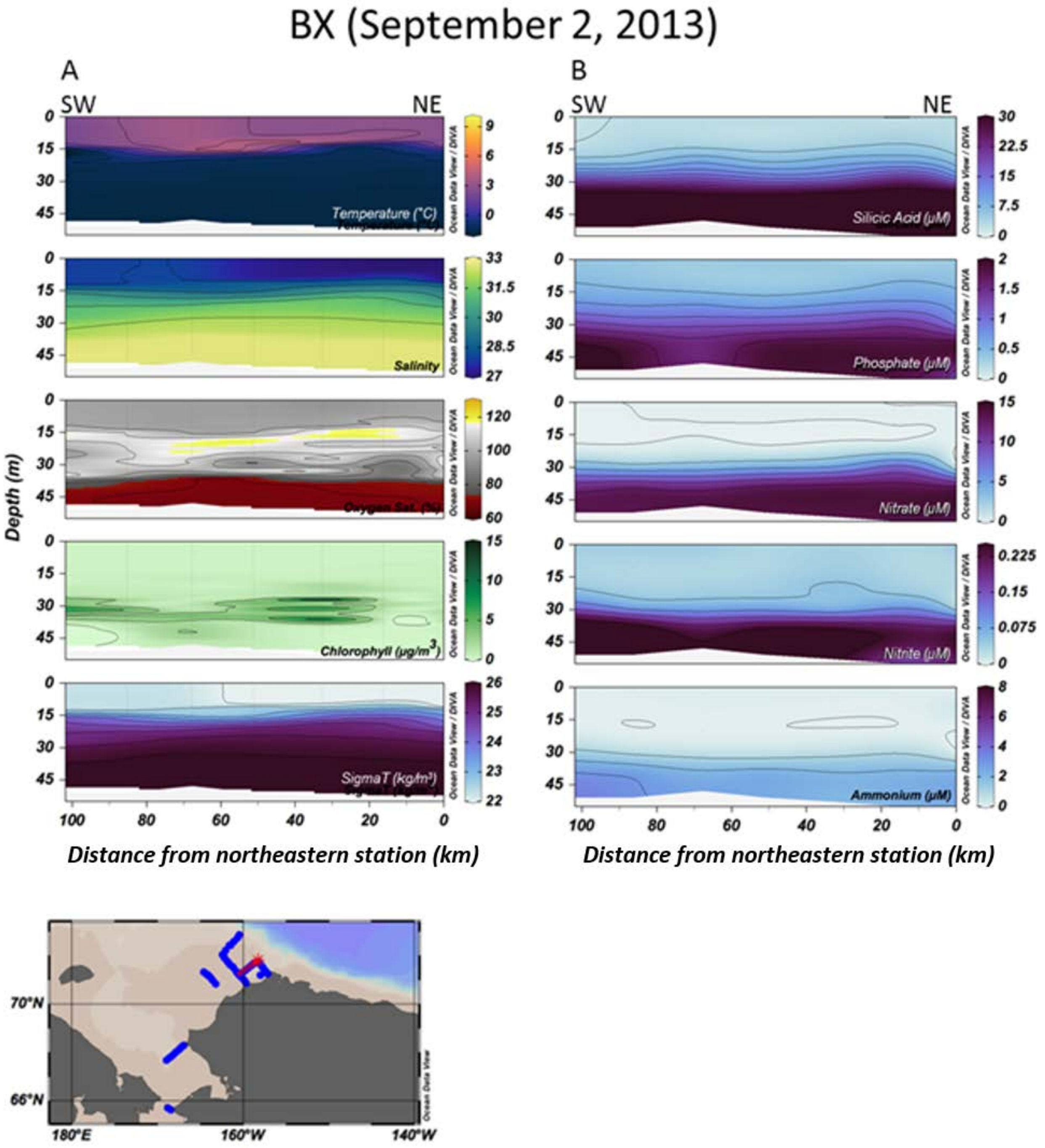


Figure 96. Hydrographic measurements along the BX Line in September 2013. (A) Temperature, salinity, oxygen (percent saturation), chlorophyll fluorescence and sigma-t. (B) The five nutrients (silicate, phosphate, nitrate, nitrite and ammonium). Northeast is toward the right side of each plot. The line occupied is indicated in red in the bottom left panel.

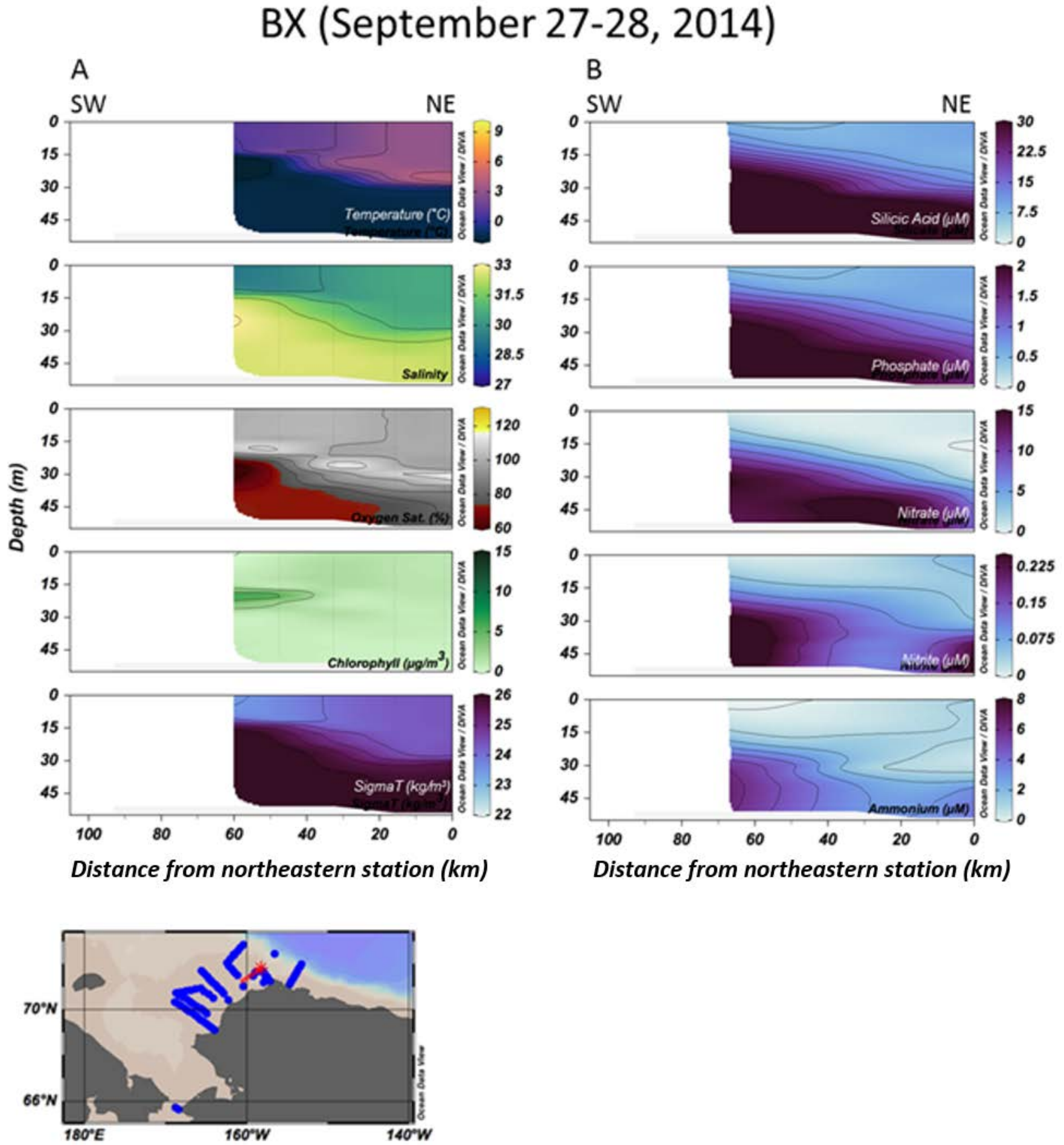


Figure 97. Hydrographic measurements along the BX Line in September 2014. (A) Temperature, salinity, oxygen (percent saturation), chlorophyll fluorescence and sigma-t. (B) The five nutrients (silicate, phosphate, nitrate, nitrite and ammonium). Northeast is toward the right side of each plot. The line occupied is indicated in red in the bottom left panel.

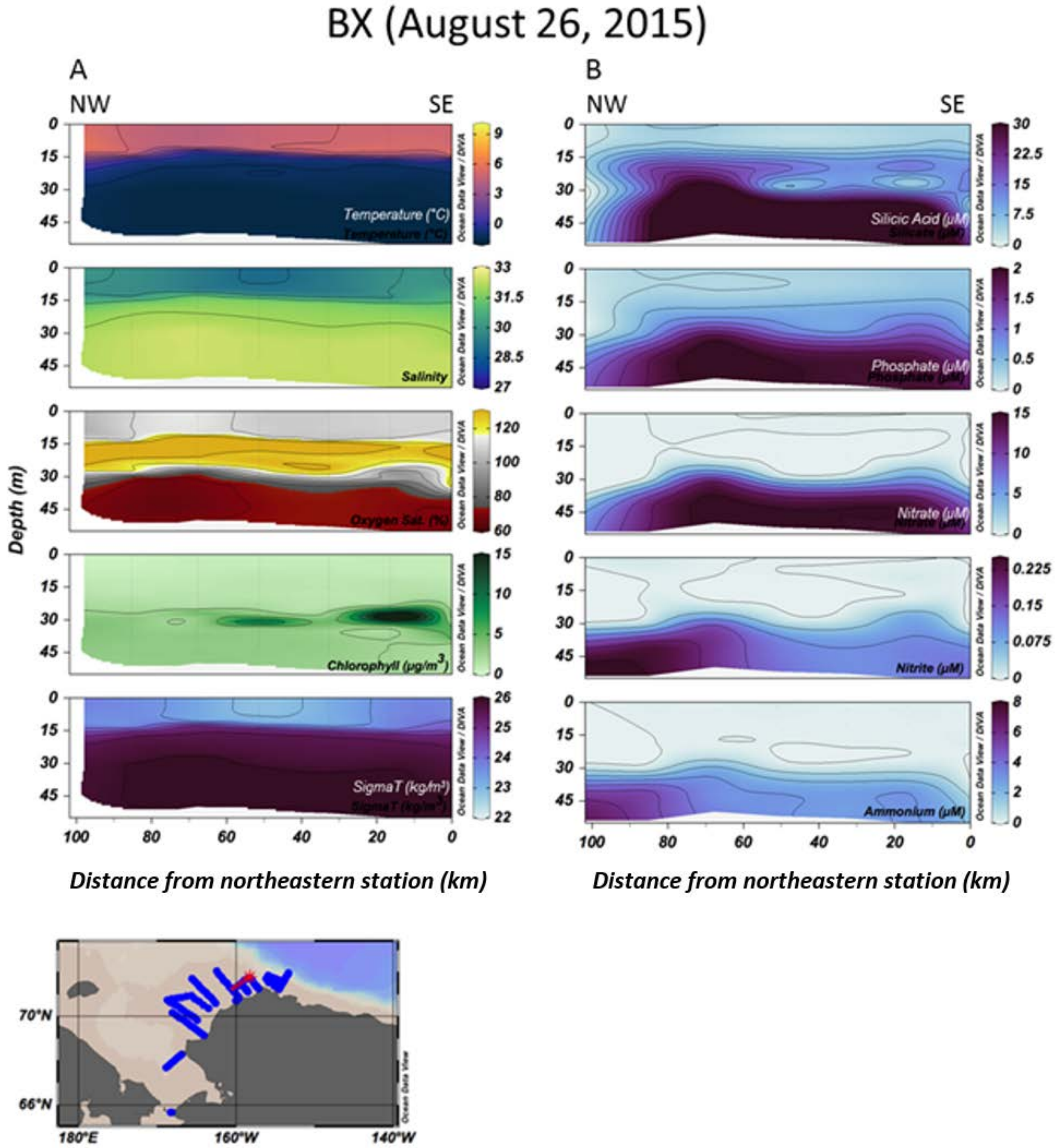


Figure 98. Hydrographic measurements along the BX Line in August 2015. (A) Temperature, salinity, oxygen (percent saturation), chlorophyll fluorescence and sigma-t. (B) The five nutrients (silicate, phosphate, nitrate, nitrite and ammonium). Northeast is toward the right side of each plot. The line occupied is indicated in red in the bottom left panel.

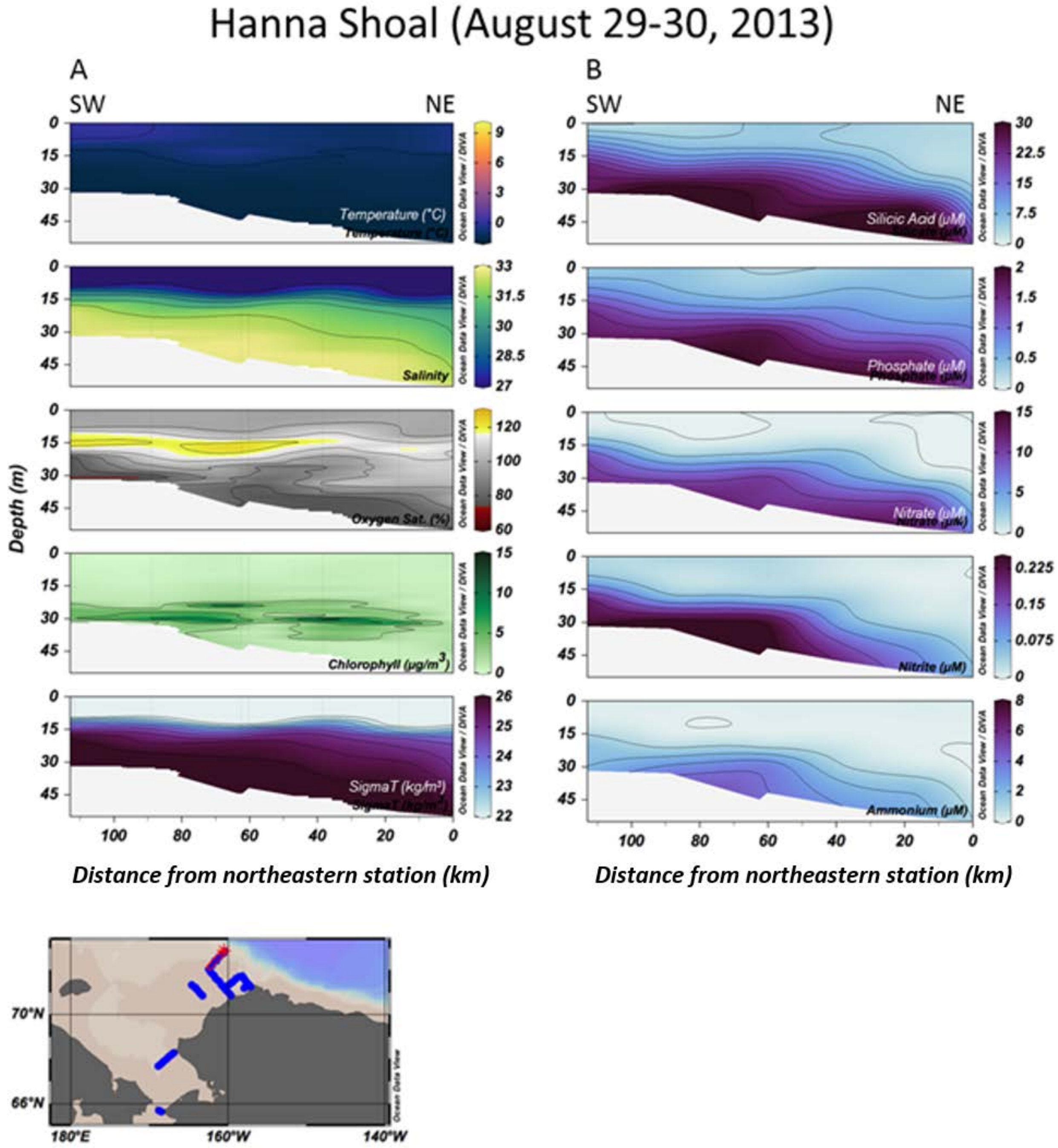


Figure 99. Hydrographic measurements along the Hanna Shoal Line in September 2013. (A) Temperature, salinity, oxygen (percent saturation), chlorophyll fluorescence and sigma-t. (B) The five nutrients (silicate, phosphate, nitrate, nitrite and ammonium). Northeast is toward the right side of each plot. The line occupied is indicated in red in the bottom left panel.

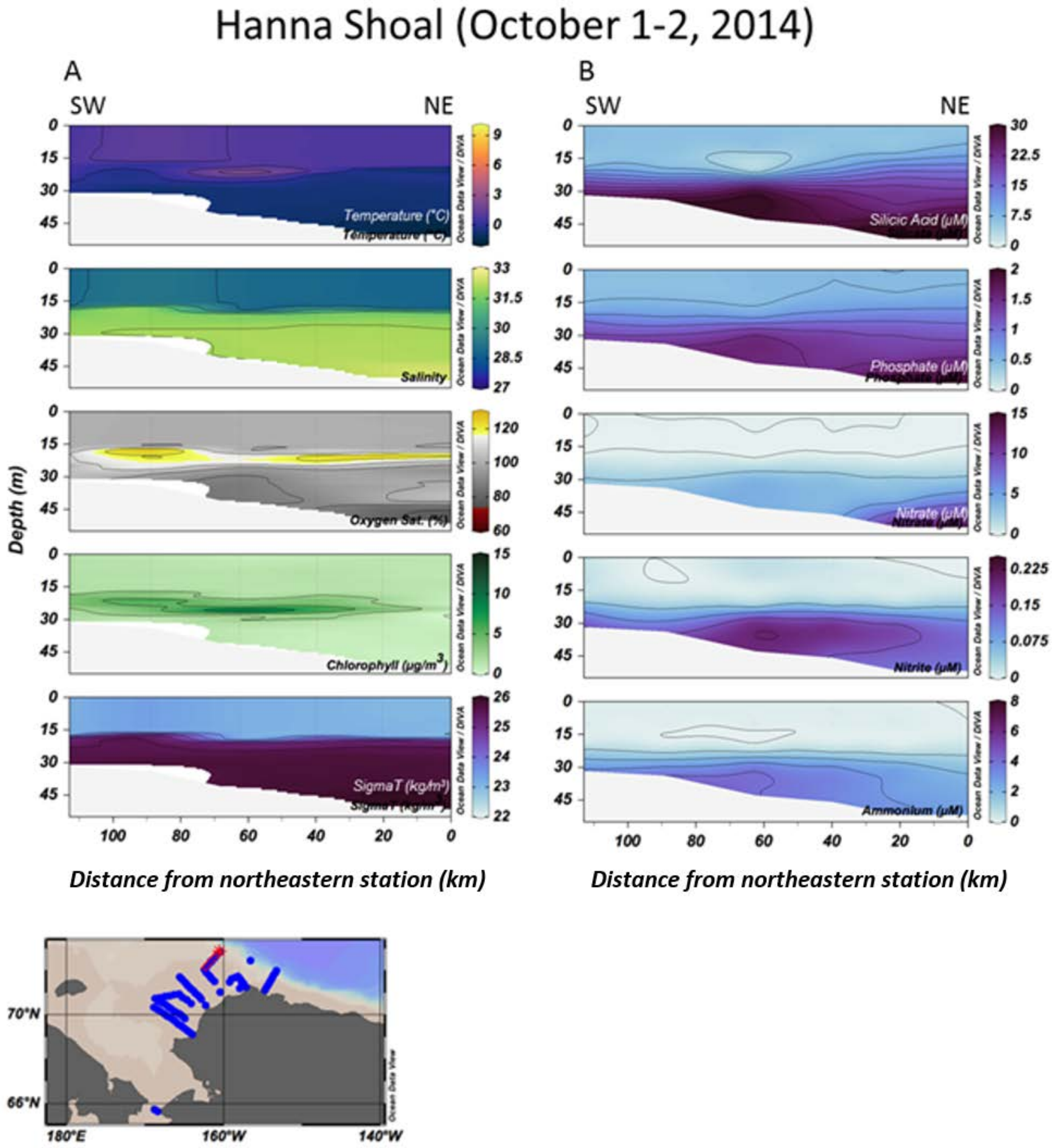


Figure 100. Hydrographic measurements along the Hanna Shoal Line in October 2014. (A) Temperature, salinity, oxygen (percent saturation), chlorophyll fluorescence and sigma-t. (B) The five nutrients (silicate, phosphate, nitrate, nitrite and ammonium). Northeast is toward the right side of each plot. The line occupied is indicated in red in the bottom left panel.

Chlorophyll

Mean and Integrated Chlorophyll

Station occupation varied among years (2013 – 2015) depending on the scientific focus for the year, available shiptime, and ice distribution (Figure 101).

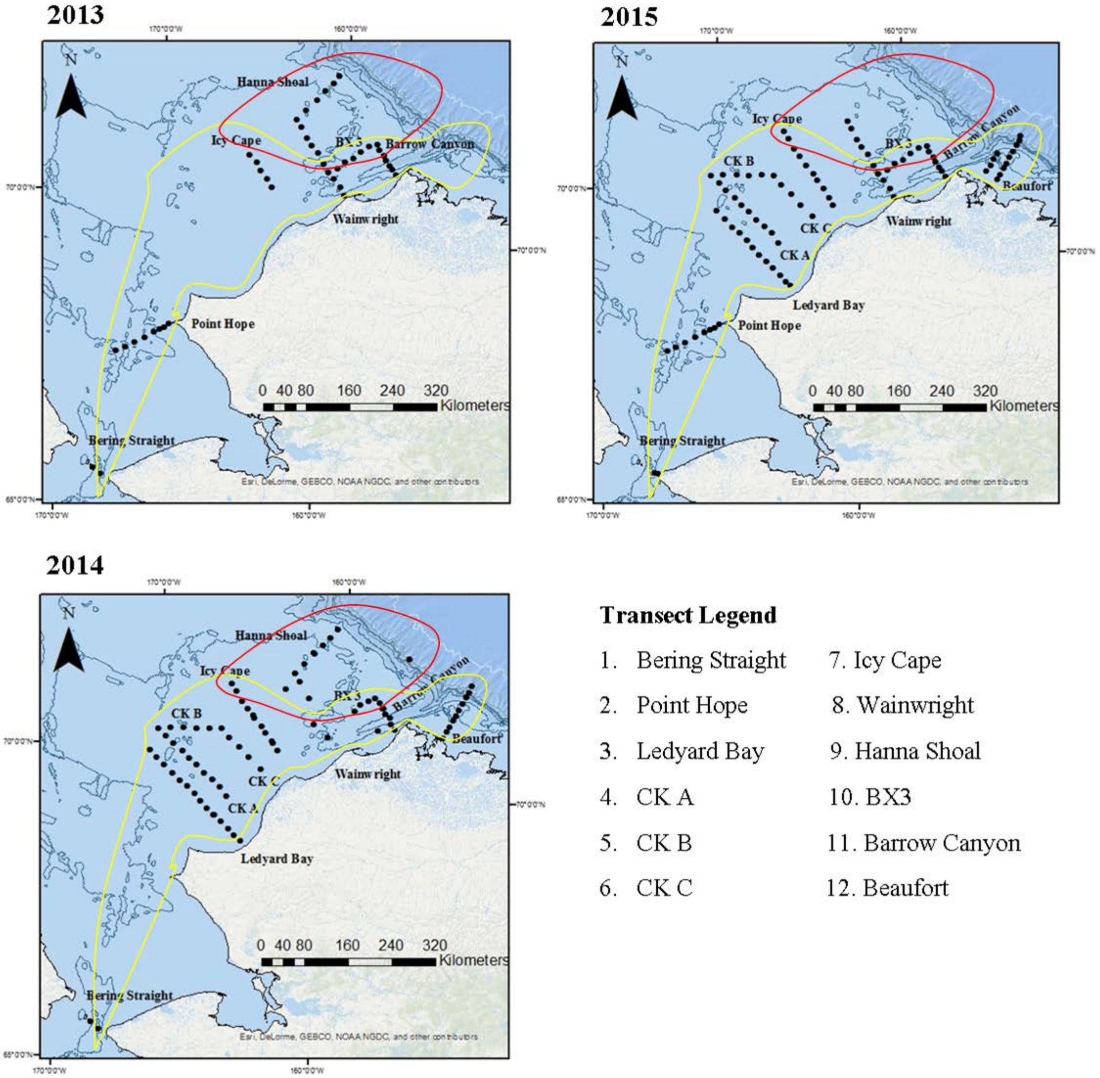


Figure 101. Stations where discrete depth chlorophyll samples were taken during the ARCWEST and CHAOZ-X field surveys (2013-2015).

Annual summer mean chlorophyll concentration across all stations had a very small range from 0.968 mg m^{-3} (± 0.10 SE) in 2013 to a low of 0.844 (± 0.05) mg m^{-3} in 2014 (Table 34), however annual means were significantly different from each other ($p < 0.001$; ANOVA). Two transects, Wainwright and Icy Cape, were sampled in all three years. The annual means for these transects were higher than the mean of all stations combined. Wainwright and Icy Cape ranged from a low of 0.887 (±0.19) in 2014 to a high of 1.45 (±0.35) mg m^{-3} in 2015. Annual means for these two transects were significantly different between 2013 and 2014 ($p = 0.047$), but not 2015.

When examining chlorophyll concentration within transects, the Bering Strait stations in 2014 had the highest mean overall of 2.19 (± 0.48) and the Wainwright transect in 2015 was the most variable among depths and stations. Spatially, across all years, mean chlorophyll was higher near the intersection of the Wainwright and Hanna Shoal transects, as well as the inshore stations of Ledyard Bay. In contrast, areas of lower chlorophyll concentration were located near the Icy Cape and all Ck transects (Figure 101). Integrated chlorophyll concentration decreased with year. Note that integrated chlorophyll is influenced by depth and the mean depth was not constant among years; mean depth in 2015 was 84.8 m with a standard error of ±28, having greater depths and variability than the other two years.

Table 34. Mean chlorophyll concentration (mg m^{-3}) and integrated chlorophyll (mg m^{-2}) from the surveyed area.

Year	All Stations			Wainwright/Icy Cape		
	Mean (± SE)	Integrated (± SE)	(n)	Mean (± SE)	Integrated (± SE)	(n)
2013	0.968 (± 0.10)	37.45 (± 3.86)	37	0.978 (± 0.12)	29.38 (± 6.19)	10
2014	0.844 (± 0.05)	28.81 (± 3.07)	65	0.887 (± 0.19)	26.18 (± 10.08)	5
2015	0.919 (± 0.09)	14.87 (± 2.03)	54	1.451 (± 0.35)	15.01 (± 3.83)	11

Mean and Integrated Phaeopigments

Annual summer mean phaeopigment concentrations across all stations also had a small range from 0.359 (± 0.04) in 2013 to 0.412 (± 0.02) in 2014 (Table 35). All years were significantly different from each other ($p < 0.001$, ANOVA) when all stations sampled were combined. The Wainwright and Icy Cape annual summer means were higher than the mean phaeopigment of all stations combined. Only the years of 2013 and 2014 were significantly different from each other ($p < 0.001$). The Bering Strait transect in 2013 had the highest mean in 2013.

Table 35. Mean phaeopigment concentration (mg m^{-3}) and integrated phaeopigment (mg m^{-2}) from the surveyed area.

Year	All Stations			Wainwright/Icy Cape		
	Mean (± SE)	Integrated (± SE)	(n)	Mean (± SE)	Integrated (± SE)	(n)
2013	0.359 (± 0.04)	15.84 (± 2.54)	37	0.369 (± 0.04)	14.95 (± 2.02)	10
2014	0.412 (± 0.02)	14.09 (± 1.28)	65	0.434 (± 0.03)	13.06 (± 4.48)	5
2015	0.401 (± 0.03)	6.49 (± 0.81)	54	0.571 (± 0.09)	7.05 (± 2.17)	11

Depth discrete chlorophyll

Depth-discrete chlorophyll concentration was mapped for all transects (Figures 102-104). Each plot is oriented geographically, with offshore to the left (up to 700 km offshore) and nearshore to the right. Transects which run parallel to shore are oriented south to north (BX3, CkB, Hanna Shoal).

The 2013 transect maps (Figure 102) reflect large subsurface patches of higher than average chlorophyll (mg m^{-3}) approximately 50-100km long. The subsurface patches are consistently centered near 30 meters depth. Transects with stations close to shore, Wainwright and Point Hope, show high levels of chlorophyll throughout the water column where mixing occurs. In 2014 all transects (Figure 103), except Hanna Shoal and BX3, do not show large subsurface chlorophyll maxima, instead show chlorophyll maxima near surface and patch length extending across more stations than 2013. Lines CkB and CkC show chlorophyll less than 1 mg m^{-3} and the chlorophyll appears to be well mixed throughout the water column. The distribution of chlorophyll in 2015 is more similar to 2013, with chlorophyll maxima centered near 30 m. Summer 2015 had the highest chlorophyll-a values of all years. The highest value, 9.25 mg m^{-3}, was along the bottom located 485 km from shore on the Wainwright transect at a depth of 31 m (Figure 104). At this location the shelf is shoaling as it approaches Hanna Shoal.

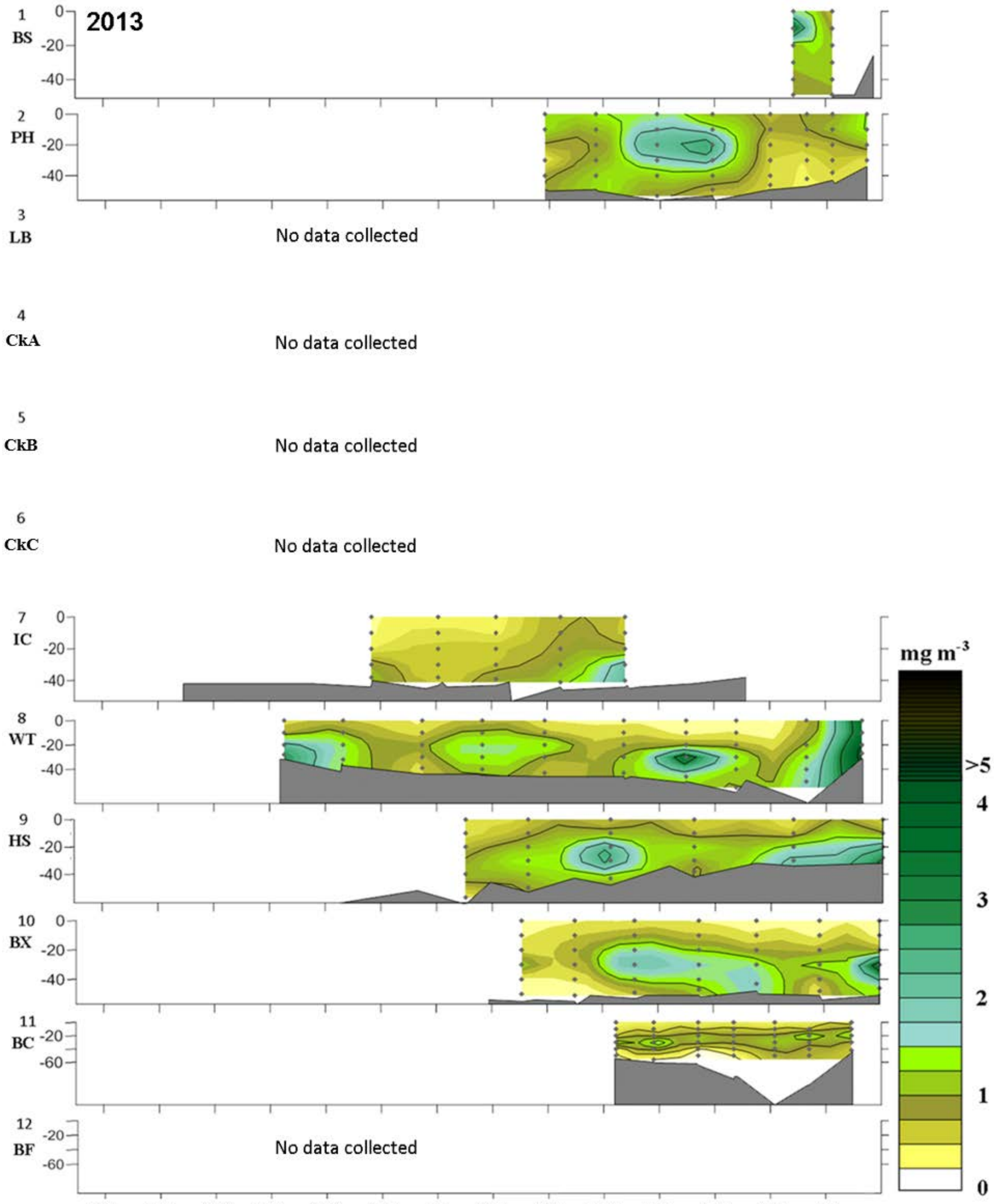


Figure 102. Section plots of chlorophyll-a concentration (mg m^{-3}) along transects sampled in 2013. Twelve unique transects were surveyed, but transects sampled among years varied. Dark diamonds denote collection depths.

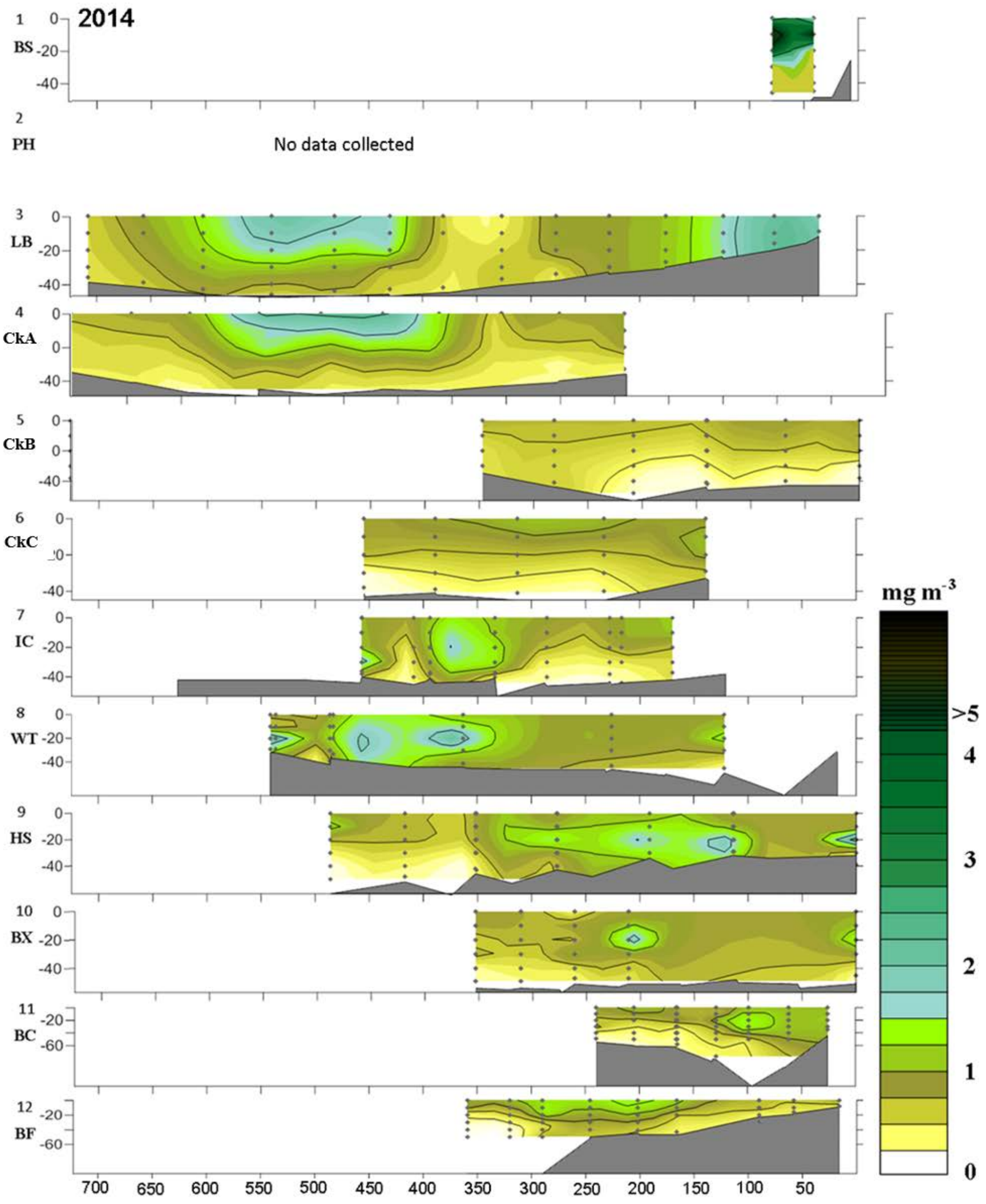


Figure 103. Section plots of chlorophyll-a concentration (mg m^{-3}) along transects sampled in 2014. Twelve unique transects were surveyed, but transects sampled among years varied. Dark diamonds denote collection depths.

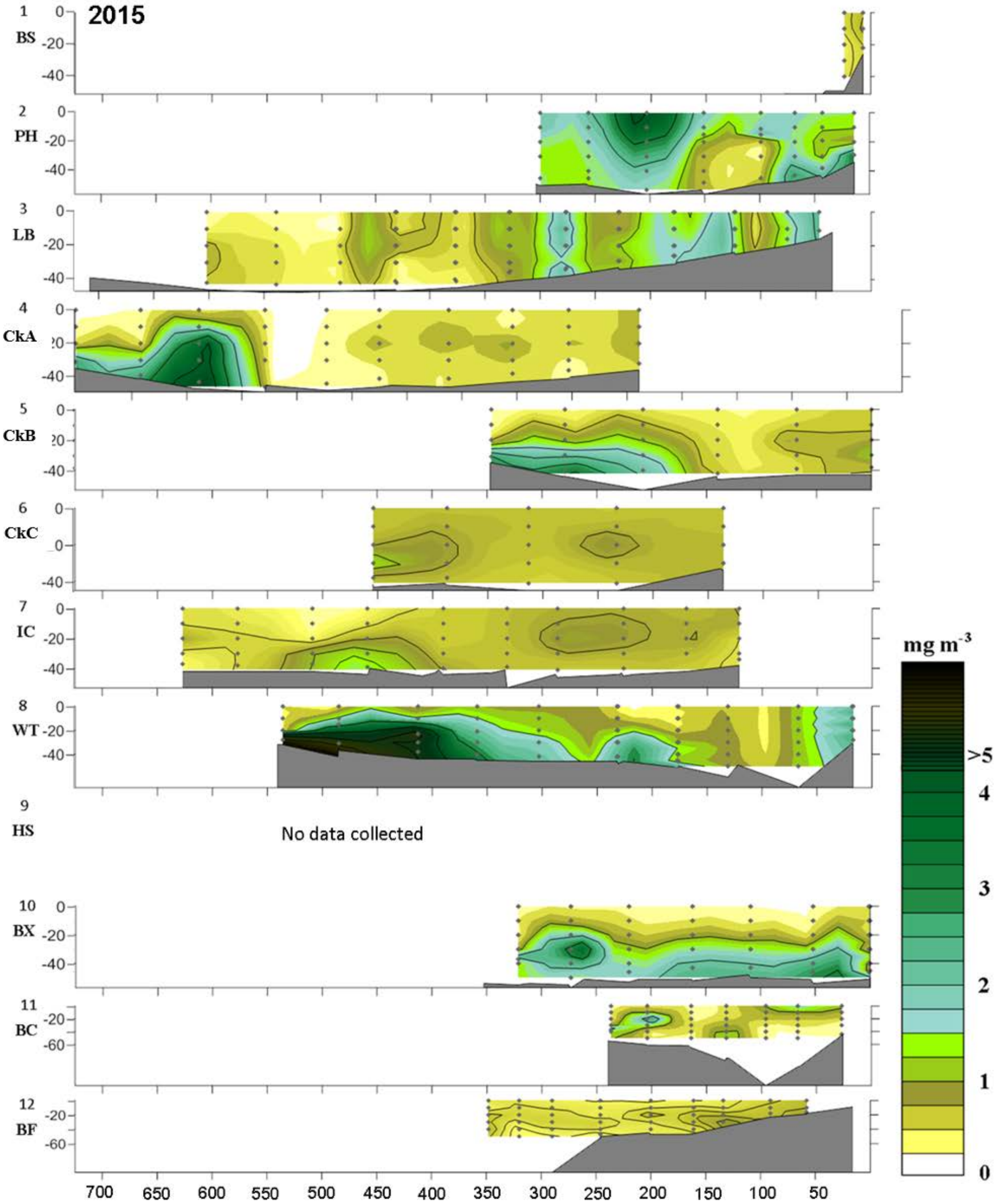


Figure 104. Section plots of chlorophyll-a concentration (mg m^{-3}) along transects sampled in 2015. Twelve unique transects were surveyed, but transects sampled among years varied. Dark diamonds denote collection depths.

Subsurface chlorophyll maxima (SCM) were identified for each year following methods of Martini (2016). The SCM threshold is defined as the chlorophyll concentration that must be equaled or exceeded for a station/depth to be considered part of the SCM. The SCM threshold was highest in 2014 (1.62 mg m^{-3}) and lowest in 2013 (1.03 mg m^{-3}). Values under the determined SCM threshold were not displayed nor were the nearshore (<50 km) stations, where the SCM breaks down due to mixing. The percentage of stations with a SCM was highest in 2013 (Figure 102), where 70% of stations and all transects had a least one depth where chlorophyll concentration met or exceeded the SCM threshold. The plots for 2013 also show SCM emerging at 10-20 meters depth and extending to near bottom. The Barrow Canyon transect SCM resides in same depth strata as the other transects but does not extend to the near bottom where average bottom depth was 75.7 m. In 2014 the SCM nearly disappears from all stations, where only 18% of the stations met or exceeded the threshold (Figure 103). When chlorophyll maxima were present they occurred at the surface or at 20 m depth. The 2014 data may show that stable SCM patches started to degrade by October through seasonal oceanographic processes. The SCM in 2015 exhibited patterns observed in both 2013 and 2014 (Figure 104). This year had the highest recorded chlorophyll mg m^{-3} for all three years, but met the threshold for SCM at only 39% of the stations. The Ledyard Bay and CkA transects showed chlorophyll maxima at the surface extending throughout the water column and not representative of an SCM. None of the stations of the CkC, Icy Cape, and Beaufort lines met the threshold for the SCM. The largest SCM was located offshore on the Wainwright line near the Hanna Shoal area.

Zooplankton Net Data – General Trends Among Years

Zooplankton data were analyzed based on the three different collection categories: small zooplankton from the oblique portion of the tows, large zooplankton from the oblique tows and large zooplanktonic organisms from just above the bottom (the net open when the sled was towed along the seafloor). Small zooplankton taxa/stages were those enumerated from the 153µm mesh net; in general these were numerically dominated by small copepods, bivalve larvae, appendicularians, and echinoderm larvae. These broad categories constituted 87.6% of the total integrated abundance across all three years. Specifically, the small copepod taxa were *Oithona similis* and *Pseudocalanus* spp. and the appendicularians were from the genus *Fritillaria* (individuals less than 2 mm in length). Large zooplankton taxa were those enumerated from the 505 µm mesh. They were numerically dominated by chaetognaths which constituted 74.4% of the total integrated abundance; specifically the species *Parasagitta elegans*. The appendicularian *Oikopleura spp*., the euphausiid *Thysanoessa raschii,* and the large calanid copepod *Eucalanus bungii* comprised 13.3%. Planktonic organisms, collected along the seafloor using a 505 µm mesh, were numerically dominated by organisms similar to the large zooplankton category from the water column. These were *Parasagitta elegans*, *Thysanoessa rashii, Eucalanus bungii,* and *Oikopleura* spp.

When the data from individual years were examined separately, the community composition was remarkably similar among years. Total integrated abundance of zooplankton from the small zooplankton category was lowest in 2013 (3.96×10^6 m^{-2}), and highest in 2014 (1.95×10^7 m^{-2}) for a range of about 5X among the three years. The small calanoid copepod *Pseudocalanus* was the most abundant and comprised nearly a third of the integrated abundance in 2013 and 2014. In 2015, *Pseudocalanus* numbers were reduced in half and the dominant zooplankton taxon was echinoderm larvae which comprised a third of the yearly total abundance.

The second most abundant taxa in each year were *Oithona similis*, bivalve larvae, and lastly in 2015, *Fritillaria* spp. Of particular interest from the small mesh net was *Calanus glacialis*, a medium size copepod and an important prey item for planktivorous fish, seabirds, and marine mammals, which had the highest integrated abundance in 2013 and comprised 12.4% of the integrated abundance. In 2014 and 2015 it comprised less than 2.5% of the total integrated abundance.

In the large zooplankton category, the total integrated abundance increased markedly during the course of our study, 3.59 x 10^4 m^{-2} in 2013, to 7.28 x 10^4 m^{-2} in 2014, and 1.29 x 10^6 m^{-2} in 2015, a greater than 30 fold change. *Parasagitta elegans* numerically dominated in all three years, comprising from 44-68% of the total integrated abundance. Appendicularian abundance varied widely between the three years comprising 40.3% in 2013, 1.7% in 2014, and 8.9% in 2015. *Thysanoessa raschii* was highest in 2014, comprising 6.1% of the total abundance and lowest in 2013 at 2.3%. *Eucalanus bungii* was highest in 2014 comprising 15.1% of the total abundance and lowest in 2013 at 0.3%.

The integrated abundance of epibenthic planktonic organisms was highest in 2014 with 5.09 x10^5 m^{-2}, moderate in 2013 at 1.64 x 10^5 m^{-2}, and lowest in 2015 at 1.02 x 10^5 m^{-2}. Therefore, in 2 of the 3 years, integrated abundance of plankton was higher in the meter above the seafloor, than the average areal abundance throughout the water column. Similar to the trends in abundance for the water column plankton, *Parasagitta elegans* dominated each of the years for the epibenthic plankton, ranging from 77-84% of the total integrated abundance. The proportion of total integrated abundance of *Thysanoessa raschii* was highest in 2014 at 11.6%, but comprised less than one percent in the other two years. Of note is 2015, where the third and fourth most abundant taxa were gammerid amphipods, in particular *Eualus* spp., and anomurans (crabs) of the family Paguridae. Each group comprised about 3.5% and 1.3% of the total integrated abundance.

Zooplankton Net Data – Spatial Trends Among Years

The abundance of small taxa was uniformly low across all stations sampled in 2013. In 2014 there were no true “hot spots,” however stations along the Ledyard Bay and Hanna Shoal transects had above average abundances. In 2015 there were several hot spots; two on the Ledyard Bay transect and several on the Barrow Canyon transect (Figure 105). In general, abundances of small taxa over Hanna Shoal were below the average. *Pseudocalanus* spp. (the small zooplankton category), had been consistently higher than mean integrated abundance offshore of the Icy Cape line and inshore on the Barrow canyon line for all three years. In general, areas of high abundance of *Pseudocalanus* also had high integrated abundance of *Oithona similis,* another small copepod. In the two years that the Ledyard Bay transect was sampled (2014 and 2015), we observed the highest integrated abundance of all the stations for *Oithona*. Abundances over Hanna Shoal were both above and below the mean with no clear trend. The appendicularians had similar abundance patterns in 2013 and 2015, where the same stations were sampled. In 2014 there was low to near zero integrated abundance on the Icy Cape transect and at stations on the CkA, B, and C transects. Abundances of appendicularians over Hanna Shoal were generally below the mean in 2013 and above the mean in 2014 while abundances in the Beaufort Sea were generally above the mean. Bivalve larvae had their highest integrated abundances in 2014 and relatively low abundances in 2013 and 2015 across the entire sampling domain.

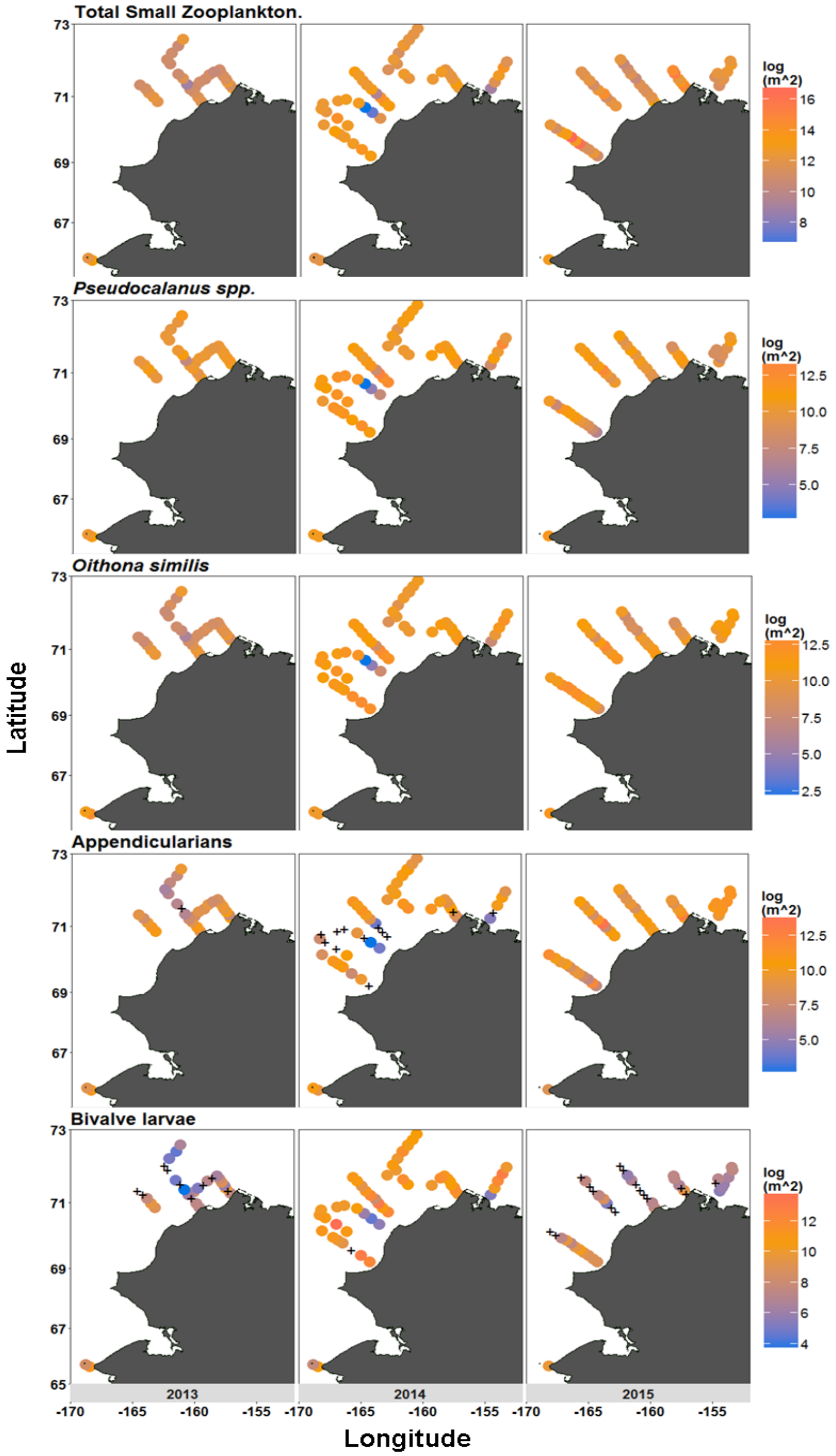


Figure 105. Integrated abundance (log no. m^{-2}) of selected small zooplankton taxa along ARCWEST and CHAOZ-X transects (2013 – 2015). Color scale indicates absolute values (log no. m^{-2}) where yellow is the average abundance for that taxon over the three years. The letter “X” denotes tows where the taxon was absent. Note that the scale differs among taxa.

The spatial patterns of large zooplankton taxa differed somewhat from those of the small zooplankton taxa. In general integrated abundance was low in 2013 and 2014 across the entire sample domain with higher overall abundance across the area in 2015, except for the Beaufort Sea transect (BfA; Figure 106). *Parasagitta elegans* (the chaetognath) had relatively low abundances across the spatial domain in 2013 and 2014 and higher abundances in 2015. Abundance over Hanna Shoal in 2013 and 2014 followed that trend. Appendicularia on the other hand, had were patchily distributed in 2014 and 2015, being absent across half or more of the stations. Their highest abundances were observed in 2015 when they were conspicuously absent from the inshore portions of many of the transects. *Thysanoessa raschii* had broad spatial coverage with low abundances in 2014, but had much higher abundances in 2015, but with obvious gaps in the distribution along the Icy Cape, Barrow Canyon, and BfA lines. The highest integrated abundances were found offshore of the Ledyard Bay transect and near Barrow canyon. *Eucalanus bungii* were predominantly confined to the western portion of the study area in 2014 with higher than average abundances at the offshore stations of the Ck transects and a notable absence along the Hanna Shoal transect. *Eucalanus* was nearly absent in 2013 and in 2015, but in 2014, higher than average abundances were found at the center of the Ledyard Bay transect.

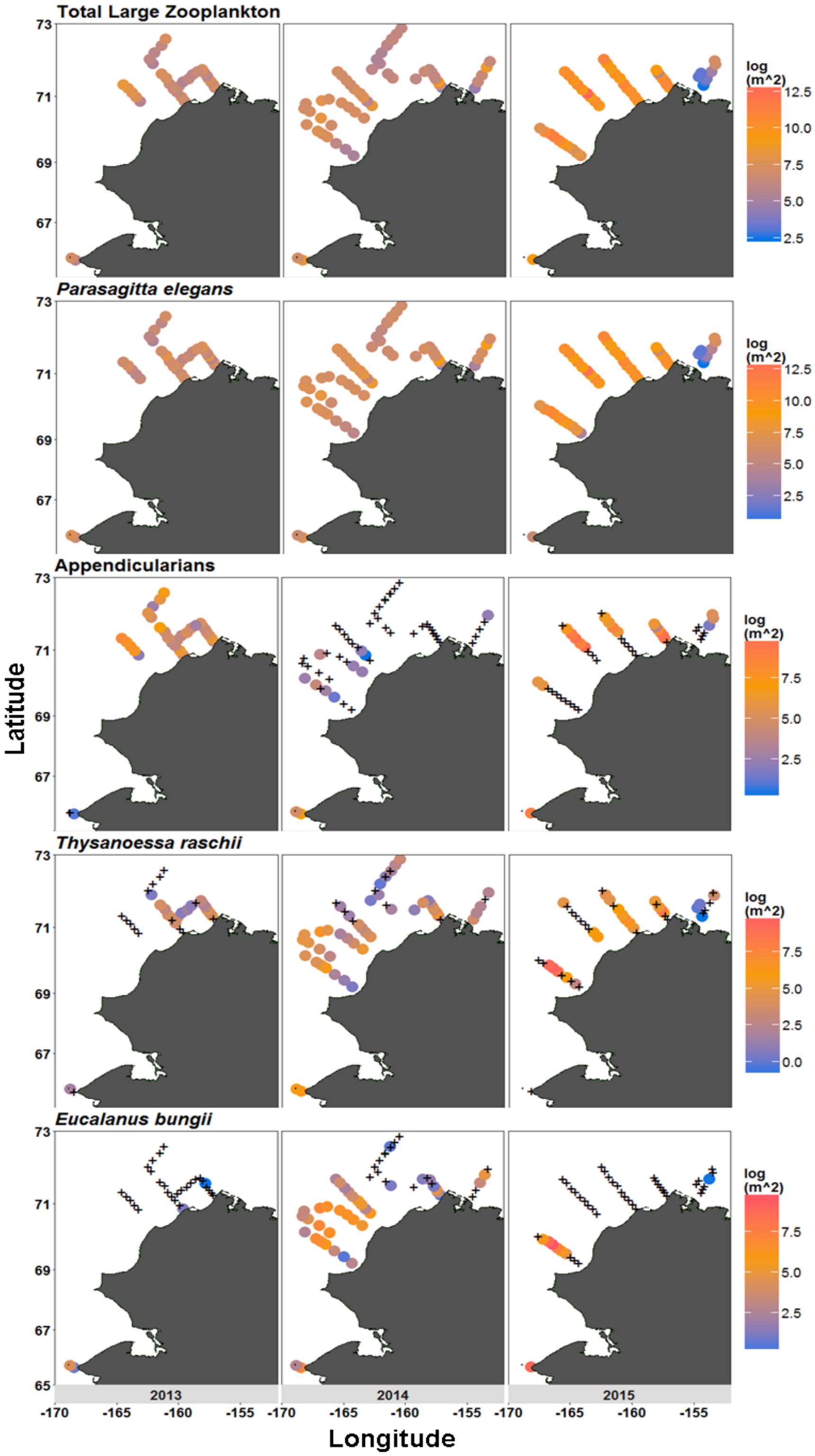


Figure 106. Integrated abundance (log no. m^{-2}) of selected large zooplankton taxa along ARCWEST and CHAOZ-X transects (2013 – 2015). Color scale indicates absolute values (log no. m^{-2}) where yellow is the average abundance for that taxon over the three years. The letter "X" denotes tows where the taxon was absent. Note that the scale differs among taxa.

The fraction of large zooplankton taxa captured just above the seafloor (epibenthic zooplankton) had opposite abundance pattern than its water column counterpart (Figure 107). In 2013 and 2014, abundances were higher than average across nearly all the stations. In 2015, a few high abundances were found at the offshore stations of the Icy Cape transect and near the midpoint of the Wainwright transect, but with lower than average abundances on the Ledyard Bay transect and on multiple stations across the Icy Cape transect. In 2013 and 2014 epibenthic plankters had moderate to high abundances over Hanna Shoal (both above and below the mean). The pattern for the chaetognath, *Parasagitta elegans*, mirrored that for total epibenthic plankters as they were the major constituent of that grouping. Unlike the other taxanomic categories examined, *P. elegans* was ubiquitous with the highest concentrations occurring along Icy Cape in 2014. Abundance was low over Hanna Shoal in 2013 and above average in 2014. Spatially, epibenthic abundances of *Thysanoessa raschii* were similar to their abundances in the water column, but abundances in 2014 were higher in the epibenthic portion than in the planktonic and the opposite in the two other years. *Eucalanus bungii* epibenthic abundances were spatially similar to the planktonic portion, but in 2014 the abundances were much higher just above the bottom. Gammerids and Anomuran crabs were a large percentage of the epibenthic samples in 2015. Areas with greater than average abundance in 2015 were near shore on the Wainwright and Ledyard Bay transects and offshore on the Wainwright and Icy Cape lines. The area of highest above average abundance was near the middle of the Icy Cape line.

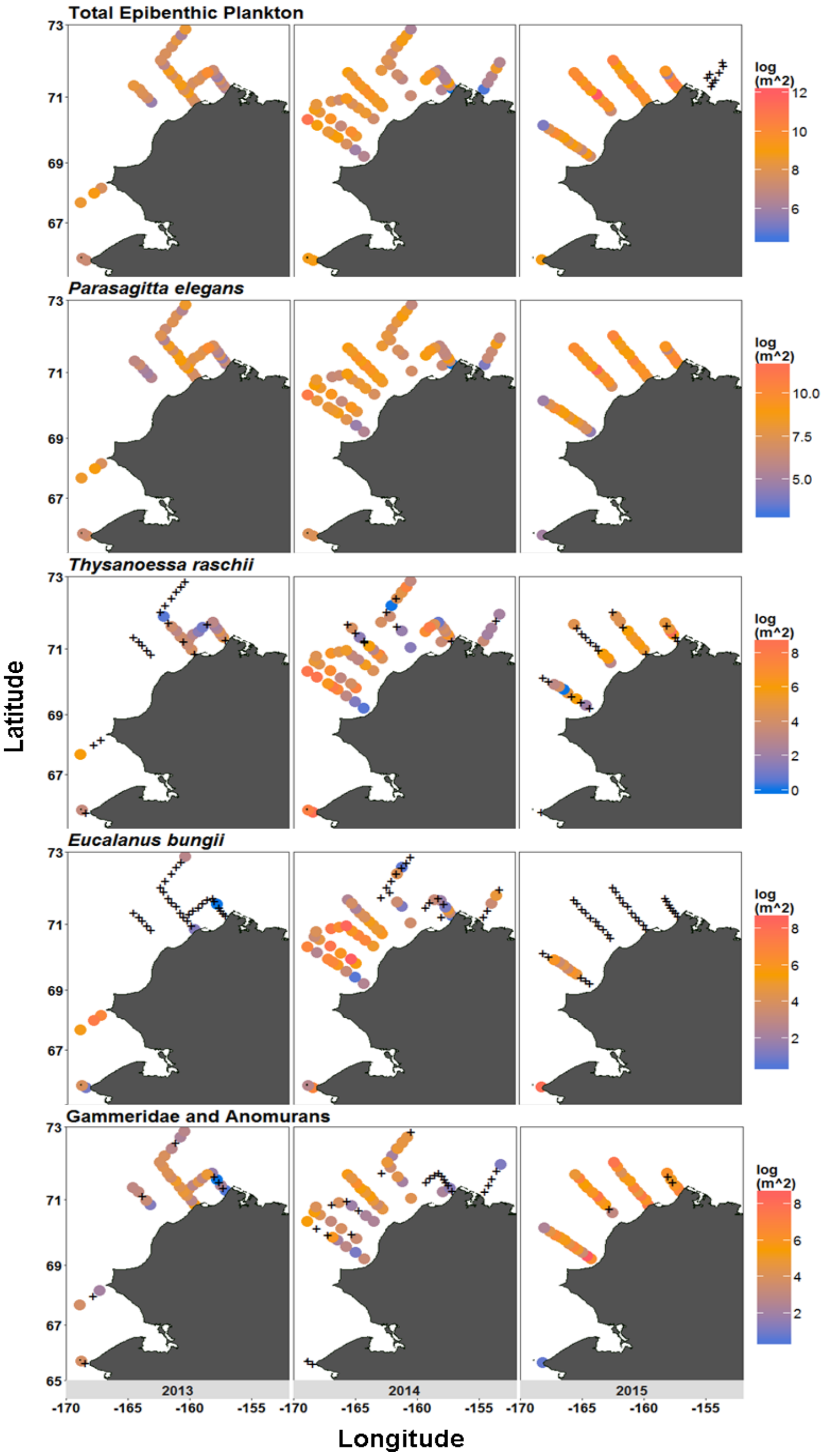


Figure 107. Integrated abundance (log no. m^{-2}) of selected epibenthic zooplankton taxa along ARCWEST and CHAOZ-X transects (2013 – 2015). Color scale indicates absolute values (log no. m^{-2}) where yellow is the average abundance for that taxon over the three years. The letter "X" denotes tows where the taxon was absent. Note that the scale differs among taxa.

Species of Interest

Groups and taxa we evaluated further because of their ecological importance were: Euphausiids, *Calanus hyperboreus*, *Neocalanus flemingeri* and N. *plumchrus* (combined), *Calanus glacialis*, *Pseudocalanus spp.*, Gammeridae, Thecosomata, and Appendicularia. The euphausiids were comprised of four species of *Thysanoessa*: *T. inermis*, *T. longipes*, *T. spinifera*, and *T. raschii*; *Thysanoessa raschii* being the most abundant of the four. The euphausiids were separated by life history stages: adults and juveniles versus furcilia. The calanoid copepods (*Calanus* spp. and *Neocalanus* spp.) were only evaluated using adults and copepodite stage fives (CV). The integrated abundances of Gammerid amphipods were taken only from the epibenthic net, while the integrated abundances of thecosomata, and appendicularia were taken from the combined catches of the small and large mesh nets towed obliquely from the bottom to the surface. Of the species of interest, *Pseudocalanus* spp. and appendicularians had the highest abundance in all three years (Figure 110). The highest median abundance for euphausiids was 2014. An analysis of variance was used to look at differences among years for each taxonomic group. The years 2013 and 2014 were significantly different from each other ($p = 0.029$) as were the years 2014 and 2015 ($p = 0.006$). When years were grouped together there were some positive correlations between the integrated abundance of species' groups across all years. *Calanus glacialis* and euphausiid furcilia were positively correlated with each other (r=0.63). *Calanus* and *Neocalanus* were also positively correlated with each other (r=0.57). Lastly, *Pseudocalanus* and appendicularians were positively correlated (r=0.36).

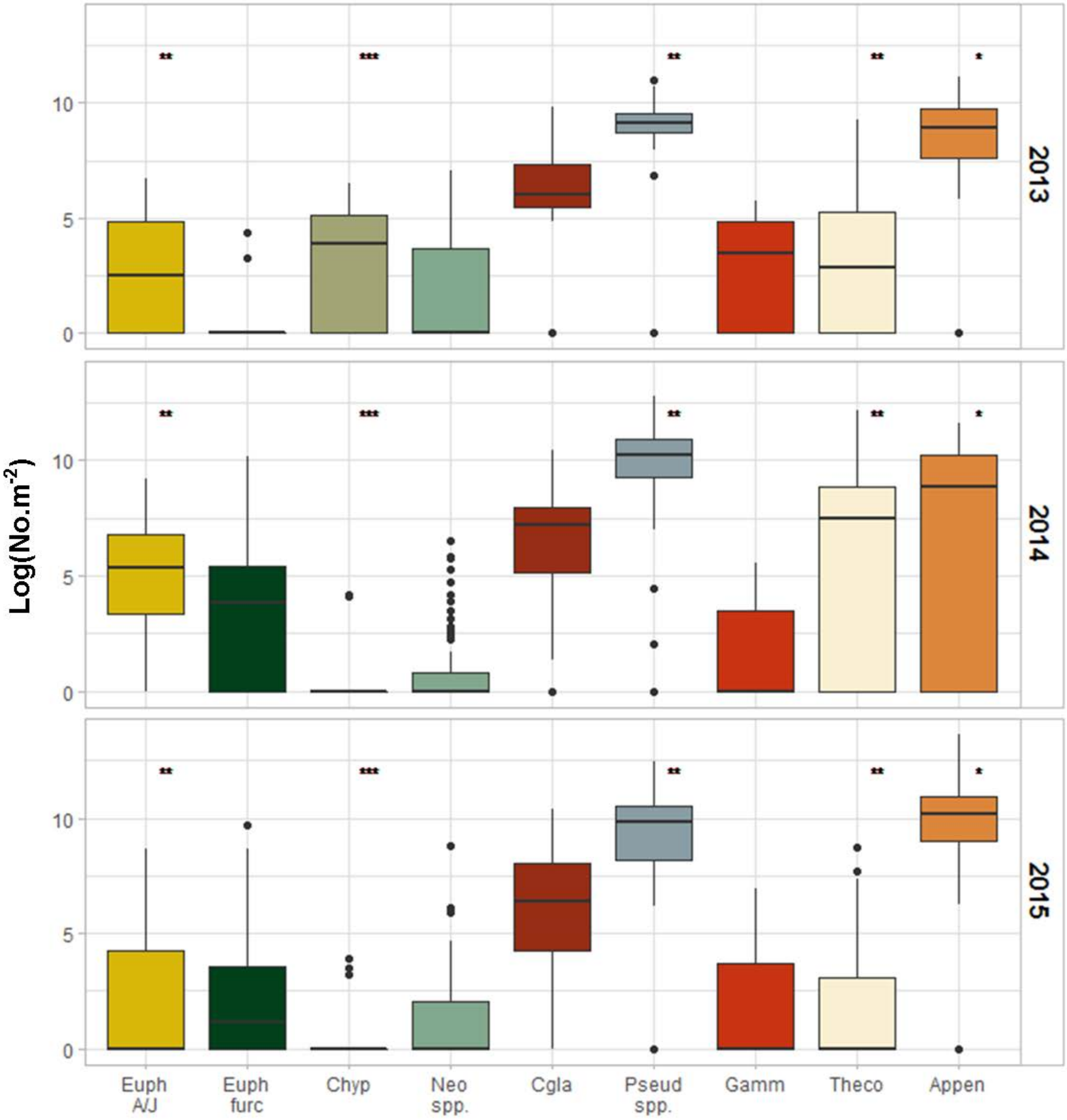


Figure 108. Box plots of the Log integrated abundances for selected zooplankton and epibenthic species by year. Abbreviations for taxa groups are: Euph A/J = Euphausiid Adults and juveniles, Euph furc = Euphausiid furcilia, Chyp = *Calanus hyperboreus,* Neo spp. = *Neocalanus flemingeri* and *N. plumchrus,* Cgla = *Calanus glacialis,* Gamm = Gammeridae, Theco = Thecosomata, and Appen = Appendicularia. Statistically significant differences in abundance among years are indicated by asterisks ($p < 0.0001$ = ***, $p < 0.001$ = **, and $p < 0.01$ = *).

Calanus glacialis

A generalized additive model (GAM) was used to determine spatial patterns and associations with environmental variables to the abundance anomalies of the copepodite stage five (CV) of *Calanus glacialis*. The anomaly at each station is the difference between the measured abundance at that station for that year and the overall mean abundance for all stations and all years. Data from 2010 to 2015 were used when available in constructing the GAM. Variables used in the GAM were mean surface temperature, mean surface salinity, mean bottom temperature, mean bottom salinity, surface transport, chlorophyll, latitude, longitude, Julian day, and year. Salinity (bottom and surface), bottom temperature, and year, were the most significant parameters in the model ($p < .001$). The model helped to explain 56.8% of the deviance in the anomaly and has an adjusted R^2 of 0.501. Highest predicted values of *C. glacialis* abundance were along the CkA line, in the middle of the Icy Cape line and where the inshore portion of the Wainwright and BX lines intersect with a hot spot at the offshore end of the transect (Figure 109). In general, the positive anomalies were at the outer stations of the Point Hope, and Cape Lisburne, and Ledyard Bay lines. Low abundances were predicted for Hanna Shoal, Barrow Canyon and the inner part of the Ledyard Bay transect.

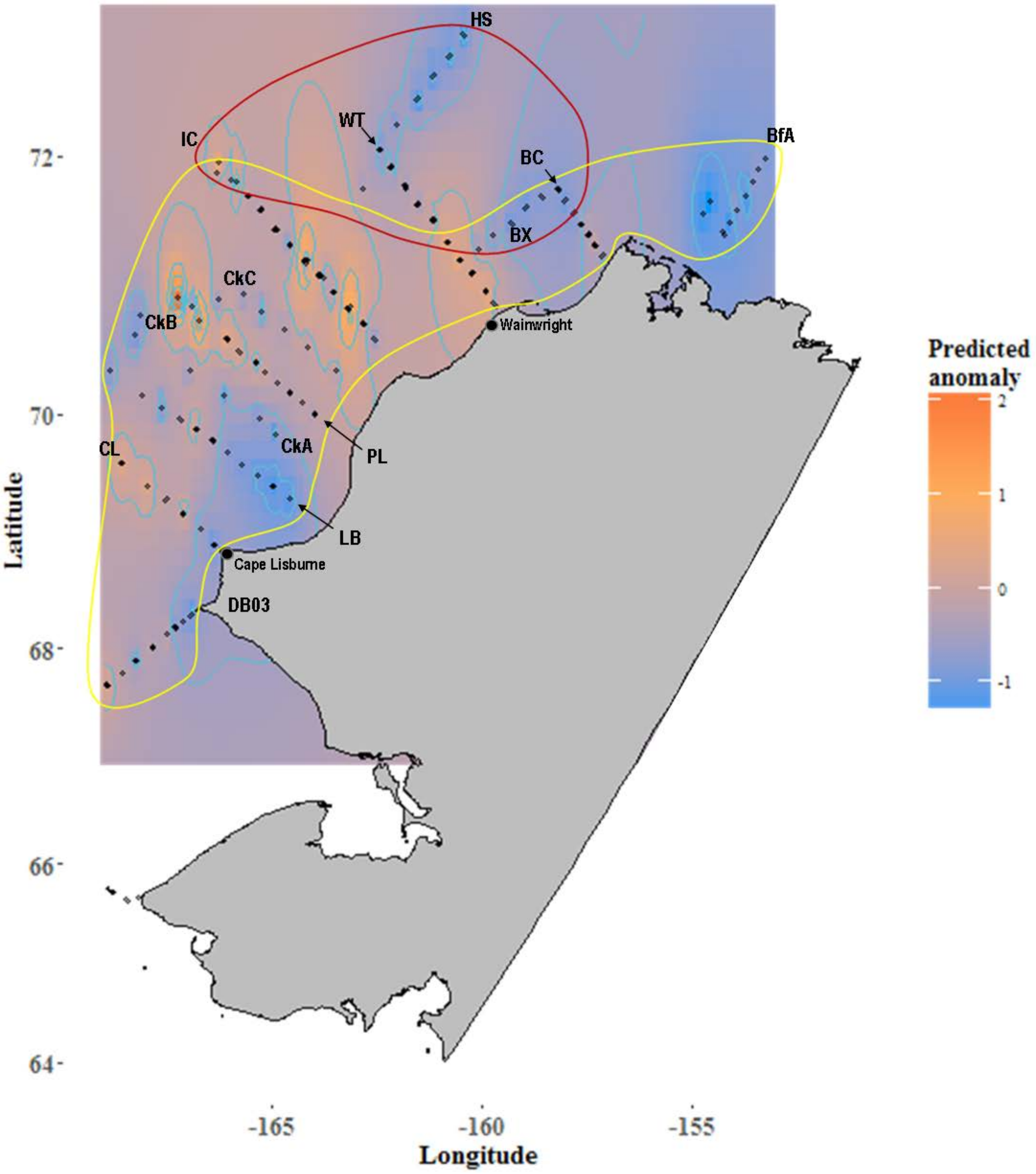


Figure 109. Modeled spatial distribution anomaly of *Calanus glacialis* CV, 2010 - 2015.

The smooth plots for bottom salinity and temperature show slight positive associations with salinities between 31.6 and 33.5 and temperatures 1.5 – 6.5 °C (Figure 110). The plot with the variable ‘year’, shows a near linear decreasing trend, although the variance associated with each year is high, except in 2013. The spatial pattern along with the salinity and temperature associations match the locations and salinity/temperature profiles of Bering Sea Shelf Water.

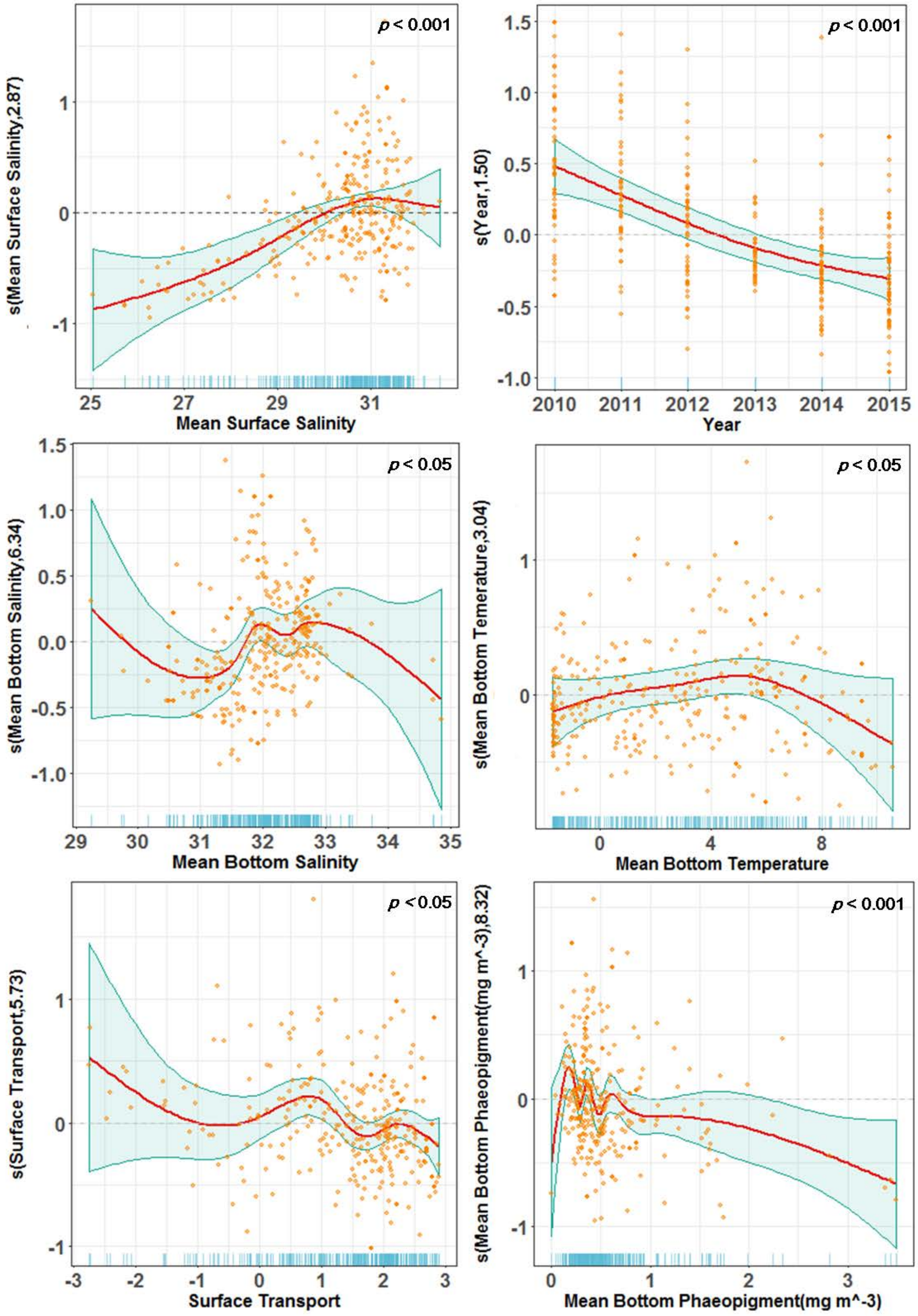


Figure 110. GAM smooth plot residuals for the distribution of *Calanus glacialis* CV, 2010 – 2015.

Zooplankton Community Analysis –All years combined

Cluster analysis and NMDS scaling were used to examine zooplankton community structure during the three years of simultaneous ARCWEST/CHAOZ-X sampling. When data from all three years were combined, six major and one minor zooplankton assemblages were produced (at 66% similarity; Figure 111). Groups 3 was observed in all three years, but only at a few stations each year (Figure 112). Group 4 dominated the survey area in 2014 and was prominent along the Ledyard Bay transect in 2015. The lack of any interannual similarity among cluster groups, shows that interannual variability in zooplankton assemblages in the study region was very high. Similarly there were years (2014) when the same assemblage dominated the entire study region. Although the data available were scarce, Hanna Shoal did not appear to support a distinct zooplankton assemblage, rather the waters over the shoal were populated by a mix of taxa very similar to the surrounding shelf area.

It was instructive to examine the composition of each species assemblage to better understand how they varied across the region. To do this, we separated the analysis by taxon size (represented by either the large or small mesh nets). Group 1 was distinguished from other groups by the high relative abundance of *C. glacialis*, *Pseudocalanus* spp., and polychaete larvae from the small mesh nets (Figure 113). Group 2 was distinguished from other groups mainly by the large contribution of *Metridia pacifica/lucens* and *Oithona* spp. (small fraction) and *Themisto libellula* (an Arctic pelagic amphipod; large fraction; Figure 114). Group 3 was distinguished from the other groups by the large contribution of *Fritillaria* spp., Cirrepedia (barnacle) larvae and the low percentage contribution of *Oithona* spp. The euphausiid, *Thysanoessa raschii* was also an important contributor to the assemblage (large fraction). Group 4 had a high relative contribution of bivalve larvae (small fraction) and euphausiids (large fraction). This was the assemblage that dominated in 2014. The increased abundance of *Fritallaria* spp. and Echinoderms were most noteworthy in Groups 5 & 6, respectively. Anomuran larvae (Family Paguridae) were relatively more abundant in Group 6 than the other groups (large fraction).

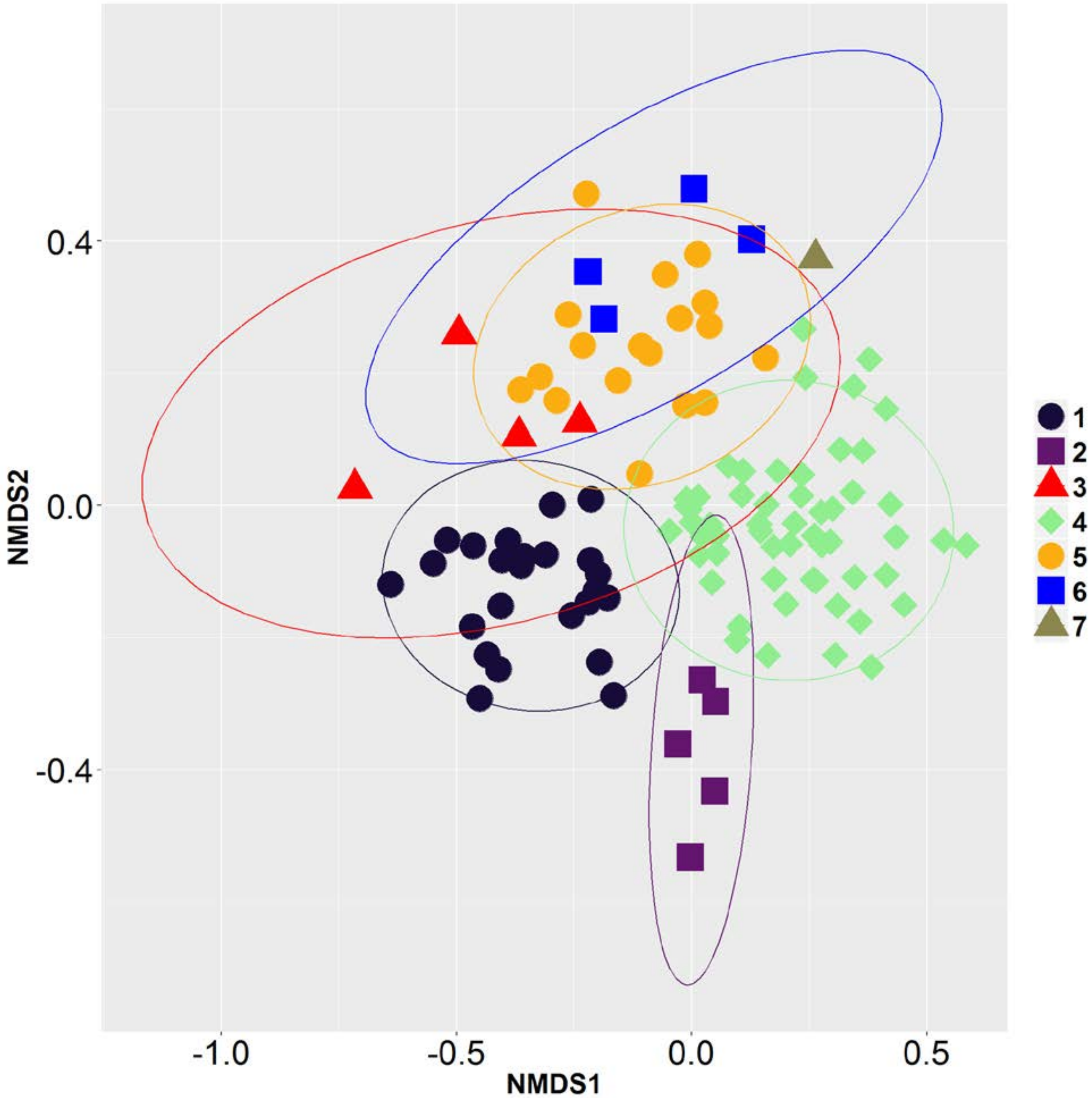


Figure 111. Non-metric multidimensional scaling plot of zooplankton abundance (2013-2015). The analysis identified 7 zooplankton assemblages or clusters.

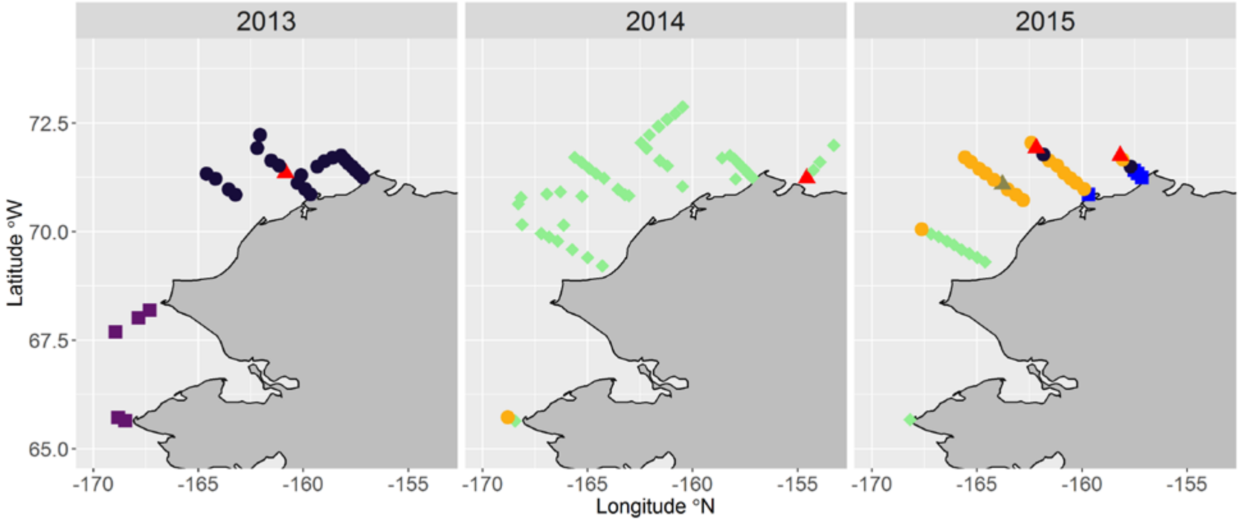


Figure 112. Distribution of the seven species assemblages (Figure 111) by year.

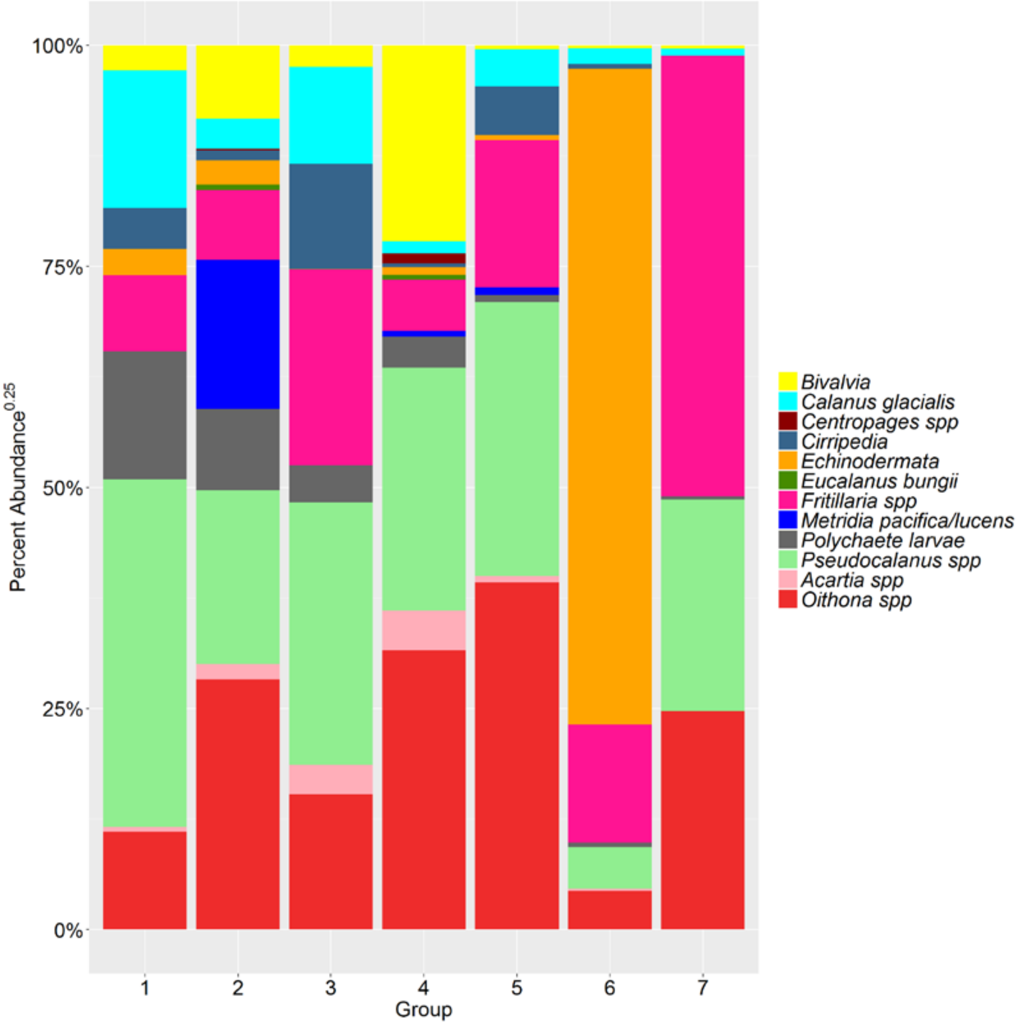


Figure 113. Percent composition of small mesh taxa from the 7 major zooplankton assemblages (Figure 111) identified by cluster analysis (2013-2015).

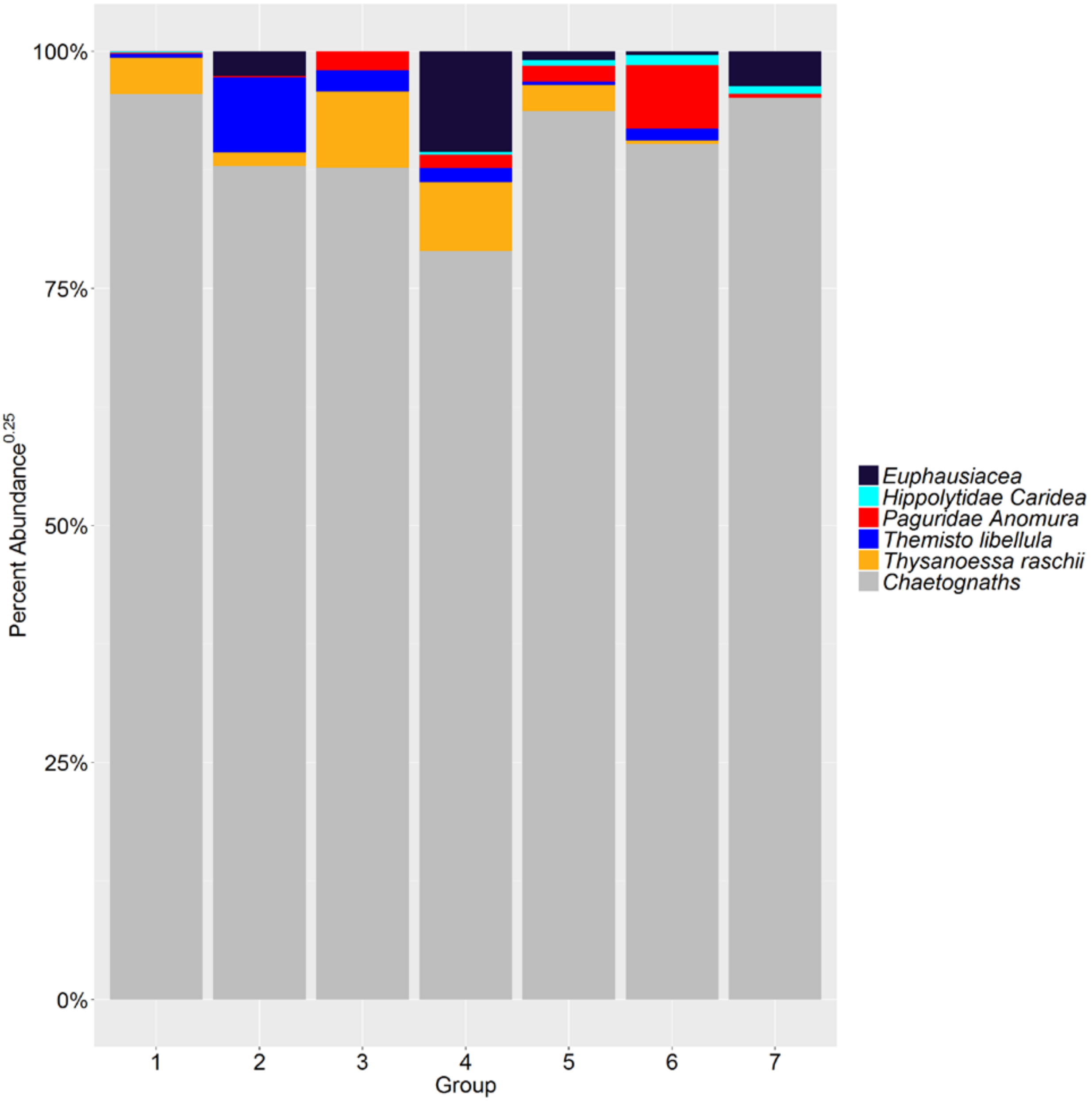


Figure 114. Percent composition abundance of large mesh taxa (2013-2015) from the 7 major zooplankton assemblages identified by cluster analysis.

Zooplankton Community Analysis – Each Year Considered Separately

The abundance data from each individual year were also used to construct similarity matrices and NMDS analysis. In each year there were two or more major groupings (2013 at 71% similarity; 2014 at 75% similarity; 2015 at 67% similarity; Figure 115). In 2013, there was some discrimination between inshore stations (Group 1) and offshore stations (Group 2) with Group 2 stations being much more prevalent at the eastern end of the study area (Figure 116). In 2014, the two main cluster groups were split up mainly into stations southwest (Group 1) and northeast (Group 2) of Icy Cape. The four cluster groups in 2015 were separated into a far northeast-inshore group (Group 1), a large offshore northeast group (Group 2), an inshore central to southwestern-inshore group (Group 3), and finally a central-offshore group (Group 4). There was a clear separation of zooplankton groups when plotted in temperature-salinity space for each individual year, suggesting zooplankton community structuring that was mainly influenced by water masses (Figure 117). Note the large temperature and small salinity range in 2015.

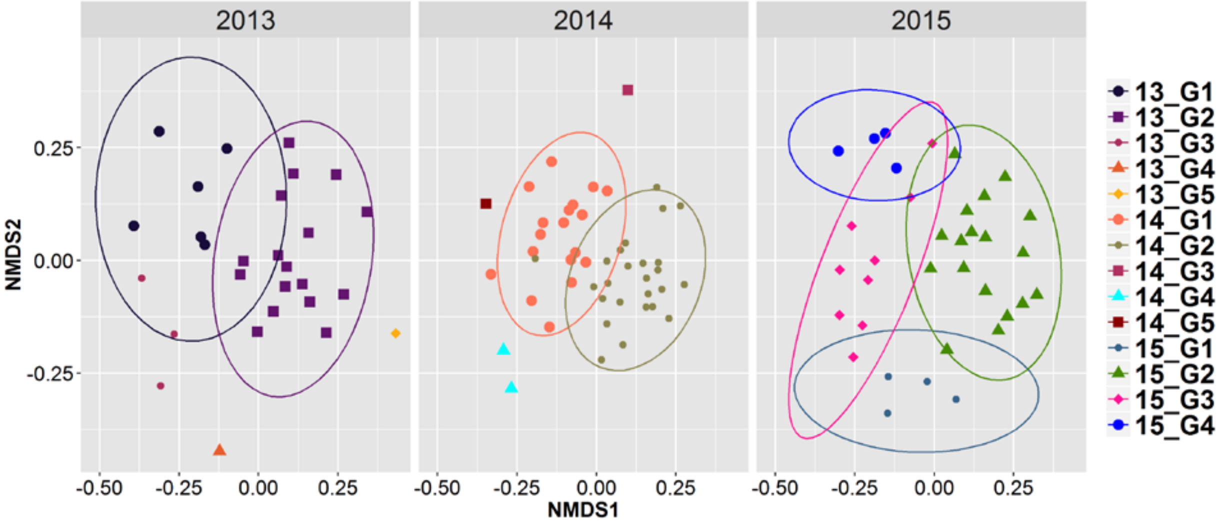


Figure 115. NMDS plots of zooplankton abundance during each individual year (2013-2015).

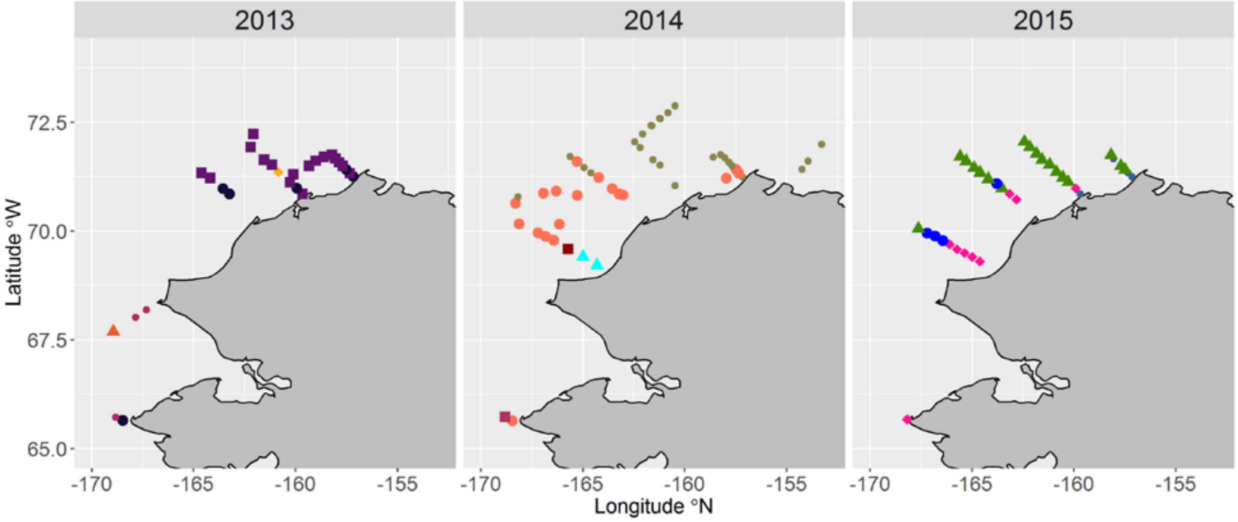


Figure 116. Distribution of the species assemblages within each year that were characteristic of that year. Symbols are defined in Figure 115.

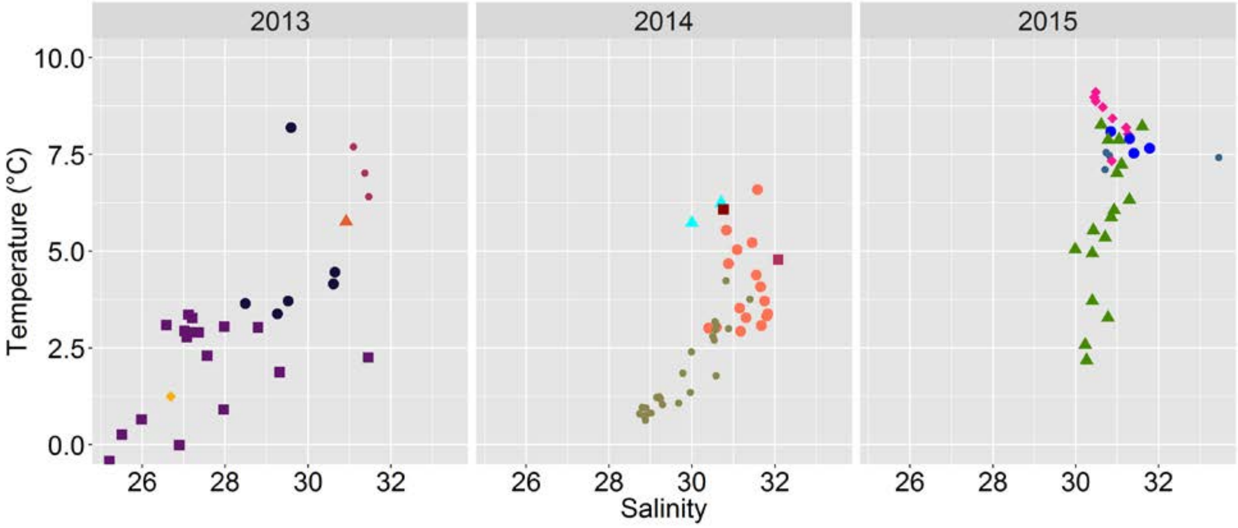


Figure 117. Relationship between the temperature and salinity of a particular station and the zooplankton assemblage found at the station. Symbols are defined in Figure 115.

Calanus glacialis, a lipid bearing, medium sized copepod is important in the transfer of energy from lower to higher trophic levels. Therefore, we examined the abundance of the various developmental stages relative to the different species groupings. High values with low variance may indicate more recent reproduction across large areas. In 2013, *C. glacialis* was abundant across all stages within Group 1, but with very high variability in the earliest copepodite stages (Figure 118). Contrary to this, Group 2, the offshore and eastern assemblage cluster, had high abundances and much lower variability across all stages, particularly the first two stages. In 2014, Group 1 concentrations of CI and CII stages were near zero and abundances of CIII, CIV, CV, and adult were highly variable for this group that dominated the southwest portion of the study area. Group 2, the northeastern most group, had low and highly variable abundance for CI and CII, but high abundances with lower variance for the later stages (CIII-adult). Similarly, 2015 had low and highly variable abundances for all four groups. Group 2 in 2013 had the most consistent concentrations across all stages compared to other years/groups suggesting that local production and advection were important processes for those stations.

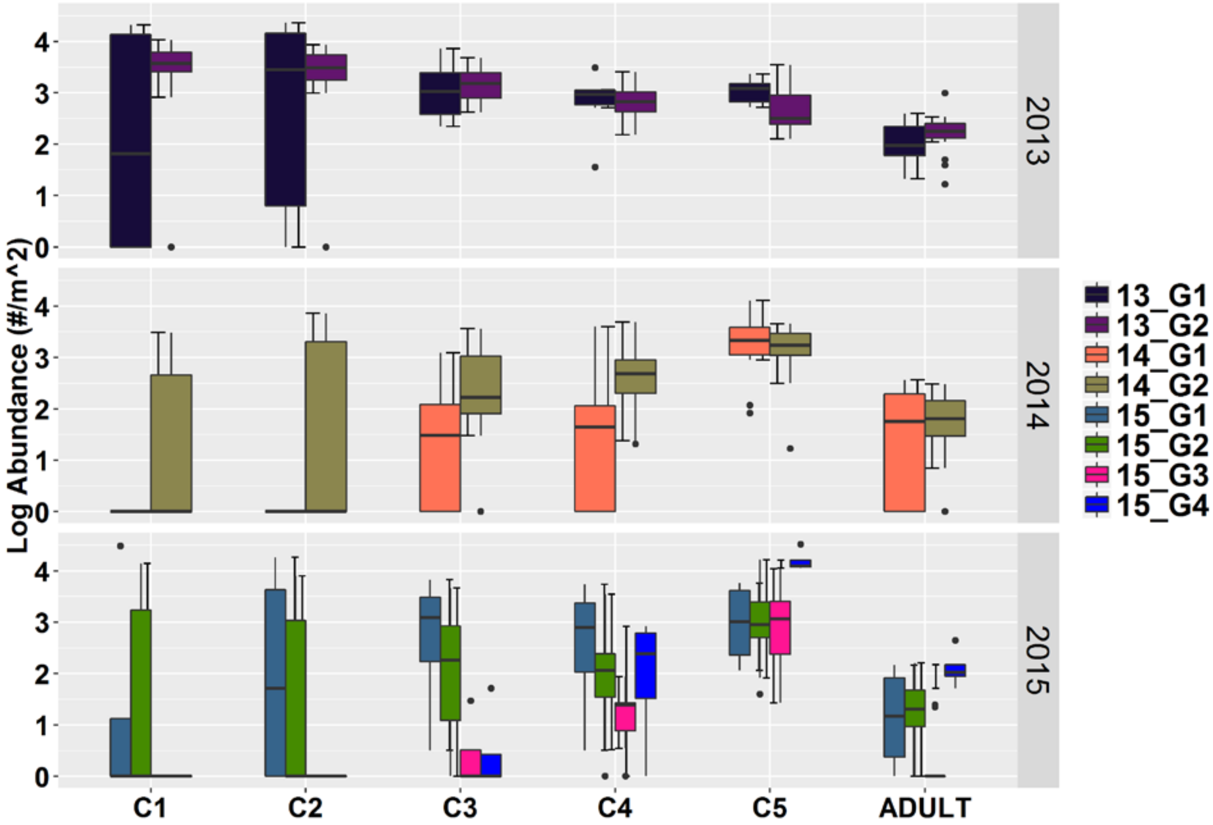


Figure 118. Box plots of the abundance of *C. glacialis* in each of the annual assemblages by developmental stage and year.

3. *Discussion*

Study of Hanna Shoal was somewhat limited by access to the area during periods of prolonged ice cover, when other areas were already ice free. We were able to occupy stations over the southwest flank and top in all three years (2013-2015), while occupation of the northeast flank was limited to two years (2013 and 2014).

Dissecting our data to examine causal factor was also made difficult by differences in sampling periods among years. For example, the 2014 survey, delayed by vessel contract issues, began more than one month later than the 2013 and 2015 surveys. Due to ship time constraints and the difficulties of using vessels that could not support 24-hr operations, not all transects were occupied in all years. In addition, nature provided us with three very different sets of environmental conditions for the study years. While having different environmental conditions is advantageous in exploratory projects such as ARCWEST and CHAOZ-X, the short duration of the projects precluded having two or more years with similar conditions. Environmental characteristics during the surveys for the three years were very different. Overall there was a decline of average April sea-ice extent across the entire Arctic from 1979 – 2017 (http://nsidc.org/arcticseaicenews/) with a monotonic decline from 2012 (ca 14.74 x 10^6 km^2) to 2016 (ca. 13.8 x 10^6 km^2).

We will focus on two hydrographic lines (WT and HS) which provide the most information of conditions around Hanna Shoal. These CTD stations largely coincided with the zooplankton stations. Temperatures varied among the three years, with the warmest temperatures in 2015 and the coldest in 2013. Bottom temperatures were particularly cold in 2013; we hypothesize that this was result of persistence of ice in the region. This is supported by the very low (27) salinities on both the HS and WT lines. Bottom salinities in 2013 were >32.5. In addition, nitrate concentrations were >15 µM in 2013, while in the other two years concentrations were < 5 µM. This implies that the subsurface bloom had already occurred when we were sampling. The lack of similarity among the years, makes it difficult to establish a baseline.

We found elevated levels of chlorophyll and chlorophyll fluorescence over the southwest flank, top, and northeast flank during all occupations, with the highest extracted chlorophyll near the seafloor. Hanna Shoal had the highest chlorophyll concentrations measured for the entire Chukchi Shelf during our 2015 survey. The depth of the shoal is only 30 m at the center and it is likely that sunlight reaching to that depth plus the nutrient reservoir below the pycnocline help to support primary production for much of the summer season until nutrients are exhausted.

We examined both the areal distribution of zooplankton and the community structure over the shoal relative to our other transect lines on the shelf to better understand if this region provides enhanced prey resources for planktivorous species. Zooplankton abundance by species over the shoal and its flanks did not appear to be higher than the surrounding areas. In fact, several of the taxa examined (adult + juvenile euphausiids, *C. glacialis* CV copepodites) appeared to have lower abundances over the shoal than along other transects. There were no apparent differences in the zooplankton community structure over the shoal relative to our other transects. There were differences among years for community structure over the shoal, but these differences followed the general patterns seen over the offshore portion of the shelf.

4. Conclusions

- Temperatures were coldest in 2013 because of the persistence of ice near Hanna Shoal, and warmest in 2015.
- Near bottom salinities were greatest in 2013 and slightly fresher in 2014 and 2015. The lowest near surface salinities were observed in 2013, likely as a result of the persisting sea ice.
- The water column over the shoal was strongly stratified in both years (2013, 2014) with a pool of nutrients below the pycnocline. Nutrient concentrations below the pycnocline were much higher in 2013 than in 2014.
- Areas of elevated chlorophyll and chlorophyll fluorescence were detected over the shoal and two of its flanks. The depth of the maximum fluorescence over the flanks was that same depth as the top of the shoal creating subsurface maxima that extended beyond the top of the shoal.
- In 2015 concentrations of extracted chlorophyll-a over the shoal were the highest measured over the shelf during that year’s survey.
- The zooplankton community over the shoal was different among the three years, but it was not markedly different than the community over the surrounding shelf areas.
- Total large zooplankton over the shoal was somewhat less abundant than over the surrounding shelf and may have been due to lower abundances of krill and late stage *Calanus* copepodites.

5. Recommendations

Hanna Shoal is associated with unique features in biological production, despite the small differences in depth between the top of the shoal and the surrounding shelf. Climate induced changes to summer conditions over the entire Chukchi Sea shelf may be much easier to detect at Hanna Shoal than other locations. Therefore we recommend continued deployment of moorings over the shoal and flanks, as well as annual shipboard monitoring. A recommendation to include this region as part of the international Distributed Biological Observatory (DBO) would help to make this a reality.

Summer primary production is necessary to keep pelagic ecosystems healthy. In deeper coastal areas, this often occurs when storms mix the water column bringing nutrients from below the pycnocline to the surface where there is sufficient light. This creates episodic blooms where the total annual primary production may strongly be influenced by the number and strength of wind events (e.g., southeastern Bering Sea, Sambrotto et al. 1986). On the other hand, it is likely that Hanna Shoal is shallow enough that sufficient light to support primary production reaches the top of the shoal during the summer if the areal ice cover is not 100%. How low the percent of areal ice cover must be depends on month (e.g., solar radiation), ice thickness and snow cover (albedo). When nutrients over the shoal are still plentiful below the pycnocline, primary production can occur and that will create a biological pump. Investigations into the health, species mix, and productivity of phytoplankton over the shoal in summer would help us to better understand this mechanism and how it impacts the flow of carbon in this ecosystem.

Determining the importance of this shoal’s influence on the shelf as a whole is important to understand whether the production that occurs there is locally retained or helps to support production in the surrounding areas. From measurements of the ocean currents, it appears water and planktonic material on the shoal or to the north would either remain in the vicinity of the shoal or be advected eastward. A first step to understand the fate of production in the vicinity of the shoal would be repeated mapping of the physics, chemistry and biology of the area using a towed vehicle (e.g., Martini et al. 2016) or glider. A subsequent step would be modeling of carbon flow in the system, such as done by Ciannelli et al. (2004) for the Pribilof Islands. This would provide opportunity to include the carbon and nitrogen flow on top trophic level consumers such as marine mammals, seabirds, and humans.

C. ***Other Observations*** *(Prawler, wave gliders,)*

1. Methods

Prawler

In 2015, we deployed a Prawler mooring in the Chukchi Sea ~75 NM northwest of Icy Cape, AK at EcoFOCI mooring site C2, 71° 14.459'N, 164° 18.067'W, as part of PMEL’s Innovative Technology for Arctic Exploration (ITAE) program (Figure 119). The system was deployed 10 July and recovered 17 September 2015. The mooring also recorded meteorological data including winds, atmospheric temperature, relative humidity and barometric pressure, though these details are not reported here. The Prawler (Osse et al. 2015) is a wave powered profiling crawler that ratchets up and down the mooring line with a CTD (SBE Prawler-CTD) and dissolved oxygen sensors (Figure 119). The Prawler profiled the upper water column, between 2 m and 27 m, at user specified times, but nominally at ~1 hour intervals (with some coverage gaps). Because of this, all data were averaged and/or interpolated to hourly intervals for analysis.

Wave Glider

In 2015, a modified Wave Glider (Liquid Robotics, Inc), was deployed in the Chukchi Sea ~140 km northwest of Icy Cape, AK at EcoFOCI mooring site C2, 71° 14.15'N, 163° 46.63'W, and included 1 m resolution of temperature in the upper 7 m of the water column, and salinity measurements at 0.5 and 7 m. A Wave Glider is a remotely controlled autonomous vehicle consisting of a surfboard-like surface float connected to a louvered submarine situated at ~6 m below the surface (Figure 119). The submarine portion converts wave energy into forward motion of ~ 1 kt. Solar panels provide power for the sensors. Temperature was measured at meter intervals from surface to 6 m and conductivity (salinity) was measured at the surface and at 6 m.

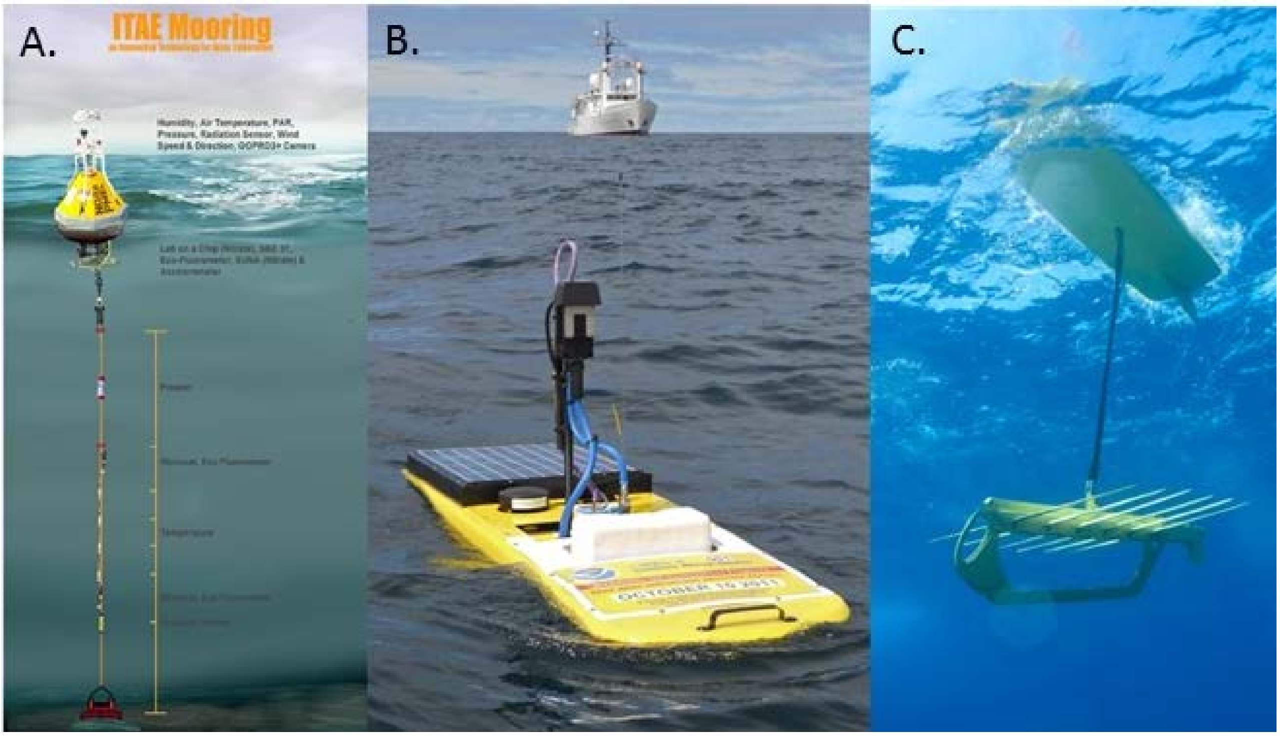


Figure 119. A.) Schematic of the ITAE mooring with Prawler; B.) A wave glider above, and C.) below the water's surface.

2. Results

Prawler

While the main moorings provided a time series of temperature in the near bottom, time series of temperature in upper water column were lacking. The ITAE mooring, which contained a number of instruments, including the Prawler, provided time series of temperature in the upper 25 m of the water column (Figure 120). Unfortunately, there were some gaps in the temperature time series, but this data set gives us a two month record of how the upper water column changed. First, depth of the interface between the surface and bottom layer was not steady, but varied by approximately 5 m on a time scale 3-5 days. This fluctuation did not appear to be related to wind mixing. Second, the near surface temperature changed rapidly, likely as a result of advection of different water masses past the mooring site. There were periods of rapid warming and of rapid cooling. Finally, a strong mixing event was evident in late August, when winds exceeded 10 m s-1 for several days (top panel). The vertical mixing of the water column was evident in the water column (bottom panel). Warm water (>5°C) was introduced to near bottom, but this warmer water was eventually replaced by cold (<2°C) water.

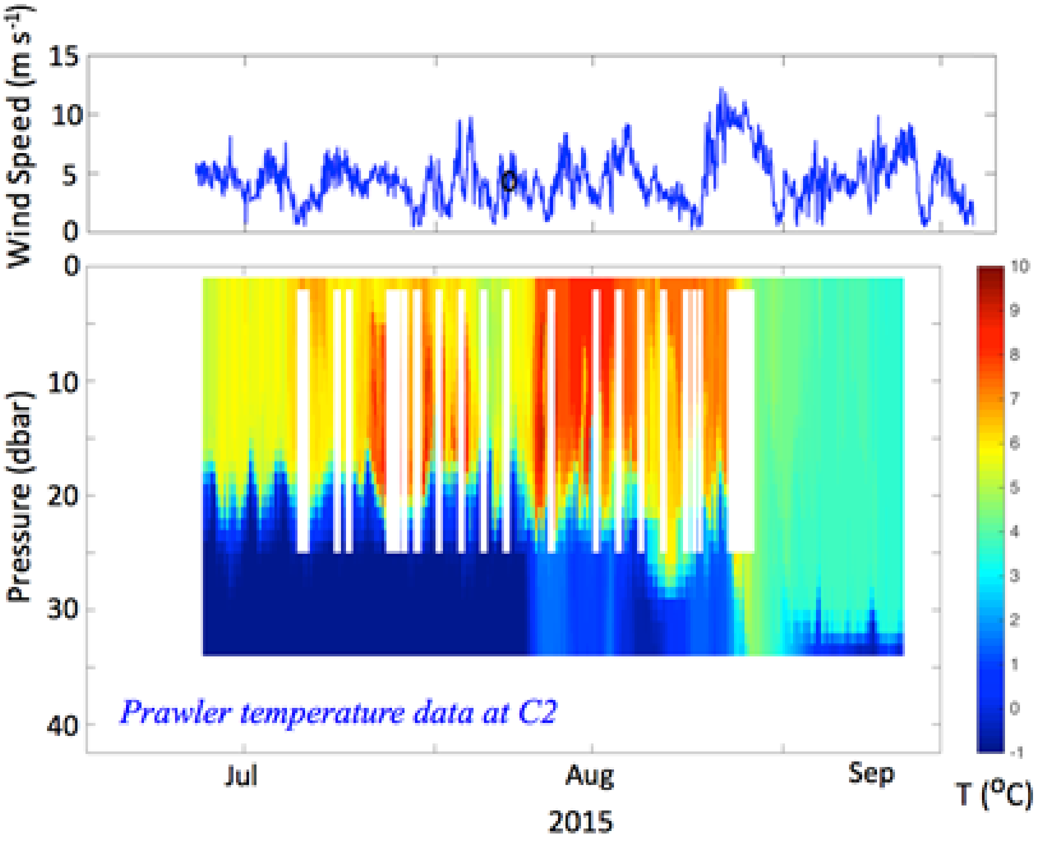


Figure 120. Measurements of wind speed (top) and temperature (bottom) at mooring site C2. All data were collected on the ITAE mooring. The gaps in temperature resulted from technical problems with the Prawler.

Wave Glider

A Wave Glider was used to explore the spatial variability around mooring site C2 and compare it to that of near Hanna Shoal. Temperature and salinity are shown in Figure 121 (upper panels) along a ~2 week trajectory (bottom panel). The transit began south of Hanna Shoal on 17 August 2015 and moved northwestward toward the shoals. On 21 August retraced its path until it intersected the Icy Cape transect. It then turned toward C2, collected data on a square around mooring and finally headed south to be recovered 31 August 2015. At the beginning of its trajectory temperatures exceeded 8°C and salinity was ~31. As the Wave Glider neared Hanna Shoal, the surface salinity dropped to ~27 and ocean temperatures cooled to ~4°C. Upon its return south, temperatures and salinity increased.

An interesting feature occurred on 22-24 August 2015, when the upper 6 m of the water column was stratified, with fresher, colder water on the surface and warmer, more saline water at 6 m. Such structure could well indicate ice melt that has warmed. The late August storm (Figure 121) likely played a role in mixing the water column.

The spatial complexity of the surface water is evident in the Wave Glider data. Hanna Shoal tends to maintain ice longer than the surrounding waters, so as it melts it would continue to cool and freshen near the surface (e.g., Martini et al. 2016). However, even areas away from the shoal show a patchwork of varying surface temperatures and salinities.

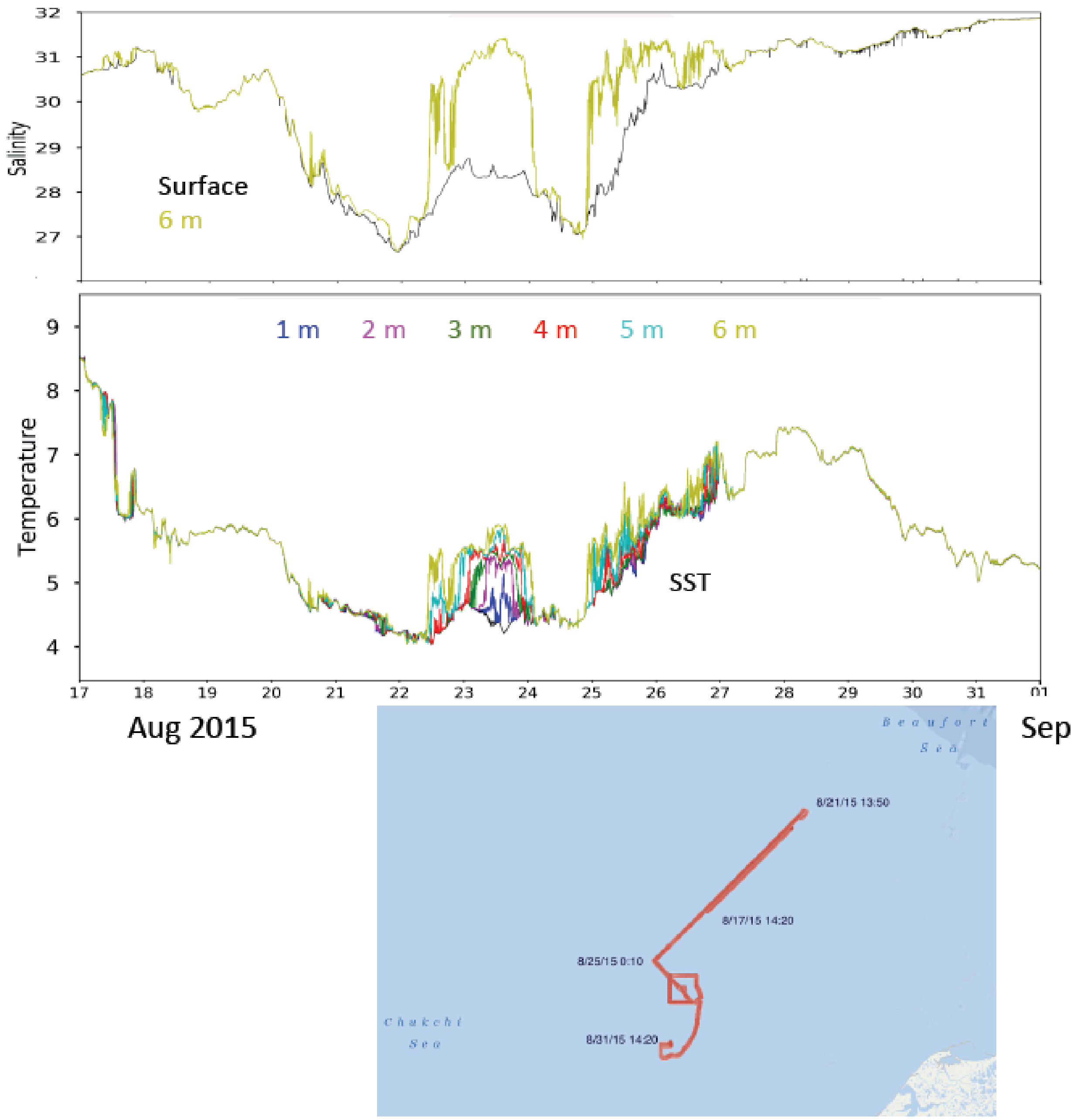


Figure 121. Time series of salinity (top panel) and temperature (middle panel) collected during the transit of the Wave Glider in the Chukchi Sea (bottom panel). Salinity was measured at the surface and 6 m while temperature was collected at 1-m intervals from the surface to a depth of 6 m. The Wave Glider was deployed in the south, repeatedly sampled a box around the C2 mooring, and then made several passes over Hanna Shoal.

3. Discussion and Conclusions

The remoteness of the Chukchi Sea and the presence of sea ice limit shipboard measurements to a few months during the year. The presence of ice restricts winter mooring measurements to the near bottom. New technology provides cost effective ways of increasing our observations in this region. The Prawler measures a variety of parameters in the water column. While this first deployment of this instrument in high latitudes was of limited success (the fluorometer, oxygen sensor, conductivity cell and sampling rate all had technical problems), the temperature measurements revealed interfacial waves, the horizontal patchiness of the water column and strong mixing in response to a summer strong. This technology was deployed in Bering Sea in 2016 and functioned well. In late July 2017 it was deployed in the Chukchi once again at C2.

While the Prawler is designed to measure high temporal variability at one point, the waveglider is designed to measure high spatial variability. In 2016, the wave glider transited across the front between Hanna Shoal and the stronger flow on the Icy Cape line. The colder low salinity near surface water around Hanna Shoal was evident. Such technology is a cost effective way of monitoring how the boundary (front) around Hanna Shoal would evolve over a several month period.

4. Recommendations

These pieces of technology are part of the Innovative Technology for Arctic Exploration (ITAE) program conducted at NOAA/PMEL. The goal of this program is to develop new technology to help improve our understanding of the complex Arctic systems. The development and use of such new technology improves our understanding of the marine ecosystem, as does collaboration among various research groups.

IX. AMBIENT NOISE CONTRIBUTORS AND ACOUSTIC ENVIRONMENT ANALYSIS (OBJECTIVES 5, 6)

Moored Observations for ambient noise analysis *(Moorings: WT1, PH1, IC2, and BF2 or HS1)*

1. Methods

Equipment

A subset of the moored recorders deployed by MML for the long-term marine mammal distribution work, described in Section VII.A, were selected for this acoustic analysis (Table 36). The selection criteria were based on a relatively wide spatial coverage of the U.S. Arctic, areas of biological importance, and areas of elevated anthropogenic influence. Section VII.A above describes the recorder moorings deployed by MML. The same data with the same recording characteristics (16 kHz sample rate, 16-bit resolution, 16 dB gain, duty cycle of 85 min of recording every 5 hours) were used for this analysis. However, due to the substantial presence of low-frequency flow noise and strumming caused by high current periods in many of the mooring locations, data were high-pass filtered below 50 Hz to reduce this source of self-noise; unfortunately this also eliminated the acoustic contribution of fin whales and thus, this species is not considered in this analysis.

Data analysis

The acoustic analysis was conducted for data from each mooring location (Table 36) for two different categories of ice concentration: open-water and ice. See Section VIII.C.1 *Satellite remote sensing and ice data* for a description of how ice concentrations were derived. This decision to categorize our database on ice was made because ice presence modifies sound propagation, decouples the water column from atmospheric processes such as wind or rain, which are sources of noise, and contributes to the background noise from sound generated by thermal and frictional ice stress. The limit we used to differentiate between seasons of open water versus ice was determined by an ice concentration lower/higher than 15%, respectively.

Table 36. List of deployment information for MML moored passive acoustic recorders selected for ambient noise analysis. Note: HS1 was included if data from BF2 were not suitable for analysis.

Mooring	**Water Depth (m)**	**Location**		**Recorder start date**	**Recorder end date**	**Number of days with data**
		Latitude (N)	**Longitude (W)**			
WT1	49	71.046°	160.509°	8/30/2012	10/3/2013	400
PH1	58	67.909°	168.195°	8/22/2012	8/23/2013	367
IC2	43	71.202°	164.199°	8/27/2012	7/31/2012	338
BF2	93	71.751°	154.471°	8/31/2012	8/31/2013	365
HS1	45	72.427°	161.629°	8/30/2013	10/1/2014	397

In order to characterize each contributor of the acoustic environment, per mooring site and season, results of species and noise occurrence obtained through methods explained in Section VII.A.1 were used to select recording periods with different sound contributors. For example, only file segments containing bowhead whale signals were used to calculate acoustic metrics corresponding to the sound contribution by this species. Acoustic metrics were calculated using Cornell's noise analysis software tool, referred to as the Acoustic Ecology Toolbox (AET: originally referred to as SEDNA [Dugan et al. 2011], and further developed during CHAOZ-X). The name Acoustic Ecology Toolbox (AET) embodies a primary motivation for this analytical tool and methodology, which is to quantify the relative individual and/or aggregate contributions from various sound sources and to assess their influences on the marine acoustic environment, in general, or specifically on the acoustic habitats of selected species of concern. In this case, individual contribution was measured by calculating the spectral empirical probability density in 1 hour averages and power spectral density percentiles (1st, 25th, 50th, 75th and 99th) using only file segments that included exclusively one sound source (e.g., bowhead whale, Figure 122).

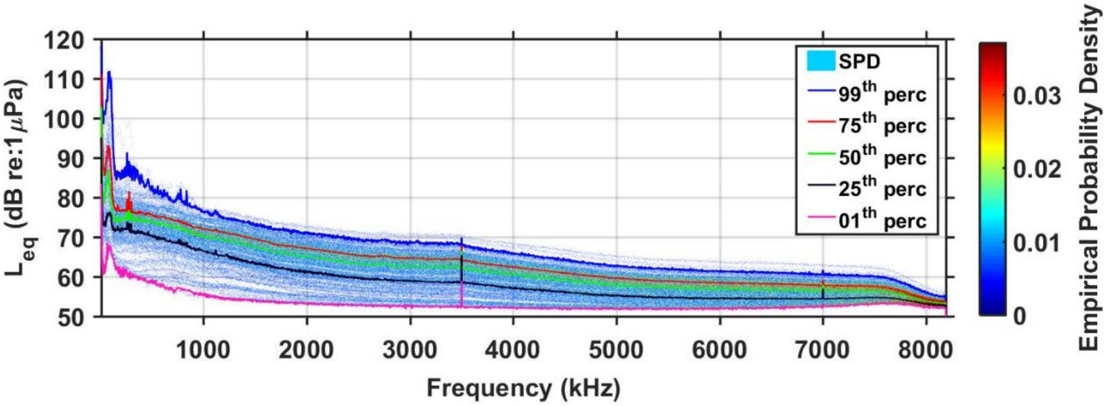


Figure 122. Spectral probability density and power spectral density percentiles for bowhead whale files during the 2012 ice season at WT1.

Acoustic metrics were calculated for each sound contributor per open water or ice season identified in each mooring. Sound contributors included in this analysis were all the species and abiotic sources described in Section VII.A.2. These metrics were also calculated for the recording periods that included 15% or more ice concentration and no other sound source other than ice, defined as the ice period, as well as less than 15% ice concentration where no source was identified, defined as the open water period, per mooring location. The results of these measurements were considered to represent the natural ambient noise of each mooring location, composed of all aggregated distant sources influencing the mooring area during the open water season, plus ice noise during the ice season. For this study, "ambient noise" refers to a natural noise condition in which no discernible anthropogenic sources are included, versus "background noise" condition in which all types of sources are included. The ambient noise measurements obtained for both the ice and open water seasons, were used as the baseline reference to compare against all sound contributors. This comparison was achieved by importing into Excel the 50th spectral percentile (corresponding to the median spectrum) for each sound contributor per season and plotting against the 25th, 50th and 75th spectral percentiles of ambient noise. This approach allows characterizing the dominant frequencies for each contributor (i.e., peak frequencies in the median spectral curve), as well as differences between contributors (i.e., differences in the shape of the median spectral curve), while considering the differences in ambient noise by season and location (i.e., the level of overlap between ambient noise percentile curves and each contributor's median curve). Results from this analysis will aid discussions on the seasonality of biotic, abiotic and anthropogenic sound sources, including the dominant sources for each season and year, as a basis for a long-term, multiyear, evaluations of changes in the acoustic components of the Arctic environment.

Noise Masking Modeling

Two different data sets were used for the analysis undertaken in this section. This included recorders deployed by Cornell specifically for development of the Chukchi Sea noise model, and a subset of the recorders deployed by MML for the long-term marine mammal distribution work (Table 37). Section VII.A.1 above describes the recorder moorings deployed by MML. Cornell deployed three types of acoustic instruments: marine autonomous recording units (MARUs; Parks et al. 2009), double-bubbles (DBs), which are MARUs configured with a second sphere containing only batteries, and auto-detection buoys (ABs). There were five deployments of MARUs, five deployments of DBs, and two deployments of ABs (Figure 123; Table 37). For consistency we refer to a specific instrument by its instrument type (MARU, DB or AB), deployment year, and unit number (e.g., MARU14_01 refers to the first MARU deployed in 2014).

Table 37. List of deployment information for all Cornell moored passive acoustic recorders, 2013-2016 for auto-detection, and sound event analyses.

Mooring	Mooring Cluster	Latitude (°N)	Longitude (°W)	Water Depth (m)	Recorder Start Date	Recorder End Date	Number of Days with Data	Sampling Rate (Hz)	Duty Cycle (min on/min total)	Deployment Date	Retrieval Date
MARU14_01	PU	71.06774	-163.48502	41	08/04/14	10/13/14	69	8000	Continuous	8/4/2014	10/13/2014
MARU14_02	PU	71.12916	-163.68437	41	08/05/14	10/13/14	69	8000	Continuous	8/5/2014	10/13/2014
MARU14_03	PU	71.19074	-163.48329	41	08/05/14	10/13/14	69	8000	Continuous	8/5/2014	10/13/2014
MARU14_04	PU	71.2519	-163.68326	41	08/05/14	10/13/14	69	8000	Continuous	8/5/2014	10/13/2014
MARU14_05	PU	71.30836	-163.47092	41	08/05/14	No Data	0	8000	Continuous	8/5/2014	10/13/2014
DB13_01	DB	71.02795	-163.65765	42.5	08/27/13	08/03/14	342	2000	Continuous	8/27/2013	8/4/2014
DB14_01	DB	71.0004	-163.682	43	08/20/14	08/05/15	350	2000	Continuous	8/20/2014	9/18/2015
DB14_02	DB	71.0005	-163.6531	43	08/20/14	08/05/15	350	2000	Continuous	8/20/2014	9/18/2015
DB15_01	DB	71.298933	-163.27718	43	09/18/15	09/12/16	360	2000	Continuous	9/18/2015	9/15/2016
DB15_02	DB	71.496533	-163.19082	44	09/18/15	No Data	0	2000	Continuous	9/18/2015	Not recovered
AB_2014	AB	70.999957	-163.67671	41	08/20/14	10/07/14	48	8000	Continuous	8/20/2014	10/13/2014
AB_2016	AB	70.9944707	-163.71253	42	08/23/16	No Data	0	8000	Continuous	8/23/2016	NA

In August 2014, five MARUs (MARU14_01, MARU14_02, MARU14_03, MARU14_04, MARU14_05) were deployed with inter-unit spacings of approximately 10 km. Units were deployed in a saw-toothed formation such that the long axis of the five recorders ran from south-southwest to north-northeast so as to be approximately perpendicular to the direction of the anticipated fall 2014 offshore bowhead migration. This geometry was intentionally designed so as to maximize the area over which acoustically active bowheads could be detected, and not as a localization and tracking array. This was because we wanted to use the resultant acoustic detections of bowheads as input into the spatially explicit capture-recapture (SECR) algorithm (Marques et al. 2009; Efford et al. 2013). As it turned out, there were very few bowhead acoustic detections, so it was not possible to conduct a viable SECR analysis.

Around the same time that the five MARUs were deployed, the DB deployed in that area in 2013 (DB13_01) was recovered, and two DBs were deployed very close to DB13_01's location and very close to each other. By this arrangement the two DBs deployed in August 2014 (DB14_01 and DB14_02) added a sixth element to the 5-element MARU array (Figure 123). A second DB (DB14_02) was deployed in 2014 because it was on board as a backup, and the first DB was responding properly after deployment: therefore, we decided to deploy the backup DB in case the first DB failed to record or could not be recovered. In October 2014 all five MARUs were recovered, and the two DBs remained to record continuously until recovery in 2015. In September 2015 the two 2014 DBs (DB14_01 and DB14_02) were recovered and replaced (DB15_01 and DB15_02). In September 2016 only one of these two 2015 DBs (DB15_01) was recovered, but was not replaced.

All five MARUs were programmed to record continuously at a sampling rate of 8 kHz, and all five DBs were programmed to record continuously at a sampling rate of 2 kHz. Other than these different sampling rates and battery capacities, all ten recording systems were identical (HTI 94-SSQ hydrophone, sensitivity with preamplifier of -168 dB re: 1 V/ 1 µPa, 23.5 dB gain, 11.3 bit depth, flat [± 3dB] frequency response from 10-585 Hz, variable [± 10dB] frequency response above 585 Hz). All recorders were moored 1-2 m above the seafloor in water depths of 41-44 m.

Data extraction and archiving

Once recovered, all available data from the five MARUs were extracted and evaluated. Data from MARU13_01, 02, 03 and 04 were validated as acceptable, but MARU13_05 failed to collect any useful data. Data from the four good channels were synchronized to ±1 ms and merged, along with blank data (all zeroes) representing MARU13_05, into a continuous series of 15-min, 8 kHz, 5-channel files spanning 69 days.

A similar process was followed for data from each of the DB deployments. DB data for the 2013-2014 period (DB13_01) yielded 342 days of data archived as a continuous series of 15-min, 2 kHz, single channel files. DB data for the 2014-2015 period (DB14_01 and DB14_02) yielded 350 days of data archived as a continuous series of 15-min, 2 kHz, 2-channel files (one mooring per channel). DB data for the 2015 period (DB2015_01) yielded 360 days of data archived as a continuous series of 15-min, 2 kHz, single channel files.

Complete copies of the MARU and DB data sets were made and archived at a site in Ithaca, NY separate from the Bioacoustics Research Program. The file naming convention was adopted using Cornell's standard file naming convention, which includes the following information in order: project identification number-contract institution, sampling rate in kHz, number of channels, single or multi-channel, year-month-day and hour-minute-second in GMT (e.g., 71664WHOI01_008K_M05_multi_20140923_224500Z). The MML data used in these analyses were processed and archived as described in Section VII.A.1 above.

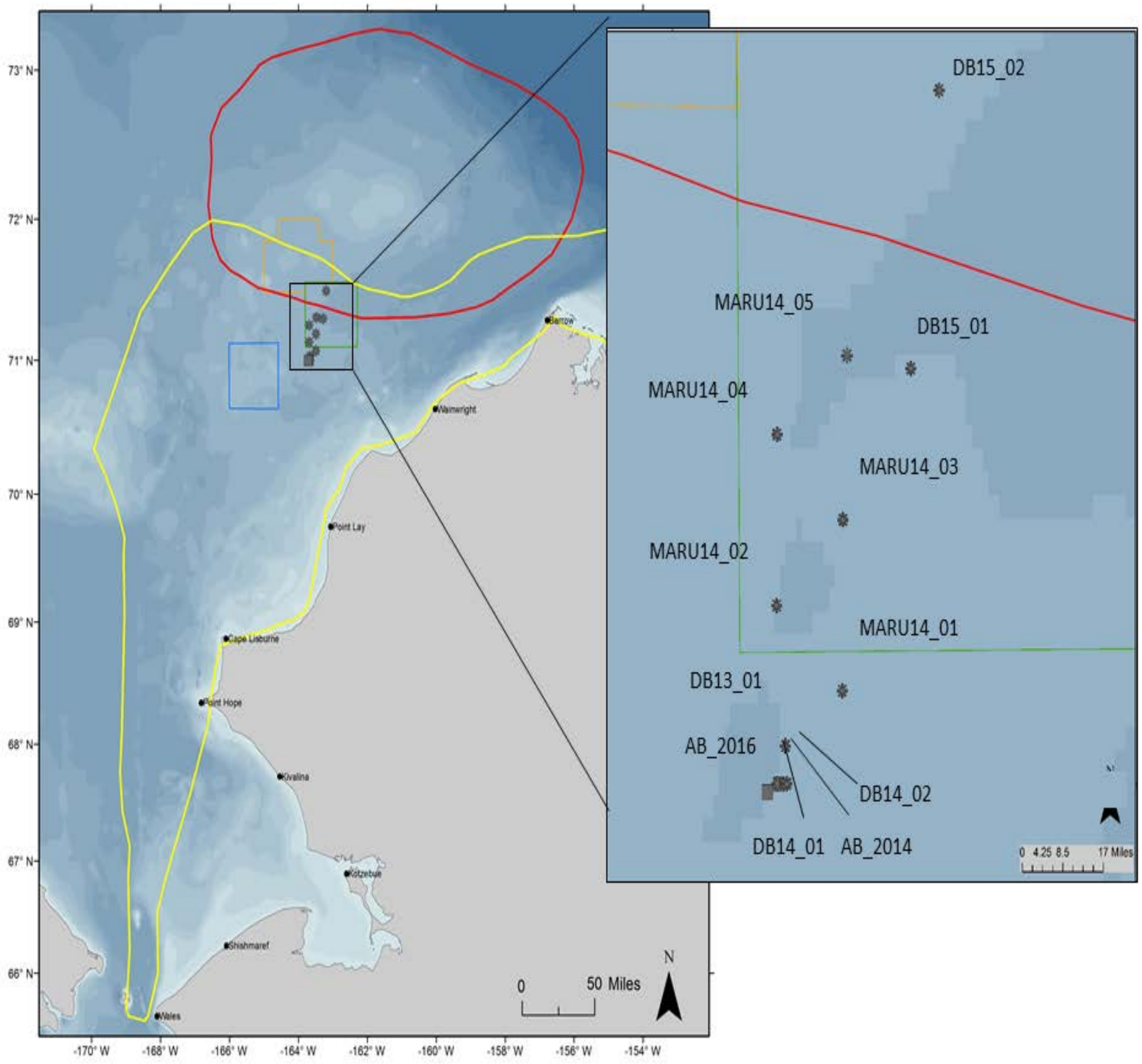


Figure 123. Deployment arrangement of five Cornell MARUs in 2014 (MARU14_01, MARU14_02, MARU14_03, MARU14_04, MARU14_05) relative to double-bubbles (DB) deployed in 2013, 2014 and 2015 (DB13_01, DB14_01, DB14_02, DB15_01, and DB15_02), and an auto-detection buoy in 2014 and 2016 (AB_2014 and AB_2016).

Data analysis

Cornell data:

All MARU and DB data were processed using Cornell's noise analysis software tool, referred to as the Acoustic Ecology Toolbox (AET). The name AET embodies a primary motivation for this analytical tool and methodology, which is to quantify the relative individual and/or aggregate contributions from various sources of sound and assess their influences on the marine acoustic environment, in general, or specifically on the acoustic habitats of selected species of concern. The AET provides an analytical mechanism by which to: a) estimate the aggregate noise field from combinations of natural biotic, natural abiotic and anthropogenic sound sources and b) evaluate the biological-ecological costs that marine mammals likely experience as a result of changes in anthropogenically-driven background noise conditions over bio-ecological spatial, temporal and spectral scales.

This analysis represents a preliminary process that results in sound level measurements at 1 second, 1 Hz, and 1 dB (re 1 µPA) resolutions. These data processing results serve as the basis by which to calculate noise statistics, visualize basic characteristics of the data at user selectable resolutions, observe occurrences of different contributors to the ambient noise environment (e.g., marine mammals, ice, wind, vessels, seismic airguns) and otherwise gain a sense of the overall quality of the acoustic data. Typically data visualizations for these data processing results are viewed as daily four-panel plots (Figure 124). This form of analysis was used by Cornell to process data from the CHAOZ project to: a) derive noise statistics and b) calculate a regression function for the relationship between noise level and surface wind speed in the 71-708 Hz frequency band. The 95th percentile from the noise statistics was used to represent a normally quiet noise condition and combined with the regression function to model future noise conditions under a variety of acoustic scenarios (i.e., Cornell’s Chukchi Sea noise model).

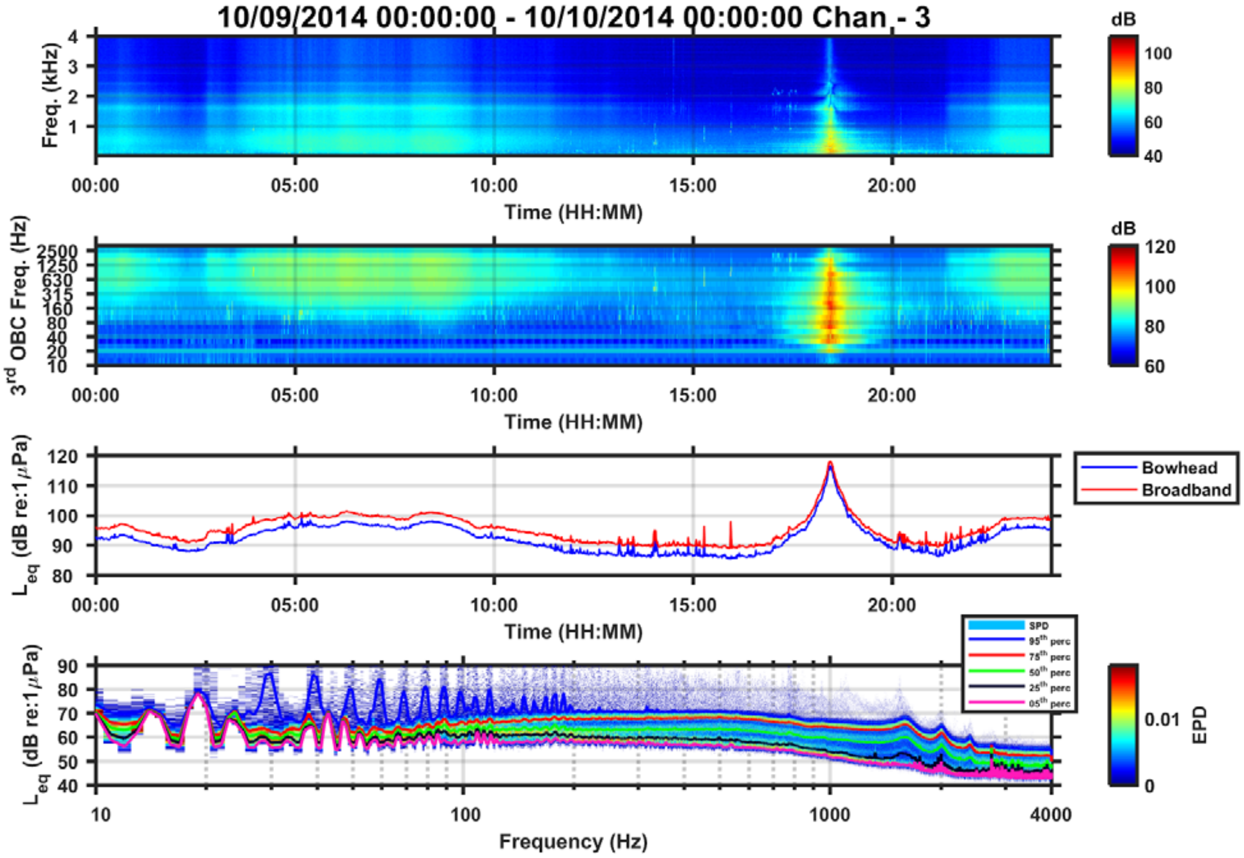


Figure 124. Example daily four-panel plot (MARU14_03, 09 October 2014)resulting from the preliminary noise analysis using AET. Top panel, long-term sound spectrogram; second panel from top, 3rd-octave spectrogram; third panel from top, time-varying sound level equivalent within a default bowhead whale frequency band (71-710 Hz) and the full frequency band (10 – 4000 Hz); bottom panel, statistical distribution of noise levels at 5th, 25th, 50th, 75th and 95th percentiles. The longer period of moderate acoustic energy from 04:00 to 10:00 represents noise from wind, while the shorter period of more intense acoustic energy at around 18:30Z represents noise from a passing vessel.)

For the Cornell analysis, the AET operated on a high-performance computer system and was applied to explore data from long-term recording systems (MARUs and DBs). This enabled exploration of relationships between wind speed, ice concentration and ambient noise levels, as well as the development of a model by which to assess the potential influences of different anthropogenic sound sources on the acoustic environment and acoustic habitats of different marine mammal species.

AET data processing results (e.g., spectrogram figures, noise distribution plots for different time scales) revealed a variety of acoustic events. These, in combination with additional analysis and careful listening were used to identify obvious biotic (e.g., bowhead whales and bearded seals) and abiotic types of sound sources (e.g., vessels, seismic airguns, wind noise and ice) that were contributors to the ambient environmental noise measurements and scenes. In particular, an effort was made to analyze the data for possible structure in the relationships between noise metrics, wind level and percent ice coverage. This was undertaken in order to inform models to predict future ambient noise levels under reduced ice concentration and likely higher surface wind speed conditions (see Roth et al. 2012).

The general mechanism by which changes in noise conditions impact an animal’s ability to engage in acoustically mediated activities (e.g., communication, prey detection, navigation) is referred to as “masking”. The comparative metric by which to assess the influence of masking on a bioacoustic activity is referred to as a “masking metric”. Here we are primarily concerned with bowhead whales, but secondarily with bearded seals and beluga whales.

The masking model metric includes two primary components that are probabilistic in nature: the probability of the bioacoustic event’s occurrence (e.g., the animal produces the sound) and the probability of biological event detection (e.g., the sound is detected). The first is dictated by such factors as behavioral context, and the density and distribution of animals, for which we utilize results from observations and existing models. The second is based on a combination of physical acoustics (e.g., environmental conditions, transmission loss, aggregate noise fields) and biology (e.g., audition, behavior, context), for which we can use some existing data, models, proxies, or best guesses. In any case, increased background noise level decreases the chances of detection.

For this analysis we combined satellite wind data (6 hr resolution), satellite sea ice concentration data (see Section VII.A.1 above), and ambient noise metrics (6 hr resolution), while accounting for known anthropogenic source occurrence (e.g., seismic airgun survey) and bowhead whale occurrence. These initial correlation analyses between a) daily noise level in the bowhead frequency band and daily wind speed, and between b) daily noise level in the bowhead frequency band and daily ice concentration provided a relational model between these factors. We conducted a preliminary evaluation to predict future noise levels by combining daily wind speed, sea ice concentration and both broadband and bowhead-band noise level data in a multivariate regression analysis. Results from the regression analysis were used to estimate future noise levels under future open water conditions (see Synthesis Section XI.E below).

2. Results

Data have been processed for mooring WT1 for the period August 2012 to October 2013 and for mooring PH1 for the period August 2012 to August 2013 (see Table 1, Section VII.A.1).

Mooring WT1

Results from the seasonal occurrence of marine mammals for this mooring location and period are presented in Figure 125 and suggest that the acoustic environment during the open water season might be dominated by vessel noise, bowhead sounds, and to a lesser extent, walrus sounds. For the ice season, main contributors to the acoustic environment were bearded seals, bowhead whales, ice noise, and to a lesser degree, beluga whales. Airgun noise was not detected in this mooring location and period. Walrus did not look like an important contributor when inspecting the percent of time per day detected: however, when exploring the spectral results, walrus contributions to the acoustic environment were substantial. Sample sizes in number of files and total amount of recordings containing these sound contributors are presented in Table 38.

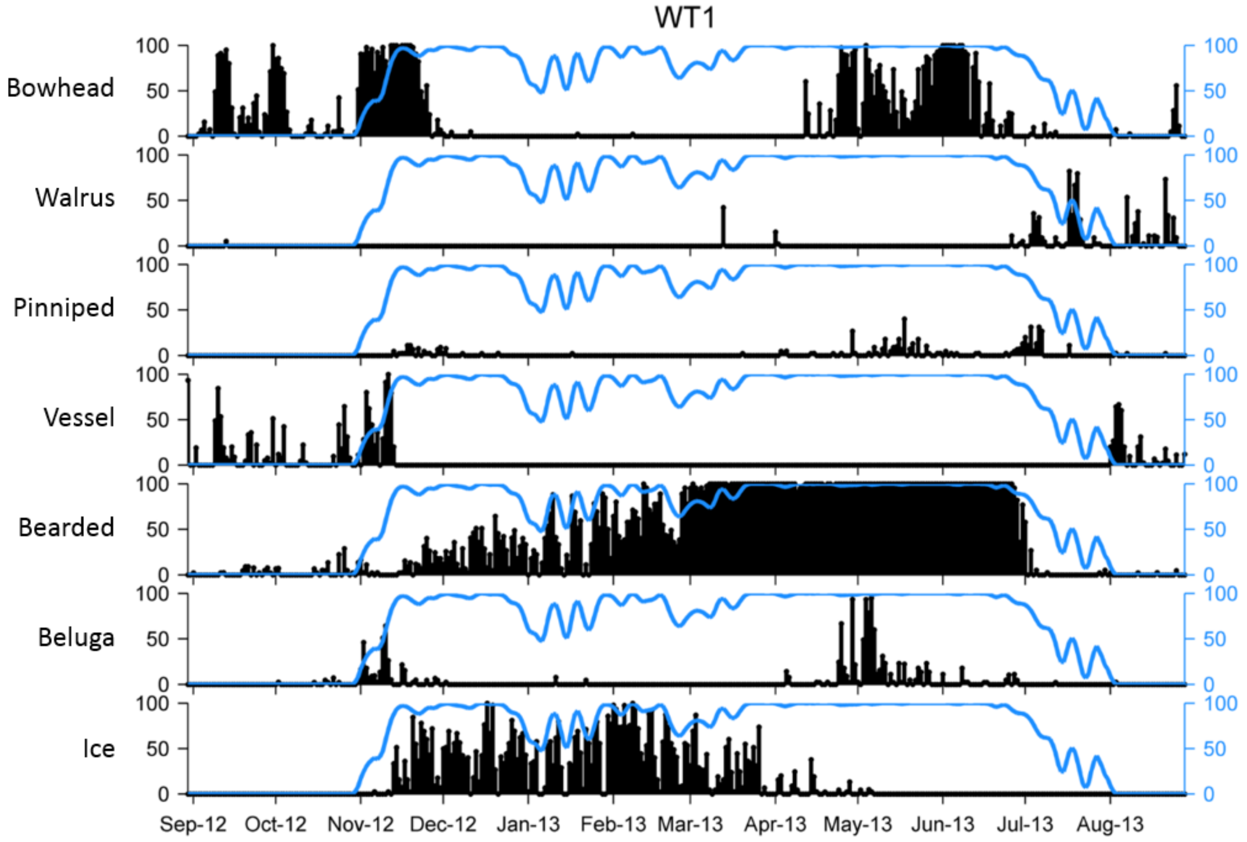


Figure 125. Seasonal occurrence (percent of time per day) at mooring WT1 during the period August 2012 to October 2013 for each of the seven acoustic contributors (black histogram) and for ice concentration (blue).

Table 38. Sample size, in number of files, and total recording time for the amount of time where each of the main contributors in WT1 (August 2012 to October 2013) were detected in isolation (e.g., when no other co-occurring sound source was identified).

Sound contributor	# files	Total recording time
Ambient noise (ice season)	19083	439 h 18 m
Ambient noise (open season)	19101	440 h 3 m
Bearded Seal	23909	555 h 38 m
Beluga whales	31	42 h
Bowhead whale	5090	115 h 52 m
Walrus	1084	24 h 32 m
Vessel noise	1985	45 h 11 m

The spectral probability density plot and spectral percentiles for the baseline ambient noise during the ice and open water seasons are presented in Figure 126. Ambient noise during the ice season, despite including ice noise generated by thermal and mechanical stress, showed lower levels across the spectrum, as can be seen in the comparison of their 50th percentiles in Figure 127. Differences in the average Sound Pressure Level (SPL) values between seasons were not so elevated: the average broadband (50 - 8192 Hz) SPL values for the open water season and the ice season were 109.6 dB and 105.7 dB, respectively.

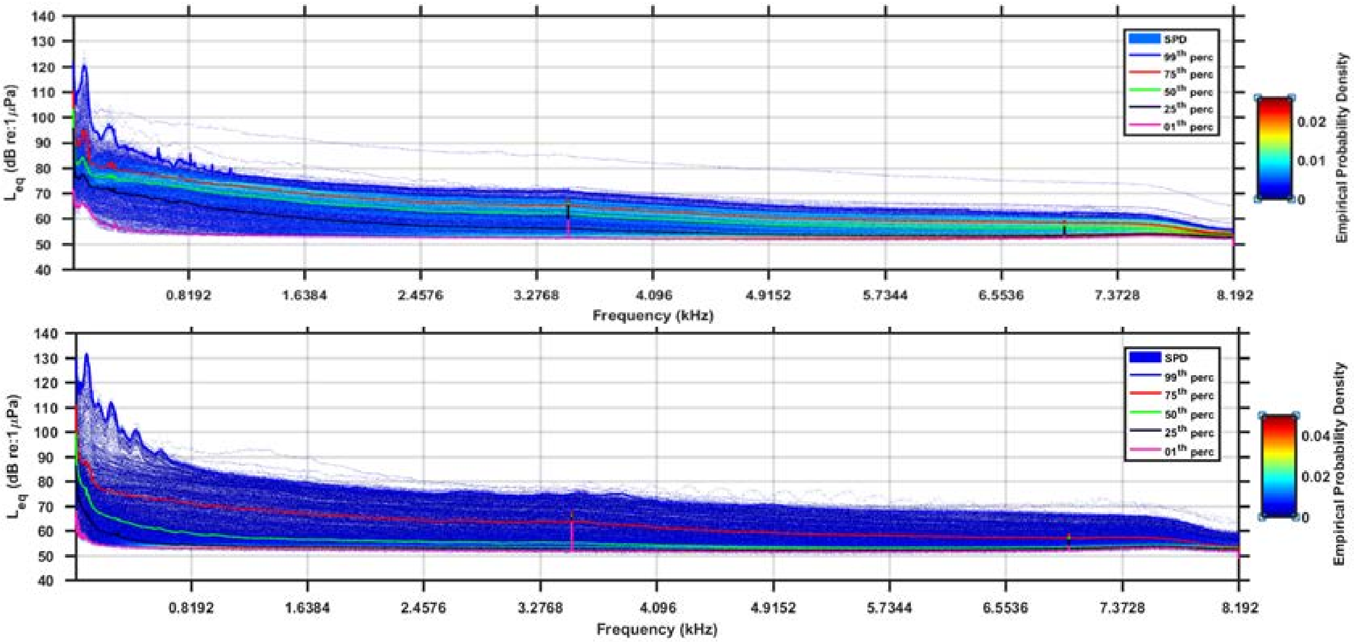


Figure 126. Spectral probability density plots and spectral percentiles for baseline ambient noise during the ice season (upper panel) and during the open water season (lower panel), for WT1 2012-2013.

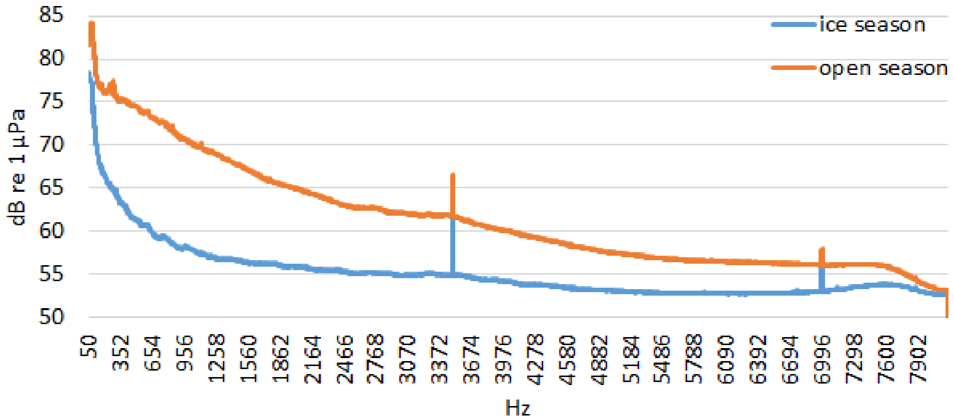


Figure 127. Spectral 50th percentile for ambient noise during the ice and open water seasons for WT1 2012-2013. Spikes at 3400 Hz and 7000 Hz are artifacts likely from electrical system noise.

The acoustic contributions of each of the dominant species, expressed as spectral 50th percentiles, was compared against ambient noise spectral percentiles per season. Here we present a selection of the most relevant results for each season.

Vessel noise spectral content and received levels differed between seasons, with highest contribution during the ice season for the lower frequencies, up to 1000 Hz. Noise at higher frequencies than 1000 Hz were more relevant during the open water season (Figure 128, upper panel). Average broadband SPL for vessel noise for the ice season was 110.9 dB, and for the open season 106.8 dB. Even if vessel noise was more prevalent during the open water season, its contribution was more acute during the ice season as can be seen in Figure 128, lower right panel, where its spectral curve exceeds the ambient noise 75th percentile at frequencies up to 800 Hz, and the 50th percentile at frequencies up to 3500 Hz. These results are a combination of louder ship noise during the ice season for the low frequencies, in a lower ambient noise condition.

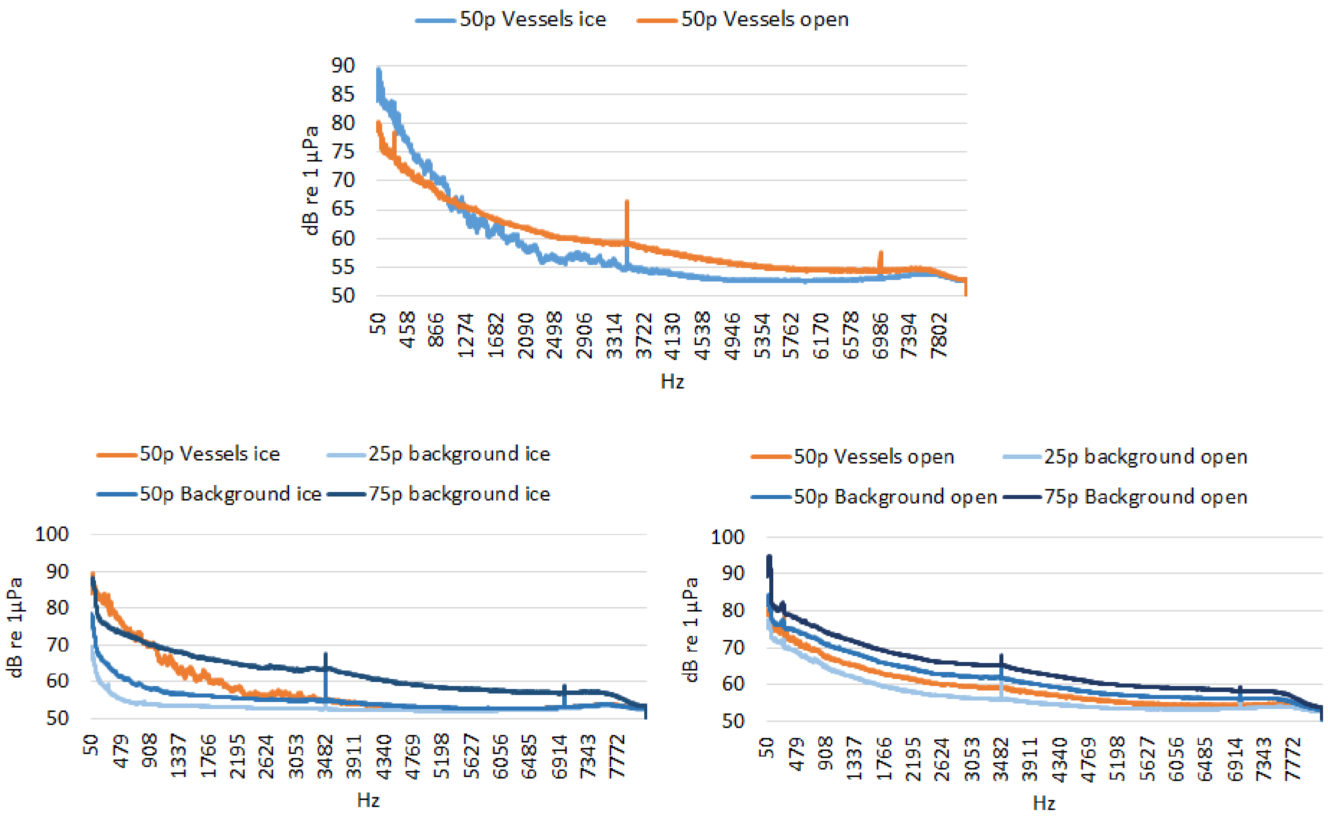


Figure 128. Upper panel - Spectral 50th percentile for vessel noise at WT1 2012-2013 during the open water (orange) and ice (blue) seasons. Lower left panel - Spectral 50th percentile for vessel noise at WT1 2012-2013 during the ice season and the 25th, 50th and 75th percentiles for ambient noise. Lower right panel - Spectral 50th percentile for vessel noise at WT1 2012-2013 during the open water season and the 25th, 50th and 75th percentiles for ambient noise. Spikes at 3400 Hz and 7000 Hz are artifacts likely from electrical system noise.

Bearded seal contribution was very prevalent during the ice season, and exceeded the ambient noise 50th percentile in the 385-1100 Hz frequency band, and the 25th percentile in the 210-3500 Hz frequency band (Figure 129). However, during the open water season, bearded seal contribution barely exceeded the 50th percentile, and just over a few frequencies in the range 200-750 Hz. Both their dependence on ice and the increased background noise might have played a role in reducing the contribution of bearded seal sound into the environment during the open water season.

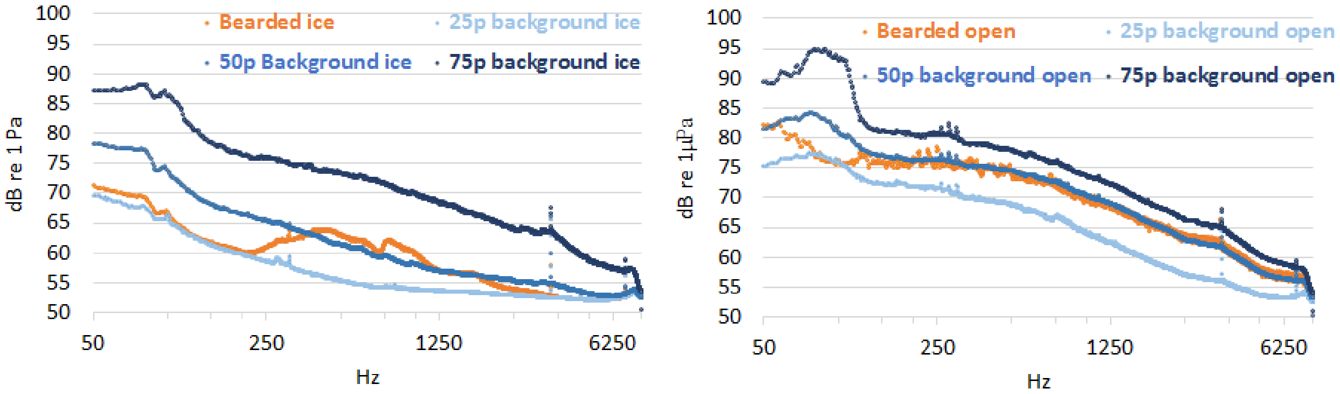


Figure 129. Left panel - Spectral 50th percentile for bearded seal signals at WT1 2012-2013 during the ice season and the 25th, 50th and 75th percentiles for ambient noise. Right panel - Spectral 50th percentile for bearded seal signals at WT1 2012-2013 during the open water season and the 25th, 50th and 75th percentiles for ambient noise. Spikes at 3400 Hz and 7000 Hz are artifacts likely from electrical system noise. Note, the x-axis is presented in a base 5 logarithmic scale to highlight the lower frequencies.

Bowhead whale acoustic contribution was concentrated in the spring and fall migration periods. Acoustic presence in fall overlapped with both the ice and open water seasons (Figure 125). However, bowhead signals were near or at the 75th percentile for ambient noise during the ice period, whereas these barely exceeded the 50th percentile during the open water season (Figure 130). Bowhead singing behavior clearly marked these differences in acoustic contribution.

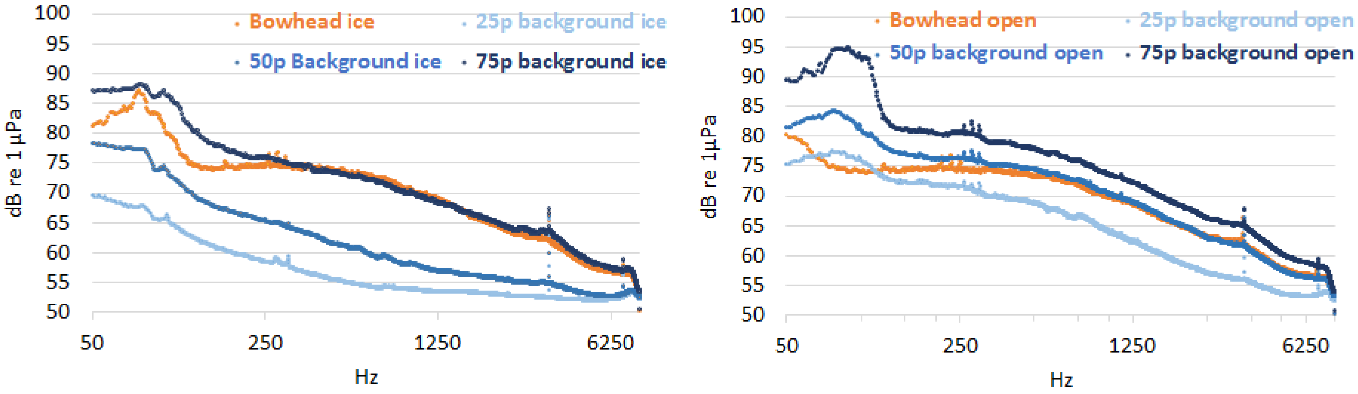


Figure 130. Left panel - Spectral 50th percentile for bowhead whale signals at WT1 2012-2013 during the ice season and the 25th, 50th and 75th percentiles for ambient noise. Right panel - Spectral 50th percentile for bowhead whale signals at WT1 2012-2013 during the open water season and the 25th, 50th and 75th percentiles for ambient noise. Spikes at 3400 Hz and 7000 Hz are artifacts likely from electrical system noise. Note, the x-axis is presented in a base 5 logarithmic scale to highlight the lower frequencies.

Walrus calls were detected at the end of the ice season and beginning of the open water season. The spectral 50th percentile during the ice season falls within the ambient noise spectral 25th and 50th percentile with louder received levels at lower frequencies up to 100 Hz. During the open water season, walrus signals were fainter, below the ambient noise spectral 25th percentile, particularly in the lower frequency range, but louder than ice season signals above 200 Hz (Figure 131).

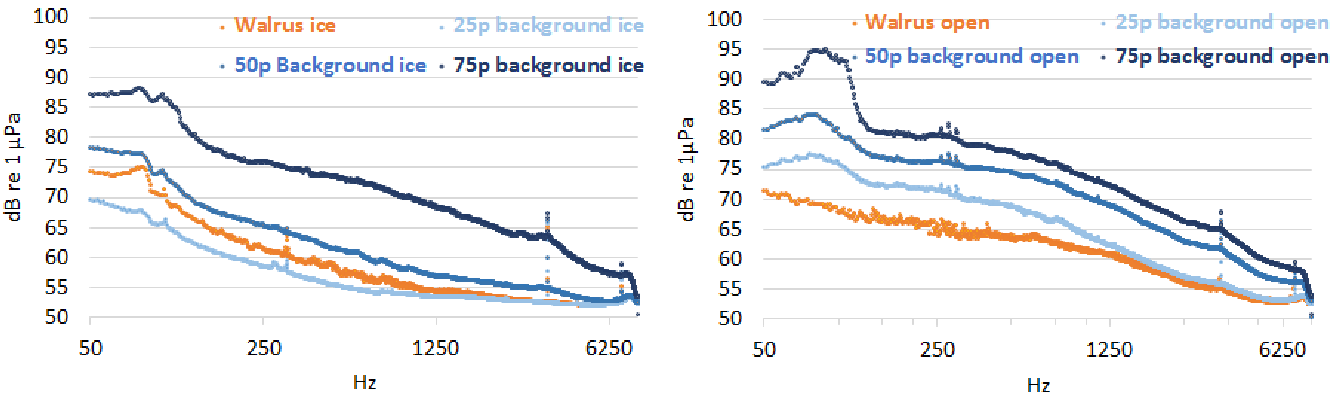


Figure 131. Left panel - Spectral 50th percentile for walrus signals at WT1 2012-2013 during the ice season and the 25th, 50th and 75th percentiles for ambient noise. Right panel - Spectral 50th percentile for walrus signals at WT1 2012-2013 during the open water season and the 25th, 50th and 75th percentiles for ambient noise. Spikes at 3400 Hz and 7000 Hz are artifacts likely from electrical system noise. Note, the x-axis is presented in a base 5 logarithmic scale to highlight the lower frequencies.

When the three predominant species and vessel noise are compared by season, the higher acoustic contribution by bowhead whales is evident, however, for frequencies above 100 Hz during the open water season, the bearded seal contribution matches the curve of bowhead whales (Figure 132). When vessel noise contribution is considered, this anthropogenic disturbance clearly alters the acoustic environment at WT1. During the ice season, the median spectral curve for vessel noise exceeds all marine mammal curves up to 1000 Hz. During the open water season, vessel noise only exceeds the spectral curve of walrus signals, and partially overlaps the bearded seal and bowhead whale curves in the range 120-230 Hz.

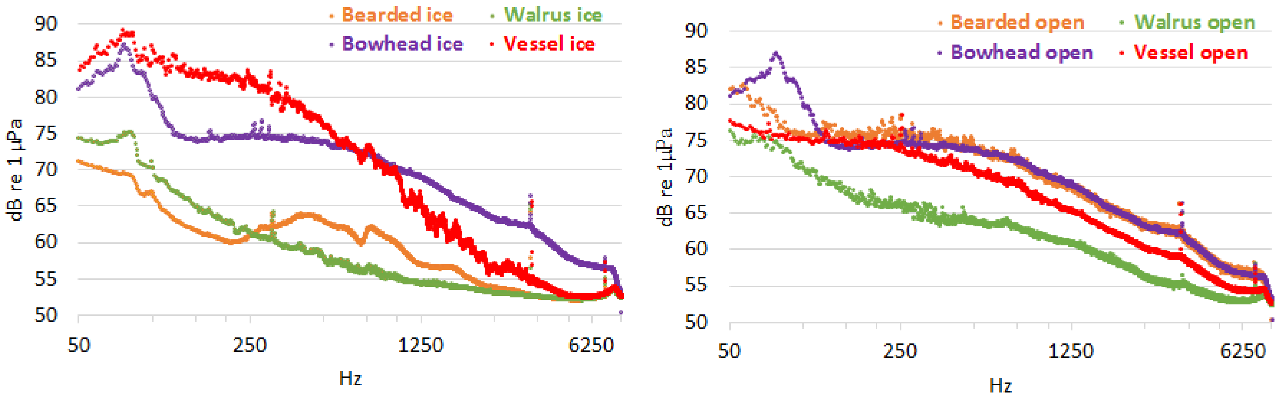


Figure 132. Spectral 50th percentile for bearded seal, bowhead whale, and walrus sounds, and vessel noise at WT1 2012-2013 during the ice season (left panel) and during the open water season (right panel). Spikes at 3400 Hz and 7000 Hz are artifacts likely from electrical system noise. Note, the x-axis is presented in a base-5 logarithmic scale to highlight the lower frequencies.

Mooring PH1

Results from the seasonal occurrence of marine mammals for this mooring location and period are presented in Figure 133 and suggest that the acoustic environment during the open water season might be dominated by fin whale, humpback, gray, bowhead, and to a lesser extent, vessel, beluga and bearded seal sounds. For the ice season, main contributors to the acoustic environment were bearded seals, bowhead whales, ice noise, and to a lesser degree, beluga whales. Airgun noise was only detected for a short period in August 2012. Sample sizes in number of files and total amount of recordings containing these sound contributors are presented in Table 39.

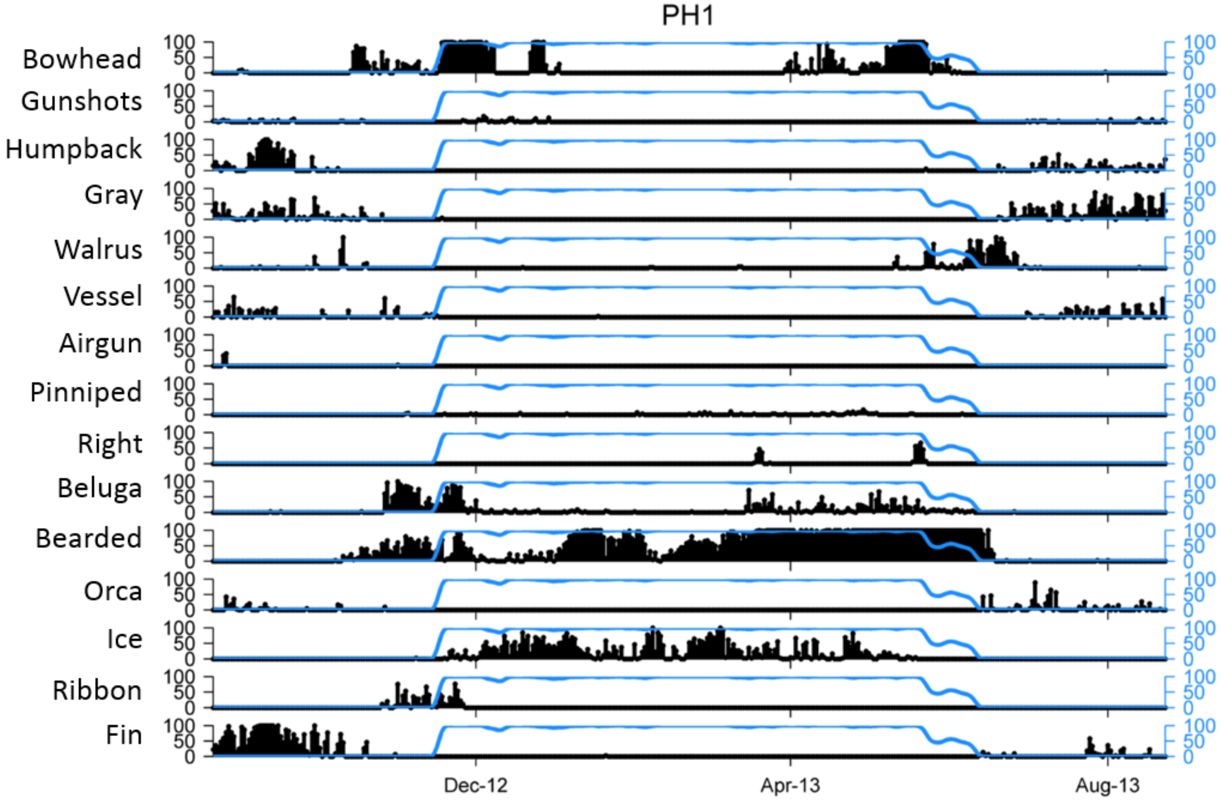


Figure 133. Seasonal occurrence (percent of time per day) at mooring PH1 during the period August 2012 to August 2013 for each of the seven acoustic contributors (black histogram) and for ice concentration (blue).

Table 39. Sample size, in number of files and total recording time, for the amount of time where each of the main contributors in PH1 (August 2012 to August 2013) were detected in isolation (e.g., when no other co-occurring sound source was identified).

Sound contributor	# files	Total recording time
Ambient noise (ice season)	17147	400 h 8 m
Ambient noise (open season)	20870	477 h 3 m
Bearded Seal	10837	254 h 53 m
Beluga whales	706	108 h 21 m
Bowhead whale	4700	15 h 54 m
Gray whale	2414	52 h 52 m
Humpback whale	942	20 h 24 m
Orca	688	15 h 36 m
Walrus	19	23 m
Vessel noise	1942	45 h 2 m

The spectral probability density plot and spectral percentiles for the baseline ambient noise during the ice and open water seasons are presented in Figure 134. As opposed to WT1, the ambient noise at PH1 did not differ as much between seasons. This can be seen in the comparison of their 50th percentiles in Figure 135. The open water season showed more variability but its median spectral density values remained very close to the ones from the ice season. Ambient noise was higher during the ice season only in the band 60 -600 Hz, and slightly lower for frequencies above 4000 Hz. Differences in the average SPL values between seasons were small: the average broadband (50 - 8192 Hz) SPL values for the open water season and the ice season were 103.6 dB and 105.2 dB, respectively. The average broadband SPL for the open water season in PH1 was 6 dB lower than for WT1, and just 0.5 dB difference for the ice season between mooring locations.

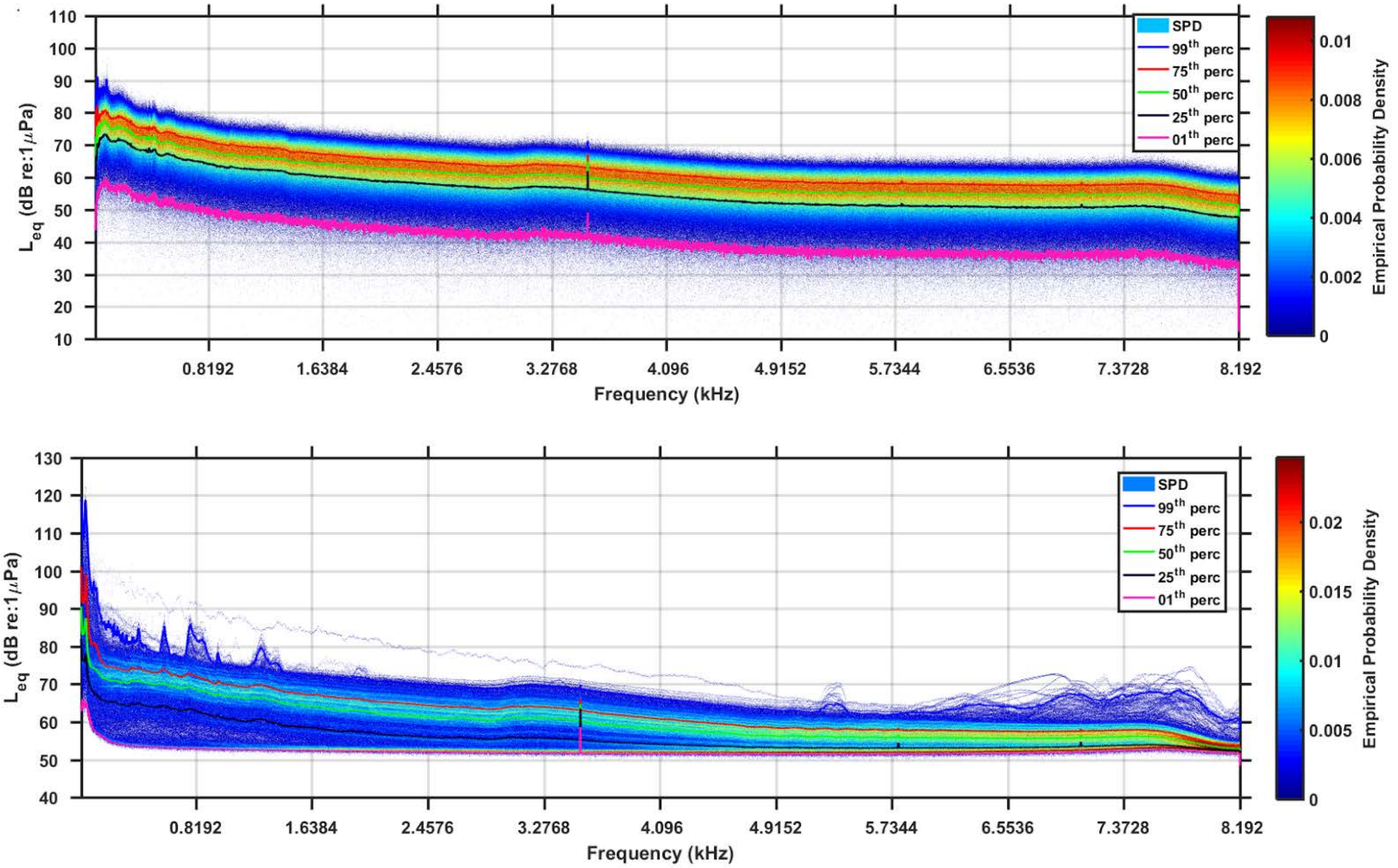


Figure 134. Spectral probability density plots and spectral percentiles for baseline ambient noise during the ice season (upper panel) and during the open water season (lower panel), for PH1 2012-2013.

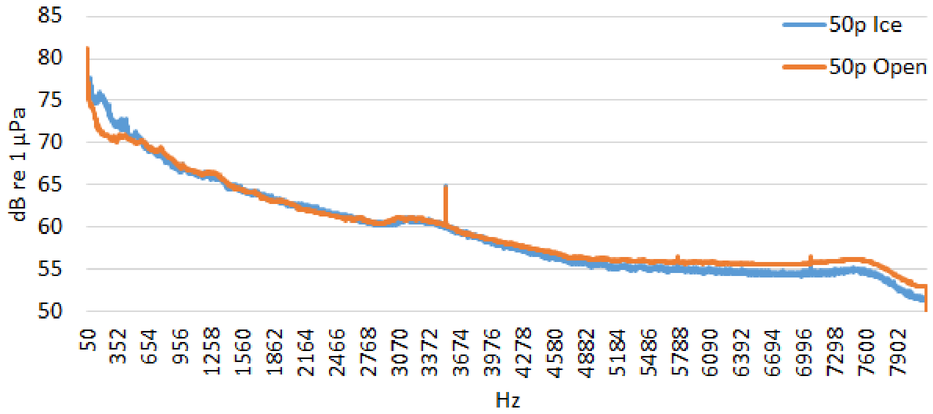


Figure 135. Spectral 50th percentile for ambient noise during the ice and open water seasons for PH1 2012-2013. The spike at 3400 Hz is an artifact likely from electrical system noise.

When PH1 ambient noise is compared to WT1 for the same time period and seasons, differences are observed for both seasons. The PH1 location is louder during the ice season but quieter during the open season (Figure 136).

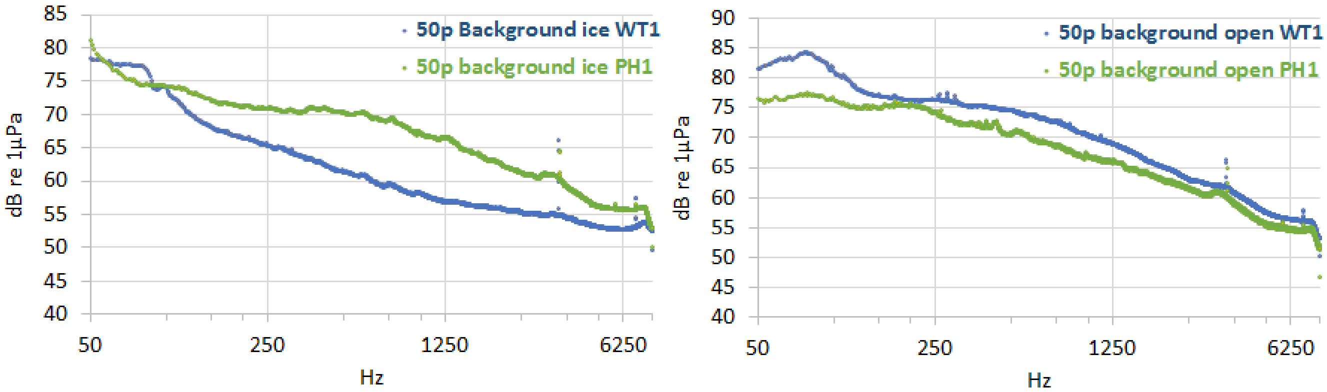


Figure 136. Spectral 50th percentile for ambient noise during the ice and open water seasons for PH1 (green) and WT1 (blue) for the period 2012-2013. The spikes at 3400 Hz and 7000 Hz are an artifact likely from electrical system noise.

As with the WT1 results, we present a selection of the most relevant PH1 acoustic contributions compared against ambient noise spectral percentiles per season. Vessel noise at PH1 was only evident during the open water season. The median spectral curve was at or exceeded the ambient noise 75th percentile up to 135 Hz (Figure 137). In general, vessel noise at PH1 was fainter than the levels reported at WT1 (Figure 138).

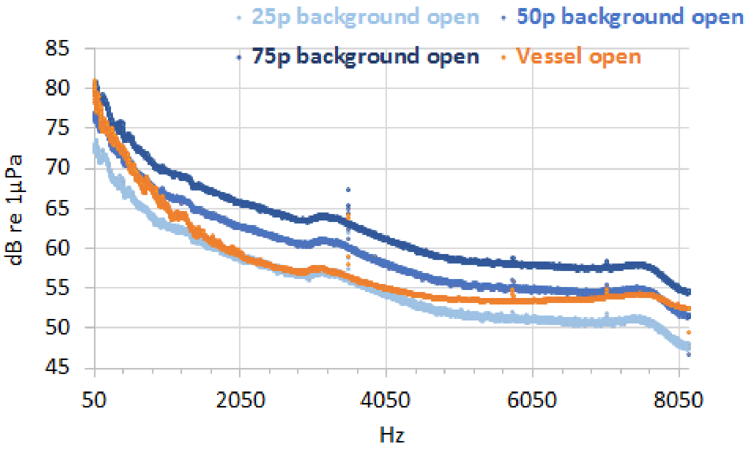


Figure 137. Spectral 50th percentile for vessel noise at PH1 2012-2013 during the open water season and the 25th, 50th and 75th percentiles for background noise. Spikes at 3400 Hz, 5500 Hz, and 7000 Hz are artifacts likely from electrical system noise.

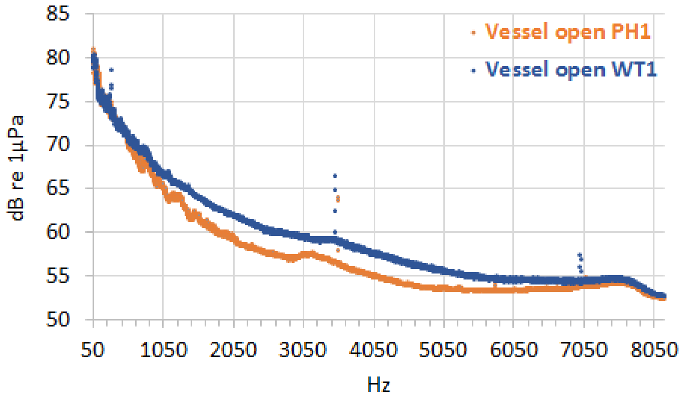


Figure 138. Spectral 50th percentile for vessel noise at PH1 and WT1 in 2012-2013 during the open water season. Spikes at 3400 Hz and 7000 Hz are artifacts likely from electrical system noise.

Bowhead whale acoustic contribution was concentrated in the spring and fall migration periods. Acoustic presence in fall overlapped with both the ice and open water seasons (Figure 133). However, bowhead signals were near or at the 25th percentile for ambient noise during the ice season, whereas these exceeded the 50th percentile during the open water season (Figure 139). This is an opposite pattern to the one found in WT1, where bowhead whale contribution was stronger during the ice season.

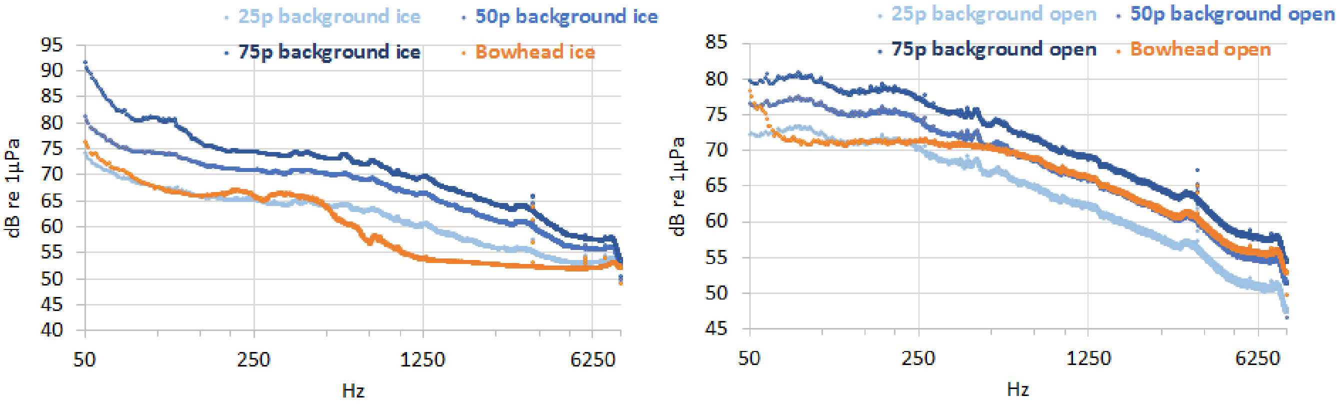


Figure 139. Left panel - Spectral 50th percentile for bowhead whale signals at PH1 2012-2013 during the ice season and the 25th, 50th and 75th percentiles for ambient noise. Right panel - Spectral 50th percentile for bowhead whale signals at PH1 2012-2013 during the open water season and the 25th, 50th and 75th percentiles for ambient noise. Spikes at 3400 Hz, 5500 Hz, and 7000 Hz are artifacts likely from electrical system noise. Note, the x-axis is presented in a base 5 logarithmic scale to highlight the lower frequencies.

The contribution of beluga vocalizations was stronger during the open water than ice season. Its median spectral curve reached the 75th percentile for frequencies above 770 Hz during the open water season, but remained below the 25th percentile for the ice season (Figure 140).

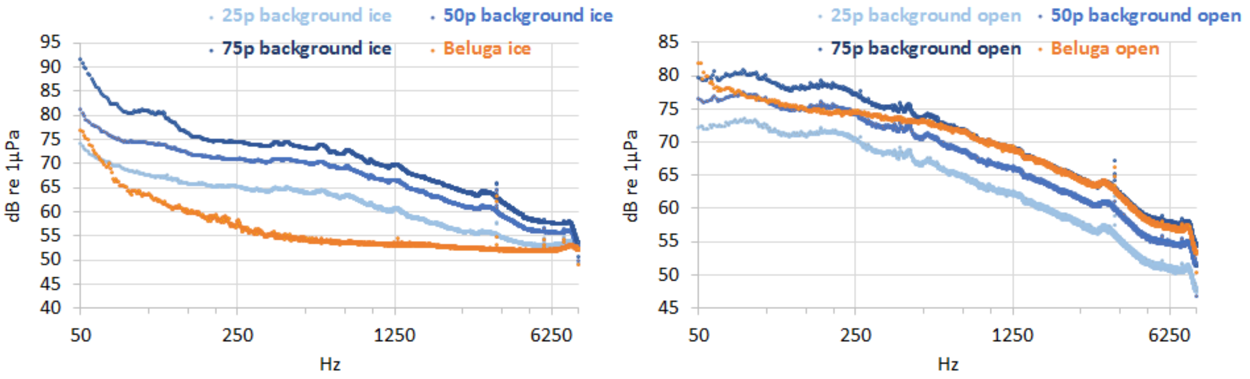


Figure 140. Left panel - Spectral 50th percentile for beluga signals at PH1 2012-2013 during the ice season and the 25th, 50th and 75th percentiles for ambient noise. Right panel - Spectral 50th percentile for beluga signals at PH1 2012-2013 during the open water season and the 25th, 50th and 75th percentiles for ambient noise. Spikes at 3400 Hz, 5500 Hz, and 7000 Hz are artifacts likely from electrical system noise. Note, the x-axis is presented in a base 5 logarithmic scale to highlight the lower frequencies.

Bearded seal contribution dominated the ice season, but was also present during the fall 2012 (Figure 133). However, all the files where bearded seals were detected in the open season overlapped with other species or vessel noise, and thus this species could not be properly extracted to quantify its acoustic contribution during the open water season. Here we present the bearded seal median spectral curve only for the ice season. Even if their presence during the ice season was very persistent, their acoustic contribution was modest, below the ambient noise 25th percentile (Figure 141).

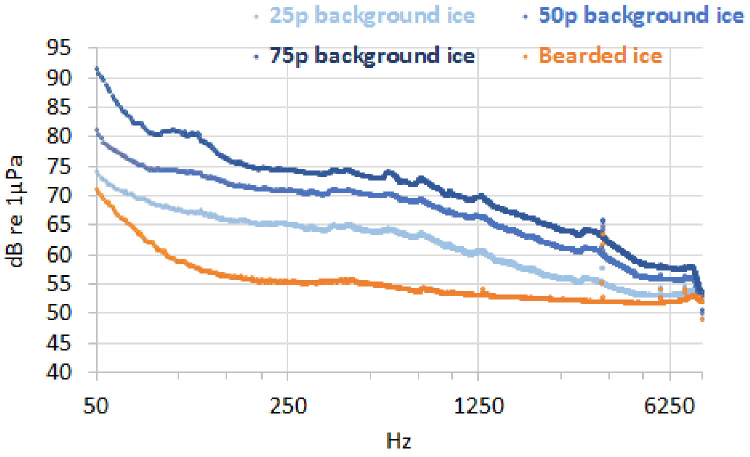


Figure 141. Spectral 50th percentile for bearded seal signals at PH1 2012-2013 during the open water season and the 25th, 50th and 75th percentiles for ambient noise. Spikes at 3400 Hz, 5500 Hz, and 7000 Hz are artifacts likely from electrical system noise. Note, the x-axis is presented in a base 5 logarithmic scale to highlight the lower frequencies.

Some contributors were important in only one of the two seasons. For the open water season, humpback whale signals exceeded the ambient noise 25th percentile up to 150 Hz (Figure 142).

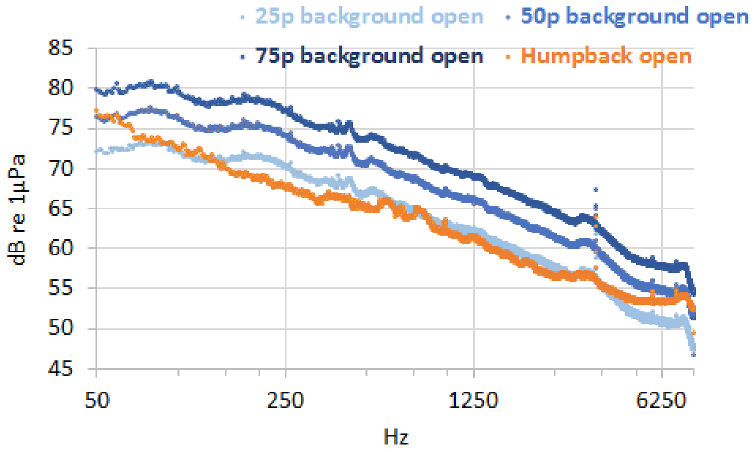


Figure 142. Spectral 50th percentile for humpback whale signals at PH1 2012-2013 during the open water season and the 25th, 50th and 75th percentiles for ambient noise. Spikes at 3400 Hz, 5500 Hz, and 7000 Hz are artifacts likely from electrical system noise. Note, the x-axis is presented in a base 5 logarithmic scale to highlight the lower frequencies.

Gray whale signals were also present during the open water season, but their acoustic contribution was very modest, with a median spectral curve below the ambient noise 25th percentile for most of the frequency spectrum (Figure 143).

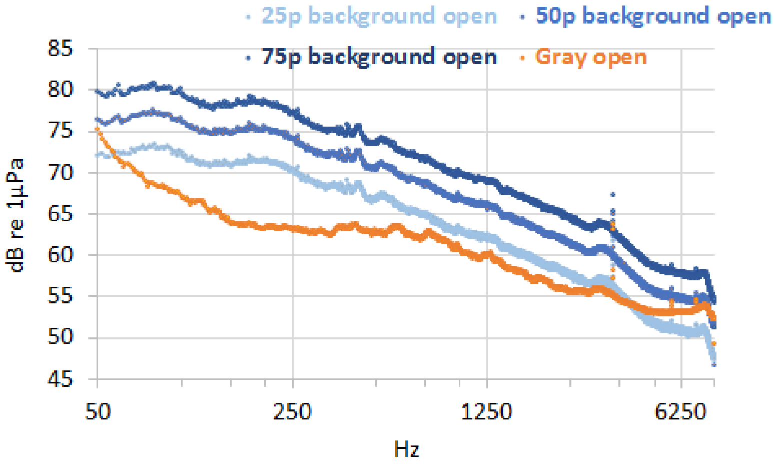


Figure 143. Spectral 50th percentile for gray whale signals at PH1 2012-2013 during the open water season and the 25th, 50th and 75th percentiles for ambient noise. Spikes at 3400 Hz, 5500 Hz, and 7000 Hz are artifacts likely from electrical system noise. Note, the x-axis is presented in a base 5 logarithmic scale to highlight the lower frequencies.

Killer whale signals were part of the acoustic environment during the open water season, more in 2013 than 2012. Their contribution was modest, with their median spectral curve below the ambient noise 25th percentile, except for the overlapping range 600-2000 Hz (Figure 144).

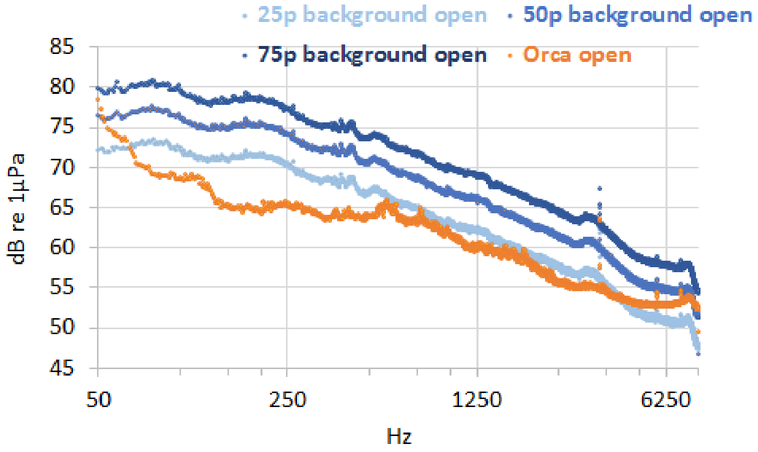


Figure 144. Spectral 50th percentile for killer whale signals at PH1 2012-2013 during the open water season and the 25th, 50th and 75th percentiles for ambient noise. Spikes at 3400 Hz, 5500 Hz, and 7000 Hz are artifacts likely from electrical system noise. Note, the x-axis is presented in a base 5 logarithmic scale to highlight the lower frequencies.

For the ice season, walrus were other important contributors. Their median spectral curve reached the ambient noise 50th percentile at the lower frequencies (50-100 Hz), but dropped below the 25th percentile for frequencies above 400 Hz (Figure 145).

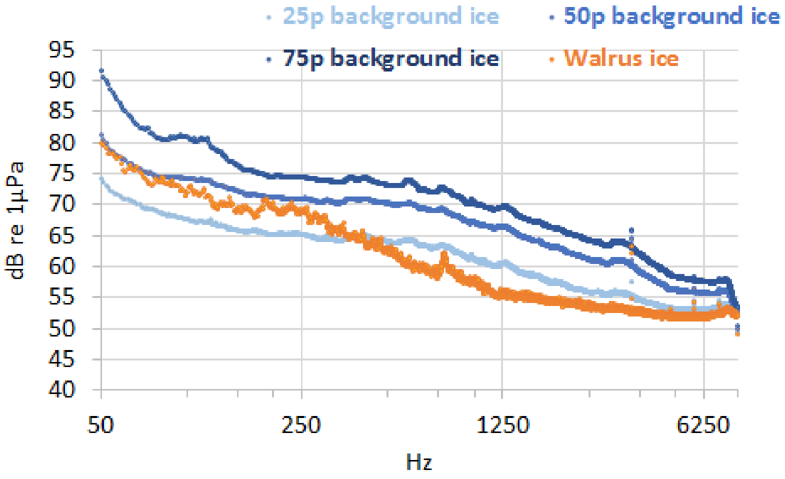


Figure 145. Spectral 50th percentile for walrus signals at PH1 2012-2013 during the open water season and the 25th, 50th and 75th percentiles for ambient noise. Spikes at 3400 Hz, 5500 Hz, and 7000 Hz are artifacts likely from electrical system noise. Note, the x-axis is presented in a base 5 logarithmic scale to highlight the lower frequencies.

When the three predominant species and vessel noise are compared by season, the higher acoustic contribution by bowhead whales is evident for the open water season (Figure 146). When vessel noise contribution is considered for the open water season, this anthropogenic disturbance exceeds the full spectral curve of humpback whale signals, and the lower frequencies of beluga and bowhead whale curves.

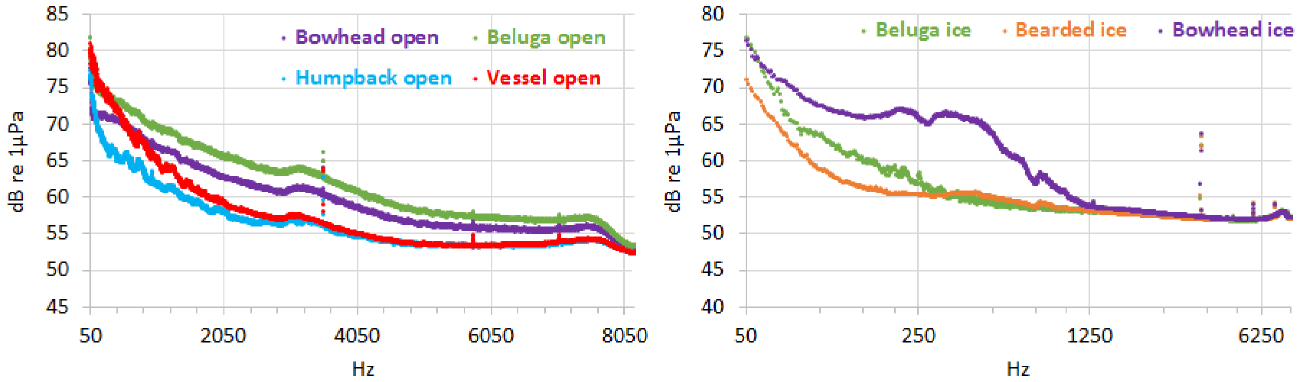


Figure 146. Spectral 50th percentile for bearded seal, bowhead whale, beluga sounds, and vessel noise (detected only during open water season) at PH1 2012-2013 during the ice season (left panel) and during the open water season (right panel). Spikes at 3400 Hz, 5500 Hz, and 7000 Hz are artifacts likely from electrical system noise. Note, the x-axis is presented in a base 5 logarithmic scale to highlight the lower frequencies.

3. *Discussion*

Mooring WT1

While the ambient noise average broadband SPL values between seasons were just 3.9 dB apart, the spectral content was markedly different between the ice and open water seasons. As expected, the open water season was noisier due to the influence of atmospheric processes (wind generating waves, rain, etc.), but also because of the increased vessel traffic in the area. These contributors exceeded the acoustic influence of ice-generated noise in winter. The key frequencies for marine mammal communication (in general, below 5 kHz) showed the strongest differences between open water and ice seasons.

Vessel noise differences between seasons are interesting. Vessel noise was present throughout the open water season whereas detections of vessel noise during the ice season (11 November 2012 to 15 July 2013) were limited to just three days at the beginning of the season (11-13 November 2012), when ice concentration ranged from 71.5 to 90% coverage. We expected to find higher vessel noise levels during the open water season as this region is more accessible at this time of the year; however, both the broadband SPL as well as the spectral content indicated that vessel noise was higher, especially in the low frequencies up to 1 kHz, during the beginning and ending of the ice season. Vessel traffic was expected to be higher during the accessible time of the year (Fletcher et al. 2017). However, it is assumed that barge transits will peak as soon as ice allows after the winter to resupply the highly barge-dependent villages, as well as to restock soon before the ice is too thick to navigate. The peak in vessel noise detected on 11-13 November 2012, occurred right at the beginning of the ice period considered for this analysis. SPL values were 4.1 dB higher in winter, and even if the 50th percentile curve is shallower for the open water season, the pronounced steepness of the curve for the ice season at low frequencies makes the overall acoustic contribution of vessel noise higher in winter. A more detailed analysis of vessel traffic in this area would provide cues to better understand the occurrence of peaks in traffic and their influence in the acoustic environment. Source levels of ice breaking vessels have been documented to be higher than non-ice breaking vessels (Roth et al. 2013), but slower speeds are normally used when navigating in ice, and speed has been directly related to increased source level in vessels (Veirs et al. 2016). The shipping routes used in this region could also influence the received levels of this noise source, maybe vessels transiting this area during the open water season are further away from the mooring site than during the ice season.

When the median spectral percentile for vessel noise and the main marine mammal contributors are compared per season, it is evident how the acoustic environment is altered by this type of anthropogenic noise source. All dominant marine mammal signals are masked by ship noise for more than half of the time when vessel noise is present in this location during the ice season. A similar magnitude of masking occurs for walrus signals during the open water season.

The seasonal occurrence analysis for marine mammal sounds clearly identified the main biological contributors for the open and ice seasons. However, some discrepancies were found between the occurrence of a species and its amount of acoustic energy recorded. For example, bearded seal sounds are very prevalent, reaching 100% of presence per day during most of the second half of the ice season, however their median spectral curve is higher during the open water rather than the ice season when compared to the corresponding ambient noise levels. This effect could be explained by a lower bearded seal singer density during the ice season, but this does not fit with the seasonal results. It could also be explained by lower source level intensities in their acoustic signaling during winter, but this is contrary to the function of singing for this species during their mating season (Van Parijs et al. 2001). Other possible explanations could be related to increased ambient noise during the open water season, forcing the bearded seal median spectral curve to higher dB values; or a behavioral effect where bearded seals actively select quieter periods during the ice season to sing, forcing their spectral curve to lower dB values. Alternatively, because the vocal activity of bearded seals is related to variations in sea ice (MacIntyre et al. 2015), these differences in the relationship between their presence and the acoustic energy in their vocal activity could be related to differences in ice conditions between seasons, positioning singers at greater distances from WT1 during the ice season.

When comparing bearded seal and bowhead whale acoustic contribution during the ice season, despite bearded seals being the most acoustically prevalent species, bowhead whale signals show a spectral curve in higher dB values across the entire frequency range than the curve for bearded seals. Bowhead whale acoustic contribution is at the level of the 75th percentile ambient noise spectral curve while the bearded seal curve is between the 25th and 50th percentile ambient noise curve. These results suggest that bowhead whales have a stronger contribution than bearded seals and the acoustic environment is dominated by this species when they are present, which is limited to their migration periods. Outside these time windows, bearded seal signals dominated the environment during the ice season, and a combination of bearded seal, walrus, and vessel noise dominated the open water season.

Mooring PH1

As opposed to WT1, the ambient noise in PH1 did not differ as much between seasons, with just 1.6 dB difference in broadband average SPL. The average broadband SPL for the ice season in PH1 doubled the one in WT1 (a difference in 6 dB). These differences could be due to higher ice related noise in PH1 than WT1.

Vessels provided a lower contribution to the acoustic environment in PH1 than in WT1. Not only were these absent during the ice season but their spectral 50th percentile curve for the open water season was lower. The PH1 mooring is closer to the Bering Strait and acoustic data from this site would be expected to show a stronger vessel traffic influence; however, WT1 was exposed to the traffic related to oil and gas operations in the Chukchi Sea because Wainwright was a main logistics hub for those activities in 2012 and 2015.

The PH1 mooring location had a higher diversity of biological contributors than WT1 for both seasons. Bowhead whale signals predominated the ice season and humpback whale signals the open season (with the exception of fin whales that due to the bandpass filter at 50 Hz these were excluded from the analysis). Similarly to WT1, bearded seals signals were very commonly detected but their acoustic contribution was modest, never exceeding the 25th percentile for ambient noise during the ice season, suggesting that singer seals were generally far from the mooring location or that this species has a singing preference for quiet periods. Walrus signals were substantial in spring periods and their acoustic contribution was similar to the one reported in WT1. Other visiting species during the open season contributed to the acoustic environment of PH1, like killer and gray whales, which were absent in WT1, but their contribution was modest and generally below the ambient noise 25th spectral percentile, indicating that received levels for these species signals were low and signaling was not intense, perhaps reflecting a low species spatial density or a transient nature of their presence in this area.

4. Conclusions

The manual analysis of acoustic data to detect, classify and describe seasonality, provided a powerful basis to characterize the ambient noise and the acoustic contribution of the different sound sources identified at these mooring locations for the 2012-2013 deployment period. The acoustic environments at both PH1 and WT1, when vessel traffic was absent, were clearly dominated by three marine mammals: bowhead whales, bearded seals and walrus. When vessel traffic noise was present at both PH1 and WT1, regardless of ice or open water season, it exceeded the contribution of all dominant marine mammals. The analysis methodology applied to these data shows how this approach will allow comparing the acoustic environment across mooring sites and seasons, describing the contribution of each different species detected, as well as the level of disturbance generated by human activities in this region of the Arctic. The 50th spectral percentile is a useful representation of each species median contribution, as its dB/Hz levels can be directly compared across species and seasons to identify the most important contributors to the acoustic environment. The shapes of these spectral curves are also indicative, when compared to those for ambient noise, that this contribution can be placed into context. An elevated (high dB/Hz values) curve does not necessarily imply an important acoustic contribution if the shape is matching one of the ambient noise curves. It just indicates that the species presence occurred when ambient noise was high. However, if the species spectral curve departs from the shape of the ambient noise curves, it highlights the frequencies of influence by those species.

5. *Recommendations*

All acoustic data from the MML moorings was bandpass filtered to eliminate any sound below 50 Hz, which forced our analysis to exclude fin whale signals. This was due to the contamination by flow noise when water circulates around the hydrophone capsule fast enough to generate low frequency sound emission due to friction. It would be useful to further explore how to reduce these effects, maybe by redesigning the mooring line to relocate the AURAL recorders as close as possible to the seafloor, as this approach has been effective by other research groups (Bruce Martin, JASCO pers. comm.; Jennifer Miksis-Olds, Penn State Univ. pers. comm.). Some of the low frequency self-noise in our recordings could also be related to strumming effects in the mooring line by the current. Because the mooring lines include an acoustical release, it would be necessary to install them in tandem on the mooring line. This would allow reducing the vertical profile length of the mooring, placing the AURAL closer to the seafloor to avoid higher speed currents, and making the mooring design more resistant to strumming. An alternative to modifying the mooring design, or in addition to this modification, would be to explore hydrophone flow protection materials, to reduce the water flow around the hydrophone capsule, similar to the approach developed by Greeneridge Sciences Inc. for their DASAR system (Norman and Greene 2000).

X. NEW PASSIVE ACOUSTIC METHODS (OBJECTIVE 6)

A. ***Auto-detection-buoy, Moored Observations*** *(Moorings: AB_2014, AB_2016)*

1. Methods

Equipment

Auto-detection buoys (ABs; Spaulding et al. 2010) were originally developed for application to North Atlantic right whales (*Eubalaena glacialis*) off New England (for an operational example of this system (see http://www.listenforwhales.org, http://stellwagen.noaa.gov/protect/whalealert.html). For the CHAOZ and CHAOZ-X projects, ABs were physically modified with improvements to deal with the harsh conditions in the Arctic and were improved with firmware and software upgrades for acoustic detection of frequency-modulated (FM) bowhead whale calls and *in-situ* ambient noise measurements.

The AB system transmitted clips of potential bowhead whale sound detections and spectral frames of acoustic energy distribution (ensemble averages at a 10-minute resolution) to Cornell-BRP in near-real-time via Iridium satellite. The sound stream was continuously processed and a section of sound, referred to as a sound clip, was scored relative to its similarity with acoustic features of bowhead whale sounds. The detection score range was 1-20 (1 = least similar, 20 = most similar). Auto-buoys were programmed to transmit sound clips of detections with the top ten detection scores every 12 hours, and at a higher rate as more sounds with higher scores were detected, and this transmission rate could be increased back at Cornell by an operator command via Iridium to the buoy. By this process, during periods without any calling or singing bowheads, transmissions contained only low score detections.

For CHAOZ-X, the software was modified so that potential bioacoustic sounds were transmitted as variable duration sound clips, without filtering out clips with very low detection scores. This system was designed to provide timely information on a) the acoustic presence of the endangered bowhead whale that is of critical importance to subsistence hunters, and b) ambient noise levels in the 10-4000 Hz frequency band, because this is the frequency band in which bowheads and other Arctic marine mammals utilize for basic life functions and in which anthropogenic noise sources (seismic and vessels) generate the highest levels of noise.

AB_2014 and AB_2016 were programmed to sample continuously at 8 kHz (10-4000 Hz effective bandwidth), detect potential bowhead FM sounds and compute ambient noise spectral distribution measurements. The detection process ran continuously and was maintained using an on-board data management system. The system transmitted the top 10, 2-s acoustic detections, referred to as sound clips, to Cornell via Iridium satellite on a user-defined schedule (e.g., every hour). A sound clip’s detection rating was based on how well its acoustic features matched the features of modeled bowhead FM sounds derived from >10,000 validated bowhead calls recorded in the Beaufort Sea (Charif et al. 2013). The on-board noise analysis process also computed a 1024-point discrete Fourier transform ensemble every 30 seconds, stored these data onboard the AB and transmitted collections of spectral data on a user-defined schedule (e.g., every 2 hours). The process of computing spectral distribution data was specifically motivated by the expectation that such data would provide timely information on the occurrence and received levels of abiotic acoustic events (e.g., from seismic airgun activity, vessel traffic, weather, ice) and biotic events (e.g., choruses of singing bowheads or bearded seals). Since it integrated acoustic data at a 30-sec resolution, it was not intended to enable observation of sparse events such as single marine mammal calls (e.g., from bowheads).

Detection and spectral data were available via a web-based, online system and visualized with a graphical user interface (GUI; https://portal.nrwbuoys.org/ab/clip/confirmed/?position=Chukchi). Several of the many enhancements of the system included ruggedization of the mooring by Woods Hole Oceanographic Institution (WHOI) ocean engineers for the demanding Arctic environment; modularization of the onboard data acquisition, signal conditioning, processing, management, and transmission subsystems by Cornell engineers; and implementation of bi-directional communications by Cornell engineers. The latter improvement provided a mechanism by which, for example, Cornell could reprogram onboard code and request transmissions of selected portions of acoustic data. The buoy was outfitted with a Xeos tracker, which provided a mechanism by which WHOI and Cornell could observe the GPS position of the system in the event that it drifted from its mooring location.

Auto-detection pre-deployment testing and evaluation

Cornell developed a methodology for evaluating the expected performance of the automated bowhead whale call detector. Since bowhead acoustic detections are relatively rare, we chose to use Precision/Recall curves to measure performance, because such curves are not subject to the issues of uneven class size that can be a problem when using Receiver Operating Characteristic (ROC) curves. The general procedure started by running the detector/classifier with a low detection threshold, yielding a large number of candidate detections, most of which were false. We then computed, *a posteriori,* the precision and recall at various intermediate thresholds, yielding various performance curves. We measured performance in this way for several different methods of sound classification. As a control, we scored detected events according to the maximum signal-to-noise ratio during the event.

We developed and tested a simple Discrete Hidden Markov Model (HMM) classifier. A short-time Fourier Transform (STFT) spectrogram was computed using a discrete Fourier Transform (DFT) size of 256 points, and an overlap of 192 point, and then a bank of four binary image filters was applied, each intended to enhance ridges in one of four “directions”, vertical, horizontal, and both diagonals. Finally, a measure of local ridge energy was computed as the max of the directional filtered energies, and a local directional estimate was assigned according to which filter produced the maximum energy output. The HMM observed symbols were represented by a pair of variables per spectrogram time slice, the modal (max) frequency index, and the estimated contour direction at the modal frequency. This gave 4 * 256 possible symbols, but we further reduced this by integer-dividing the frequency index by 4, leaving 256 symbols. The HMMs used 16 hidden states, and were trained as “forward” models, allowing only increasing internal state index. Using this pair of models, we were able to improve upon the trivial classifier. Some operating points offered a precision of about 80%, while keeping more than 30%. Analysis revealed that performance was only slightly degraded between the training and test sets, indicating that we were most likely not over-fitting the models. The HMM training and test data were drawn from the same recording, so our initial performance estimates were likely to be optimistic.

Deployment and Recovery

There were two deployments of ABs. The first (AB_2014) occurred on 20 August 2014, and the second (AB_2016) occurred on 23 August 2016 (Figure 148, Table 37). Deployment and recovery operations for the AB_2014 were relatively straightforward. Deployment of AB_2016 was delayed due to the limited availability of a vessel operating in the Chukchi Sea during the early August deployment period. Fortunately, the USCGS Healy was working with WHOI in the Chukchi Sea in August and was able to deploy AB-2016 on 23 August. Unfortunately, deployment conditions were such that Cornell and WHOI technologists could not conduct the full suite of in-water tests after deployment and before leaving the deployment site. At the time of deployment the system seemed to be working as best as we could determine. Recovery of AB_2016 was not possible due to heavy ice and high wind conditions during the anticipated October recovery period, despite multiple recovery attempts. Fortunately, there was a slight break in conditions, and the USCGS Healy-WHOI team was able to recover AB-2016 on 3 November as the USCGS Healy was leaving the area.

Data extraction and archiving

Transmission of detection and noise data from AB_2014 was successful throughout its 48-day period of operation. In contrast, once AB_2016 was deployed it failed to successfully transmit any data. Both ABs were equipped with onboard FLASH memory. Upon arrival in Ithaca, the FLASH memory data were downloaded into the CHAOZ-X acoustic data system along with any sound clips received from the AB while it was operating. The FLASH from AB_2014 contained data for the entire deployment, but FLASH memory from AB_2016 contained no data. We have not been able to determine the source of the AB_2016 failure. We strongly suspect there were multiple physical failures somewhere on the buoy (e.g., connector, cable failure), because when the data collection systems (detection firmware and software) were retested back in Ithaca after the recovery, they performed as expected.

A complete copy of the AB_2014 data was made as FLAC (Free Lossless Audio Codec) formatted files organized in day folders and archived at a site separate from the Bioacoustics Research Program. The FLAC file naming convention within day folders, which follow the Cornell folder naming convention (e.g., 71664_WHOI01_FLAC_AB_20141002), is hhmmss in Zulu (e.g., 225500).

Post-season data analysis

Near-real-time detections from AB_2014 were compared with FLASH memory data to evaluate detection performance and to provide a secondary evaluation of bowhead whale call validation as conducted by Cornell analysis during the time period when AB_2014 was operating.

2. Results

Auto-detection Buoy, Near-real-time Bowhead Sound Detections

A fundamental feature of an auto-detection buoy is its ability to detect and transmit potential bowhead whale sounds in near-real-time. During its 48 days of operation from 20 August through 6 October in 2014, AB_2014 transmitted 424 sound clips. Within hours of deployment, AB_2016 transmissions became erratic and contained no data. The buoy continued to attempt to establish a communication up-link to the satellite, but these were unsuccessful. Multiple attempts to reboot the AB_2016 system from Cornell via the satellite channel were made; none of these attempts were successful. The net result was that AB_2016 failed to transmit any data via satellite during its deployment. Upon return of the technical package to Cornell in early 2017, there was some hope that AB_2016's on-board data recording system had been functional, however, we determined that no acoustic data were ever recorded on the buoy. At this point the specific cause of these data collection and transmission failures on AB_2016 remains unknown. Only data from AB_2014 are included in further sections of this report.

All sounds detected and scored as potential bioacoustic sounds were transmitted as sound clips over the duration of the deployment (from 20 August 2014 through 06 October 2014) without filtering out clips with very low detection scores. Over the 48-day operational period for AB_2014, a total of 424 sound clips were transmitted from the buoy to Cornell. Evaluation of these clips relative to their detection scores revealed that clips with scores of ≤4 should be considered unacceptable, resulting in a total of 251 acceptable sound clips. Figure 147 shows a variety of bowhead sounds detected by, archived on and transmitted from AB_2014, and verified by bioacoustic experts back at Cornell after return of the buoy's data package.

Of the 251 audio clips with detection scores ≥4, 176 were confirmed as being a bowhead sound, while 23 were confirmed as bearded seal sounds. All 176 confirmed bowhead sounds were judged to be calls and not part of a song. Figure 148 shows the daily comparison between the number of sounds detected by AB_2014 and the number of those validated as bowhead sounds (70%). For the latter part of the AB_2014 deployment, from 18 September through 06 October, when there was a clear increase in detection scores and bowhead acoustic occurrence, the percentage of detections confirmed as bowhead sounds was 93%. Both of these percentages of validated sounds are higher values of precision than we saw when testing the performance of the detector against the Beaufort Sea training data during CHAOZ. This higher performance level was not totally unexpected, and likely represents many of the software improvements implemented early in this CHAOZ-X project.

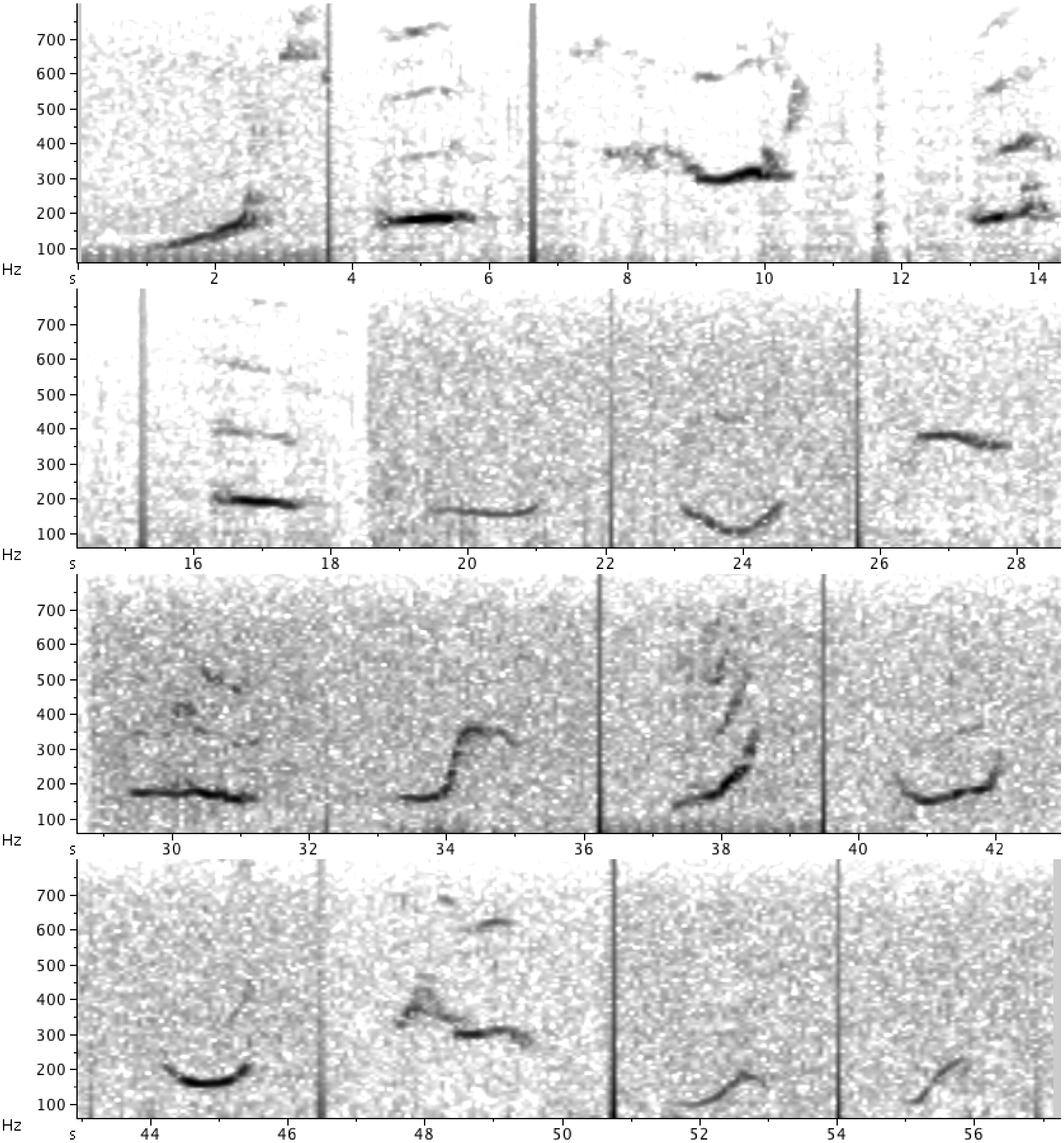


Figure 147. Spectrogram examples of 16 bowhead sounds as first detected at and transmitted from ab_2014 and subsequently validated by experienced Cornell analysts (data from 22 September through 04 October 2014; 1024 pt. FFT, 50% overlap, hamming window).

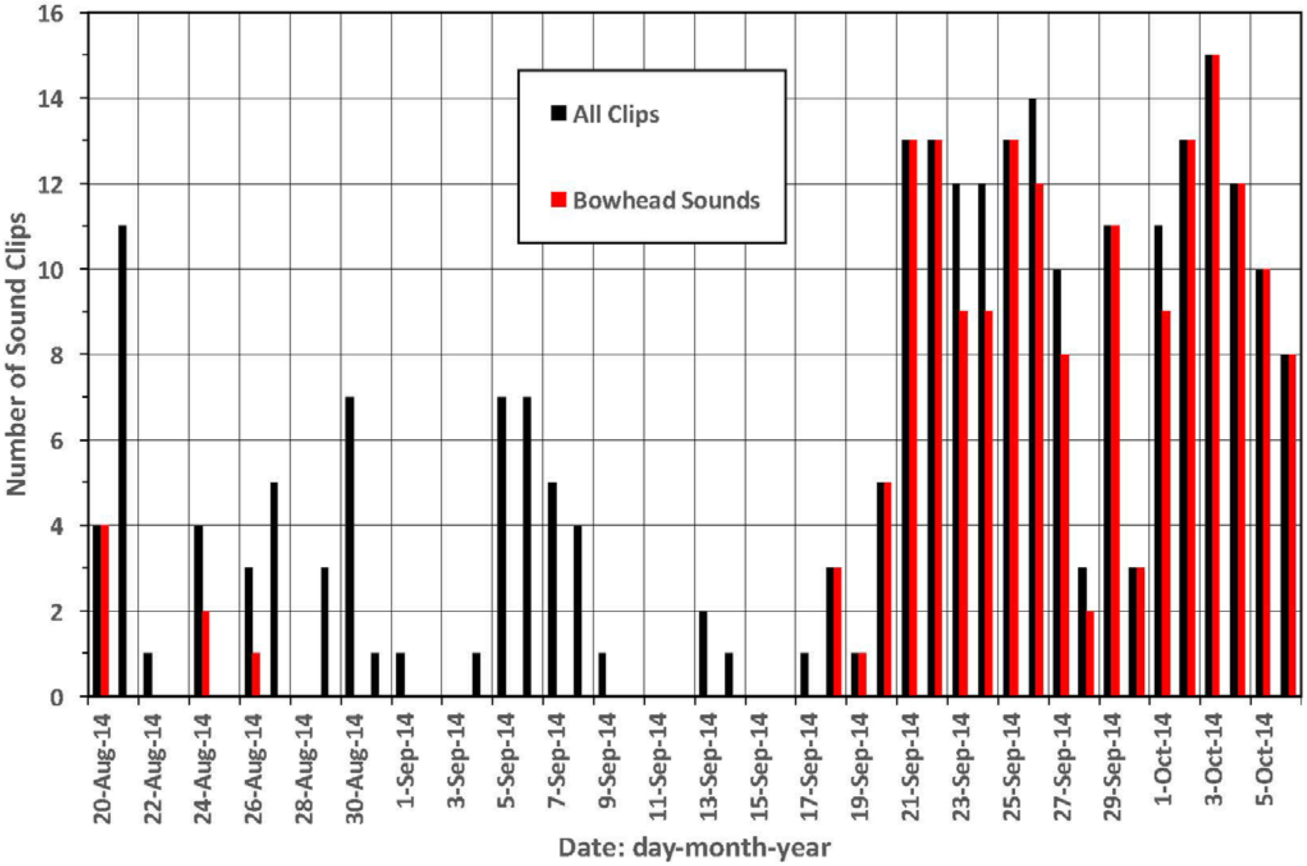


Figure 148. Daily counts of sound clips (n = 251) transmitted from AB_2014 and with detection scores ≥ 4 during the 48-day deployment period from 20 August through 06 October 2014, and daily counts of clips identified as bowhead sounds (n = 176).

Auto-detection Buoy, Noise Spectral Distribution

The auto-buoy features added during the latter part of the CHAOZ project, but improved during the CHAOZ-X project, provided mechanisms for observing major types of acoustic events in near real-time. This feature is particularly valuable for assessing the occurrences and received levels of anthropogenic sounds sources (e.g., offshore energy exploration and operational activities, commercial shipping), natural abiotic sources (e.g., wind and ice), and biotic sources (e.g., singing bearded seals, pods of acoustically active beluga whales, singing bowhead whales, possibly walrus). Two important feature improvements that were implemented were the ability to: a) request the AB to send sound clips of various durations (as opposed to the original 2 s, fixed duration clip), and b) compute and send spectral distribution data at a specific temporal resolution (e.g., 30 s versus 10 min). Given that transmissions are achieved via Iridium satellite, there is an inherent cost to these special transmission requests in terms of on-board battery capacity (transmitting is energetically demanding) and satellite charges (transmitting is relatively expensive).

Figure 149 shows the noise spectral distribution data for the entire 48-day AB_2014 deployment period (20 August through 06 October 2014), while Figure 150 shows the noise spectral distribution data for just the four-day, 02 - 05 October period: both originally processed at the default, 10-min resolution. Neither of these images reveals any indication of bowhead acoustic occurrence. The obvious, high levels of very low-frequency energy (below approx. 40 Hz) represent various, non-biological and often non-acoustical forms of energy (e.g., cable strumming). Examination of the obvious whitish striations in Figure 150, from approximately noon on 03 October until approximately noon on 04 October, do not come from bowheads or any biological source, but rather are most likely from wind energy. These translations of acoustic data into visual images that at first might appear to represent whales or seals are manifestations of data processing parameters. In this case, the spectral energy distributions were calculated at a 10 min resolution, and because of the long acoustic integration time, the occurrences of bowhead transient calls would not be visible, but instead were essentially averaged out. However, at this 10-min integration time, if bowhead whales or bearded seals had been singing, the total energy (or time-bandwidth products of their acoustic efforts) would have been high enough to appear in this visual display. For the same reason, acoustic energy from an anthropogenic sound source (e.g., vessel or seismic airgun) or abiotic sound source (e.g., wind as evident in both these figures) that was nearly continuous and/or loud, would also appear as an obvious form of energy in this type of display.

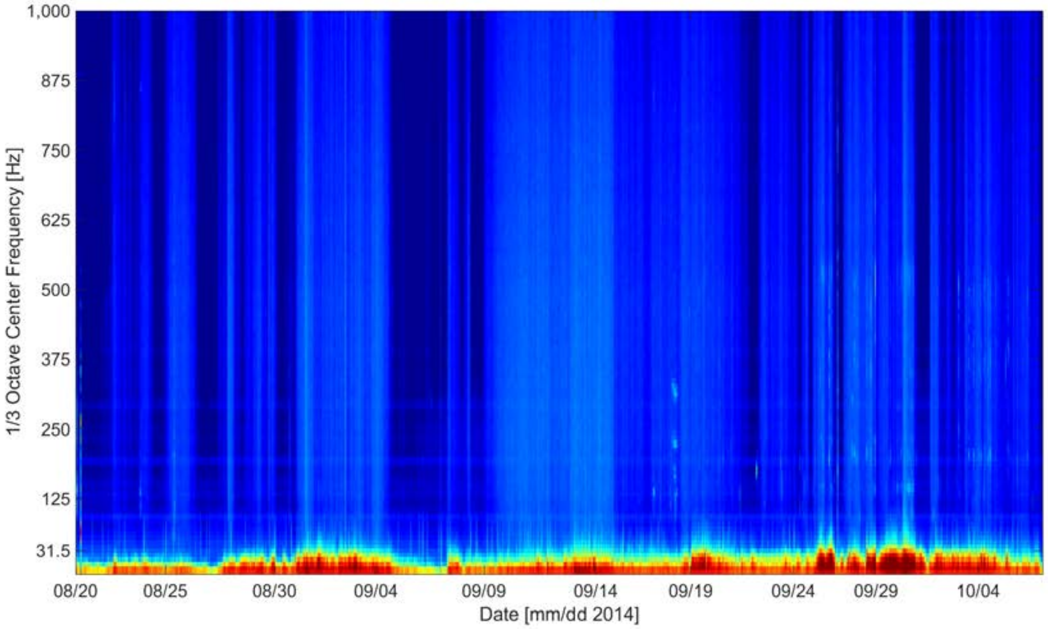


Figure 149. Example of the noise spectral distribution data (similar to a spectrogram) for the period from 20 August 2014 through 06 October 2014. The spectral data were computed on the ab at 10-min resolution and transmitted via iridium satellite as part of the regular data package.

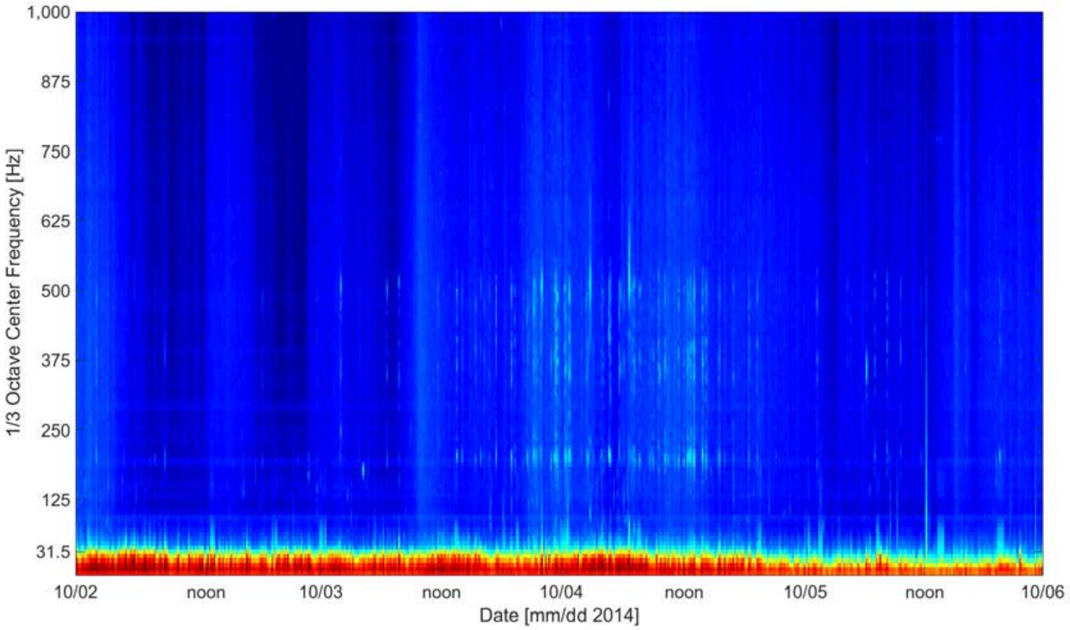


Figure 150. Expanded version of the noise spectral distribution data shown in Figure 149, only here for the 4-day period from 02 through 05 October 2014.

3. *Discussion*

The auto-detection buoy system (AB) utilized in this project evolved from the network of 10 ABs operating in near-real-time in the Boston, MA shipping lanes. This system was designed to monitor and mitigate the potential acute impacts (ship strikes) and more chronic effects (e.g., noise masking of communication sounds) from ships transporting liquefied natural gas (LNG) through North Atlantic right whale (NARW) critical habitat and the Stellwagen Bank National Marine Sanctuary (SBNMS)(Spaulding et al. 2010; see http://www.listenforwhales.org). LNG ships transiting in the shipping lanes are required to slow to <10 kts if NARWs have been acoustically detected within the last 24 h. As a result, the CHAOZ-X project took advantage of the existing technologies developed and routinely advanced by that ongoing LNG project. Whenever possible, advances in AB efficiencies (e.g., data transmission algorithms, bi-directional reprogramming) were included in this project’s ABs.

Considerable effort and resources were devoted to achieving the primary objective of deploying, operating and recovering an AB in the Chukchi Sea during the late summer into early fall season. As expected there were logistical challenges in this effort. An AB has a surface expression that houses batteries, the ruggedized housing containing the auto-detection technologies, and the Iridium antenna system. Ice conditions posed challenges either in the form of physical damage to the buoy (e.g., antenna breakage) or making it difficult for vessel deployment and/or recovery. The availability of a vessel with a technically appropriate trained crew for deployment and recovery, especially late in the fall season, were common challenges. Thus, for example, we decided not attempt an AB deployment in 2015 because we could not secure an appropriate vessel-crew to conduct the deployment, nor could we secure a vessel for recovery.

The overarching motivation for the AB system was to provide near-real-time monitoring of the acoustic environment in the region in which seismic airgun surveys and initial drilling operations were expected to occur. Near-real-time access to the acoustic environment is seen as a much more timely mechanism than autonomous recorder systems for assessing whether or not a particular species of concern is in an area, what types of anthropogenic noises are detected in the area, the characteristics of those anthropogenic noises, and whether or not some type of mitigation should be implemented for that real-time condition. For the NARW situation near SBNMS off Boston, the AB network is a mechanism by which ship strikes are mitigated by requiring a speed reduction if whales are known to be in the general area.

A secondary benefit from the AB network in the Boston shipping lanes has been the collection of acoustic data since the spring of 2007. The AB data along with a suite of autonomous seafloor recorders represents a long-term dataset that has been used, in part, to assess the relative contributions of commercial shipping (including just LNG shipping) to the acoustic environment in SBNMS and NARW critical habitat (see Hatch et al. 2012). The parallels with our CHAOZ-X project are not a coincidence. As scientists we know that evaluating hypotheses (e.g., anthropogenic noise activities in the Arctic influence the region's acoustic environment and the behaviors of marine mammals) requires observations and data spanning multiple spatial and temporal scales. Indeed, this is a fundamental underpinning of the CHAOZ-X project.

4. *Conclusions*

The auto-detection buoy effort was only partially successful. This qualification is really a result of logistics, which includes the fundamental difficulties of working in a distant, harsh environment. For example, when the AB_2016 system failed to transmit data and failed to respond properly to commands issued from Cornell through the Iridium satellite system there was nothing Cornell technologists could do. We could only hope that AB_2016 was functioning properly, and that after recovery we would we would find that the acoustic data collection system had been operating properly and archiving those data. Unfortunately, this was not the case.

In contrast, the first AB deployed during CHAOZ-X, AB_2014, operated properly and provided near-real-time detections and a granular form of a sound spectrogram. AB_2014's detection performance was 70% during a period of relatively low bowhead acoustic occurrence, but was 93% during a period of relatively high bowhead acoustic occurrence. These are very good performance metrics, and there is every reason to conclude that future AB systems could be improved to yield even higher scores. In fact, given the dramatic technical improvements in battery technology, power efficiencies, data processing, and satellite transmission, this initial partially successful effort in the Chukchi Sea will eventually be viewed as pioneering, but relatively primitive.

5. *Recommendations*

Near-real-time, moored, passive acoustic data collection and transmission systems, along with their mobile system cousins (e.g., gliders), will be a core component of future research and operations in the Arctic. One of the directions of bioacoustic development that should be a high priority is the integration of passive acoustic sensor systems with suites of other types of oceanographic sensor systems. A second obvious technical development is the investment into and inclusion of advanced automated detection algorithms. These will essentially install and integrate “deep learning” systems into multi-sensory, autonomous, marine moorings and vehicles. The data from these moorings and vehicles will enable in-ocean, marine “weather” systems by which to predict and assess “ocean health”, including such important features as forcing mechanisms, primary productivity, secondary productivity, densities, and distributions.

B. Acoustic detection–clustering analysis

1. Methods

Sound Events Counts

The number of sound event types per unit time, referred to here as the sound event count, can be applied to reveal the time-varying distribution of different types (i.e., classes) of sound events; for example, the seasonal occurrences of bowhead whale song or seismic airgun impulses. When there are multiple types of acoustic events, but they are not temporally clustered (i.e., the acoustic activities of different species occur at different times of day or times of year), these patterns of event type occurrence emerge when viewed in a time-of-day versus time-of-year plot, which we refer to as a diel plot.

In the Sound Event Count process (Figure 151), an input sound stream of data is divided into segments of pre-defined duration (e.g., 10 min), and converted from its time-varying waveform domain into the time-frequency domain. Instead of applying the widely used Short-Time Fourier Transform (STFT) to produce a series of spectral frames that form a spectrogram, a Constant-Q Transform (CQT) is used to do the same, which takes advantage of a fundamental benefit of the CQT: its window length varies inversely with frequency (i.e., longer window lengths in low-frequency range and shorter window lengths in the high-frequency range). Thus, the CQT offers a logarithmic frequency scale in a manner similar to mammalian hearings and similar to a musical scale. This implementation of the CQT as part of the event detector is a customized process that is not part of the AET system.

Next, the generalized power-law detection (GPL) algorithm (Helble et al. 2012) is applied to the time-frequency domain of CQT in order to find every potential sound event. GPL reliably mitigates the effect of acoustic noise on sound event detection. Finally, in each time bin of pre-defined length (e.g., 10 min) the number of sound events are counted and reported as the output.

Figure 151. A block diagram of the Sound Event Count process.

Sound Event Classification

The sound event approach can work well as long as the acoustic environment is not cluttered. When it is, the sound event count process cannot reliably identify specific sounds or the specific source of those sounds. When the acoustic environment is not cluttered, the raw sound data can be processed to reveal the similarity of sound events. In this case, for example, a seismic airgun impulse will be more similar to other seismic airgun impulses than it is to a bowhead whale call. The similarity between every pair of sound events can help classify those sound events into a predefined number of sound classes. In each sound class, the sound events will be similar to one another, based on the feature vectors used to characterize them. Once such sound classes have been objectively assembled, human experts can verify sound event types within each class and associate the sound class label with known biological sounds, natural abiotic sounds or anthropogenic sounds.

The first two steps in the Sound Event Classification process (CQT and Power-Law Energy Detection process) are the same as those in the Sound Event Count process (Figure 152). These are followed by two additional steps to classify sounds in an unsupervised manner. The first step characterizes each sound event by applying the Histogram of Orientated Gradient (HOG) process (e.g., Freeman and Roth 1995), which calculates features of a histogram that summarizes the directional gradient of the power distribution over the sound's time-frequency CQT matrix. For each spectrogram containing a sound event, there are M-by-N cells, where M and N are the number of cells vertically (frequency) and horizontally (time), respectively. For each cell, a gradient is calculated and a histogram is generated summarizing the direction of the gradient. In our analysis, each bin covered 20 degrees, and there were 18 bins in the histogram.

To classify the analytical results from these analyses of the sound events in an unsupervised process, the K-means clustering technique is applied (see Forgy 1965). All unsupervised classification techniques are based on the similarity between (or its inverse, the distance between) a pair of sound events represented in an abstract space. However, the computer memory requirement is very high when both the number of sound events (in millions) and the dimension of the feature vector are high (in hundreds). K-means is one of the most efficient clustering techniques that can cope with this high computational demand.

The result of K-means unsupervised classification is that each sound event is assigned a class label. Sound events of the same class label are similar to each other in terms of their feature vectors. Since the HOG process is used, events are similar by their a) frequency distribution, b) time distribution, and c) orientation in the time-frequency domain.

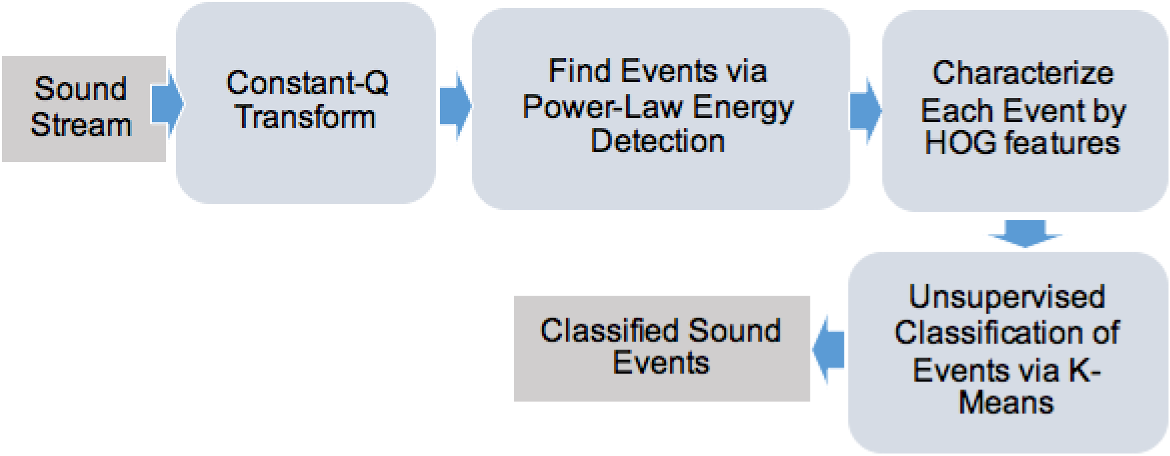


Figure 152. A block diagram of the Sound Event Classification.

A typical challenge in unsupervised classification is how to estimate the number of classes. Before engaging in an extraordinarily sophisticated analytical method for sound classification, a simple rule-of-thumb for the purpose of data exploration is to choose a value for the number of possible classes that is much larger than the expected number of sound types in the recording. If a value is used that is smaller than the actual number of sound types, sound events with very diverse sound characteristics will be forced into the same class and the similarity of sound events within that class will be low. For this reason, we chose 100 as the number of classes in our application.

A fully automatic, unsupervised classification process was applied to two years of acoustic data from DB13_01 and DB14_01 (Table 37) to categorize large numbers of sound events into classes based on their sound characteristics within the five one-octave bands comprising the 25-800 Hz frequency band. Without knowledge from human experts, however, this process cannot associate a sound class label (e.g., a number) with a descriptive sound type label (e.g., “seismic airgun impulse” or “bowhead whale call”). That step requires a human expert to verify an association between sound class labels and actual sound events in order to build the relationship between the sound class and the sound description.

To complete this step in our unsupervised classification process, Cornell scientists with expertise in the recognition of Arctic bioacoustic events, abiotic natural acoustic events, and anthropogenic acoustic events made the associations between sound class labels and actual sound events. The time-varying occurrences of different sound classes for all sound events are then illustrated in diel plots using color to identify the number of sound events (sound event counts), the most common class of sound event (Dominant Class of Sound Events), and the distribution of sound events in a class (distribution of sound classes).

2. *Results*

Sound Event Counts

The analyses of the individual and combined data from DB13_01 and DB14_01 using an unsupervised process revealed some interesting large-scale patterns for this recording location that is approximately 130 km northwest of Wainwright and about 40 km southwest of the Shell drill site. Figure 153 shows that the number of sound events (i.e., sound event counts) is neither uniform throughout the day (Hour of the Day) or throughout the year (Date). For 2013 (DB13_01), from somewhere around 01 November through somewhere around the first week of January, there are high numbers of events throughout the day. This period is followed by an obvious triangular shaped pattern centered on midday (local AK time), indicating that the daily hours with high numbers of events decreased until disappearing around mid-April 2014. For 2014 (DB14_01), from somewhere around mid-November through around the end of January 2015, there are high numbers of events throughout the day, and this period is followed by a less pronounced, more rectangular shaped pattern centered on midday (local AK time), that ended around mid-April 2015. In both years, from around mid-April through mid-June there is a lull in events, indicating that the ocean is quieter than other days of the year.

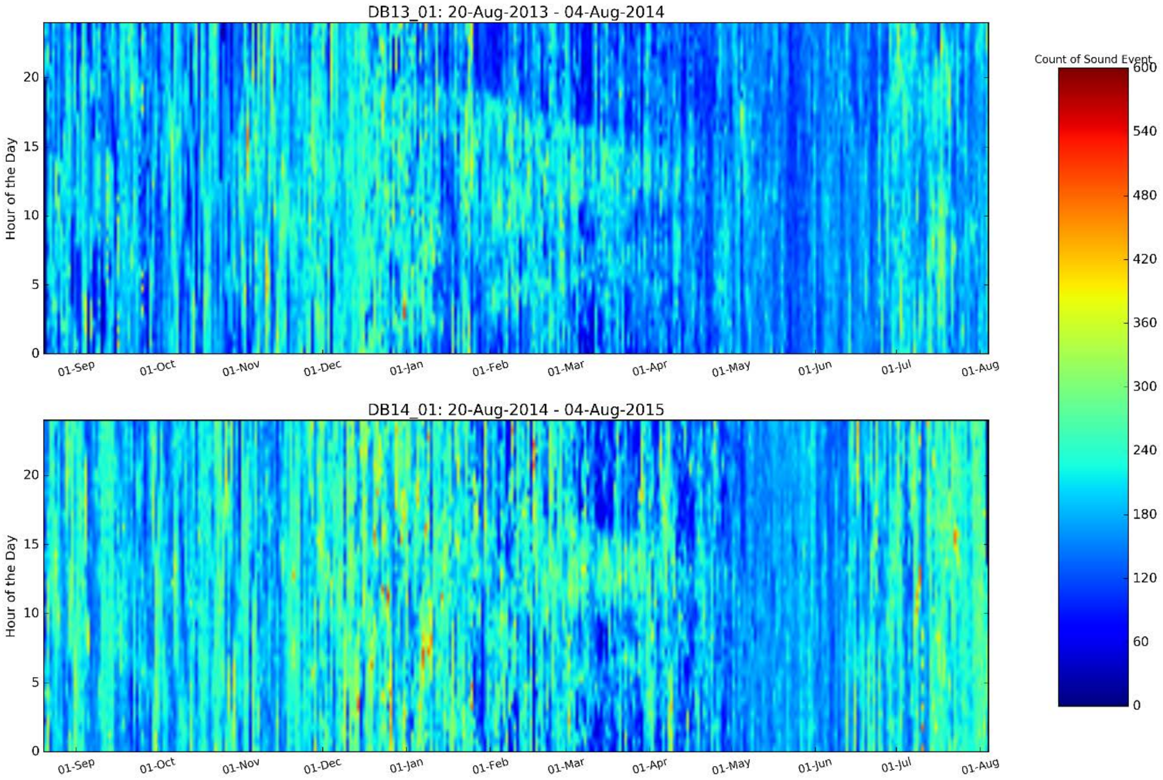


Figure 153. Diel plots of sound event counts for acoustic recorders DB13_01 (top) and db14_01 (bottom) (see Table 37). The color represents the number of sound events per daily 30-min time bin for the approximately 1-year data collection period.

Dominant Class of Sound Events

In our unsupervised, sound clustering analysis, sound events from both years (DB13_01 and DB14_01) were classified based on the similarity of HOG features, which are designed to capture the frequency range and orientation gradient of sound energy distribution within a spectrogram. In Figure 154, the color represents the index of the dominant sound class (n = 100 classes) in each 30-min time bin, where “dominant” refers to the sound class with the highest number of events for the 30-min time bin. It is important to note that the perceived similarity of colors in this figure does not represent a similarity of classes. Throughout the course of a year, changes in the dominant sound class represent the progressive changes in features of the acoustic environment. Sound classes tend to be localized at certain times of the year and do not reoccur at multiple times throughout the year.

For the most part, in Figure 154 the patterns of dominant event occurrence are different between the two years. One exception to this occurs in both years as evidenced by the prevalence of light blue (sound class #38) between around mid-December and late January. We do not recognize a consistent sound source for this class, although some of the sound types in this class are from ice events. During other times of the year, the two years do not share the same patterns of sound class occurrence. It seems that each year has its own distinct characteristics of sound events. For example, from 20 August into early December, prior to the shared prevalence of the light blue sound class, each of the two data sets has a distinctive mosaic of event types that is both different from other times within the year and from the other year. It is also interesting to note that in the 2013 data set, during the early part of December, there is unique patch of royal blue color (sound class #22), which coincides with a period dominated by bowhead songs during the westward migration.

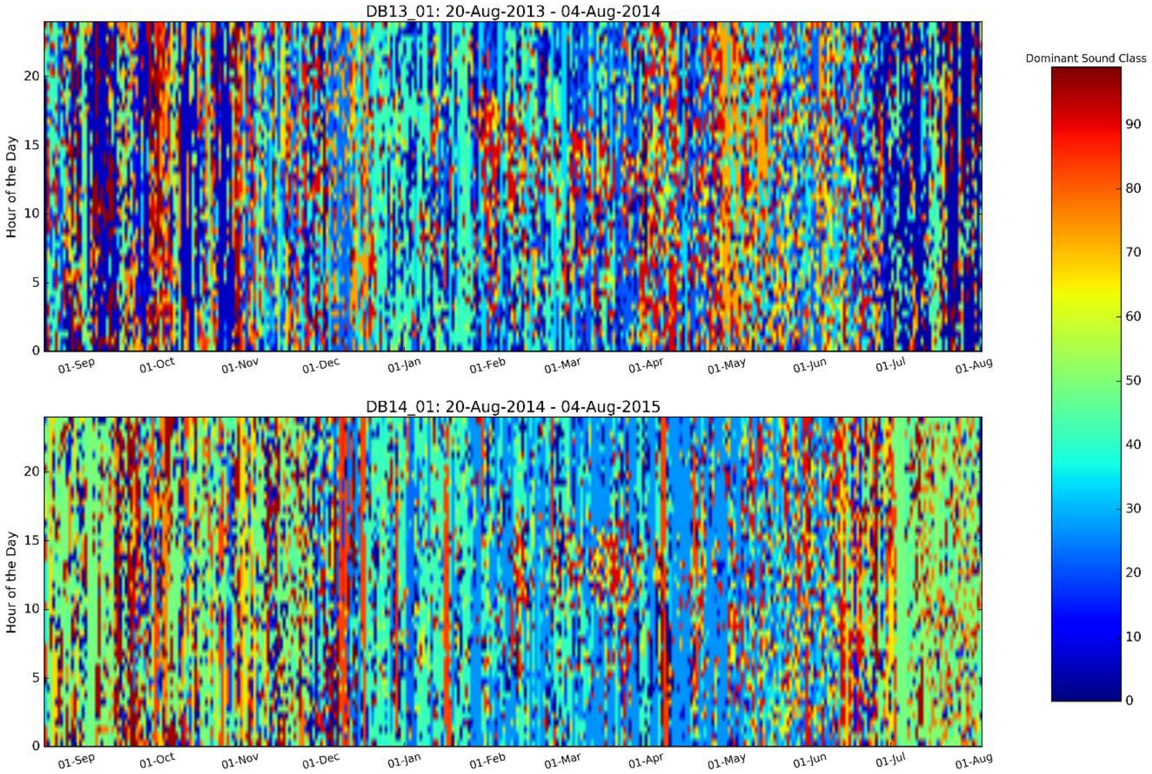


Figure 154. Diel plots showing the dominant sound event class for recorders DB13_01 (top) and DB14_01 (bottom) (see Table 37). The color represents the sound class (n=100 classes) per daily 30-min time bin for the approximately 1-year data collection period.

Distribution of Sound Classes

We investigated the daily distribution of sound class detections for both years (DB13_01 and DB14_01) to look for patterns in how sound class occurrence (not just the dominant sound class as shown in Figure 154) changes throughout the year. We did this, in part, because this dominant sound event class figure (Figure 154) prevented us from seeing possible patterns in the daily distribution of sound classes (i.e., number of sound class events per day). Figure 155 shows this distribution and close inspection reveals that there is structure in this data representation: firstly, there are periods of time during which the sound class distribution (which is really a histogram in which the number of events in a sound class is represented as a color according to the color bar to the right of the figure) tends to remain relatively static and unchanged over periods from weeks to months. During these periods a particular set of classes is dominant. For example, there is one pattern of dominant sound classes during the period in the first weeks of December 2013 (DB13_01) when bowhead singers were obvious from expert analysis of the sound recording, which is followed by a period of many months during which a different set of sound classes appears to remain rather stable. A somewhat similar situation happened in the DB14_2014 data set during a 10-day period in mid-November. Thus, this process has the possibility of providing a relatively objective and rapid way of assessing changes in the acoustic environment, and the reliability of this process could become more robust with the addition of year-long data sets from multiple locations and years throughout the Arctic and when cross-validated with identifications of the types of sound sources as identified by human experts.

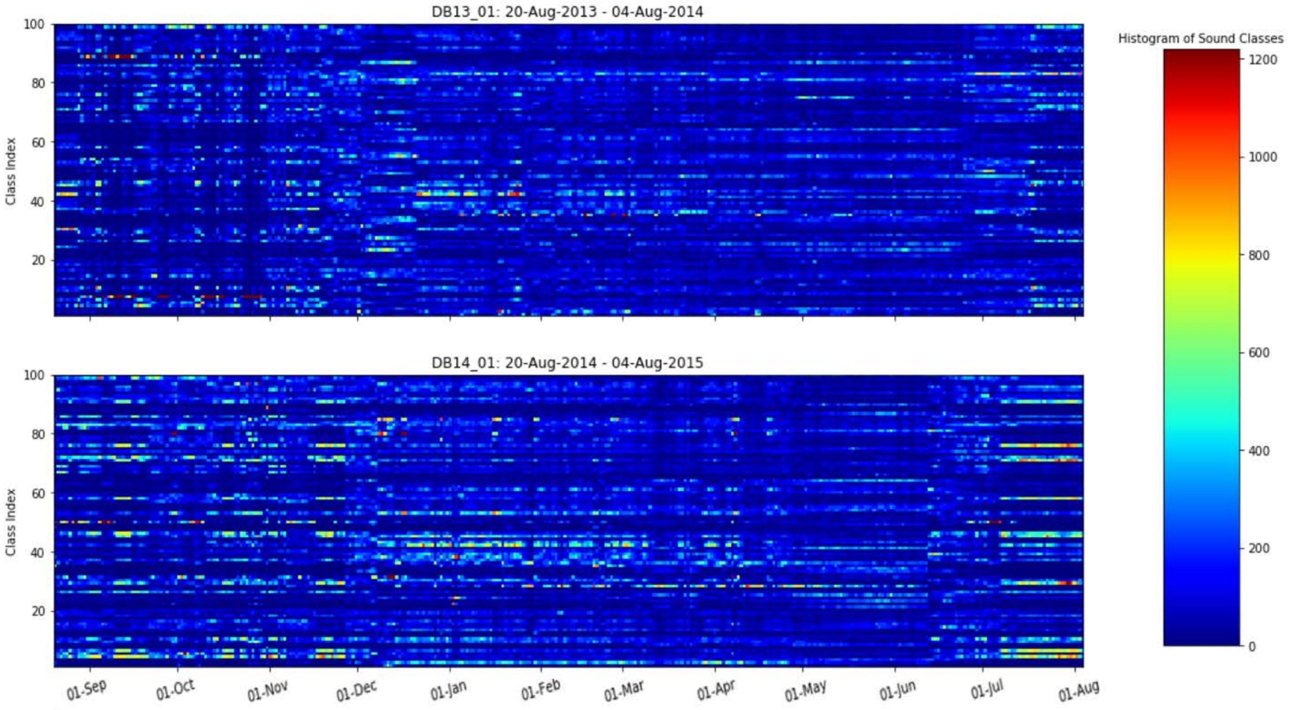


Figure 155. Diel plots showing the number of sound events per day for Cornell acoustic recorders DB13_01 (top) and DB14_01 (bottom) (Table 37).

3. Discussion

A core pillar in the CHAOZ-X project has been the explicit application of passive acoustic mechanisms to observe and describe the spatial and temporal occurrences of acoustically active marine mammals throughout an important Arctic marine ecosystem. Based on the sheer spatial and temporal scales of the overall project, the seemingly simplest task of detecting acoustic occurrence has been an incredible challenge. This challenge has been made even more difficult given that during the time period of the CHAOZ and CHAOZ-X projects the physical and biological characteristics of the study area have been in flux. Thus, for example, the amount of open water, as measured by daily percent open water or number of days with less than 5% ice cover, has increased, and there has been an associated increase in the numbers, types and distributions of marine mammals. As a result, the bioacoustic scene has often been more complex and more difficult to analyze. For example, there are now regular occurrences of other baleen whales in the study area during the open-water season. Most notably this includes humpback and fin whales, both of which can be very acoustically active and whose calls and song notes can be confused with the songs and calls of bowhead whales.

In cases when one is searching for occurrences of very important bioacoustic events (e.g., occurrence of an endangered species), during times of the year and in places where a species rarely occurs, the analysis task can become extremely difficult. In such cases, automatic detection processes can and cannot offer an effective and efficient solution. In some cases, if one is attempting to detect a high proportion of species-specific sounds at a fine grained time scale, detector performance is so poor and returns such high numbers of false detections and/or high numbers of missed true detections, auto-detection is unreliable and inefficient. The challenge and solution becomes one of resolution. That is to say, at what spatial and temporal scales does one need to determine if a species is acoustically present in order to address the primary objectives? Would a solution emerge if acoustic occurrence was not constrained by detection at the species level but by a certain bioacoustic clade: for example, baleen whale singers, or ice seals or fish?

Cornell has confronted this difficult detection situation many times under a variety of objectives and ecological contexts. These experiences have taught us to pay particular attention to analytical scales and methods, and not to defer to traditional bioacoustic approaches (e.g., template, matched-filter or feature vector detection). This is because inevitably, as one confronts analysis of larger and larger data sets, a high resolution analytical paradigm (e.g., species-specific detection at 10 min resolution) becomes untenable and often leads to overdetermined results. As sampling moves from lower to higher spatial and temporal scales, as is the case in this CHAOZ-X project, and data quantity increases by orders of magnitude, new data processing solutions are needed.

The approach that Cornell took in this particular effort was to use existing algorithms and analytical paradigms that have been applied successfully to visual event recognition and apply those to the acoustic event detection challenge by using an image of the acoustic data as input. The objective was to see if there were patterns in the daily and seasonal occurrences of events that were consistent with known and expected patterns of bioacoustic occurrence. For example, we know that calling and singing bowhead whales migrate along the coast and through the Chukchi Sea in the later winter and spring, that singing bearded seals occur in the Chukchi Sea during approximately the same season, and that bowhead calls and songs are very different from bearded seal songs. Thus, we might expect to observe these phenomena in our results from recorders operating in locations through which bowheads migrate and bearded seal males aggregate during the breeding season.

Our results so far for the two years from September 2013 through August 2015 do not reveal these patterns, at least not with unambiguous clarity. The resultant images of the event detection data (e.g., Figures 153-155) reveal structure, but not a diel and seasonal structure that we can yet relate to the expected biological phenomena. This does not necessarily mean that the process is flawed, only that we have not gained enough experience with how to apply it to this particular data set. Thus, for example, we chose 100 as the number of classes in our application, knowing that 100 was greater than the expected number of acoustic classes. So obviously we could vary the number of classes and observe whether it leads to some improved clarity in the results. Another obvious avenue for improved understanding and validation of this approach is its application to a well-studied data set.

4. Conclusions

The U.S. Arctic is in a profound period of transition. The causes of this transition are complex and not well understood, but certainly involve all aspects of oceanography and atmospheric physics, which in turn are the undercurrents driving changes in the acoustically active biota. Here in this project we have only scratched the surface at best. When I (C.W. Clark) first went to the Arctic in the early spring of 1979 to observe and record the bowhead whale migration off Point Barrow, Alaska, the multi-year ice was everywhere with keels grounded in the seafloor. There were massive ice ridges. The migration included only several thousand whales, only a handful of which were singing. In 2011, the most recent year of a new bowhead census, the population estimate was around 18,000 animals, and singers were so prolific that analysts had trouble detecting, locating and tracking calling bowheads (Givens et al. 2016). Barrow canyon in the spring of 2017 is not the same canyon it was just 40 years ago.

In this project, we developed an analytical process and used passive acoustic data to describe the seasonal and spatial occurrences of bioacoustic events within an arctic acoustic environment from a relatively high level of synthesis. With this process, we can now achieve this type of synthesis at different spatial (e.g., 100 km^2, 100,000 km^2) and temporal (e.g., daily, monthly, yearly, decadal) resolutions so as to match the resolutions for other scientific components of this major, multi-discipline project. Thus, for example, it is now quite reasonable to apply high level data analytics to find structure in the passive acoustic data and use clues from those results to look for links with the oceanographic data at regional, yearly, and decadal resolutions. This process can then be tuned to explore for further relationships between physical and biological factors at different spatial-temporal resolutions. The meticulously difficult work of annotating validated marine mammal acoustic detections has been accomplished (see Section VII.A). Through those results we have a clear pathway by which to tune, test and quantitatively validate results from the unsupervised, acoustic event detection approach. With this combination of assets, we should expect a very real chance for a breakthrough in the revelations of relationships between oceanography and biology at multiple trophic levels.

5. Recommendations

Technically, the bioacoustics community needs to find and validate novel analyses techniques that would greatly expedite and improve acoustic detection performance. A critical part of this evolution is recognition and agreement as to the resolutions one is attempting to achieve together with the resource costs and scientific-applied benefits from any proposed solution. The recommendations are as follows:

a) The bioacoustics community engage with data scientists outside of our traditional havens.

b) Use big-data platforms and software so as to integrate the acoustics layer with as many other data layers as feasible.

c) Make as much of the data as possible available to the world at large.

d) Embrace ideas and hypotheses that might have once seemed absurd, but which scientists in other branches of science have used to reach novel conclusions (i.e., consciousness and self-awareness).

XI. SYNTHESIS (OBJECTIVES 1, 4)

A tremendous amount of data were collected during the CHAOZ-X and ARCWEST studies. We are only beginning to skim the surface of the power possible from these integrated time series. For this Synthesis chapter we will explore five main topics: patterns of marine mammal distribution with biophysical parameters, biological hotspots, winter residence by walrus, long-range predictive capabilities, and an examination of three different noise impact scenarios.

A. Patterns of marine mammal distribution to biophysical parameters

1. Introduction

Physically, Hanna Shoal is unique in the northeastern Chukchi Sea. Strong flow occurs to the south (C2 and C3). This is where most of the flow up Central Channel turns eastward to join the coastal flow that exits through Barrow Canyon (Figure 67). The remainder of the northward flow in Central Channel appears to parallel the bathymetry on the western and northern side of the shoal. This flow is much weaker than the flow on the Icy Cape line and along the coast. The flow over Hanna Shoal is very weak. This structure allows ice to be maintained over the shoal, and allows considerable stratification even though the water depth is only 30 m. As mentioned before, the shallow bottom allows primary production to occur on the top of the shoal. In this section we examine how these unique qualities affect the presence of marine mammals on the shoal. We will present general findings, then highlight a few key results.

2. Methods

An iterative approach involving regression tree analysis and generalized additive models (GAMs) was used to explore the relationships between oceanographic conditions, zooplankton abundance, and marine mammal distribution (Friedlaender et al. 2006). Regression trees are a form of classification analysis which allows for the identification of important variables and the results can be graphically expressed in a tree form (Breiman et al. 1984; Venables and Ripley 2002). They can be used to select key variables which can then be included in more comprehensive regression modeling such as generalized linear models (GLMs) and GAMs. Regression models in ecology seek to find relationships and patterns to provide insight into the ecological processes which are occurring. GLMs are an extension of linear models that allow for non-linearity and non-constant variance structures in the data (McCullagh and Nelder 1989; Dobson 2002; Venables and Ripley 2002). GAMs are semi-parametric extensions of GLMs where the only underlying assumptions are that the functions are additive and that the components are smooth[21] functions whose form is chosen from a flexible family by the fitting procedure (Hastie and Tibshirani 1999; Venables and Ripley 2002; Wood 2006).

Analyses were run in the R programming language (R Core Team 2017) through RStudio (RStudio Team 2016). Regression tree models were fitted using the *rpart* and *prune* functions from the rpart package (Therneau et al. 2017). Default setting were used including allowing rpart to use surrogate variables or the majority direction to split observations with missing data

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[21] Smooth in this case means that data are allowed to be non-linear.

points. Plots of the relative error (xerror) versus the complexity parameter (cp) were used to determine where to prune the tree. In the interest of variable selection (rather than classification), complex trees were further pruned to roughly 12 splits. Finally, *rpart* provides information on the primary variables which could be used at each node. All primary variables for the first node were also explored.

There were 36 different biophysical measurements available to include for each regression tree of individual mooring data (Table 40), and an additional 4 location variables for the analysis of multiple moorings. Because of differences in instrument deployment between years and moorings and instrument failure, all biophysical variables are not always available for days when there are acoustic data. To minimize misleading results, analyses were limited to CHAOZ-X moorings C6, C7, and C8 (those near Hanna Shoal) and to biophysical variables which have 41% or fewer missing data points. Sufficient acoustic data existed for the analysis of bowhead and beluga whales, bowhead whale gunshot calls, bearded seals, and walrus. There were insufficient gray whale acoustic data at C6, C7, and C8 for analysis. For bowhead whales, bearded seals, and walrus, regression trees were constructed for C6, C7, and C8 individually with the biophysical measurements, and for the combination of all three moorings with both the biophysical measurements and location variables and with only the biophysical measurements. For beluga whales and bowhead whale gunshot calls, regression trees were constructed for C6 individually with the biophysical measurements, and for the combination of all three moorings with both the biophysical measurements and location variables and with only the biophysical measurements. For these species, C7 and C8 were not individually analyzed because of a lack of calling activity by these species at these moorings. Adding the location variables did not change the top five primary variables for the first split for bowhead and beluga whales, bearded seals, or walrus, and will not be considered further for these species. Adding the location variables did change the top five primary variables for the first split for bowhead whale gunshot calls. For future analyses we plan on examining the individual moorings by deployment year to see if additional data from moorings could be included without increasing the percentage of missing explanatory data. In addition, temperature data from the AURALs will be explored to supplement where the Seabird temperature data are missing.

GAMs were fitted for the presence/absence of calling activity for bowhead and beluga whales, gunshot calls, bearded seals, and walrus. As a first run, the explanatory variables used were the five primary variables identified for the first node in the regression analysis using all three moorings (C6, C7, and C8) combined and only biophysical measurements (i.e., location variables were not included). These variables were chosen to give spatial coverage across Hanna Shoal with a focus on the biophysical drivers behind marine mammal presence. Models were fit using the *gam* function in the *mgcv* package for R (Wood 2017). For each species, GAMs were constructed for each primary biophysical variable alone to check for significance. For numeric variables, linear and smooth single variable models were compared using Akaike Information Criterion (AIC) to determine the most parsimonious functional form to use (Burnham and Anderson 2002). A final model was run using all significant ($p<0.05$) primary variables. Final models were further examined to ensure that all explanatory variables were significant ($p<0.1$) and the relationship in the full model was similar to that from the single variable model. A higher p-value was used to retain variables which might provide insight even with a weak signal. For bowhead whales, month was dropped because it was not significant (p-value ranged from 0.95 to 1.00 for the month factors). Note that the y-scale on the GAM plots was occasionally reduced to show the pattern in the explanatory variable. In those plots, the confidence bands were cut off which visually under-represented the uncertainty in the results; the figure legends indicate if a variable was displayed with a compressed y-scale.

Because our dataset is made up of measurements collected from multiple instruments at multiple locations with various failure dates, some models contained larger datasets than others. Also, note that although a larger dataset of passive acoustic recordings was used in the marine mammal distribution section above (Section VII), only those that were deployed in clusters with the biophysical moorings are included in the regression tree and GAM analyses. An additional caveat of our analysis is that although the datasets were collected over similar time and spatial scales, the overlap between the passive acoustic results and the oceanographic measurements is sometimes patchy[22]; as a result the top models selected may not be the best suited to explain the variability seen in the calling activity distributions, but they are the best models for these data at this time. All variables were included regardless of possible correlations between variables.

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[22] All samples (i.e., available days) were input into the R programs; for the regression trees, missing explanatory variables were predicted at each node based on the proportions of known variables at the node, and for GAMs, days with missing explanatory variables used in the model were removed.

Table 40. Variables used in the regression tree models. Listed are the variable codes, descriptions, the percentage of missing data on all CHAOZ-X and ARCWEST moorings combined, and the percentage of missing data on C6, C7, and C8 combined. Variables with 41% or fewer missing data points at C6, C7, and C8 combined were used in the regression tree analysis.

Variable	Description	All	C6, C7, and C8
Ice.Conc	Ice Concentration (%)	0	0
Winds.u	Zonal Wind (Component of Horizontal Wind towards East, m s^{-1})	0	0
Winds.v	Meridional Wind (Component of Horizontal Wind towards North, m s^{-1})	0	0
Winds.spd	Wind Speed (m s^{-1})	0	0
Month	Month data was collected	0	0
Year	Year data was collected	0	0
lat	Latitude (°)	0	0
long	Longitude (°)	0	0
d.to.shore	Distance to shore (km)	0	0
d.along.shore	Distance along shore (km)	0	0
Transport	Transport (Sv)	0	0
Temp	Temperature (°C)	24	20
Salinity	Salinity (psu)	26	20
PAR	Photosynthetic Active Radiation (mEin cm^{-2} s^{-1})	40	41
Currents.U.bottom	Bottom Zonal Velocity (Current toward East, cm s^{-1})	43	60
Currents.V.bottom	Bottom Meridional Velocity (Current toward North, cm s^{-1})	43	61
Chlorophyll	Chlorophyll concentration derived from fluorescence (µg L^{-1})	45	38
O2.bottom	Bottom O_2 (mMol kg^{-1})	56	79
O2.bottomSat	Bottom O_2 Saturation (%)	56	79
Ice.Thick.Ave	Average Ice Thickness (m)	58	86
Ice.Thick.Med	Median Ice Thickness (m)	58	86
Ice.Thick.SD	Standard Deviance in Ice Thickness (m)	58	86
ADCP.300.Bottom.Sv	Acoustic Doppler Current Profiler at 300 kHz, Bottom Layer Only Volume Backscattering (dB re 1 m^{-1})	72	82
ADCP.300.Column.Sa	Acoustic Doppler Current Profiler at 300 kHz, Entire Water Column, Area Backscattering (dB re 1(m^2 m^{-2}))	72	82
ADCP.600.Bottom.Sv	Acoustic Doppler Current Profiler 600 kHz, Bottom Layer Only, Volume Backscattering (dB re 1 m^{-1})	72	75
ADCP.600.Column.Sa	Acoustic Doppler Current Profiler 600 kHz, Entire Water Column, Area Backscattering (dB re 1(m^2 m^{-2}))	72	75
Currents.U.surface	Surface Zonal Velocity (Current toward East, cm s^{-1})	85	100
Currents.V.surface	Surface Meridional Velocity (Current toward North, cm s^{-1})	85	100
Turbidity	Turbidity (FNU)	88	100
Nitrate	Bottom Nitrate (µM)	89	100
TAPS.BioVol.Full.col	Tracor Acoustic Profiling System, Total BioVolume (mm^3/m^3) of the Water Column	100	100
TAPS.BioVol.Bottom	Tracor Acoustic Profiling System, Total BioVolume (mm^3/m^3) at the Bottom	100	100
TAPS.Euphausiid.Full.c	Tracor Acoustic Profiling System, Euphausiid Abundance (/m^3) of the Water Column	100	100
TAPS.Euphausiid.Botto	Tracor Acoustic Profiling System, Euphausiid Abundance (/m^3) at the Bottom	100	100
TAPS.420.Full.col	Tracor Acoustic Profiling System, 420 kHz Volume Backscatter (Sv) of the Water Column (dB re 1(m^2 m^{-2}))	100	100
TAPS.420.Bottom	Tracor Acoustic Profiling System, 420 kHz Volume Backscatter (Sv) at the Bottom (dB re 1 m^{-1})	100	100
TAPS.50.Full.col	Tracor Acoustic Profiling System, 50 kHz Volume Backscatter (Sv) of the Water Column (dB re 1(m^2 m^{-2}))	100	100
TAPS.50.Bottom	Tracor Acoustic Profiling System, 50 kHz Volume Backscatter (Sv) at the Bottom (dB re 1 m^{-1})	100	100
ADCP.75.Column.Sa	Acoustic Doppler Current Profiler at 75 kHz, Entire Water Column, Area Backscattering (dB re 1(m^2 m^{-2}))	100	100
ADCP.75.Bottom.Sv	Acoustic Doppler Current Profiler at 75 kHz, Bottom Layer Only, Volume Backscattering (dB re 1 m^{-1})	100	100

3. Results

Although the regression tree analysis was run on the individual CHAOZ-X C6, C7, and C8 moorings and on the combination of these moorings, the GAM analysis focused on the combined set of moorings and on the primary variables identified for the first node of the combined regression tree analysis. Future analyses should include examination of the individual moorings and include a more thorough examination of other possible explanatory variables. In addition, the acoustic data were reduced to presence/absence for the GAM analyses for ease of analysis as the modeling of acoustics data is still being developed by the statistical community at large. This reduction loses the detail of the level of calling activity present on each day and makes all days with calling equivalent regardless of the amount of calling. As methods for modeling acoustic data develop, these data should be reanalyzed using the percent calling activity data.

The results below are organized by species. For each species except gray whales, we present the pruned regression tree, the primary variables for the first node of the tree, and the GAM results using the primary variables as explanatory variables.

Bowhead whale

The regression tree indicated most bowhead calling activity occurs in October and November (Figure 156). The October and November data were then divided by year (before 2014 and during or after 2014) with different variables being used on each branch to isolate conditions of high calling. During and after 2014, low ice concentration, wind speed, and transport result in higher average calling activity. Before 2014, multiple scenarios result in higher calling activity: 1) low chlorophyll, 2) high chlorophyll with low winds, high PAR, and high ice concentration, 3) high chlorophyll with low winds, low PAR, during 2012, and high transport.

Four of the five primary variables for moorings C6, C7, and C8 combined are also in the pruned regression tree (Figure 156, Table 41) with temperature being the only variable not in the tree. Examining the individual mooring results, all three have similar results. Month and temperature are the top two variables on all three moorings. Ice concentration, year and chlorophyll are the next three variables in various orders for moorings C6 and C7; for C8 meridional wind replaces chlorophyll.

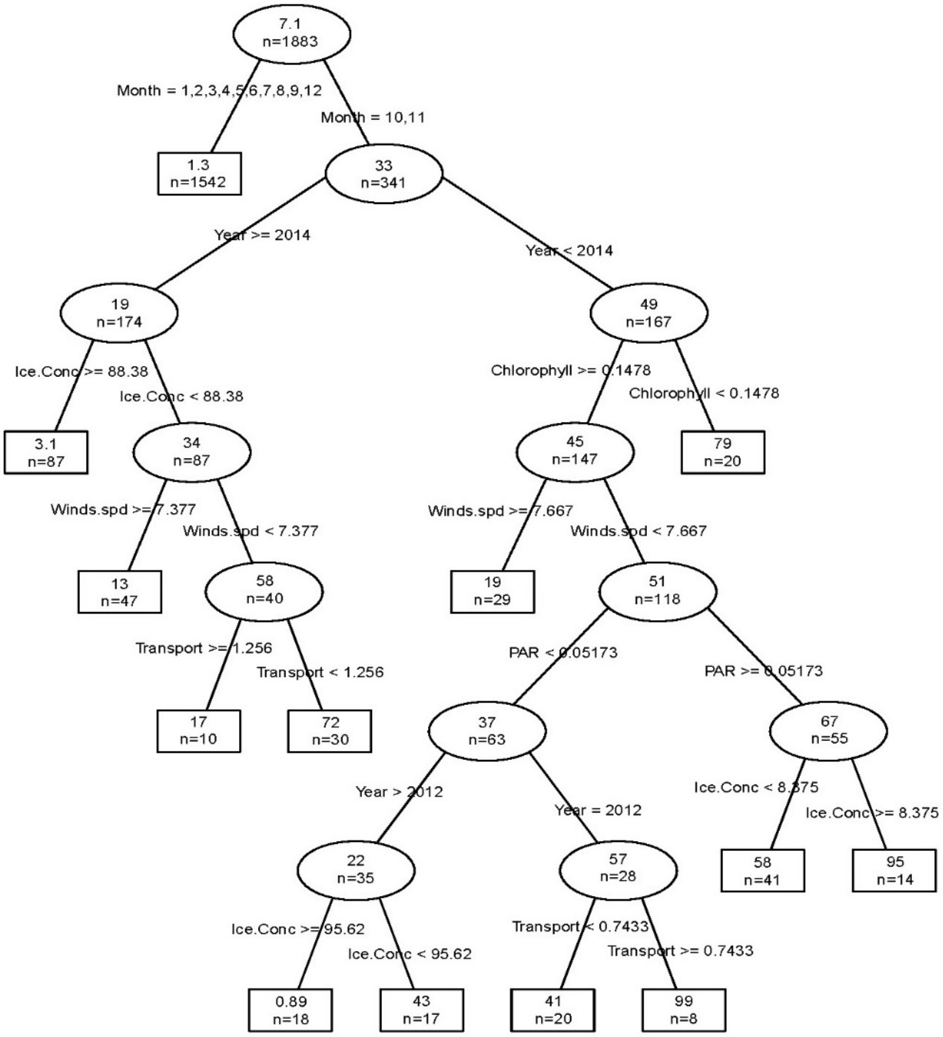
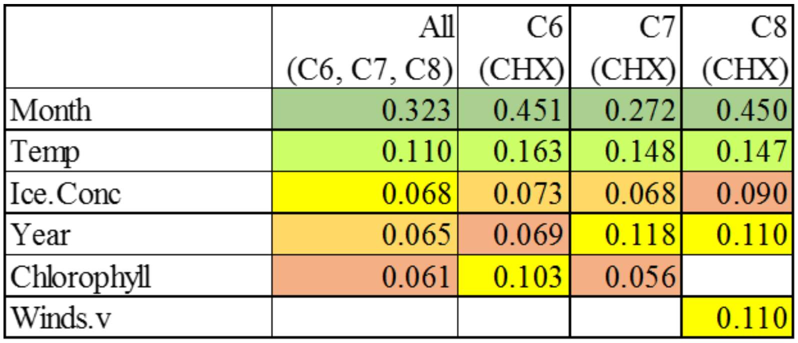


Figure 156. Pruned regression tree for bowhead whale calls including CHAOZ-X moorings C6, C7, and C8. The original pruned tree accounts for relative error (xerror) versus the complexity parameter (cp). The values in each node are the predicted daily calling activity (%) for the node and the number of cases (i.e., number of days) reaching the node.

Table 41. The primary variables for the first node of the regression tree for bowhead whales using CHAOZ-X moorings C6, C7, and C8 combined and each alone. Variables are color coded by the level of improvement in the model for that location, with dark green providing the most improvement (and is the variable defining the first node) and dark orange providing the least.



	All (C6, C7, C8)	C6 (CHX)	C7 (CHX)	C8 (CHX)
Month	0.323	0.451	0.272	0.450
Temp	0.110	0.163	0.148	0.147
Ice.Conc	0.068	0.073	0.068	0.090
Year	0.065	0.069	0.118	0.110
Chlorophyll	0.061	0.103	0.056	
Winds.v				0.110

The GAM results indicated that bowhead whale calls decrease with higher temperature (above -0.25°C), very high ice concentration (above 80-85%), increasing chlorophyll, and later years (Figure 161). However, sample sizes are low for higher temperature and higher chlorophyll resulting in large confidence bands. When GAM models were run with individual variables, month was found to be not significant and was not included in the final model.

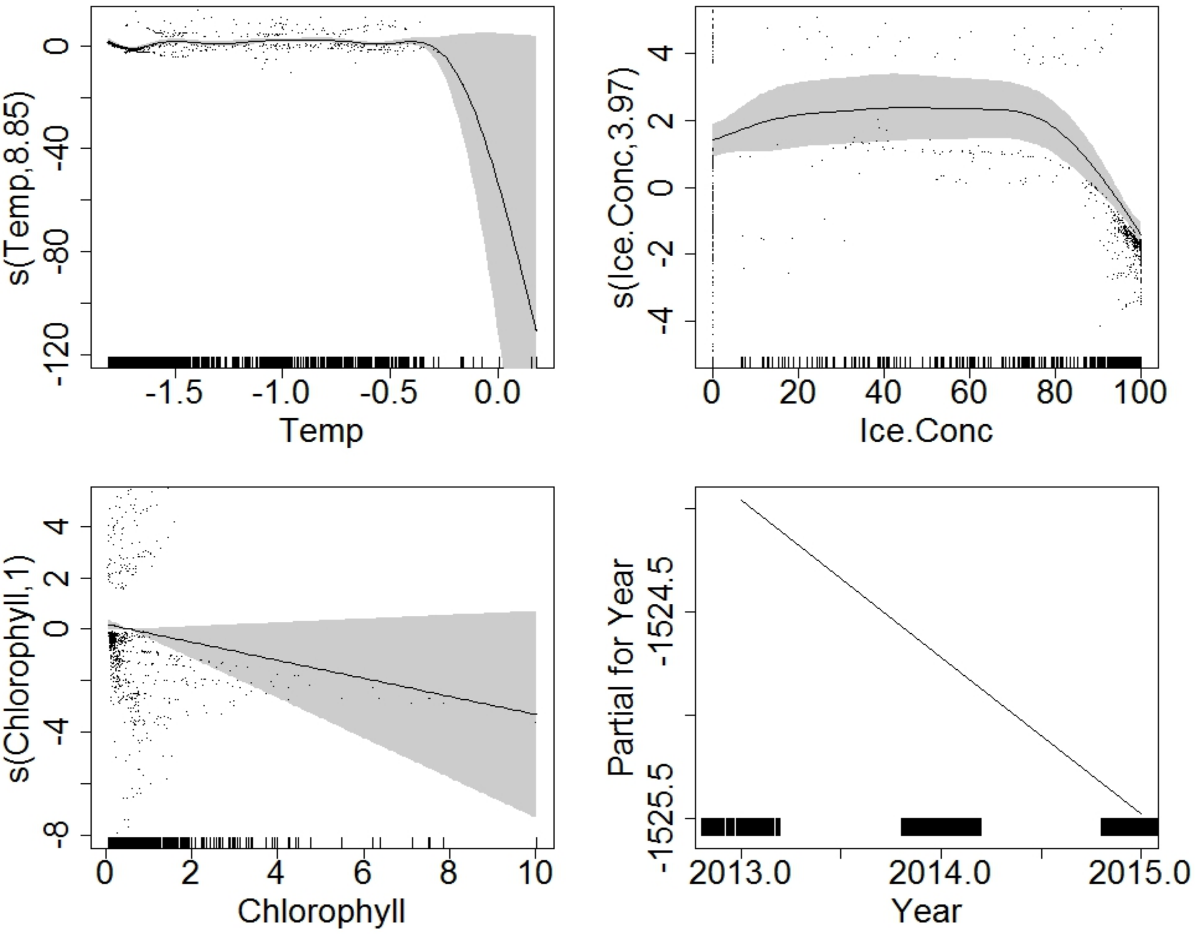


Figure 157. GAM results for bowhead whale call presence/absence using the primary variables for node one from the combined C6, C7, and C8 regression tree (Table 41) as explanatory variables. Temperature, ice concentration, and chlorophyll were included as smoothed variables and year as linear. Month was excluded because the single variable model was not significant. Gray shaded regions indicate the confidence bands for smooths functions.

Gunshot calls (Bowheads)

Gunshot calling activity was low, in general. The regression tree indicated that calling activity was higher in 2012 with higher ice concentration in December and November (Figure 158). Examining the gunshot call data from moorings C6, C7, and C8, most of the days with calling occurred on mooring C6 (81 days versus 7 and 18 days for C7 and C8, respectively) and from June through January, with most activity during December and November. Because of the low number of days with gunshot calling activity at moorings C7 and C8, individual results for these moorings will be not be presented.

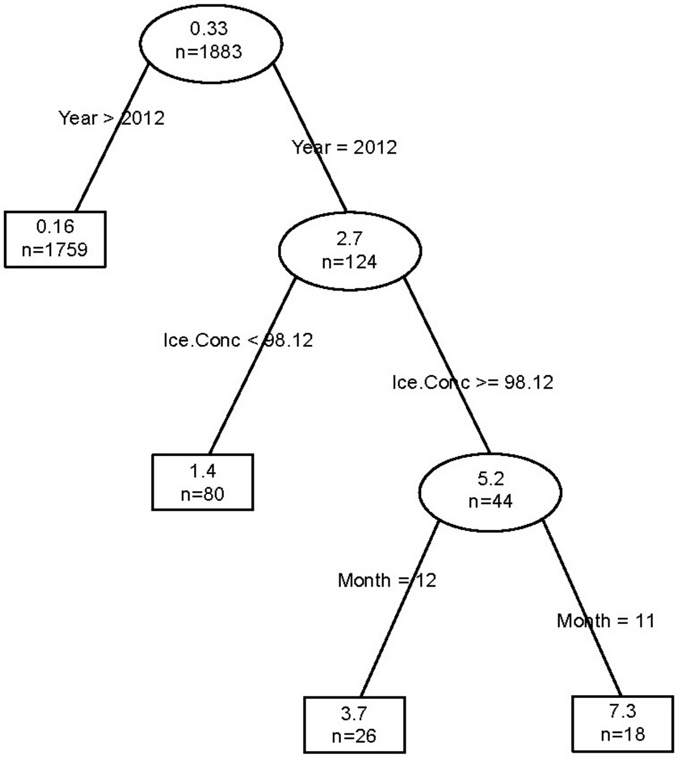


Figure 158. Pruned regression tree for gunshot calls including CHAOZ-X moorings C6, C7, and C8.The pruned tree accounts for relative error (xerror) versus the complexity parameter (cp). The values in each node are the predicted daily calling activity (%) for the node and the number of cases (i.e., number of days) reaching the node.

Table 42. The primary variables for the first node of the regression tree for gunshot calls using CHAOZ-X moorings C6, C7, and C8 combined and C6 alone. Variables are color coded by the level of improvement in the model for that location, with dark green providing the most improvement (and is the variable defining the first node) and dark orange providing the least.

	All (C6, C7, C8)	C6 (CHX)
Year	0.132	0.134
Month	0.060	0.131
Winds.spd	0.005	0.010
Transport	0.004	
Winds.u	0.004	
Salinity		0.017
PAR		0.009

Year and month are important variables in the regression tree and as primary variables for the first node (Figure 158, Table 42). However, ice concentration is in the regression tree but not a primary variable for node one. Adding the location variables to the regression tree analysis, latitude, longitude, and distance to shore replaced wind speed, transport and zonal winds in the top five primary variables for the first split. Examining the C6 results, year, month, and wind speed are primary variables, but transport and zonal winds are replaces by salinity and PAR and wind speed becomes the fourth variable.

The single variable model using zonal winds as an exploratory variable to describe gunshot calling activity had low significance, and the general pattern of the relationship broke down when wind speed was added to the model. Therefore, zonal winds were not used in the final GAM. The GAM results indicate that gunshot calls decrease with high wind speed, later years, and February through May (Figure 159). The relationship with transport shows a possible peak at mid-transport levels, but there is low sample size at extreme levels.

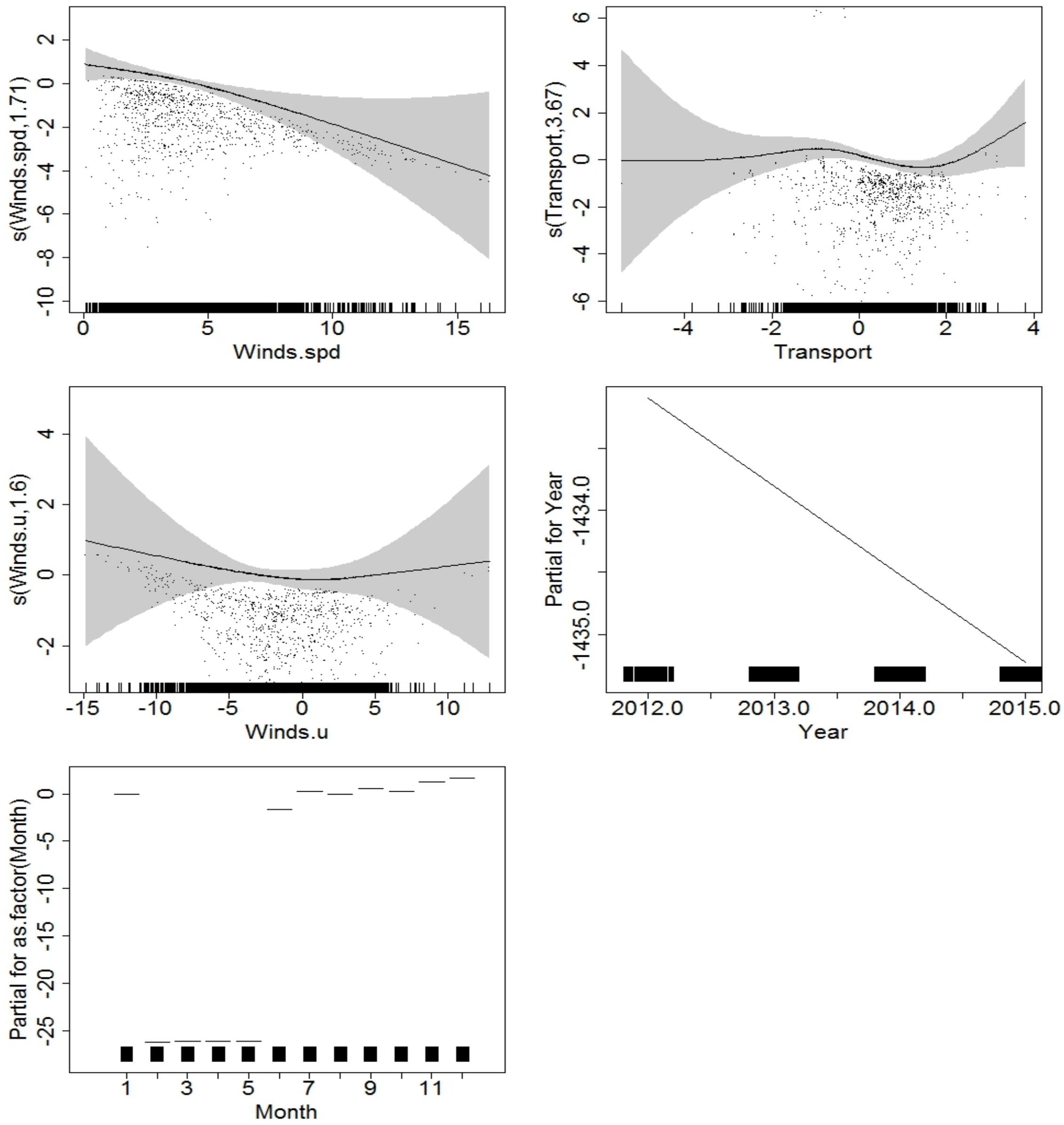


Figure 159. GAM results for gunshot call presence/absence using the primary variables for node one from the combined C6, C7, and C8 regression tree (Table 42) as explanatory variables. Wind speed and transport were included as smoothed variables, year as linear, and month as a factor. Zonal winds were excluded because of low significance and an interaction with wind speed. Gray shaded regions indicate the confidence bands for smooths functions.

Beluga whale

The regression tree analysis indicated those days in April and May with high meridional winds or with low winds, high temperatures, and before 2014 have more calling activity (Figure 161). However, there are relatively few days with calling activity compared to other species such as bowhead whales, walrus, and bearded seals. Because of the low number of days with beluga calling activity at moorings C7 and C8, individual results for these moorings will be not be presented.

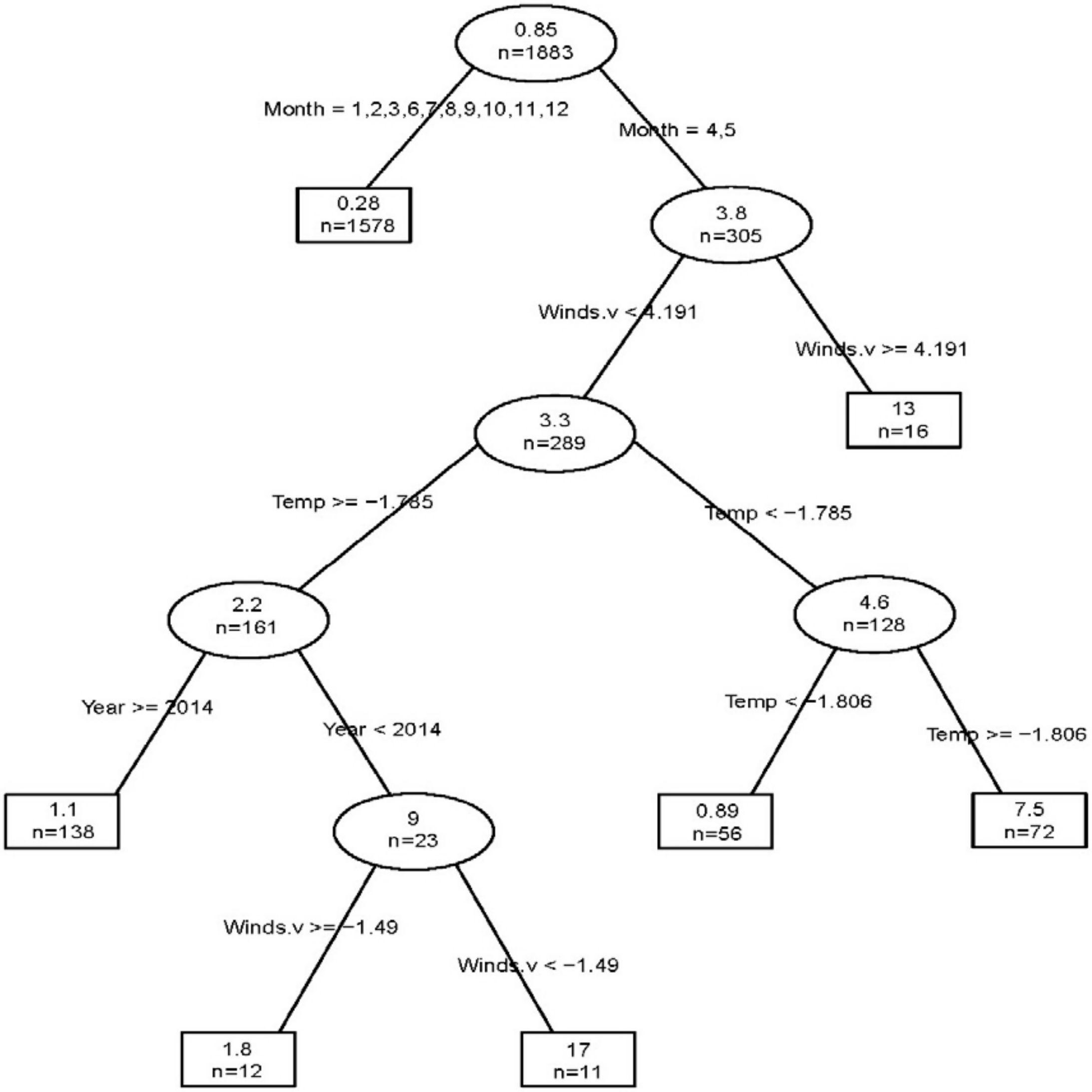


Figure 160. Pruned regression tree for beluga whale calls including CHAOZ-X moorings C6, C7, and C8. The original pruned tree accounts for relative error (xerror) versus the complexity parameter (cp). The values in each node are the predicted daily calling activity (%) for the node and the number of cases (i.e., number of days) reaching the node.

Table 43. The primary variables for the first node of the regression tree for beluga whales using CHAOZ-X moorings C6, C7, and C8 combined and C6 alone. Variables are color coded by the level of improvement in the model for that location with dark green providing the most improvement (and is the variable defining the first node) and dark orange providing the least.

	All (C6, C7, C8)	C6 (CHX)
Month	0.082	0.125
Temp	0.054	0.018
Salinity	0.031	0.019
Winds.v	0.014	0.027
Winds.u	0.010	
Ice.Conc		0.019

Month, temperature, and meridional winds are important variables in the regression tree and as primary variables for the first node (Figure 160, Table 43). However, salinity and zonal winds are the primary variables for node one but not in the regression tree. Examining the C6 results, ice concentration replaces zonal winds as the primary variable and the order of the variables is different, except for month which remains as the first primary variable.

When all five primary variables are included in the model, temperature is not significant and was removed from the final model. The GAM results indicate that beluga calling increases with increasing meridional winds and moderate zonal winds (Figure 161). The relationship with salinity is more complex and is confounded by low sample size at high levels. The relationship with month seems to be bimodal with peaks in June (April-July) and October (October to December).

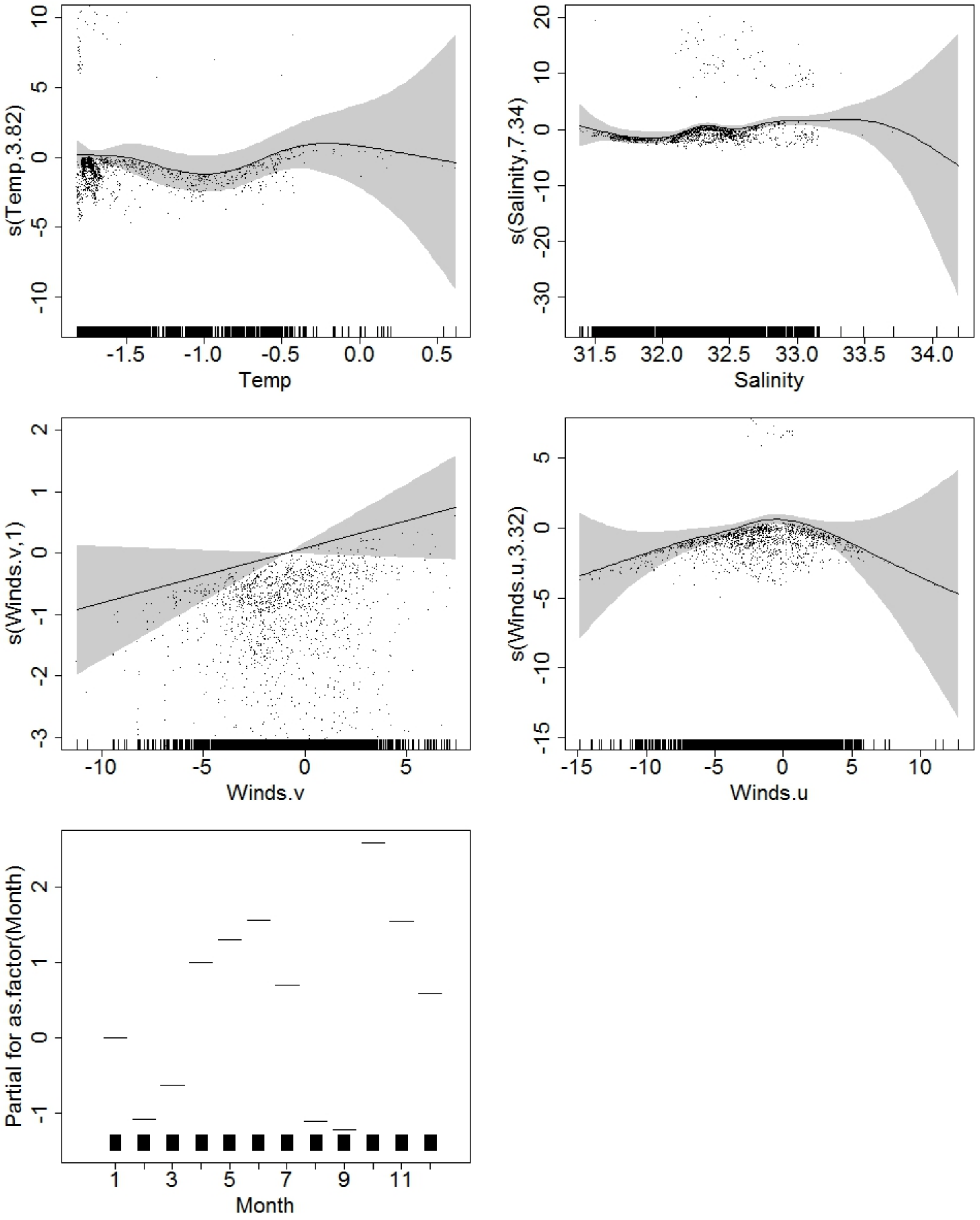


Figure 161. GAMs results for beluga whale call presence/absence using the primary variables for node one from the combined C6, C7, and C8 regression tree (Table 43) as explanatory variables. Salinity, meridional winds, and zonal winds were included as smoothed variables and month as a factor. Temperature was excluded because it was not significant in the full model. Gray shaded regions indicate the confidence bands for smooths functions.

Gray whale

There were few days during the CHAOZ-X and ARCWEST projects when gray whale calls were detected. Most of the calling activity was found on ARCWEST moorings C1 (25 days) and C5 (56 days), with two days of calling on moorings C3 (both projects) and C4 (ARCWEST), only one day of calling on each of C2 (ARCWEST) and C7 (CHAOZ-X), and no gray whale calls on CHAOZ-X moorings C6, C8, and C9. Because of lack of days with calling detected on the CHAOZ-X moorings (C6, C7, and C8), there were insufficient data to conduct either the regression tree analysis or the general additive modeling.

Walrus

The regression tree analysis indicated that June through September had the highest walrus calling activity (Figure 162). Within this time period, conditions under which more calling occurred can be isolated with differing levels of ice concentration, chlorophyll, PAR, wind speed, month, year, salinity, and zonal winds. The highest calling activity (10 days with an average of 91%) occurred between June and September on days with high ice concentration, low chlorophyll, and low PAR.

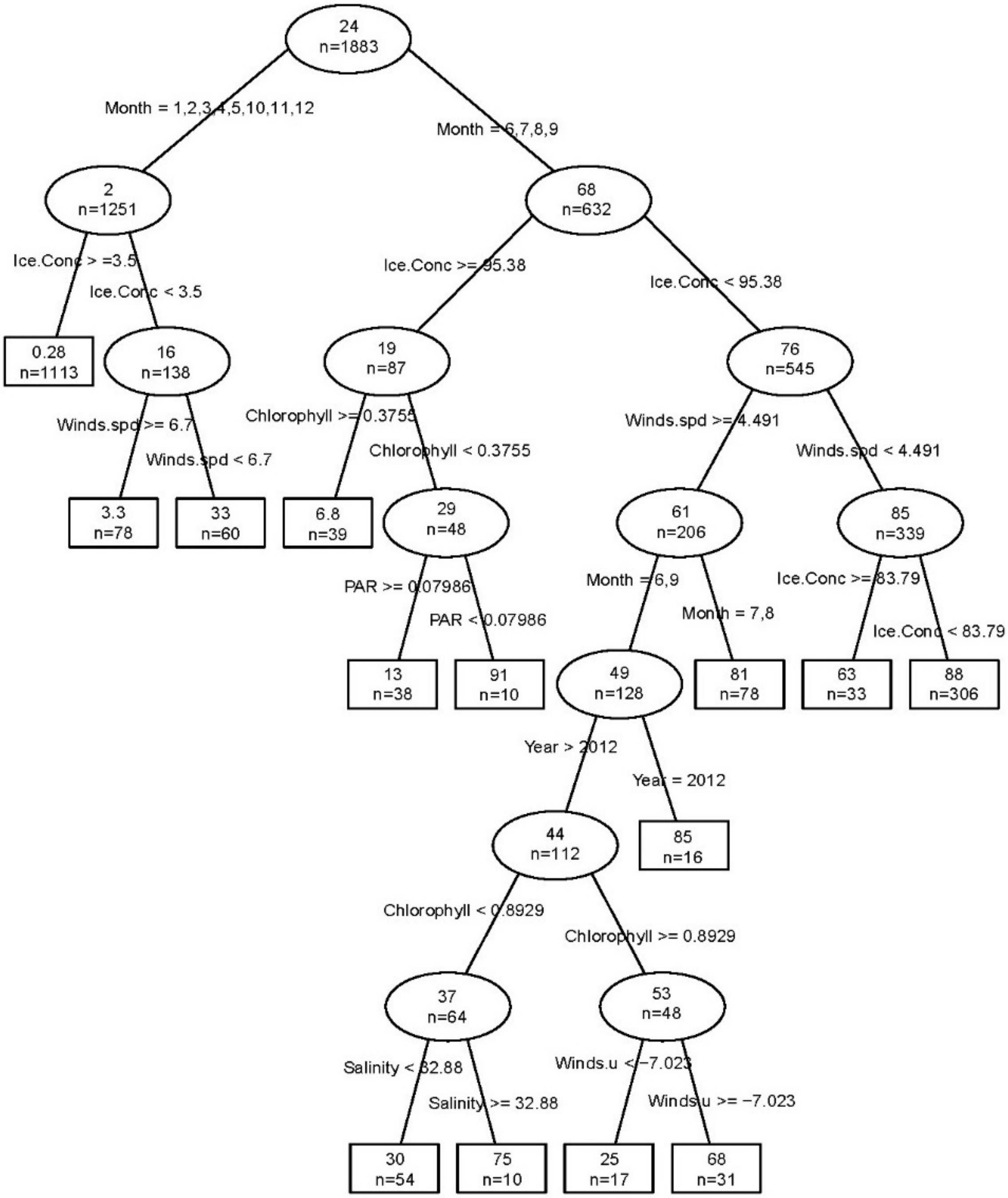


Figure 162. Pruned regression tree for walrus calls including CHAOZ-X moorings C6, C7, and C8. The original pruned tree accounts for relative error (xerror) versus the complexity parameter (cp). The values in each node are the predicted daily calling activity (%) for the node and the number of cases (i.e., number of days) reaching the node.

Table 44. The primary variables for the first node of the regression tree for walrus using all of CHAOZ-X and ARCWEST moorings combined and CHAOZ-X moorings C3,C6, C7, and C8. Variables are color coded by the level of improvement in the model at that location with dark green providing the most improvement and dark red providing the least.

	All (C6, C7, C8)	C6 (CHX)	C7 (CHX)	C8 (CHX)
Month	0.641	0.622	0.652	0.679
Ice.Conc	0.480	0.407	0.539	0.583
Temp	0.203	0.121	0.232	0.355
Chlorophyll	0.199		0.405	0.309
Salinity	0.077		0.156	0.106
PAR		0.079		
Transport		0.057		

Month, ice concentration, chlorophyll, and salinity are important variables in the regression tree and are primary variables for the first node (Figure 162, Table 44). However, temperature is a primary variable for node one but is not in the pruned regression tree. The individual mooring results are fairly consistent with the combined mooring results. Primary variables for the C8 mooring are identical to those of the combined moorings. C6 has the same first three primary variables as the combined moorings, but PAR and transport replace chlorophyll and salinity. C7 has the same primary variables as the combined moorings, but chlorophyll and salinity are in reverse order.

The GAM results indicate that walrus calling is bimodal with peaks at both zero and 70% ice concentration; however most of the data are at high ice concentration levels (Figure 163). Walrus calling increases with increased temperature, chlorophyll, and slightly with salinity; however, there is a lack of samples with high temperatures and moderate to high chlorophyll. Calling peaks in August.

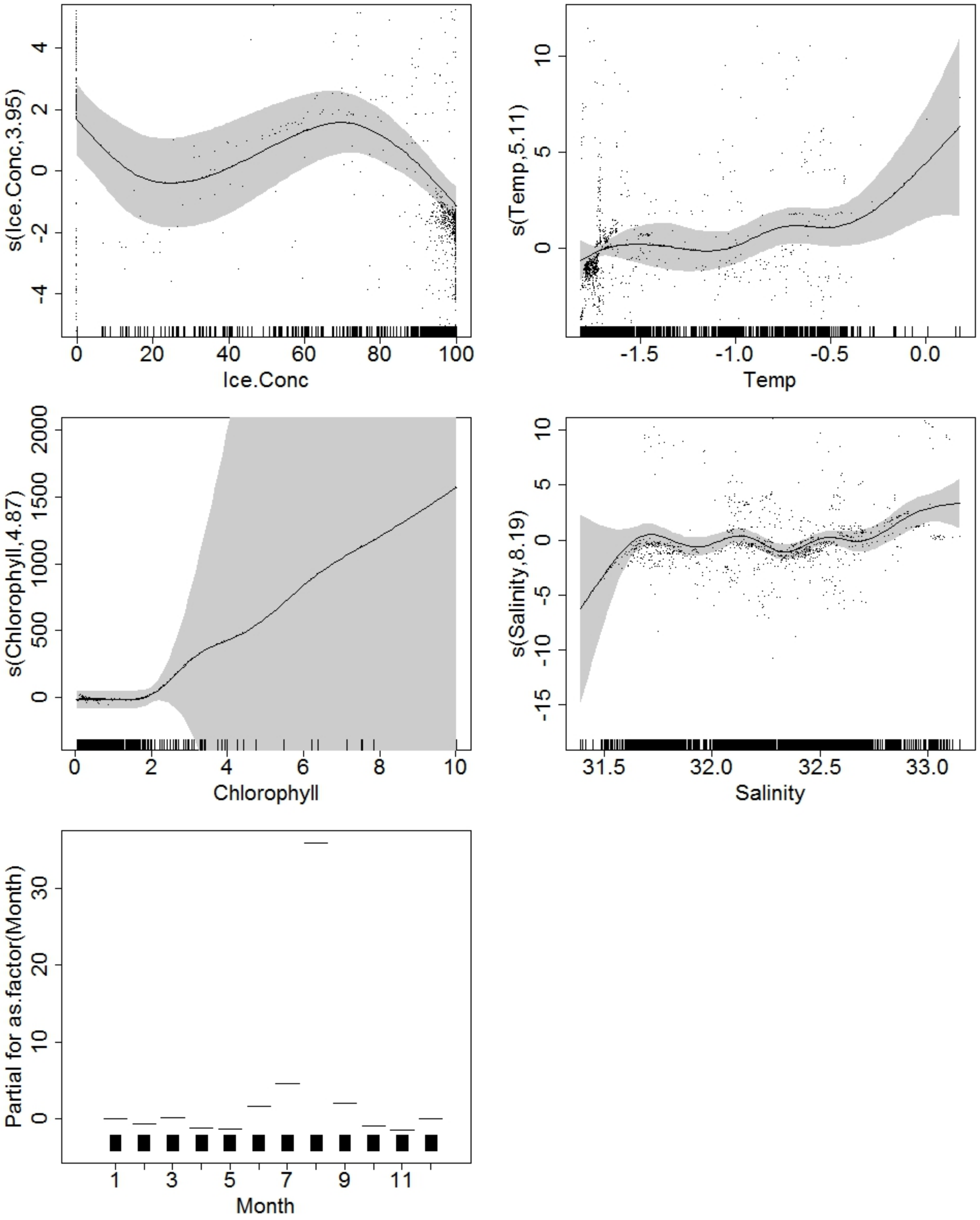


Figure 163. GAMs results for walrus call presence/absence using the primary variables for node one from the combined C6, C7, and C8 regression tree (Table 44) as explanatory variables. Ice concentration, temperature, chlorophyll, and salinity were included as smoothed variables and month as a factor. Gray shaded regions indicate the confidence bands for smooths functions. Note that the y-scale on the chlorophyll plot was reduced to show the pattern in the explanatory variable and thus the confidence bands are cut off, which visually under-represents the uncertainty in the results.

Bearded seal

The regression tree analysis indicated that February through June had the highest bearded seal calling activity (Figure 164). Within this time period, conditions under which more calling occurs can be isolated with differing combinations of months, years, and levels of salinity, temperature, and chlorophyll. The highest calling activity (42 days with an average of 99%) occurred between February and April before 2014 on days with higher temperatures and higher salinity.

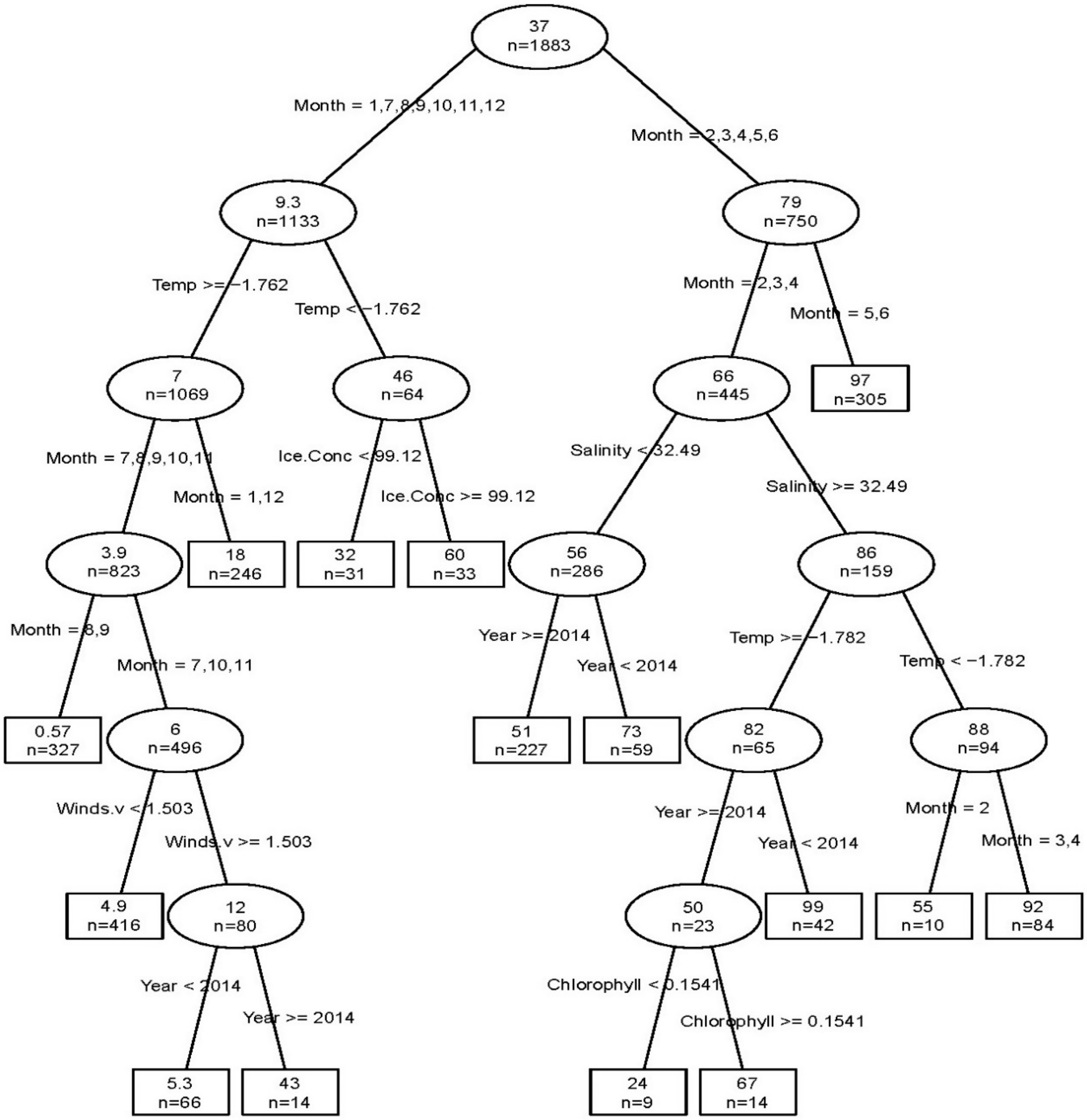


Figure 164. Pruned regression tree for bearded seal calls including CHAOZ-X moorings C6, C7, and C8. The original pruned tree accounts for relative error (xerror) versus the complexity parameter (cp). The values in each node are the predicted daily calling activity (%) for the node and the number of cases (i.e., number of days) reaching the node.

Table 45. The primary variables for the first node of the regression tree for bearded seals using CHAOZ-X moorings C6, C7, and C8 combined and each alone. Variables are color coded by the level of improvement in the model at that location with dark green providing the most improvement (and is the variable defining the first node) and dark orange providing the least.

	All (C6, C7, C8)	C6 (CHX)	C7 (CHX)	C8 (CHX)
Month	0.696	0.732	0.725	0.648
Ice.Conc	0.322	0.467	0.290	0.256
Temp	0.310	0.278	0.392	0.392
Chlorophyll	0.085		0.203	
Year	0.075	0.103	0.096	0.213
Winds.spd		0.079		
Salinity				0.177

The primary variables for node one are all included in the pruned regression tree (Figure 164, Table 45). Examining the individual mooring results, there is a fair amount of consistency between the individual and the combined results. Month as the top primary variable is consistent across all moorings. Primary variables for the C7 mooring are the same as those of the combined moorings, although the order of the second and third variables (ice concentration and temperature) are reversed. Four of the primary variables for the C6 and C8 moorings are the same as the combined results. For C6, wind speed replaces chlorophyll and is the fifth primary variable, and year is the fourth. For C8, salinity replaces chlorophyll and is the fifth primary variable with year as the fourth, and the order of ice concentration and temperature are reversed (matching C7).

Although year was significant in the single variable year model, the relationship between calling activity and year was reversed in models that included month, ice concentration, and/or temperature. The interaction between year and other variables needs to be explored further. For this analysis, year was removed from the final model. In addition, chlorophyll was not significant in the four-parameter model, and was removed from the final model.

The GAM results indicated that the seasonal pattern in bearded seal calling could be bimodal (Figure 165), with high levels in February and March, as well as in May and June. The relationships with ice concentration and temperature are more complex, with the possibility of increasing calling with increasing ice concentration (to about 85%) and decreasing temperature.

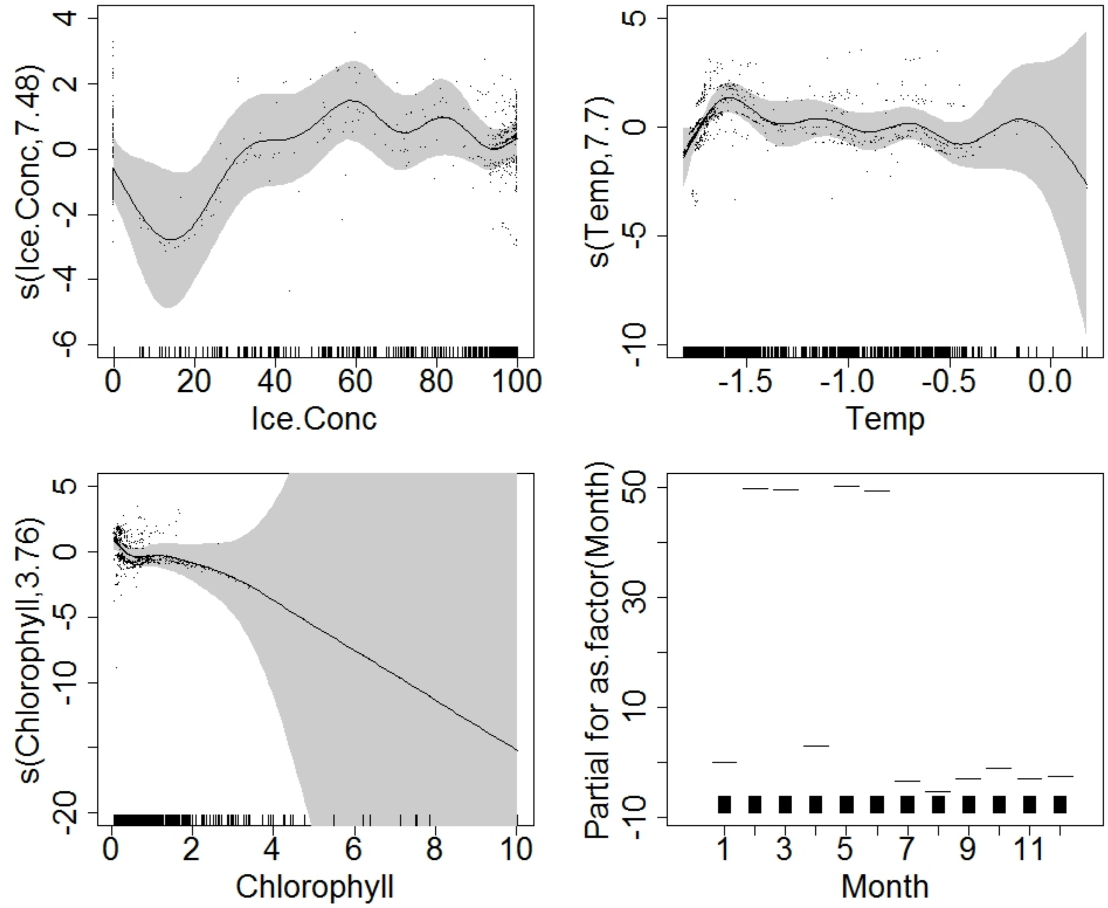


Figure 165. GAMs results for bearded seal call presence/absence using the primary variables for node one from the combined C6, C7, and C8 regression tree (Table 45) as explanatory variables. Ice concentration and temperature were included as smoothed variables, and month as a factor. Year was excluded because of interactions with month, ice concentration, and/or temperature. Chlorophyll was excluded because it was not significant in the full model or the four-parameter model. Gray shaded regions indicate the confidence bands for smooths functions.

4. Discussion

Bowhead whale

The first split in the bowhead whale regression tree is intuitive based on what is known about the migratory patterns of bowheads. Although some bowheads have been detected in the offshore waters of the ARCWEST study area during the spring migration and are correlated to leads, most of the days with high calling activity levels in the Hanna Shoal area are associated with the fall migration. The first node splits October and November from the rest of the year, which is in agreement with the fanning out of the bowhead migration offshore as it passes Point Barrow. It should be noted that although the average daily calling rate for the rest of the year is low, this does not preclude the possibility that there are days with very high calling activity levels. The regression tree analysis groups days with similar characteristics in explanatory variables when the grouping will improve the analysis. There are just not enough high calling days with similar explanatory variables to improve the understanding of patterns in the calling data, and so no further splits are present in the tree from that branch.

For the fall data (October/November), the next node splits on year, with 2014 and 2015 separating from 2012 and 2013. Looking at the long-term seasonal calling activity (Figure 7), it appears that the pulse in fall migration calling activity in later years is less broad and saturated than in the earlier years (but note that analyses ended before the end of the 2015 migration, and C8 started after the 2014 fall migration commenced). Surprisingly, this pattern of lowered persistent calling activity does not appear to be present at C3, which suggests a change in the migratory route taken in 2014. The data from the ARCWEST project, in combination with these data, suggest that they did remain inshore until they were past Hanna Shoal in 2014, as the fall migration pulse in calling activity at the C1 and C2 mooring locations were not reduced in that year. Possible reasons for this difference may be that the migration route past Hanna Shoal was blocked, the availability of food in that area was reduced, or the availability of food closer to shore increased. The branching pattern that includes the highest levels of calling activity after 2014 indicates favorable conditions are characterized by low levels of ice concentration, wind speed, and transport. As the direction of transport is west-to-east, all of these factors are associated with easier migration to the east. In 2012 and 2013 the interpretations are less clear. Higher calling activity levels are seen under conditions of lower chlorophyll levels, which suggests that feeding opportunities are not the primary driver behind the migration route. However, low chlorophyll levels may also be a result of high levels of zooplankton which have consumed the chlorophyll. Very high calling activity levels were found under other environmental conditions (including PAR, ice concentration, wind speed, and transport), but these were very specific and occurred on a small number of days.

A comparison with the other bowhead whale regression tree runs (Table 41) shows that the possible first node variables were consistent across the three moorings, and provided three to five times less improvement than month. Unlike the ARCWEST study area, where the split along month produced greater improvement for the individual moorings than when all were combined, there was no large or consistent improvement seen in the CHAOZ-X moorings. The most plausible explanation for this is that the ARCWEST moorings are distributed along the main bowhead migratory corridor, but the CHAOZ-X moorings were all situated in the same general area of the migratory corridor and so the migratory pulse should arrive at these locations at roughly the same time.

The GAM results (Figure 157) show lowest calling presence on days where temperatures were greater than -0.25°C; however, there are few samples at these higher temperatures. Since bowhead whales are an ice associative species, this makes sense; bowheads are present when ice is around and temperatures are low (see Figure 7). The results for ice concentration follow a smooth curve with the lowest calling activity levels present under high ice concentration levels (i.e., approximately >80%). Calling levels were also seen to decrease with higher chlorophyll levels. This could be a coincidence, or it could indicate that low chlorophyll levels indicate high zooplankton abundance; this should be investigated further in the future. As seen from the regression tree analysis, and as expected, calling activity decreased from 2012 to 2015.

Gunshot calls (bowheads)

The first node in the regression tree splits on year, with 2012 separated from later years (Figure 158). Similar to the situation seen for bowhead calling and month, this does not mean that days with high calling activity do not exist, but rather that there are not enough high calling days with similar explanatory variables to improve the tree. Although average calling rate was low overall, in 2012 higher rates are seen in November under high ice concentrations. Little is known about the function of a gunshot call, though it was first reported for this species by Würsig and Clark (1993). Perhaps this particular vocal signal is used by bowheads to navigate through the ice, locate leads and openings, or possibly determine keel depths. In fact, several authors have suggested that bowhead whales use their frequency modulated (FM) calls to estimate ice thickness (Ellison et al. 1987; George et al. 1989). Ellison et al. (1987) determined that the echoes of bowhead FM calls off thick pack ice are up to 20 dB greater than the echoes off new ice. These authors suggest that bowheads can use the echoes to determine ice thickness and thus help navigate through the ice and find areas thin enough to break through. Although the calls analyzed in those studies were FM modulated tonal calls, the impulsive nature of gunshots would make them an ideal call type for perceiving relative levels from echoes off ice keels. Given the tight correlation between gunshot calls and ice, it is likely that they are using these calls to determine ice thickness and to navigate. Therefore, it seems logical to assume that gunshot calls are needed at the end of the pulse of fall migratory calling when animals are passing through high concentrations of ice. If this is the case, the importance of maintaining low ambient noise in this environment during the migration period may be critical, as an increase in noise may hinder their ability to both navigate around ice and find an ice thickness suitable for breaking. Calling is lower in December because most of the whales have already left the area.

Alternatively, the positioning of the peaks of gunshot calling activity near the end of each of the regular peaks in bowhead calling activity possibly suggests it may be used as a migration cue to assemble and move. The gunshot call is also thought to have a reproductive context in right whales (Crance et al. 2017); perhaps a similar mechanism is present for bowhead whales, and the seasonality of this call type just happens to occur during the time the main migration is passing into the southern Chukchi Sea.

Results from other regression trees produced for gunshot calls (Table 42) show that year was the top variable in describing gunshot calling rates, with an improvement value twice that of month; however, looking at C6 alone, the improvement values for month and year are almost identical. All other factors are an order of magnitude less than month. However, when location variables are added to the regression tree analysis, latitude, longitude, and distance to shore replaced wind speed, transport and zonal winds in the top five primary variables for the first split and provide roughly 5 times the improvement over the variables they replace (improvement =0.022 for all three geographic variables). This indicated that there is a geographic component to the distribution of gunshot calling activity which is either not captured by the explanatory variables used in this study or is not explained by oceanographic variables.

The GAM results (Figure 159) showed higher calling activity on days with lower winds; however, this might be an artifact of higher ambient noise levels under higher wind speeds (Roth et al. 2012), potentially masking detections. The relationship with calling activity and transport is complex, but a slight increase in calling activity seems to occur with flow to the west, which would be consistent with a fall migration. The association between month and gunshot calling is different than that seen for the regression trees; November and December still show high calling activity levels, but June through January do as well. It seems likely that this is an artifact of the binary (yes/no) nature of calling activity in the GAM analysis, as it ignores the detail of the percent daily calling activity and flattens the peaked nature of the seasonal timing. The GAM results for year are consistent with the regression tree analysis in that the highest calling activity levels are present in 2012.

Beluga whale

In general, the calling activity levels for beluga whales in the CHAOZ-X study area were lower than those seen closer inshore for the ARCWEST study. The regression tree analysis for beluga whales (Figure 160), as for bowhead calling, had month being the factor influencing the first node of the tree, splitting out April and May from the rest of year, which corresponds to the spring migration. The fact that ice concentration is not a factor in the best regression tree is expected as this migration commences far before the ice concentration levels begin to decline (Figure 15). Since the ice concentration is fairly stable in April and May for this area, it is not surprising that there was not enough variability to divide this factor into separate branches in the tree. Also, the ice concentrations in this area are high (i.e., 90% of days are higher than 95% ice concentration), so the belugas detected during this time period are likely transiting through leads or fragmented ice. This fits with satellite tag results (Suydam et al. 2001), other passive acoustic studies (Delarue et al. 2011; Moore et al. 2012; Hannay et al. 2013), and visual observations which show belugas swimming within areas of high ice concentrations, and transiting between open areas up to 3 km apart (Fraker 1979).

Keeping in mind that the animals are traveling through some sort of lead system, the rest of the factors further dividing the tree (winds and temperature) should be considered in reference to their effect on leads. The only wind factor that was pulled out by the tree is meridional wind direction (i.e., north-south), but there are several node splits of varying directions. No good explanation for these results is apparent; it is assumed that the tree is finding the combination of wind direction conducive to lead formation. It is important to note that all wind data were determined from a location closer to the C2 mooring site (midshore Icy Cape) and may not be reflective of the actual winds present in the CHAOZ-X area. Temperatures during this time period vary between -1.8 °C and -1.7 °C, again consistent with belugas traveling through ice in leads. There are splits seen in the tree based on temperature, but the variations are so subtle that no clear explanation is evident. Unlike for the ARCWEST results, there were not enough days with ice thickness data to include this variable in the analysis.

The possible variables for the first split in the regression tree for beluga whales (Table 43) showed a lower (one-third less) improvement than month. All other factors (i.e., temperature, salinity, and wind direction) are consistent with leads. There were only enough data present at C6 to examine possible alternative variables individually, but at C6 month was an order of magnitude greater than the next highest variable. Ice concentration is a factor present for C6 only, which suggests there is the possibility of more variability in that factor for that mooring location than the CHAOZ-X study area as a whole.

The results for beluga calling presence/absence by month in the GAM analysis (Figure 161) are not consistent with the regression tree analysis or the data; upon further inspection, this is an artifact of the result of missing salinity data during the 2013-14 deployment. The monthly pattern by deployment will be explored at a later date. Several possible peaks in calling were found with salinity (<31.5, ~31.25, and 33), making interpretation difficult. There appears to be a higher probability of calling presence with winds from the south.

Gray whale

As mentioned in the results above, not enough days with gray whale calling were present to warrant regression tree or GAM analyses, therefore no conclusions can be discussed. Again, these results agree with other studies that have not found gray whales to be currently present on Hanna Shoal as they had been in the past (Clarke et al. 2015a).

Walrus

The regression tree for walrus (Figure 162) fits well with what is known about the presence of this species on Hanna Shoal. The first node splits on month as a factor, with the time period from June to September showing an average calling rate double that of the average calling rate during the entire year. This time period and location is well established as a prime foraging area for this species (Jay et al. 2012). The second nodes split on ice concentration. Walrus are known to prefer ice haulouts near their prey. The highest ice concentrations (>95%) result in the highest average calling rate in the tree, although there are fewer days at this ice concentration. The association with these higher calling activity levels with lower chlorophyll and PAR levels are likely associated with ice presence. During the June to September time period with ice concentrations less than 95%, there are several branches that result in high calling activity levels (>65%) depending on a combination of factors (i.e., wind speed, zonal winds, chlorophyll, salinity, ice concentration, and year). Many of these factors are likely associated with ice presence instead of having a direct effect on walrus presence.

The results from the other walrus regression trees (Table 44) are mostly consistent among individual moorings and the combined set. Month remains the most important factor, followed closely by ice concentration. There are differences in the remaining factors between the Hanna Shoal northeastern flank (C7 and C8) than the southwestern flank (C6). For the Hanna Shoal northeastern flank, chlorophyll, temperature, and salinity are important. For the southwestern flank, temperature, PAR and transport are important. All of these remaining factors except transport can be related to ice concentration.

The GAM results (Figure 163) for daily presence/absence of walrus calling is consistent with the regression tree analysis results and known distribution of this species. The months with the highest presence are June through September, with a peak in August, again agreeing with the utilization distribution estimates of Jay et al. (2012). The highest presence of walrus calling occurs at a 75% concentration level which corresponds with the findings of Fay (1982) and Jay et al. (2014), who report walrus are not present in sea ice concentrations greater than 80%, a compromise between benthic prey availability and resting sites. The curve for chlorophyll is flat until you get out to low sample sizes, and therefore is inconclusive. Again, no clear trends in calling were seen with the temperature and salinity factors, making interpretation difficult.

Bearded seals

The first node of the bearded seal regression tree (Figure 164) split by month. The February through June branch had an ~80% average calling activity level, which was eight times larger than that of the other branch (July through January). This does accurately capture the main calling period of this species at the mooring sites analyzed (Table 11) and is in agreement with their reproductive timing. For the higher calling activity level branch, the second split also has month as a factor, splitting out the saturated months (in this case May and June). For these months, the daily calling level was 97%.

The more interesting branches of the tree, to us, are the ones associated with the non-saturated months. That is, the ones associated with the ramp-up of calling, ranging from July through April, depending on the year and location. In the three months immediately preceding the saturated period, calling activity levels are still high (66%), and increase to near 100% through a branching pattern that includes potential proxies for ice formation (i.e., salinity and temperature) and year. It is unclear why there is a split between 2013 and 2014, but this could be an artifact of a lack of data from the northeast flank of Hanna Shoal (i.e., from mooring sites C7 and C8) prior to 2014. For the initial ramp-up months, July through January, ice concentration appears to have a very tight influence, with the highest calling activity levels branching off with low temperatures (suggesting ice formation) and very high (i.e., >99%) ice concentrations. These ice concentrations, however, are on the higher side of their preferred 70-90% range (Cameron et al. 2010).

Again, when comparing the results of multiple regression tree runs (Table 45), month is the highest factor. Temperature was the second-best factor for the northeastern Shoal moorings (C7 and C8), although ice concentration was the second-best factor for the southern flank mooring (C6) and for the combined moorings across the shoal. All other factors were, in general, smaller in comparison.

GAM results from the top factors identified for first regression tree split (i.e., ice concentration, temperature, and month) are shown in Figure 164. Bearded seal calling activity levels increased with increasing ice concentrations, with peaks near 60% and 85%, supporting Cameron et al.'s (2010) results. Calling activity seems to increase with lower temperatures, which corresponds to the formation of ice. Lastly, it is curious that although the regression tree split out February through June as months with high calling rates, the GAM results indicates that April has a lower calling rate, only slightly higher than January.

The results from the regression tree and GAM analyses correspond well to those found for the ARCWEST study area, with ice concentration and month driving most of trends in calling activity. There are slight differences in the timing which would be expected geographically.

5. *Conclusions*

The combination of regression tree and GAM analyses presented here appears to be relevant to the known behaviors of these species. As these techniques are in their infancy for passive acoustic data, and since the GAMs used presence/absence values, it is important not to place too high an emphasis on their results. As the field improves, and more days with concurrent interdisciplinary data are included, stronger patterns will emerge that will allow a more fine scale understanding of the natural history of these Arctic species.

Month and ice are important for all species studied. Month accurately distinguishes what we know about the distribution and migration of each species. Unfortunately, it is unknown whether month is a proxy for other variables, such as prey fields, which are driving distribution and migration or whether there is an innate seasonal driver. To be able to determine whether month is a proxy or an innate driver, it will be important to include additional variables in future analyses, especially adding prey field variables and reducing/eliminating missing data in the oceanographic variables collected. The relationship between calling activity and ice varies by species depending on the role ice plays in their life history; some species are heavily ice associated (walrus and bearded seals), others are migrating through leads (beluga, bowhead) or existing on the ice edge (bowhead). In addition to ice concentration, often the other important oceanographic variables can be linked back to ice formation, ice presence or leads in the ice.

6. Recommendations

First and foremost, it is important to include data directly measuring the abundance and/or concentrations of the prey species of these marine mammals. This will remove layers of uncertainty present when using factors that are proxies for productivity. New instrumentation is currently on the market to record what the TAPs moorings had intended to measure; including these as part of the biophysical mooring clusters will enable direct measurements of calling activity versus feeding.

There were many days of data left out of these analyses because of failures of the various instruments during certain mooring deployment years. It is possible to include specific mooring-years of data for certain locations rather than exclude all data from a particular location. In addition, a more detailed analyses of the co-dependency of correlated variables will produce much cleaner and more realistic results.

In addition, running statistical analysis using actual numbers of calls produced, instead of binned data, will allow for a finer-scale look at how oceanographic factors affect marine mammal calling rates. Although this would not directly translate into number of animals without additional call count information (i.e., knowing the percent chance an animal will vocalize), being able to investigate the correlation between call characteristics and oceanographic parameters may yield interesting results as has been seen for bowhead whale gunshot calls. As extracting individual calls constitutes a very labor-intensive process, care should be taken to do so from only those time periods where concurrent oceanographic data are available.

Finally, these passive acoustic and oceanographic data represent a wealth of interdisciplinary data that are ripe for correlative analyses. We will be working in the near future with statisticians to help develop more robust GAM, regression tree, and other analyses to help tease out interrelations and to understand where and when these Arctic mammals aggregate and what motivates them to seek out these locations.

B. Biological hotspots

1. Introduction

Hotspots are defined as areas with long-term (i.e., years to decades) presence of primary production, either *in situ* or advected from other areas (Grebmeier et al. 2015). Where this production coincides with strong pelagic-benthic coupling, persistent benthic hotspots exist, which focus benthic feeding seabirds and marine mammals into large and dense aggregations (Grebmeier et al. 2015). In other cases, these highly productive hotspots concentrate zooplankton and fish, again forming aggregations of upper trophic level species.

There are multiple hotspots within the ARCWEST/CHAOZ-X study areas; three of which are part of the Distributed Biological Observatory (DBO). The first (DBO3), in the southern Chukchi Sea off Point Hope, AK is a very persistent benthic hotspot. The second is in the area on and surrounding the southwestern flank of Hanna Shoal. The exact position of the DBO line (DBO4) passing through this hotspot has varied but generally runs offshore near Wainwright, AK, toward the western flank of Hanna Shoal. The last occurs in Barrow Canyon (DBO5). This region is home to processes that upwell and concentrate pelagic prey, and vary temporally with aggregations of upper trophic level species more pulsed than continuous.

Although long-term persistence is a defining characteristic of hotspots, there are other areas in the CHAOZ-X region where evidence of shorter-term pulses of high productivity and species diversity exist. Given that the question still remains as to what extent migrating marine mammals feed in the northeastern Chukchi Sea, it is important to note where these short-term pulses are associated with either large and/or persistent aggregations of marine mammals. Here we investigate the correlation between upper trophic level species and biophysical properties along line transects sampled during the 2013-2015 field surveys for five transects occurring in the CHAOZ-X study area: Hanna Shoal (HS), Icy Cape (IC), Wainwright (WT), Barrow Canyon/DBO5, and the Barrow Canyon to Wainwright Box (BX); these transects were occupied in multiple years.

2. Methods

Transect plots were created by combining the integrated longitudinal oceanographic parameter plots with the zooplankton abundance data and marine mammal distribution (from both visual survey and sonobuoy monitoring efforts). Six marine mammal (bowhead, humpback, gray, and fin whales, ice seals, and walrus), eight zooplankton species/life stages (Thecosomata, *Pseudocalanus* spp., *Neocalanus* spp., furcilia stage euphausiids, adult/juvenile stage euphausiids, *Calanus hyperboreus*, *Calanus glacialis*, and Appendicularia), and four oceanographic parameters (temperature, salinity, nitrate, and ammonium) were compared. See the shipboard methods sections for descriptions of the collection methods for each of these data streams. In addition the marine mammal data were extracted from the overall sighting and detection records by automatically selecting all sightings/detections at any time during that cruise within a 5 nm buffer zone around each sampling line.

3. Results

Transects were occupied in 2013, 2014, and 2015. However, the timing of the transect sampling varied among years (the oceanographic and zooplankton sampling was conducted in August in 2013 and 2015, but late-September to mid-October in 2014). In addition, the biophysical sampling in 2015 was conducted on the NOAA Ship Ronald H. Brown, which sailed one month prior to the F/V Aquila on which the marine mammal sightings and detections were made. The results, therefore, have a seasonal or monthly component that makes it difficult to clearly identify the interannual signal. This temporal mismatch may have decreased the overall strength of our conclusions. Nonetheless, there are still some interesting stories that emerge from these short-term efforts.

Results from the Hanna Shoal (HS, 2013-2014) and Wainwright (WT, 2013-2015) lines (Figures 166-167) were similar, which was expected given the intersection of these two lines near Hanna Shoal. Both varied interannually, although in each year a pycnocline was present, with fresher warmer water overlaying colder more saline water. The saltiest water was observed in 2013 and was associated with the highest concentrations of inorganic nitrogen (nitrate, nitrite, and ammonium). High levels of walrus detections and/or sightings were observed along both lines during the CHAOZ-X field survey. No corresponding higher than average abundances of zooplankton were seen. Bottom concentrations of nitrogen along the HS and WT lines were much lower in 2014 (and also in 2015 for the WT line). These concentrations, however, were still high enough to support primary production, if sufficient light was reaching the bottom. *C. glacialis* was moderately abundant along the WT line, particularly in the strongly stratified portions of the transects. Appendicularia tended to be found in the same waters. Thecosomata were also abundant, in the inshore weakly stratified region in 2013 and in the offshore more strongly stratified region in 2014. Walrus were not as aggregated as they were in 2013 for both lines.

In 2013, the Icy Cape (IC) transect line (Figure 168) had lower nitrate concentrations than along the HS and WT lines, and nitrate and ammonium appeared to have a localized hotspot compared with 2014 and 2015, although not all stations were sampled along the transect. There was considerable interannual variability along the IC line with warmer surface temperatures and fewer nutrients in 2015 compared to 2013 and 2014. There was also not much in the way of zooplankton or marine mammal aggregations; although the bearded seals and walrus detected were located near the potential hotspots in 2013 and 2014.

Along the Barrow Canyon (BC) line (Figure 169) there was evidence of ACC water near the coast and saltier, nutrient-rich bottom water seaward. The few marine mammal species detected did not appear aligned with any oceanographic or nutrient features. There appears to be a slightly higher concentration of furcilia near the outer (western) edge of the canyon.

The Box (BX) line (Figure 170) paralleling the shore between the Barrow Canyon and Wainwright lines, showed the least variability in the physical and chemical parameters. There was consistently a strong pycnocline, with low nutrients in the surface and high nitrate and variable ammonium in the bottom layers. Zooplankton abundances were similar at all stations that were sampled, with few sightings/detections of marine mammals.

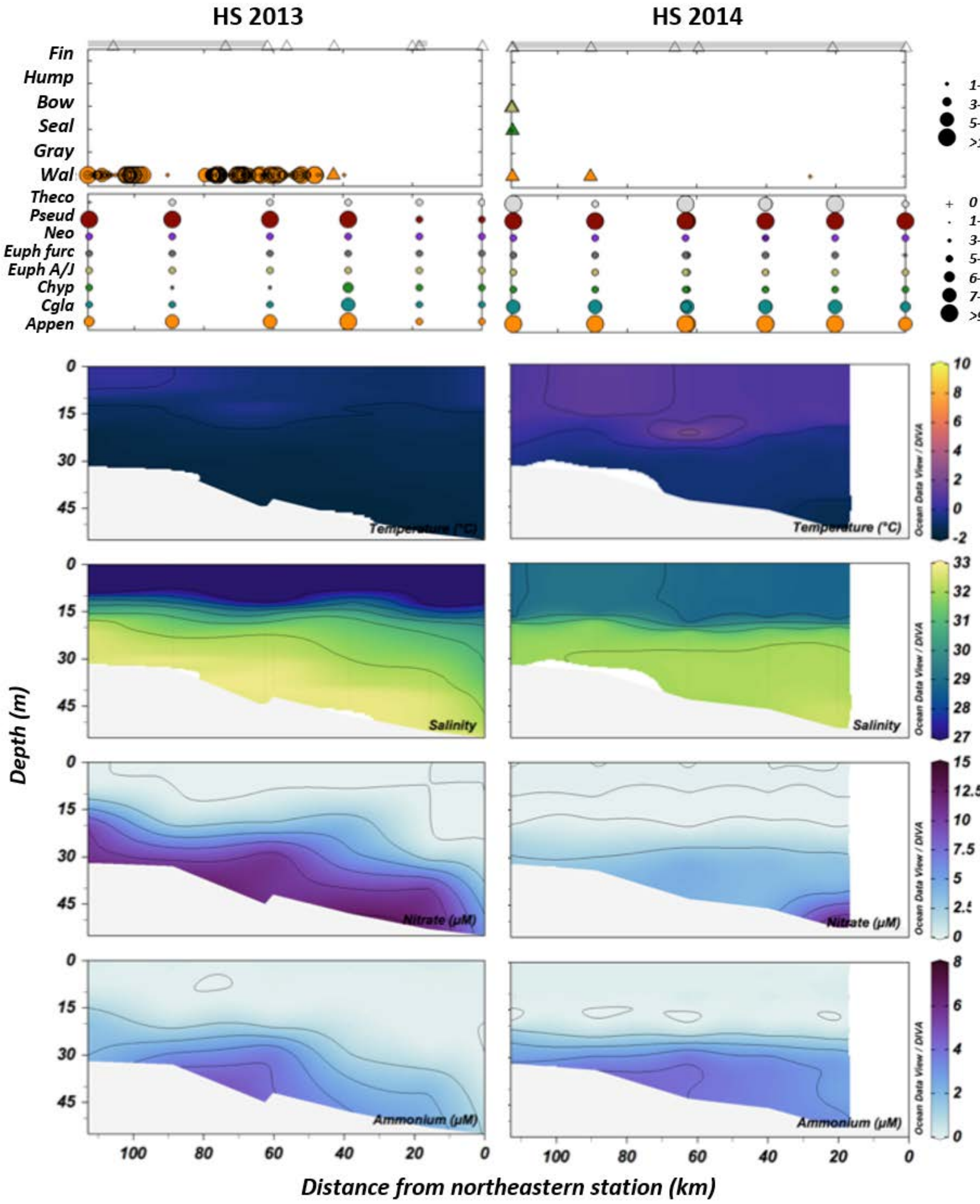


Figure 166. Hanna Shoal transect line oceanographic, zooplankton, and marine mammal survey results, 2013-2014. X-axis refers to distance along transect, where 0 km = northeastern station. Top row: sonobuoy effort (open triangles along top) and detections (filled triangles) as well as visual survey effort (gray bar along top) and sightings (filled circles), see scale to right of figures for group size. Fin = fin whale, hump = humpback whale, bow = bowhead whale, seal = all identified and unidentified seals, gray = gray whale, wal = walrus. Second row: zooplankton presence (filled circles), see scale to right of figures for abundance in log(No. m-2). Theco = Thecosomata; Pseud = *Pseudocalanus* spp., Neo = *Neocalanus* spp., Euph furc = Euphausiids (Furcilia); Euph A/J = Euphausiids (Adult + juvenile), Chyp = *Calanus hyperboreus*; Cgla = *Calanus glacialis*; Append = Appendicularia. Third row: Temperature (℃). Fourth row: Salinity (PSU). Fifth row: Nitrate (µM). Bottom row: Ammonium (µM). Note color scale for oceanographic variables is to the right.

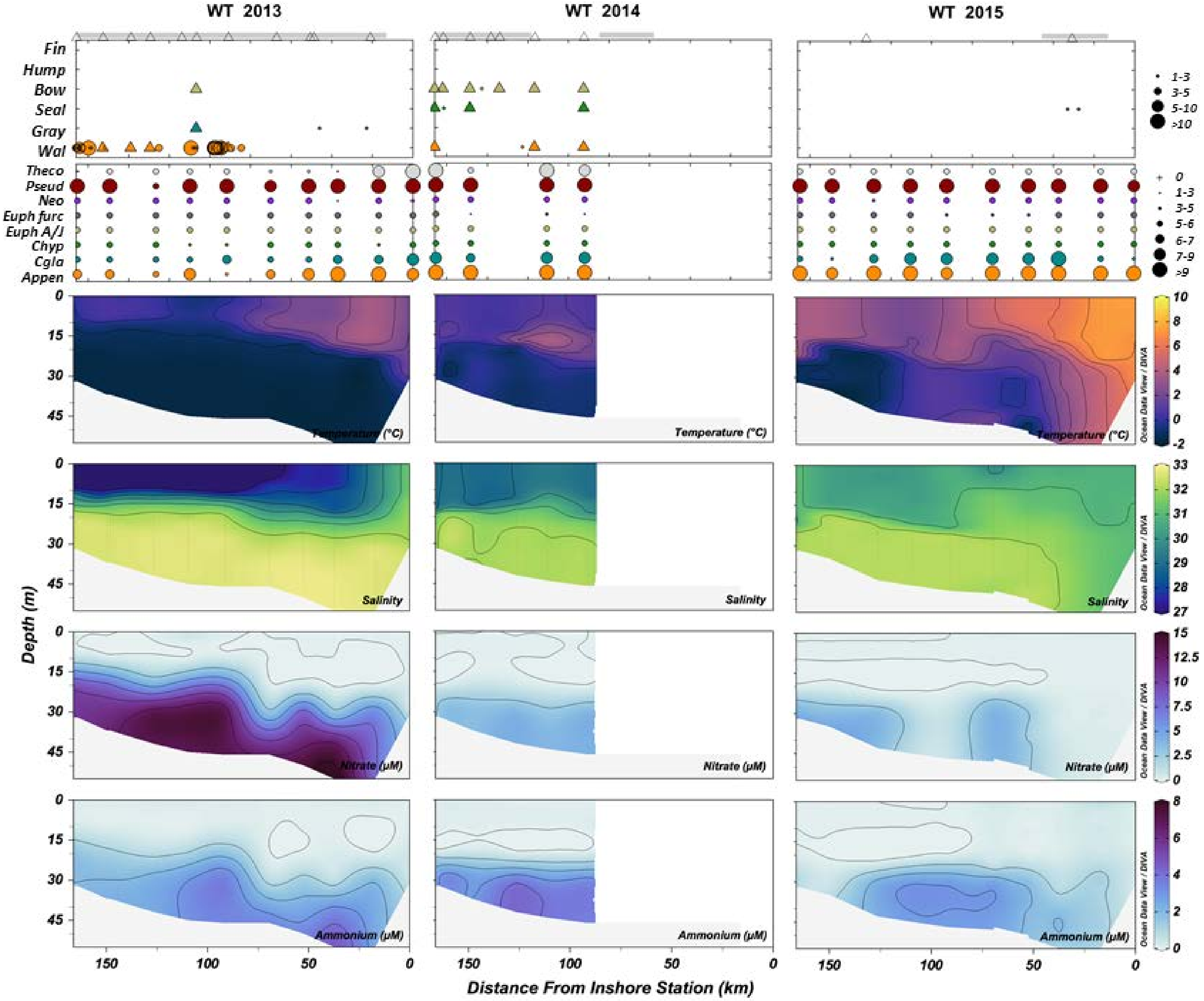


Figure 167. Wainwright transect line oceanographic, zooplankton, and marine mammal survey results, 2013-2015.X-axis refers to distance along transect, where 0 km = inshore station. Top row: sonobuoy effort (open triangles along top) and detections (filled triangles) as well as visual survey effort (gray bar along top) and sightings (filled circles), see scale to right of figures for group size. Fin = fin whale, hump = humpback whale, bow = bowhead whale, seal = all identified and unidentified seals, gray = gray whale, wal = walrus. Second row: zooplankton presence (filled circles), see scale to right of figures for abundance in log(No. m-2). Theco = Thecosomata; Pseud = *Pseudocalanus* spp., Neo = *Neocalanus* spp., Euph furc = Euphausiids (Furcilia); Euph A/J = Euphausiids (Adult + juvenile), Chyp = *Calanus hyperboreus*; Cgla = *Calanus glacialis*; Append = Appendicularia. Third row: Temperature (℃). Fourth row: Salinity (PSU). Fifth row: Nitrate (µM). Bottom row: Ammonium (µM). Note color scale for oceanographic variables is to the right.

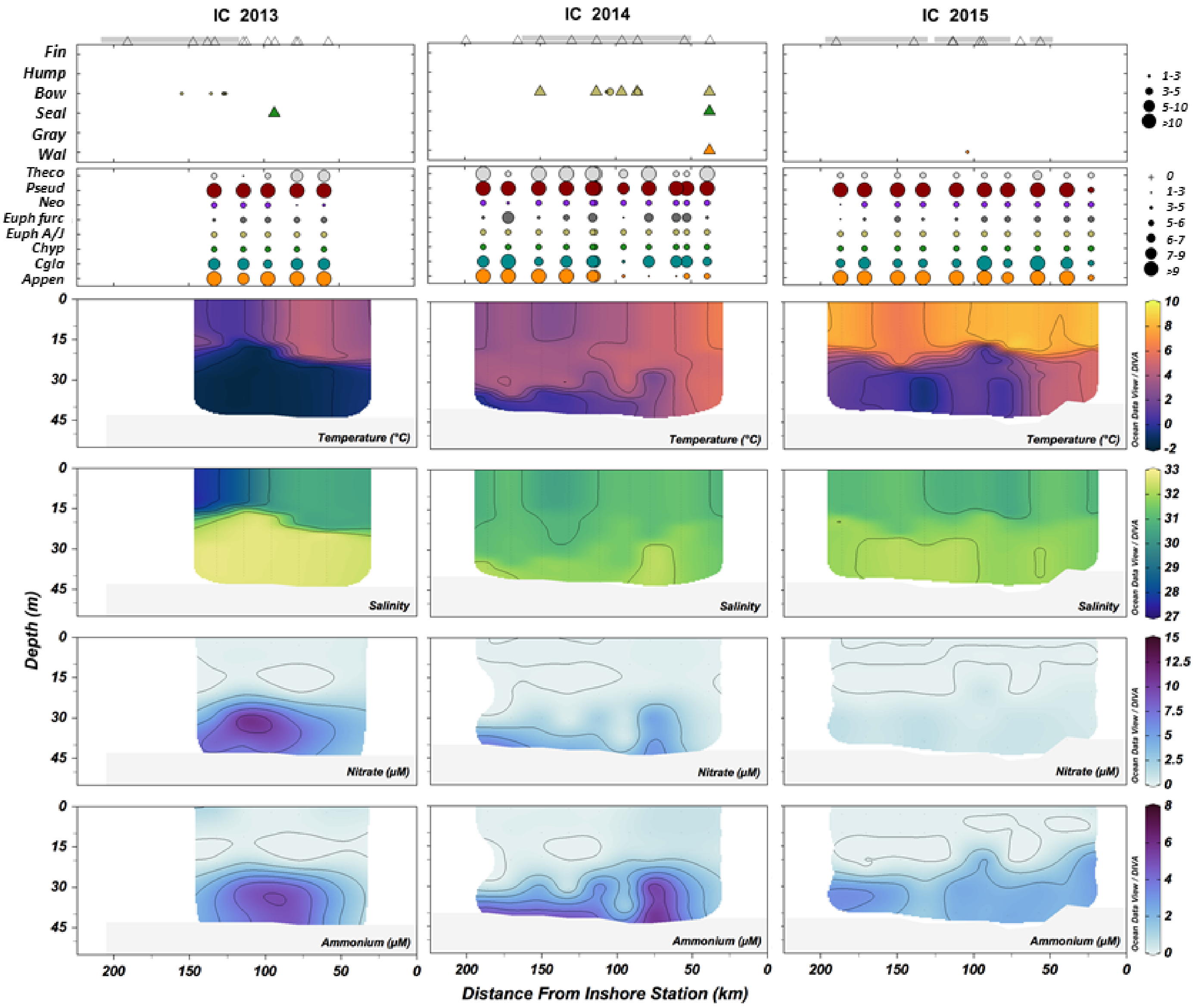


Figure 168. Icy Cape transect line oceanographic, zooplankton, and marine mammal survey results, 2013-2015.X-axis refers to distance along transect, where 0 km = inshore station. Top row: sonobuoy effort (open triangles along top) and detections (filled triangles) as well as visual survey effort (gray bar along top) and sightings (filled circles), see scale to right of figures for group size. Fin = fin whale, hump = humpback whale, bow = bowhead whale, seal = all identified and unidentified seals, gray = gray whale, wal = walrus. Second row: zooplankton presence (filled circles), see scale to right of figures for abundance in log(No. m-2). Theco = Thecosomata; Pseud = *Pseudocalanus* spp., Neo = *Neocalanus* spp., Euph furc = Euphausiids (Furcilia); Euph A/J = Euphausiids (Adult + juvenile), Chyp = *Calanus hyperboreus*; Cgla = *Calanus glacialis*; Append = Appendicularia. Third row: Temperature (℃). Fourth row: Salinity (PSU). Fifth row: Nitrate (µM). Bottom row: Ammonium (µM). Note color scale for oceanographic variables is to the right.

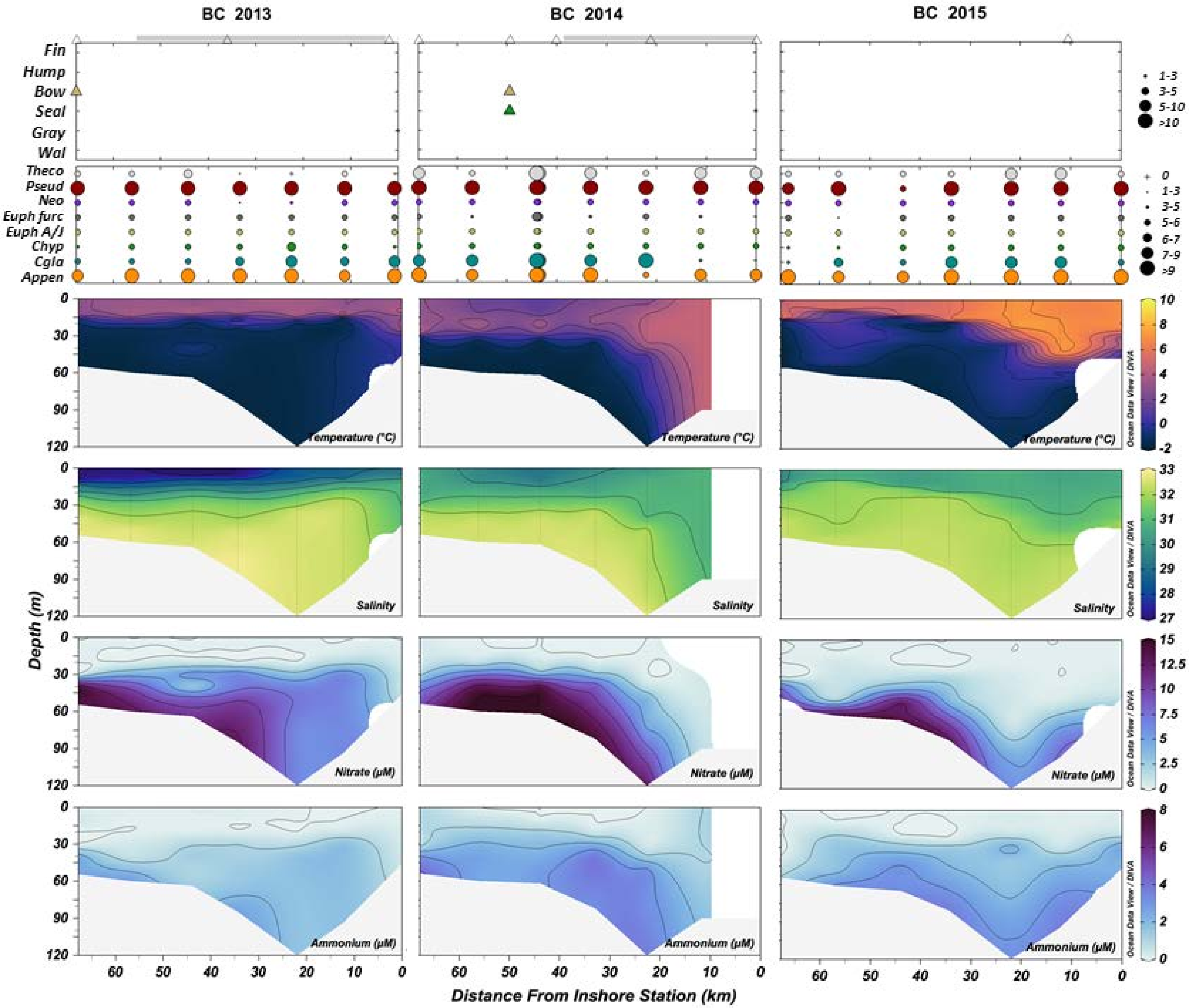


Figure 169. Barrow Canyon transect line oceanographic, zooplankton, and marine mammal survey results, 2013-2015. X-axis refers to distance along transect, where 0 km = inshore station. Top row: sonobuoy effort (open triangles along top) and detections (filled triangles) as well as visual survey effort (gray bar along top) and sightings (filled circles), see scale to right of figures for group size. Fin = fin whale, hump = humpback whale, bow = bowhead whale, seal = all identified and unidentified seals, gray = gray whale, wal = walrus. Second row: zooplankton presence (filled circles), see scale to right of figures for abundance in log(No. m-2). Theco = Thecosomata; Pseud = *Pseudocalanus* spp., Neo = *Neocalanus* spp., Euph furc = Euphausiids (Furcilia); Euph A/J = Euphausiids (Adult + juvenile), Chyp = *Calanus hyperboreus*; Cgla = *Calanus glacialis*; Append = Appendicularia. Third row: Temperature (℃). Fourth row: Salinity (PSU). Fifth row: Nitrate (µM). Bottom row: Ammonium (µM). Note color scale for oceanographic variables is to the right.

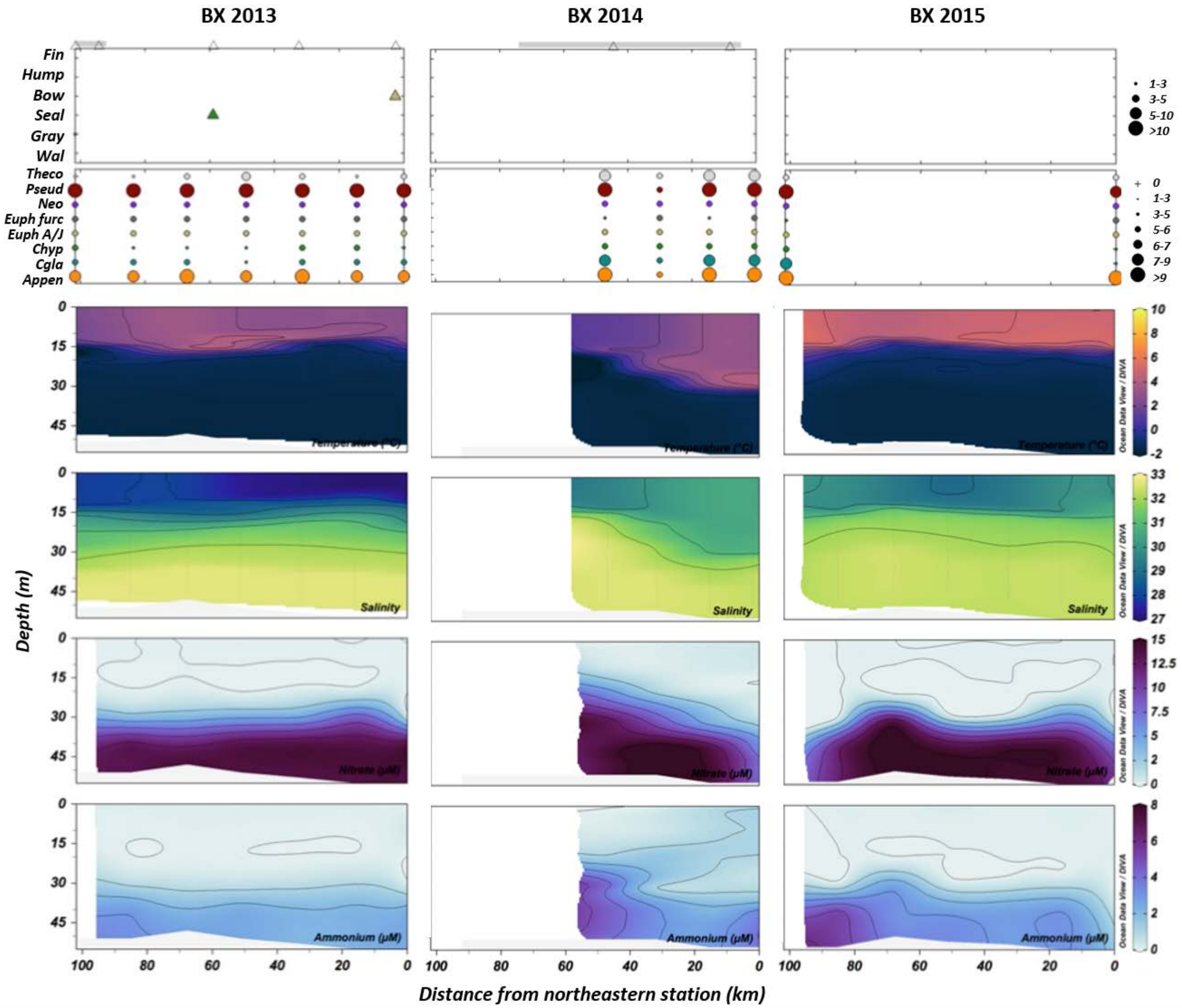


Figure 170. Box transect line oceanographic, zooplankton, and marine mammal survey results, 2013-2015. X-axis refers to distance along transect, where 0 km = northeastern station. Top row: sonobuoy effort (open triangles along top) and detections (filled triangles) as well as visual survey effort (gray bar along top) and sightings (filled circles), see scale to right of figures for group size. Fin = fin whale, hump = humpback whale, bow = bowhead whale, seal = all identified and unidentified seals, gray = gray whale, wal = walrus. Second row: zooplankton presence (filled circles), see scale to right of figures for abundance in log(No. m-2). Theco = Thecosomata; Pseud = *Pseudocalanus* spp., Neo = *Neocalanus* spp., Euph furc = Euphausiids (Furcilia); Euph A/J = Euphausiids (Adult + juvenile), Chyp = *Calanus hyperboreus*; Cgla = *Calanus glacialis*; Append = Appendicularia. Third row: Temperature (℃). Fourth row: Salinity (PSU). Fifth row: Nitrate (µM). Bottom row: Ammonium (µM). Note color scale for oceanographic variables is to the right.

4. *Discussion*

Hanna Shoal is a relatively small feature on the Chukchi Sea shelf and appears to have influence that is disproportionate to its size. Located near the outer shelf margin and with only a

~10 m water depth difference from the surrounding waters, it influences the primary driver in the system, sea ice. Through modification of sea ice patterns, Hanna Shoal has cascading effects on the food web. However, it is not the entire food web, but one very important branch whose processes transport epontic or water column primary production to the benthos, and in turn support benthic foragers such as walrus, bearded seal, and (historically) gray whales (e.g., Whitehouse et al. 2014). In addition, the transport around Hanna Shoal is weaker than that to the south (C1, C2, C3) and certainly weaker than the flow at the shelf break/slope (C9; Chukchi Slope Current).

The sampling lines and concurrent visual and passive acoustic survey efforts, undertaken during the field cruises from 2013 to 2015, were designed to investigate how Hanna Shoal currently influences parts of the pelagic food web during ice-free periods. Large interannual variability in the physical (temperature and salinity), and chemical (nitrate and ammonium) conditions was present (Figures 166-170), but no consistent patterns in the abundance of zooplankton or detection of marine mammals (fin, humpback, bowhead, and gray whales, ice seals, and walrus) tracked with this variability. However, it is important to note that this shipboard sampling provides only a brief snapshot of the ecosystem; less than a day was spent on each line per year, and so the chance of overlap between oceanographic/zooplankton sampling and whale presence is slim. Furthermore, the long-term passive acoustic results show the only species expected on the shoal during the field season are bowhead whales (at low levels), bearded seals, and walrus. Regardless of these difficulties, the concurrent shipboard sampling methods found four types of transect lines through the CHAOZ-X study area: those that include known benthic hotspots, potential benthic hotspots, pelagic hotpots, and lines that runs parallel to the coast. The discussion below is grouped into these four categories.

Known benthic hotspot: Hanna Shoal and Wainwright lines

In 2013, the oceanographic/nutrient conditions present where the Wainwright and Hanna Shoal lines intersect (i.e., high concentrations of both nitrate and ammonium topped by a strong pycnocline) suggest a high flux of primary production to the benthos that in turn feeds a vibrant benthic community. In fact, this area is a well-known benthic hotspot region (i.e., “NECS”, Grebmeier et al. 2015). As expected, this strong hotspot region correlated well with the presence of walrus, a benthic feeder (Grebmeier et al. 2015). The significant detection of walrus calls over the southern and northeastern parts of the shoal were not observed in the ACW waters at the nearshore end of the Wainwright line. Conversely, the abundance of several of the zooplankton taxa decreased seaward as we transited the northern flank of the shoal. This pattern was not repeated in 2014, and only the Wainwright line was sampled in 2015. In general, several of the large zooplankton taxa such as krill and large copepods (*C. glacialis*, CV) were less abundant over the shoal than other locations we sampled on the shelf (see Section VIII.B.2). In 2015, however, the lack of nutrient drawdown in the surface layer is indicative of recently mixed water that has not supported a phytoplankton bloom. Although no corresponding higher than average abundances of zooplankton were seen, walrus are benthic feeders and as such they would not be associated with high levels of pelagic or epibenthic prey.

The fact that the concentrations of nitrogen in 2014 and 2015 were still high enough to support primary production speaks to the great variability in patterns observed among the years. For zooplankton presence, the abundance of omnivorous grazers may be indicative of strong pelagic-benthic coupling where primary production from either the surface or bottom layer was being grazed, packaged into fecal pellets, and then transported to the bottom where it helped support the benthic food web. This is supported by the presence of walrus and bearded seal sightings/detections in 2014. The high number of bowhead detections at this time are most likely due to the timing being during fall migration which fans out over the Chukchi shelf, but the presence of abundant levels of several zooplankton species may suggest that some opportunistic feeding could have also taken place in this area. Lack of overlap in the zooplankton and oceanographic sampling with the timing and spatial coverage of the marine mammal effort in 2015 hinders further investigation of similar associations.

Potential hotspot: Icy Cape line

The next type of transect line showed a more ephemeral character; it is not a hotspot by the strict definition that they are persistent, but it exhibits enough of the same oceanographic /nutrient characteristics that its potential as hotspot should be discussed. The Icy Cape line showed evidence of small concentrations of nitrogen varying interannually. A low presence of marine mammals does occur near these areas, again supporting their importance as potential hotspots. The presence of the bowhead whale sightings and detections in 2014 were again made during their fall migration, so it is most likely coincidental that they were detected at that place and time, although the possibility that they were feeding in this area along their migration cannot be ruled out.

Pelagic hotspot: Barrow Canyon line

Although most of the DBO lines are located in areas with high benthic productivity, a few have their productivity centered more pelagically. These areas are controlled by upwellings that are more transient than the processes that control the benthic hotpots in the other DBO regions.

Although Barrow Canyon (BC) is considered a Biologically Important Area (BIA) for several marine mammal species (i.e., bowhead, beluga, and gray whales), no sightings (despite much effort) and only a few acoustic detections of marine mammals were seen along this line, and did not appear aligned with any biophysical features. The lack of bowhead whales is not surprising as Barrow Canyon is a BIA for bowhead feeding in May, far earlier than the field survey in any year. Gray whales were seen on aerial surveys in August of 2013, but clustered very close to the start of the BC line; limited sightings were made in October of 2014, again occurring near the inshore station of the line (Clarke et al. 2014, 2015b). Although beluga whales are known to feed in Barrow Canyon, aerial surveys in 2013 and 2014 show greatest number of sightings in August and October at the mouth of the Canyon, with none in the waters around the BC line (Clarke et al. 2014, 2015b). During our surveys, oceanographic conditions were not favorable for concentrating plankton in the vicinity of the canyon as observed by others (e.g., Ashjian et al. 2010).

Lines parallel to the coast: the Box

Results for the box line, which paralleled the shore between the Barrow Canyon and Wainwright lines, were as expected. In general, most changes in oceanographic parameters occur cross-shelf and not along-shelf. The uniform nature of biophysical measurements, and low zooplankton abundances help explain the low presence of marine mammals through this area. Future work will examine the inflow and outflow of water through the area encompassed by this line and the Wainwright and Barrow Canyon lines which run perpendicular to the coast.

5. *Conclusions*

The Chukchi Sea is a flow through shelf, with Bering water entering through Bering Strait, flowing northward across the shelf and exiting into the Beaufort Sea. This flow advects heat, salt (including nutrients), and zooplankton northward. Some areas of the Chukchi, such as along the Icy Cape line, where 40% of the transport through Bering Strait passes, experience net northeastward flow which is strongest in the summer months. Southwestward winds can interrupt this northeastward flow. Modifications to the water column through ice melt and summer heating can produce areas with stratification. Stratification occurs especially near the Alaskan coast, where warm, low-salinity, ACC waters overlay denser Bering water. Benthic hotspots can form when subsurface phytoplankton blooms and/or irregular export of ice algae fuel benthic secondary productivity. As a result, there is tight benthic-pelagic coupling that sustains the higher trophic levels. The Icy Cape line is an example of this ephemeral hotspot.

More permanent hotpots are found along the Hanna Shoal and Wainwright lines. Here, flow is not as constant and nutrients support primary productivity and high export of ice algae during most years, both of which support secondary benthic productivity. Research is ongoing to investigate the exact mechanisms of how these persistent hotspot areas are sustained. In this study we found high concentrations of ammonium occurring over much of the Chukchi shelf. This nutrient is a preferred source of nitrogen to many phytoplankton, and microbial processes can convert ammonium into nitrate. Therefore, winter replenishment of nitrate on the shelf occurs through two processes - advection of nitrate through Bering Strait and local regeneration of nitrate. Differentiation between advection and regeneration are being addressed in future process studies. Whether these high concentrations of ammonium are more common in hotspots is not known.

The remaining transect lines in this study are strongly influenced by bottom topography and currents. The Barrow Canyon line is situated in an area where these factors combine to bring nutrients (and prey) up from the deep basin, forming temporary hotspots by trapping prey for the upper trophic level species. The final transect line type is represented by the Box transect line. As an along-shore line, the homogeneity seen in the measurements collected for this transect line was expected as was the absence of any hotspot areas.

The presence of these various types of hotspots (temporary versus permanent, pelagic versus benthic) of the Hanna Shoal area is reflected in the upper trophic level data. For the benthic feeders (i.e., bearded seals and walrus), it was expected that they aggregate around prime benthic hotspots such as those found along the Hanna Shoal and Wainwright lines. The persistence of these hotspots is especially critical for walrus, who prefer a diet of bivalves who in turn rely on a steady stream of nutrients to fall in situ.

Other species, such as bowhead whales, are pelagic feeders that require some mechanism to concentrate prey in dense enough aggregations to be energetically cost-effective. The Beaufort Sea, with its more narrow shelf, has more instances (particularly in the eastern Beaufort) of upwelling events than the broader-shelved Chukchi Sea. Bowheads are therefore known to just pass through the Chukchi Sea during their migrations without forming feeding aggregations. However, for many marine mammal species (including bowhead whales), feeding during migration is known to take place. It is important to note that these transect lines are just snapshots, amounting to less than a day of measurements for the year. These measurements at even the most persistent of hotspots are expected to vary both seasonally as well as interannually. The degree to which migrating species take advantage of transient feeding opportunities, and for how long those ephemeral productive areas remain productive, are questions to be addressed with further intra- and interannual interdisciplinary sampling.

6. Recommendations

Based on the findings of this study, we suggest the following six recommendations:

a) Continue interdisciplinary long-term observations via moorings; especially in the vicinity of the DBO transect lines.

b) Continue sampling of the DBO regions including oceanography, zooplankton, as well as including benthic sampling, and surveys for seabirds and marine mammals.

c) Begin standardized DBO-like multi-cruise sampling of select control regions to allow investigation of the frequency of oceanographic features such as upwelling, stratification, and benthic-pelagic coupling in areas outside of known benthic hotspots. Possible candidates could include the Icy Cape and Wainwright lines.

d) Utilization of new technology to improve measurements, fill gaps, make observations more cost effective, and improve seasonal coverage (especially overwinter). Technologies on the horizon include autonomous vehicles such as the Saildrone and coastal gliders, profiling moorings, in situ incubators, genetic sampling, and expanded instrumentation on towed vehicles.

e) Regularly obtain rate measurements to elucidate trophic interactions (e.g. primary production, microzooplankton grazing, nitrification).

C. Winter residence by walrus

1. Introduction

As sea ice continues to decline in the Pacific Arctic (Wood et al. 2015), changes in the timing and distribution of marine mammal species are expected, but difficult to predict (Laidre et al. 2008). Although much is known about these species, the logistical difficulty and expense of year-round monitoring in this harsh and remote region means that there are times and locations where information on the occurrence of a species is missing, and therefore changes may be hard to detect. Even TEK is incomplete; human reliance on coastal access points means offshore areas are not as frequently observed. In addition, the confounding influence of environmental change on predators and their prey adds to the difficulty in predicting how well marine mammal species will adapt to this change (Laidre et al. 2008).

Despite these difficulties, it is important to monitor these Arctic species over the largest area and longest period of time practicable. In the Pacific Arctic, visual surveys (typically aerial based) provide a means of covering wide areas and provide abundance estimates (e.g., Clarke and Ferguson 2010; Aerts et al. 2013). However, this method is temporally constrained and produces ‘snapshots’ of marine mammal distribution as a result of the high rate of speed the surveys are flown. Telemetry data provide good spatial and temporal resolution of movements, allowing for investigation of home range and core use areas (e.g., Jay et al. 2012; Hauser et al. 2014; Citta et al. 2015). However, tagging studies involve a limited number of individuals, and therefore provide limited information on relative spatio-temporal density. Long-term passive-acoustic monitoring (PAM) is currently the only means available for collection of year-round, fine scale (i.e., daily/hourly) data on the spatio-temporal occurrence of multiple marine mammal species in the harsh, remote environment of the Arctic (e.g., Hannay et al. 2013; Berchok et al. 2015). Although PAM is constrained to the detection radii of actively vocalizing individuals, positioning multiple recorders throughout the range of a species can provide this information over a broad spatial scale. One Arctic species well-suited for passive acoustic monitoring is the walrus; they produce a wide array of stereotyped calls on a regular basis. That is, if there are walrus around, they will be detected (Hannay et al. 2013). They are also expected to be moderately sensitive to the effects of climate change (Laidre et al. 2008) since they are an ice-obligate, range-limited, feeding specialist (Laidre et al. 2008; Moore and Huntington 2008).

Pacific walrus (hereafter referred to as walrus) spend the open water season on feeding grounds in the Chukchi and Bering Seas (Fay 1982; Jay et al. 2008). Females and their young are found predominantly in the Chukchi Sea, while adult males occur in the greatest numbers in the Bering and southern Chukchi Seas. The focus area of the CHAOZ-X study, Hanna Shoal, is an important summer feeding area for this species (Figure 171a, E. Chukchi shading). They are benthic feeders and prefer to remain in areas where the water depth does not exceed 100 m (Fay 1982). Their diet varies spatio-temporally, and they forage opportunistically (Seymour et al. 2014a), but feed primarily on bivalve mollusks and other invertebrates such as worms, snails, and crabs (Fay 1982; Jay et al. 2014). During the ice season, individuals from these feeding aggregations migrate to just three areas in the Bering Sea: in Anadyr Gulf, near St. Lawrence Island, and in the southeast between Nunivak and Round Island (Jay et al. 2008; Figure 171b). The migratory timing of this species is well defined: summering grounds are occupied from June through September, followed by a fall migration in October/November (although Jay et al. (2012) do note walrus in the Chukchi in November, a result of declining ice levels), a breeding season from December through February and a spring migration that occurs in April and May. They are known to time their departure from their wintering sites based on ice movements and sea surface currents (Fay 1982). Aside from a few isolated reports of individuals[23], walrus are not known to occur north of Bering Strait from December through March.

Here, we present the results of seven[24] years of passive acoustic monitoring (from this, and the CHAOZ and ARCWEST studies) to describe the unexpected overwinter presence of walrus in the offshore shelf waters of the Chukchi Sea off Icy Cape, Alaska. Results will be compared among years and locations, and also with ice presence and condition.

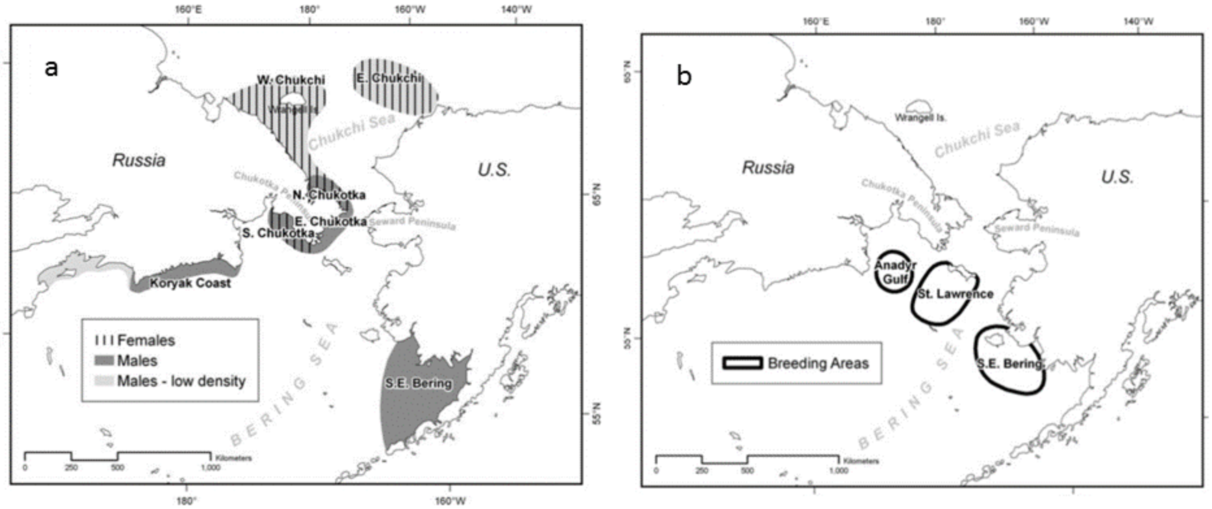


Figure 171. A) Summer feeding, and B) winter breeding aggregations of Pacific walrus. The sex composition of the summer feeding aggregations is identified by the shading in (A). From Figure 1 of Jay et al. (2008).

2. *Methods*

This case study includes data from moorings (passive acoustic recordings, ice thickness, and transport) and satellite-derived data (ice thickness and condition). The methods used for the data processing and analyses have been described earlier in this report and will not be duplicated here, with a few exceptions. First, data from outside the CHAOZ-X study area were included (i.e., the NM1 mooring site in the Bering Sea through the BF2 mooring site in the Beaufort Sea (see Figure 2)). In addition, newly analyzed passive acoustic data from the 2016-17 deployment of the offshore Icy Cape mooring site (IC3; ARCWEST-funded) are incorporated. Finally, sea ice condition was assessed by qualitative comparison of satellite imagery. We obtained Worldview images from the NASA website https://worldview.earthdata.nasa.gov which is operated by the NASA/Goddard Space Flight Center Earth Observing System Data and Information System (EOSDIS) project. The images are true color corrected reflectance composites using the satellites that were available at the time of the image. True color images

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[23] Personal communications listed in Fay (1982) describe the presence of very low (<10) numbers of walrus overwinter near the Pt. Hope and near Banks Island in the eastern Beaufort Sea.

[24] The CL1 and BF2 moorings from 2015-16 are in the final review stage of analysis and will be incorporated for the final report submission; to date, only IC3 and WT1 have been analyzed for 2016-17.

are created using data from three wavelengths from the red, green, and blue parts of the spectrum. Data from the MODIS, Aqua, and Terra were available for all the years in this case study, and the data from the Suomi NPP (National Polar-orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project) satellite was added after its launch in the autumn of 2011.

3. Results

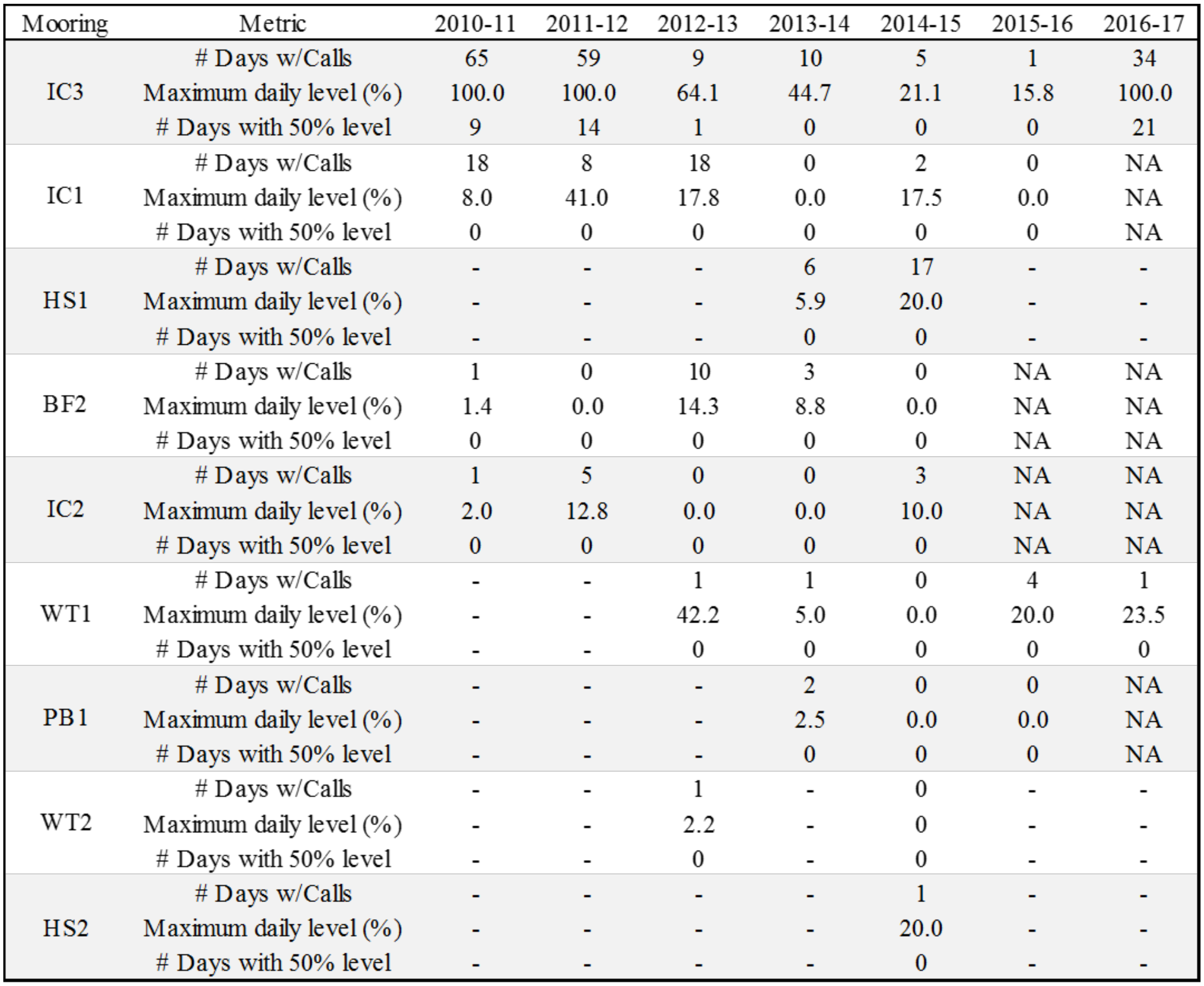
As with the earlier sections on long-term marine mammal seasonal trends, walrus presence is shown as a daily *calling activity* which is defined as the number of ten-minute time intervals per day with calling detected. It is important to emphasize, again, that calling activity does not indicate the number of individuals calling or the number of calls made. Instead, calling activity represents the persistence of calling for that day; a day with 100% calling activity could be one or more individuals calling from the same area all day, or it could be the result of a steady stream of individuals passing through that area.

Offshore Icy Cape

Figure 172 shows an expanded view of walrus calling activity at the offshore Icy Cape (IC3) mooring site with each deployment as a separate row. As expected, given this mooring's proximity to the Hanna Shoal area, there is walrus calling activity in the open water period. The major curiosity, however, was the presence of high levels of walrus calling activity in the overwinter period of 2010-11 and 2011-12 (Figure 172, top two rows) when it is thought that most walrus are south of Bering Strait. For both of these moorings, around half of the days in this overwinter period contain walrus calls (Table 46), there are days with saturated (100%) daily calling, and approximately 10% of the days with detections have calling levels greater than 50%. It is not possible at the present time to determine numbers of calling individuals – a few spot checks during the peak calling periods does not reveal many instances of simultaneous calling and it is unclear whether there are multiple individuals alternating their calling or a single individual that is switching between calling (e.g., see Figure 173). The work by Stirling et al. (1987) indicates that there is individual variability in the calling patterns of Atlantic walrus, so there is a strong probability that future analyses will be able to estimate the number of callers in a given area.

As shown in Figure 172 and Table 46, the next two years (2012-13 and 2013-14) show reduced levels of walrus calling activity compared to the first two years; only ten days in each year had calling activity detected, and these levels topped out at 64% and 46% respectively. The 2014-15 deployment showed another drop in both the number of days with calling detected and the calling activity levels (i.e., 5 days and a maximum level of 20%). Only one day with calling was detected during this period in 2015-16, completing the downward trend. However, 2016-17 turned out to be another year with high levels of (and number of days with) walrus calling activity.

Table 46. Summary of overwinter walrus calling activity at all mooring sites in the northeastern Chukchi /western Beaufort Seas, from December through March (2010-2017). Rows include (from top): number of days with calling activity greater than 0%; maximum daily calling activity level (%); and number of days with calling activity greater than 50%. NA = data are available, but not yet analyzed.



Mooring	Metric	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17
IC3	# Days w/Calls	65	59	9	10	5	1	34
	Maximum daily level (%)	100.0	100.0	64.1	44.7	21.1	15.8	100.0
	# Days with 50% level	9	14	1	0	0	0	21
IC1	# Days w/Calls	18	8	18	0	2	0	NA
	Maximum daily level (%)	8.0	41.0	17.8	0.0	17.5	0.0	NA
	# Days with 50% level	0	0	0	0	0	0	NA
HS1	# Days w/Calls	-	-	-	6	17	-	-
	Maximum daily level (%)	-	-	-	5.9	20.0	-	-
	# Days with 50% level	-	-	-	0	0	-	-
BF2	# Days w/Calls	1	0	10	3	0	NA	NA
	Maximum daily level (%)	1.4	0.0	14.3	8.8	0.0	NA	NA
	# Days with 50% level	0	0	0	0	0	NA	NA
IC2	# Days w/Calls	1	5	0	0	3	NA	NA
	Maximum daily level (%)	2.0	12.8	0.0	0.0	10.0	NA	NA
	# Days with 50% level	0	0	0	0	0	NA	NA
WT1	# Days w/Calls	-	-	1	1	0	4	1
	Maximum daily level (%)	-	-	42.2	5.0	0.0	20.0	23.5
	# Days with 50% level	-	-	0	0	0	0	0
PB1	# Days w/Calls	-	-	-	2	0	0	NA
	Maximum daily level (%)	-	-	-	2.5	0.0	0.0	NA
	# Days with 50% level	-	-	-	0	0	0	NA
WT2	# Days w/Calls	-	-	1	-	0	-	-
	Maximum daily level (%)	-	-	2.2	-	0	-	-
	# Days with 50% level	-	-	0	-	0	-	-
HS2	# Days w/Calls	-	-	-	-	1	-	-
	Maximum daily level (%)	-	-	-	-	20.0	-	-
	# Days with 50% level	-	-	-	-	0	-	-

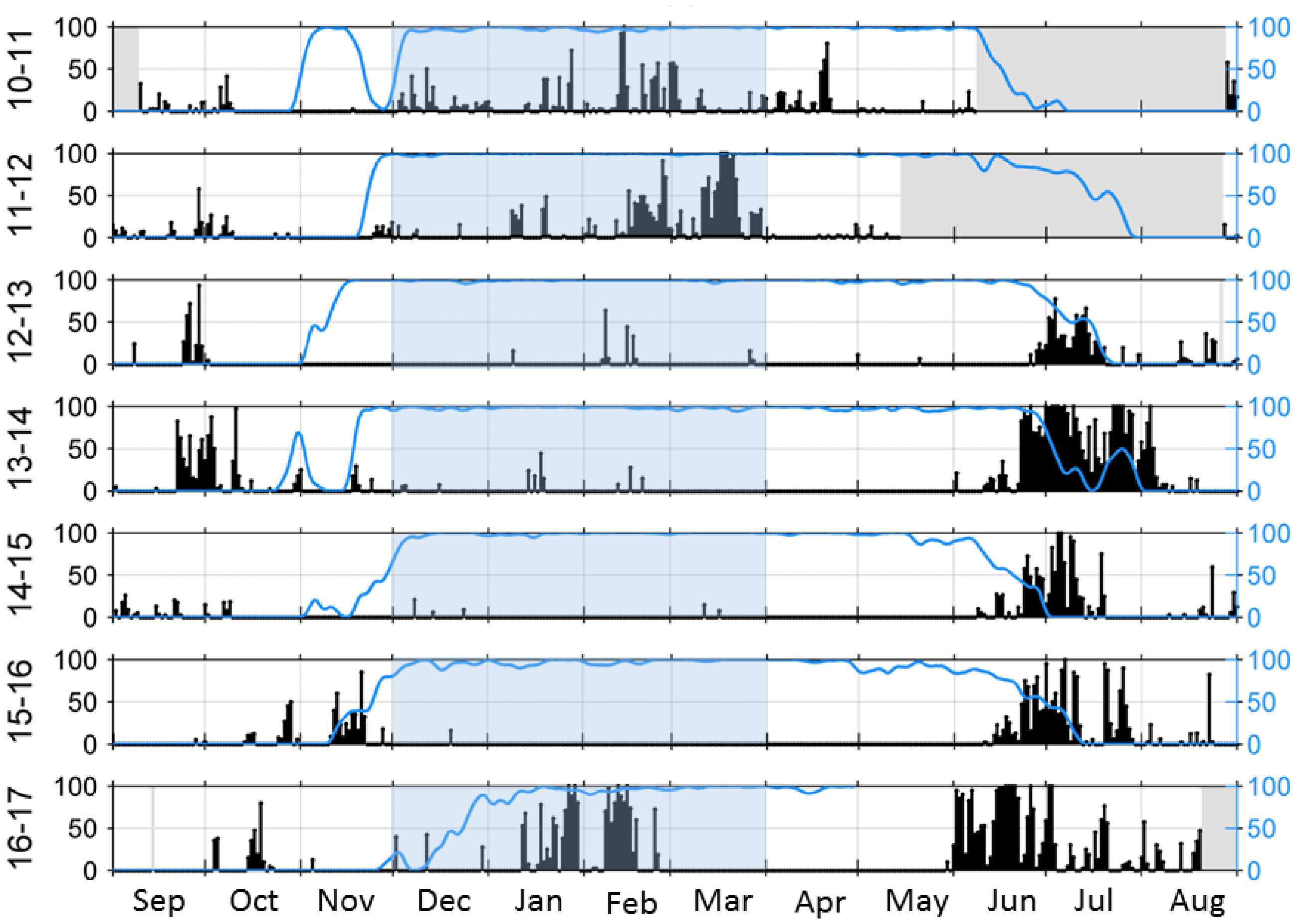


Figure 172. Walrus calling activity (presented as the daily percentage of ten-minute time intervals with calls) at the offshore Icy Cape mooring site (IC3) from 2010-2017. The range of years spanning each row is indicated on the left. Blue line indicates percent ice cover (zero-phase, three-day moving average). Gray shading indicates no data. Blue shading marks the time period when walrus are thought to be south of Bering Strait (i.e., December through March).

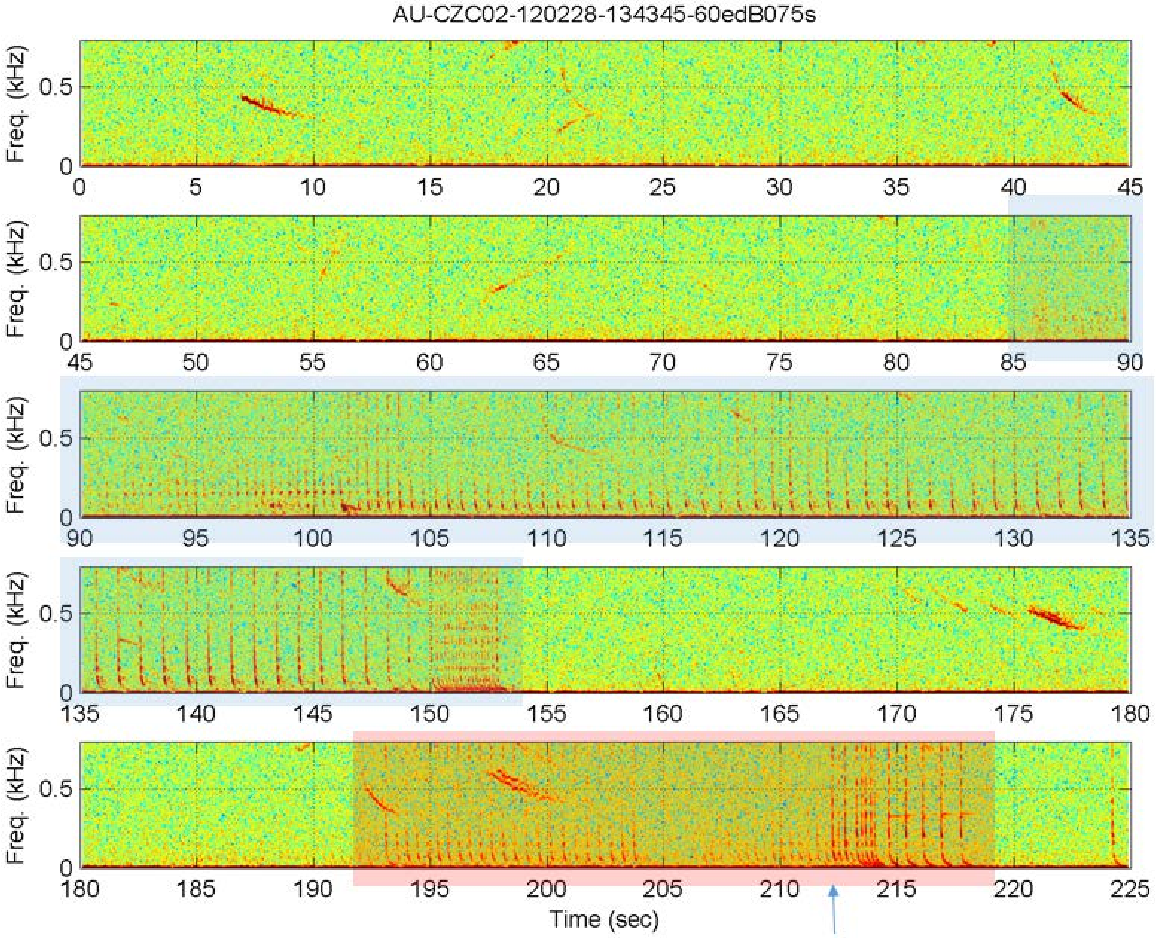


Figure 173. Example spectrogram from a day (28 February 2012) with saturated calling. Two calling patterns are seen (shown with blue and red shading). Blue arrow at ~212 s marks a transition area where calls of multiple amplitudes are interleaved, suggesting multiple callers. Spectrogram parameters: FFT 256 pt. FFT, 200 pt. zero padding, 85% overlap, Hanning window.

2010-2012 mooring results

The high levels of walrus calling activity seen on the offshore Icy Cape (IC3) mooring site from 2010-2012 were not detected on any other mooring north of Bering Strait in those same years (Figure 174). While it may appear that the inshore Icy Cape (IC1) mooring site has a comparable number of days with walrus detections, Table 46 shows that this inshore site has about a third of the number of days with detections seen at the offshore site for the 2010-11 and 2011-12 deployments. As can be seen in Figure 174 and Table 46, very few days at the middle Icy Cape site or at the BF2 site off Barrow, AK, had walrus calling, and levels were very low for the days that did.

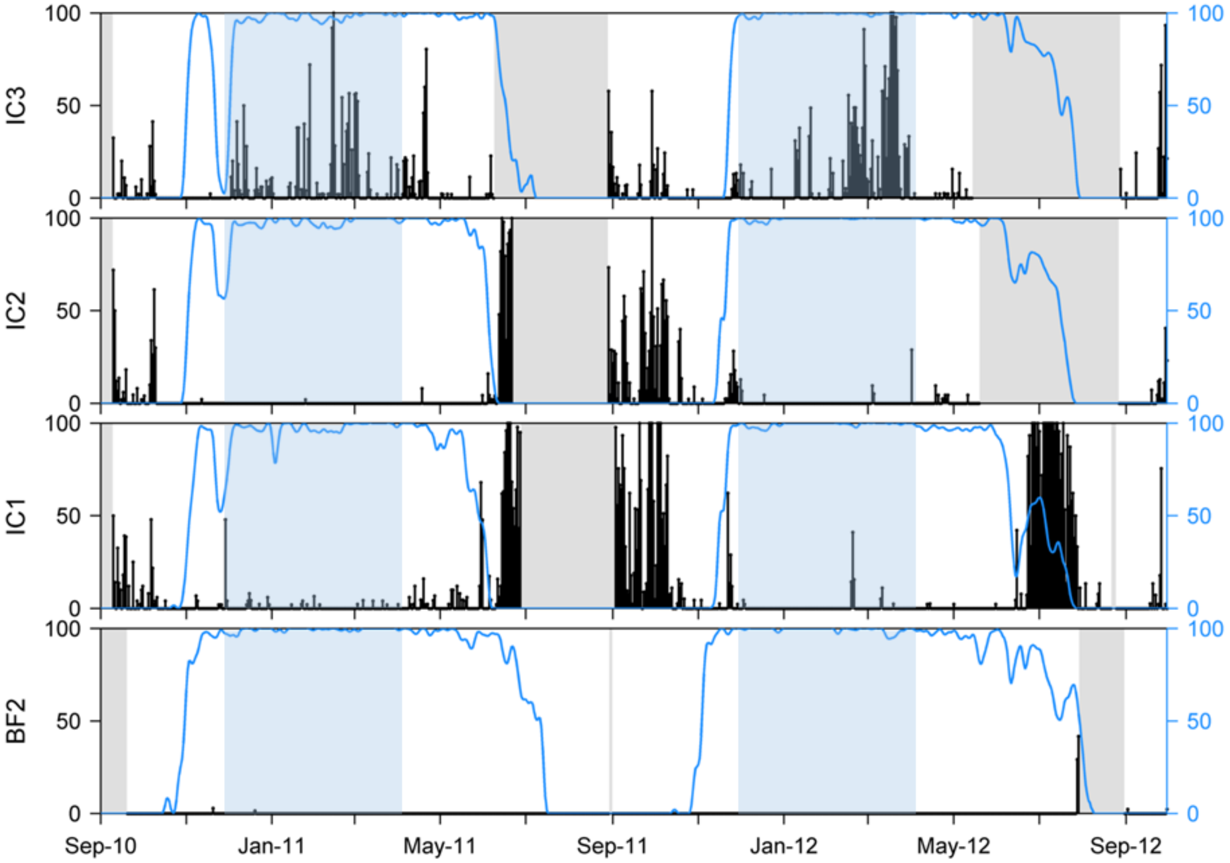


Figure 174. Comparison of the offshore Icy Cape (IC3) walrus calling activity (presented as the daily percentage of ten-minute time intervals with calls) with the three other Chukchi Sea mooring sites (see Figure 2) in 2010-2012. The mooring name is shown on the left. Blue line indicates percent ice cover (zero-phase, three-day moving average). Gray shading indicates no data. Blue shading marks the time period when walrus are thought to be south of Bering Strait (i.e., December through March).

2012-2016 mooring results

The same trend found for the 2010-2012 data was seen in the 2012-2016 data (Figure 175, Table 46): the offshore Icy Cape mooring site (IC3) shows the highest calling activity levels and the most number of days with calling during the December through March time period for all years with a few exceptions. In 2012-13 the inshore Icy Cape (IC1) and Barrow (BF2) sites had more days with detections than the offshore Icy Cape (IC3) site (18 and 10 vs. 9 days), but the maximum calling activity level is still much higher at the offshore site. In 2014-15, the inshore Icy Cape (IC1) and both sites on the northeast flank of Hanna Shoal (HS1 & HS2) had comparable calling activity levels to the offshore Icy Cape (IC3), but HS1 had more days with detections. In 2015-16 the WT1 site has a higher calling activity level than seen at IC3, with a few more days with calling detected.

Lastly, Figure 176 presents the results for walrus calling activity from the NM1 mooring site south of Bering Strait to the CL1 mooring site northwest of Cape Lisburne for the same 2012-2016 period. High and sustained levels of calling activity were expected for the NM1 mooring site, given it is the nearest in proximity to the St. Lawrence Island breeding aggregation.

Results for the KZ1 mooring site just north of Bering Strait also show high and sustained levels, although they were slightly less than at NM1. Only in the 2014-15 overwinter period does it appear that a pulse of calling extends northward from the KZ1 through the IC3 sites.

2016-2017 mooring results

Currently, the only two mooring sites with PAM analysis completed for the 2016-2017 deployment are IC3 and WT1. As mentioned above, and shown in Figure 172 and Table 46, this period marked the return of high and sustained levels of walrus calling at the offshore Icy Cape (IC3) mooring site. Only one day with calling was seen at the WT1 site off Wainwright, AK, and so no additional figures are included.

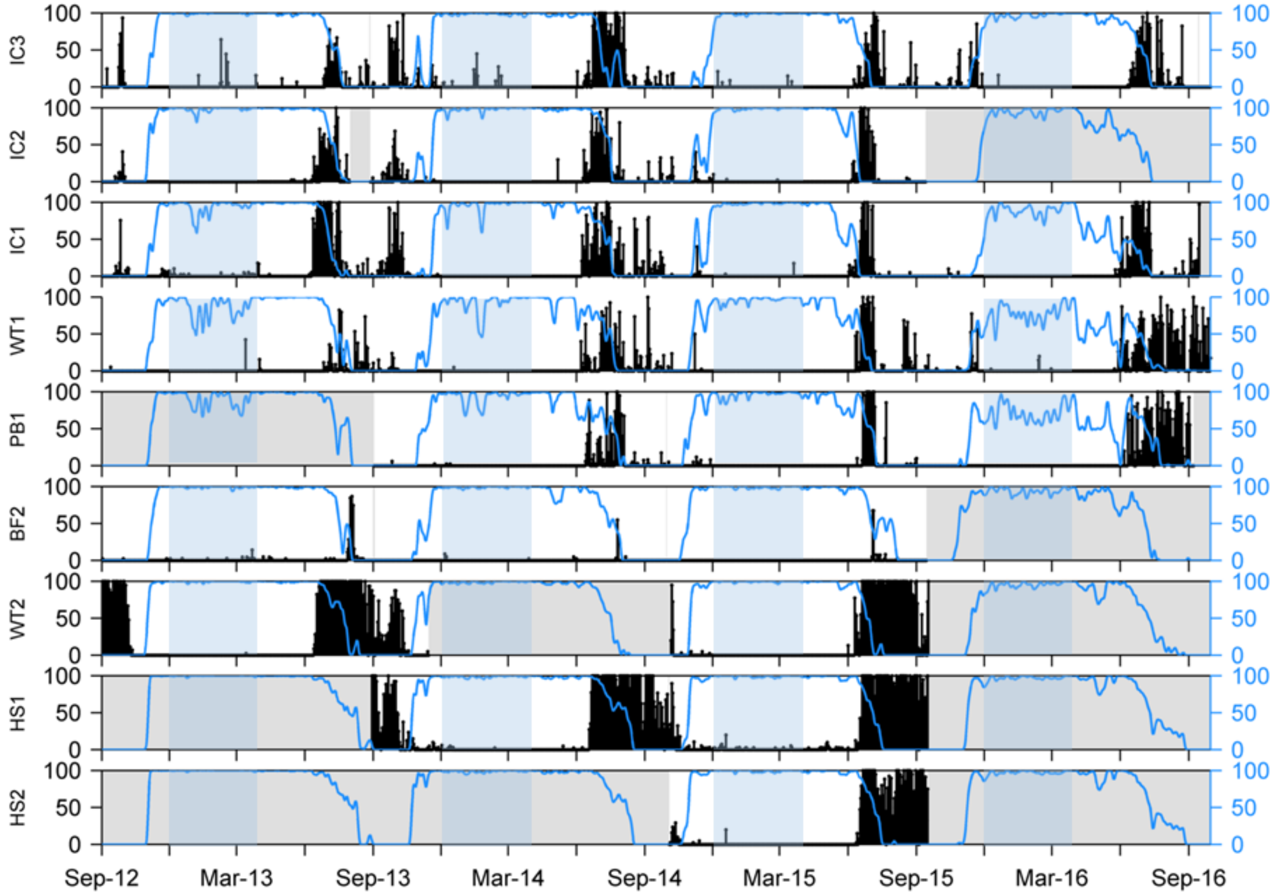


Figure 175. Comparison of the offshore Icy Cape (IC3) walrus calling activity (presented as the daily percentage of ten-minute time intervals with calls) with the eight other NE Chukchi mooring sites (see Figure 2 for map of mooring locations) from 2012-2016. The mooring name is shown on the left. Blue line indicates percent ice cover (zero-phase, three-day moving average). Gray shading indicates no data. Blue shading marks the time period when walrus are thought to be south of Bering Strait (i.e., December through March).

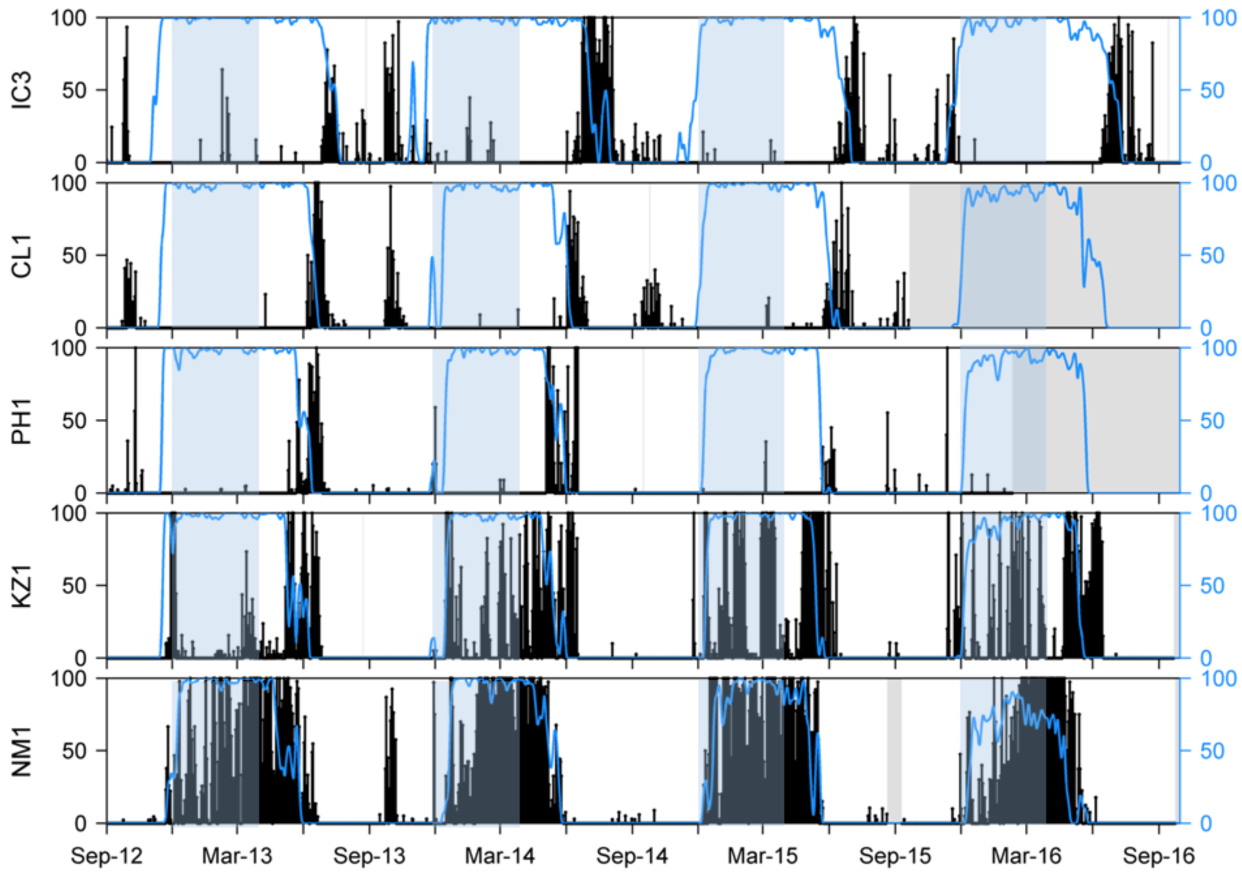


Figure 176. Comparison of the offshore Icy Cape (IC3) walrus calling activity (presented as the daily percentage of ten-minute time intervals with calls) with the four southern Chukchi mooring sites (see Figure 2 for map of mooring locations) from 2012-2016. Mooring name is shown on the left. Blue line indicates percent ice cover (zero-phase, three-day moving average). Gray shading indicates no data. Blue shading marks the time period when walrus are thought to be south of Bering Strait (i.e., December through March). The NM1 mooring site is the only one located south of Bering Strait.

Correlation with ice

As can be seen in Figures 172-176, all walrus calling activity during the December through March time period occurred under near 100% ice concentration, therefore comparisons made with walrus calling during this time period show no correlation. A quick comparison of the areal ice concentration during this 1 December through 31 March time period among years shows that the lowest averages were in 2010-11 (97%), 2015-16 (97%), and 2016-17 (80%). In contrast, the average areal ice cover during the same time period in 2011-12 and 2012-13 was 99-100% (2013-14 was 98%). Therefore one of the years with the highest overwinter calling (2011-12) had a greater ice concentration.

As walrus are not known to frequent concentrations of that magnitude, we included examination of ice thickness and ice condition as additional factors that may have a greater influence on walrus distribution. Figure 177 shows walrus calling activity at the three Icy Cape mooring sites plotted versus ice thickness from a co-located ice profiler[25]. Comparing the two years of data at the offshore mooring site (IC3), there are no clear trends seen between calling activity and ice thickness. Although there is a sharp drop-off of ice thickness that precedes the large pulse of calling activity in June/July at the middle (IC2) and inshore (IC1) mooring sites, a lack of correlation is again seen for the overwinter period from December through March.

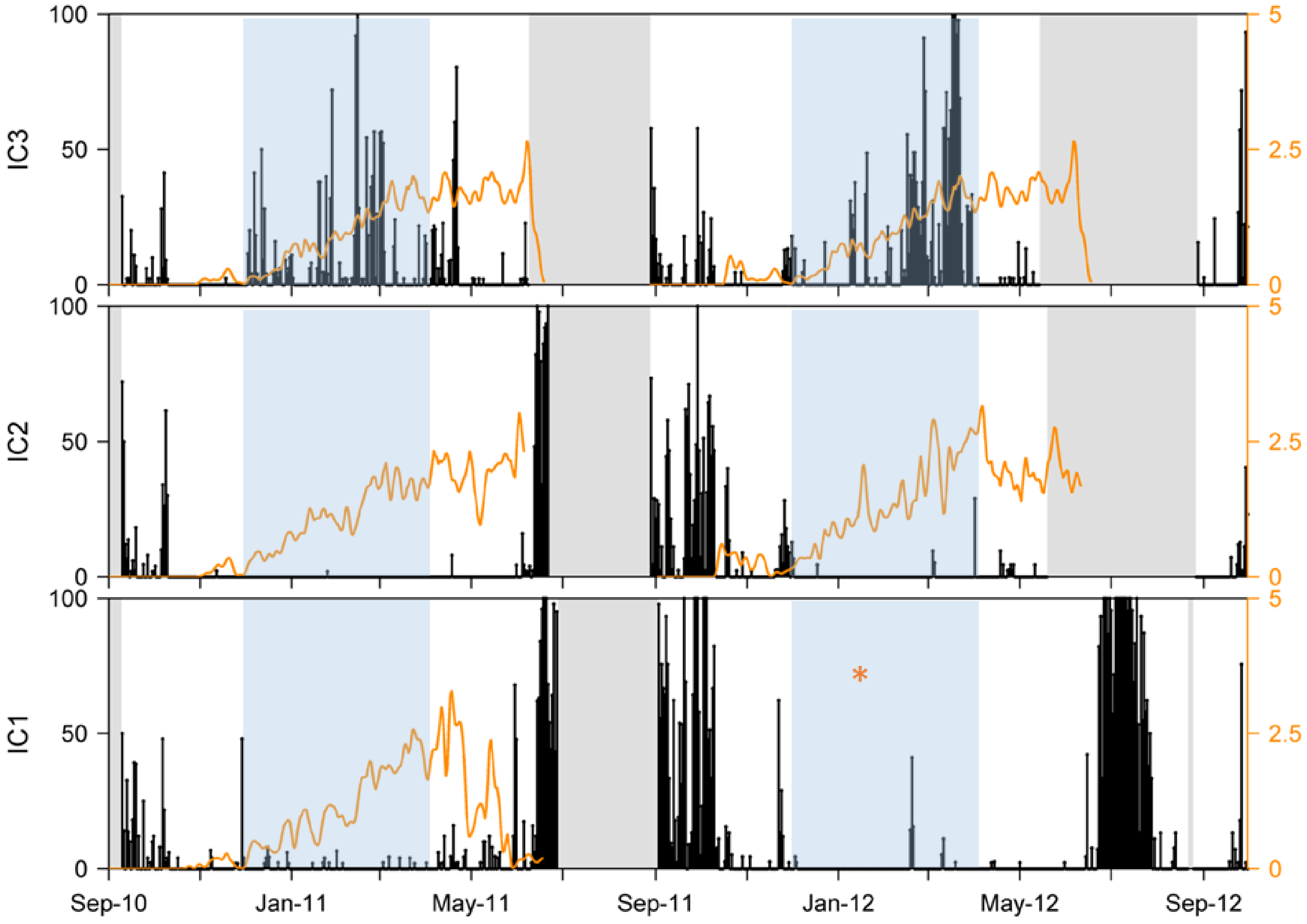


Figure 177. Comparison of walrus calling activity (presented as the daily percentage of ten-minute time intervals with calls; black) versus ice thickness (in orange) for the three Icy Cape (IC3) mooring sites (see Figure 2 for map of mooring locations) in 2010-2012. The mooring name is shown on the left. Orange line indicates mean ice thickness in meters (zero-phase, three-day moving average; * = no ice thickness data are available for 2011-2012 on the IC1 mooring). Gray shading indicates no data.

Unfortunately, the resolution of the satellite imagery used to obtain the ice concentration data (i.e., 25 km) is too coarse to detect finer scale features such as leads and polynyas. However, although limited by cloud cover, finer resolution satellite imagery provides a very

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[25] The 2010-11 and 2011-12 moorings are the only ones with ice thickness available and processed for the offshore site (IC3). There was no sensor deployed from 2012-2015; the 2015-17 data sets are currently being processed.

detailed look at the ice conditions in the Chukchi Sea during these time periods. Figures 178 and 179 show ice conditions in March of 2011 and 2012, respectively. The ice environment in both cases is highly fractured, with both leads and polynyas visible. Conditions like these were seen to varying extents throughout the December-March overwinter time period.

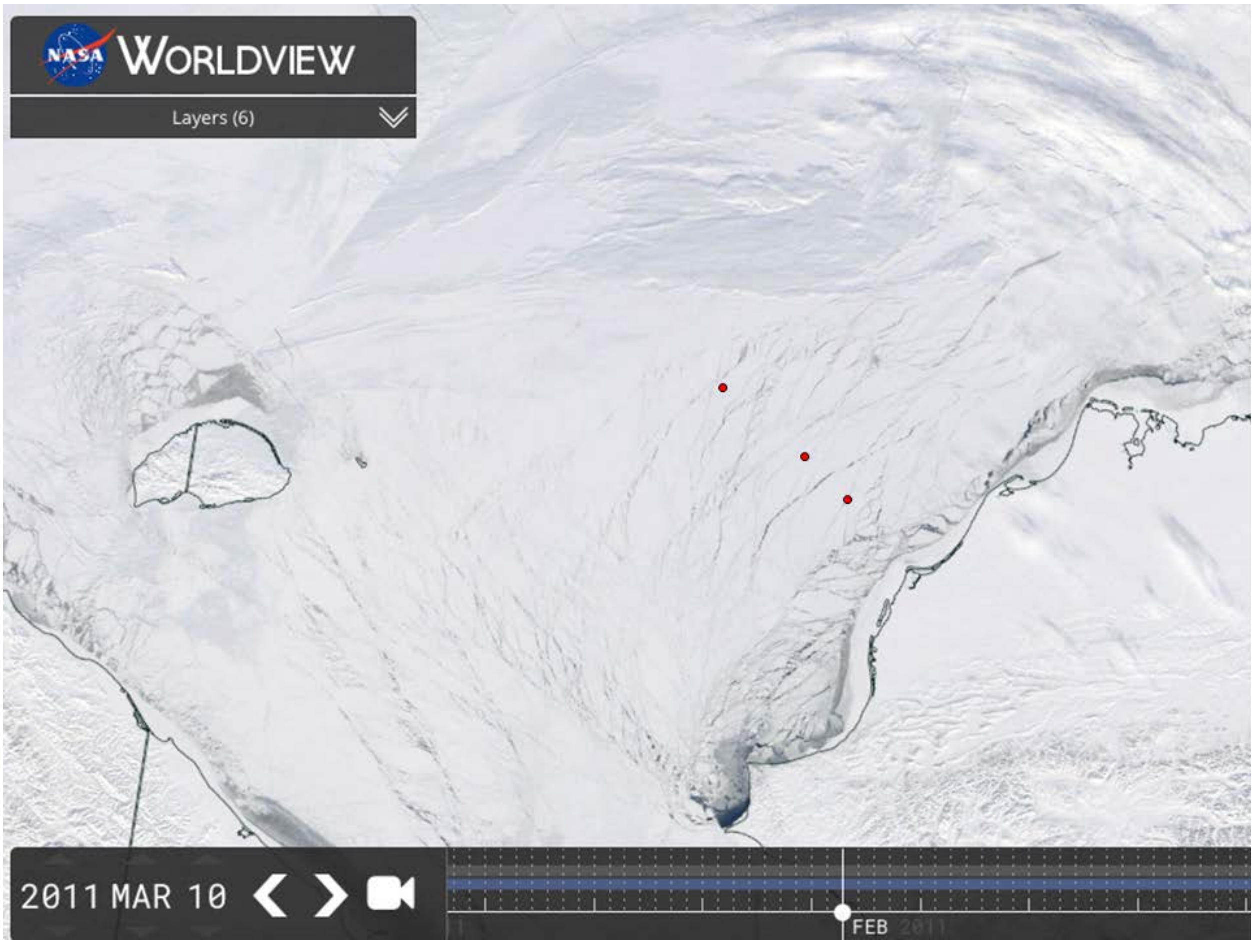

Figure 178. Sea ice conditions on 10 March 2011. Red dots mark the offshore, midshore, and inshore Icy Cape mooring sites (IC3, IC2, IC1, respectively). Substantial leads and polynyas are evident.

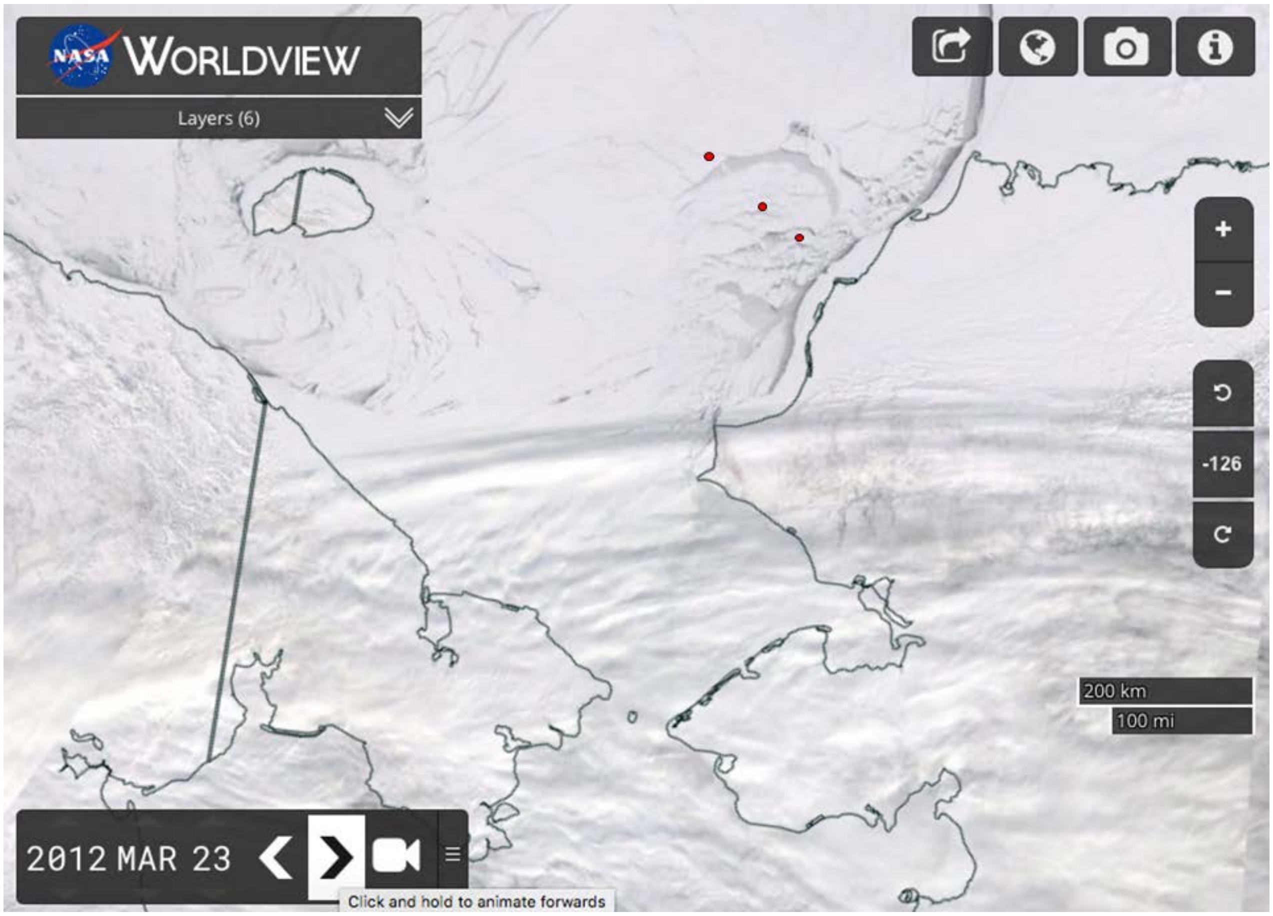

Figure 179. Sea ice conditions on 23 March 2012. . Red dots mark the offshore, midshore, and inshore Icy Cape mooring sites (IC3, IC2, IC1, respectively). Substantial leads and polynyas are evident.

Correlation with transport

Transport was investigated as it can contribute to the formation of leads and polynyas and/or assist in the movements of walrus. Figure 180 shows the interannual difference in monthly average transport versus the interannual difference in walrus calling activity, both at the offshore (IC3) Icy cape mooring site. The months shaded in red have a positive correlation between the interannual trends in walrus calling and transport to the northeast; the green shaded months show a negative correlation, therefore walrus calling activity is correlated with transport to the southwest. It is interesting that between February and March there is a switch between northeastward and southwestward transport. Further investigation into this is needed to determine whether this is due to increased ice advection transporting the walrus into the area (Fay 1982), and/or just an increase in broken ice. In addition, a focused examination of sea surface pressure anomalies will be conducted to investigate possible forcing mechanisms behind the February/March switch in transport.

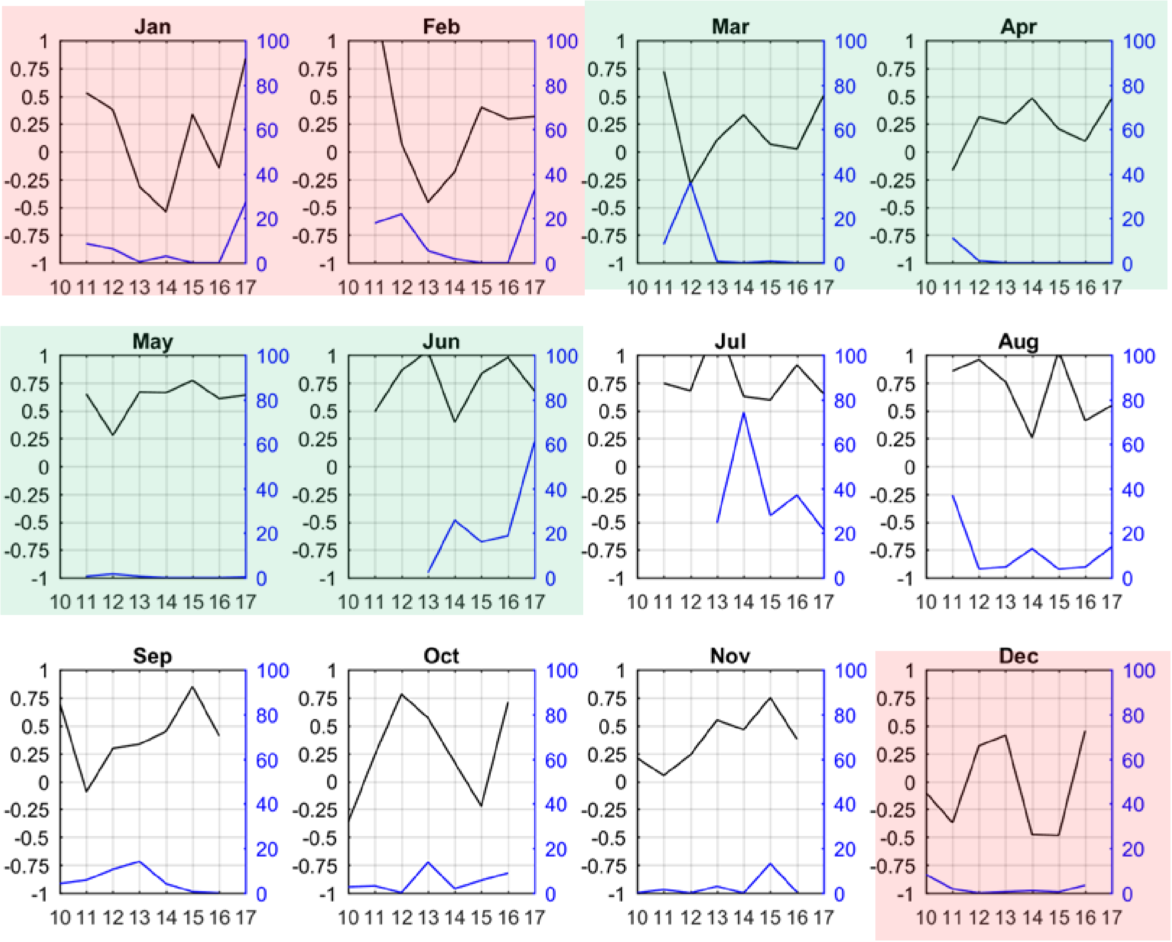

Figure 180. Monthly average values of (black and left axis) transport values (Sverdrups) versus (blue and right axis) walrus calling activity level (%) from 2010 to 2017 at the offshore (IC3) Icy Cape mooring site. Year is indicated on x axis. Pink shading indicates those months with a positive correlation between values; green shading indicates a negative correlation.

4. Discussion

For the overwinter periods of December through March of 2010-11 and 2011-12, walrus calling activity was found at high and sustained levels at the offshore Icy Cape mooring site. This was an unexpected result given individuals from this population are thought to overwinter in one of three breeding aggregations south of Bering Strait during this time period. Walrus make a variety of sounds, but we have focused our analysis on their more stereotyped knocks, bells, and grunts called ‘ou-ous’; therefore, the risk of false positives is minimal.

This overwintering does not appear to be widespread; it is focused on the offshore Icy Cape mooring site, with three times the number of days with calling and the highest calling activity levels occurring at this location. The inshore Icy Cape (IC1) and northeastern Hanna Shoal flank site (HS1) were the only other locations with more than a handful of overwintering days with calling present. This finding agrees well with the results reported by Hannay et al. (2013), who did not find any evidence of overwintering walrus at the additional 11 winter mooring sites they sampled in the northeastern Chukchi Sea. Although their array of recorders was extensive, it did not reach as far north as our offshore Icy Cape (IC3) site (see Figure 54).

This overwintering presence varied interannually at the offshore Icy Cape mooring site (IC3). The high and sustained levels seen in the first two years of monitoring decreased exponentially over the following four years, so that there was no difference in calling activity at this site versus any other mooring site in the NE Chukchi by the winter of 2015-16. The 2016-17 data show a return of a high presence of overwinter calling activity, however the delay in ice formation during that season makes it difficult to determine whether these are similar overwintering walrus as in 2010-2012 or whether the 2016-17 presence corresponds to just a delay in the fall migration. Completion of the 2016-17 analysis at the other mooring sites is needed to look for a similar delay at the more southern Chukchi mooring sites.

Does the presence of these overwintering walrus indicate that their northward migration occurred much earlier in the winters of 2011 and 2012, and to a lesser extent in the subsequent years? The lack of walrus calling activity at the other NE Chukchi sites seems to indicate that this is not the case. The results from the mooring sites closer to Bering Strait (Figure 176) do not show any consistent northerly trends among mooring sites. Given the wide spatial extent of the mooring positions, however, it is possible that the walrus are migrating north along the Alaskan coast and therefore alluding detection at the mooring sites north of the Strait to Cape Lisburne. Lack of any strong pulse of calling activity at the inshore Icy Cape site (IC1) also does not support an early northward migration as the cause for these overwintering walrus. In addition, while it has been reported that females and young will follow the ice edge as they migrate north in the spring (Fay 1982; Jay et al. 2008), the presence of near 100% ice cover, and the positioning of the peaks in these overwinter detections well away from the start and end of the 100% ice concentration season (see Figure 172), further opposes the early northerly migration hypothesis.

In the past, walrus were reported to prefer the moving pack ice and to avoid areas with heavy ice concentrations that could restrict their movements (Fay 1982). Fay (1982) also summarizes TEK that describes walrus being limited to maintaining up to two breathing holes and that they can starve when the local food resources in the vicinity of those holes is depleted. They are also capable of breaking through ice that is 20 cm thick (Fay 1982). With the reduction of sea ice comes a concurrent loss of thicker multi-year ice. The ice thickness shown in Figure 177 does not exceed 5 m, with the majority falling under 2.5 m, still over ten times thicker than they are capable of breaking. Even in this present time of rapid climate change, walrus still require access to some form of open water (e.g., polynyas, leads). Jay et al. (2012) reported large amounts of open water accompanied by high numbers of walrus in the Chukchi Sea in November of 2008-2011, so it is not unreasonable to assume that some pockets of open water existed overwinter in the years of this study. Furthermore, the overwinter presence of bearded seals and beluga whales (Figure 181), who are limited by 10 cm (Cameron et al. 2010) and 20 cm (Fraker 1979) ice thickness respectively, suggests that marine mammals like these three species could be used as proxies for ice condition when no satellite or *in situ* measurements are available.

In fact, while no correlations were seen between walrus calling activity and ice concentration and thickness, the finer scale resolution of the true color satellite imagery has revealed, when clouds are not covering the study area, the not-unexpected presence of a vast network of leads and polynyas. While leads can be ephemeral, there are a number of recurrent polynyas (Stringer and Groves 1991; Mahoney et al. 2012) in and around the study area that can provide a means of escape in the case of a closing lead. Figure 182 shows the position of these polynyas in relation to the mooring sites analyzed for this case study. Here, several routes to the offshore Icy Cape site are evident: following the polynyas along the Alaskan coast, heading up from the polynyas along the Chukotka coast (Figure 182, W), or coming across laterally from the Wrangell, Herald Shoal, and Hanna Shoal polynyas (Figure 182, X and U, N, and M, respectively). Hanna Shoal has already been well established as a prime feeding location in the open water season (Grebmeier et al. 2015). Preliminary examination of the true color satellite images (e.g., Figures 178 and 179) show that the biggest pulses in walrus calling activity seem to occur when large leads are spanning from Wrangell Island or Herald Shoal to the offshore Icy Cape site. Although it seems precarious to risk such a wide expanse of uncertain ice, USGS satellite telemetry data show that some tagged individuals do take both of these routes during the open water season (Figure 183), so there may be some habit, or innate homing (to prey fields) instinct, at play. Furthermore, these same tagging studies have shown that round trips of 200 km are not uncommon (Jay et al. 2012). With plenty of ice to rest on, travel from the any of the Chukchi polynyas[26] does not seem implausible.

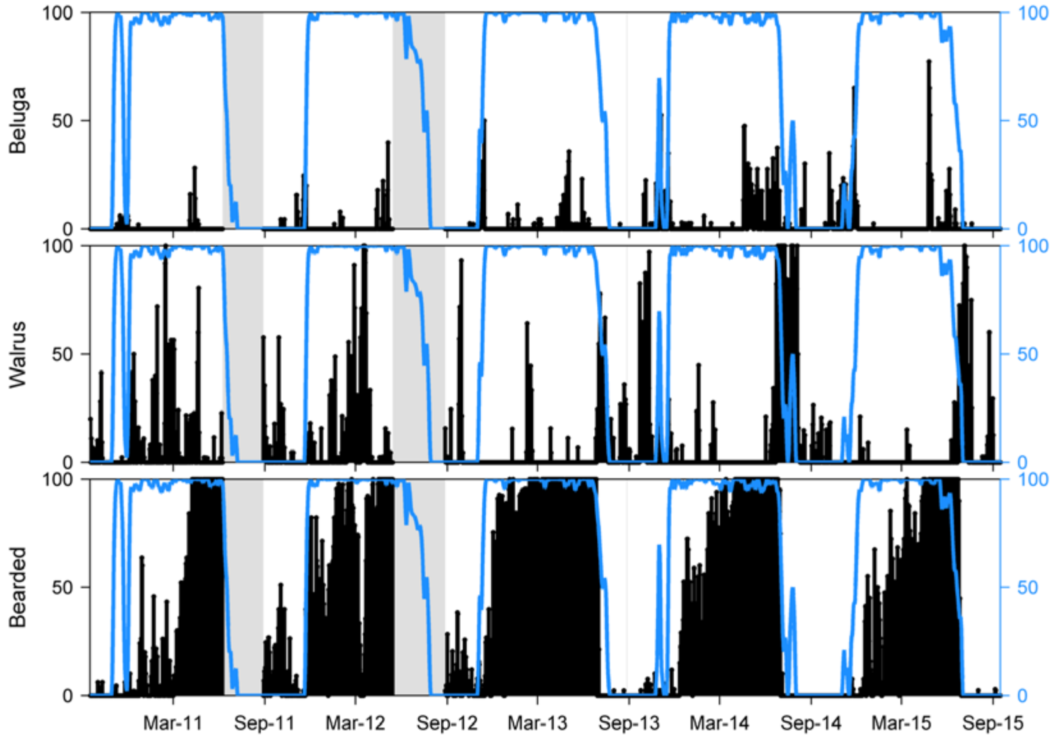

Figure 181. Comparison of walrus calling activity (presented as the daily percentage of ten-minute time intervals with calls) at the offshore Icy Cape (IC3)with that of beluga whales (top) and bearded seals (bottom) from 2010-2015. Rows labeled with species. Blue line indicates percent ice cover (zero-phase, three-day moving average). Gray shading indicates no data.

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[26] From the polynya boundaries estimated by Stringer and Groves (1991) the distance from the offshore Icy Cape mooring site (IC3) to the Wrangell polynya is ~400km; it is 200-250 km from IC3 to the Hanna or Herald Shoal polynyas, or from any of the polynyas between Cape Lisburne and Barrow.

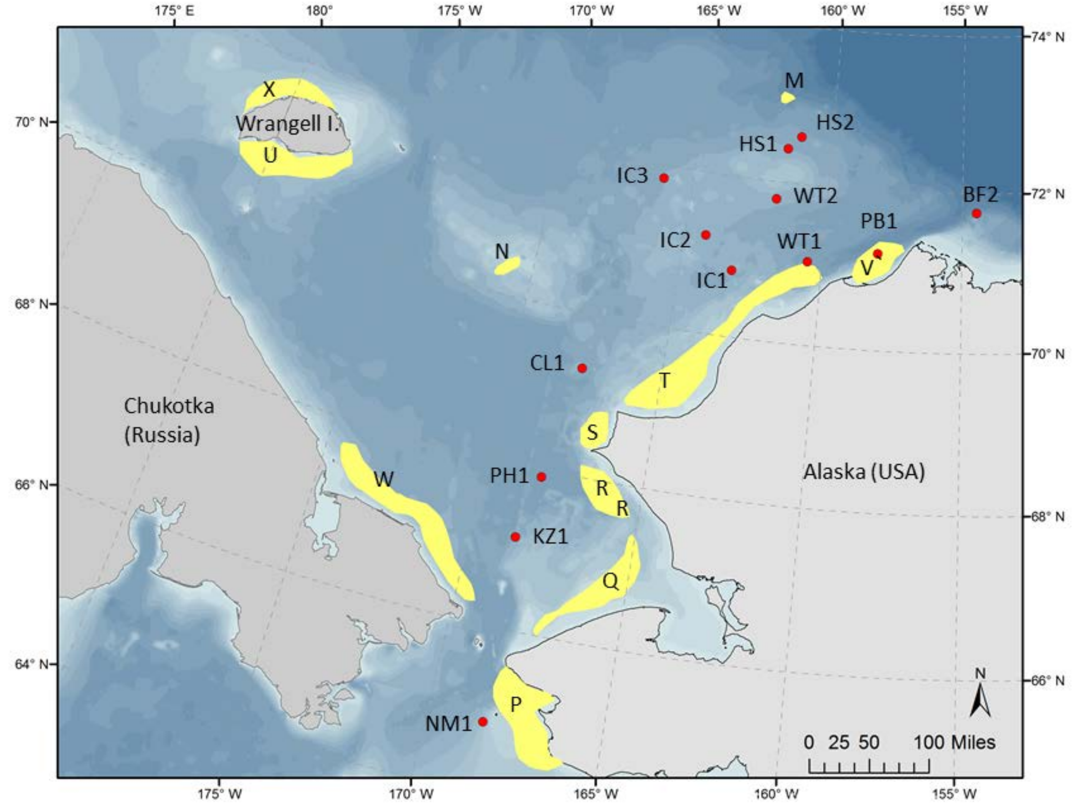


Figure 182. Map showing location of moorings used for comparison with IC3. Yellow shaded areas (lettered) represent the Chukchi Sea recurrent polynyas described by Stringer and Groves (1991).

Which brings this discussion to its final question: who are these walrus that are overwintering so far offshore on the Chukchi shelf? Although it is generally assumed that only male walrus sing (Sjare et al. 2003), recordings made in captivity have shown that females are also capable of making the same variety of sounds as males, including the knock and bell sounds (Schusterman and Reichmuth 2008). In addition, females and young are known to produce airborne grunts and barks (Sjare et al. 2003). As discussed in Section VII.A.3, this subset could be comprised of non-reproductive subadults who have no reason to expend the energy migrating to and from the Bering Sea. In fact, overwinter feasting on prey fields that have been out of reach and therefore underutilized during the open water season may be the smartest way to build up energy reserves for the next lean season. These individuals could also be subadults that have found themselves unintentionally off course; Fay (1982) reports that ‘Subadults of either sex seem most inclined to wander or to be diverted by irregular ice movements.” Miller (1975) describes instances of subadult males engaging in reproductive displays and suggests that practice sessions occur; this would explain the presence of calling activity if the animals are, in fact, subadults.

There is also no reason to assume that these individuals could not be adults that have made bad navigational choices, or have made a decision to stay where their preferred prey (i.e., bivalves) are for that overwinter period. A final possibility may be that these walrus are actually a seal-eating ecotype that have always remained north of the Bering Strait. Fay (1960) suggested there are two types of walrus: facultative and obligate mammal eaters; that is, there are some that eat seals when they have to and those that eat seals all the time. In this same paper he shares TEK from Alaskan and Russian native hunters that describes the obligate seal feeders as rogue males who were abandoned as pups. They describe these rogue males as physically different: they are lean and muscular, with powerful forelimbs and long, sharp, tusks (apparently from lack of using them to dig up clams). They also have yellowish and greasy chests from eating the seal meat. More telling, these rogue males are not hunted for their meat, which is bitter and whose liver can cause vitamin A poisoning; they are, however, killed when spotted on the beach, as their presence scares away the more desirable subsistence seal species.

As hard as it seems to believe that walrus can survive by eating upper trophic level species, there is anecdotal evidence that shows that they are adept hunters, from the report by Mallory et al. (2004) which describes an Atlantic walrus catching and eating murres at a rate of approximately one every six minutes, to old explorer accounts (Nansen 2008) which explain why walrus were considered much more of a threat than polar bears. Anecdotal evidence aside, both stomach content (Sheffield and Grebmeier 2009) and stable isotope analyses (Seymour et al. 2014b) have found evidence of upper trophic levels species in the diets of walrus. In the latter study, stable isotopes have shown levels of Upper Trophic species ranging from 2-38% per individual. Seymour et al. (2014b) also estimated the amount of lower and upper trophic level species needed to satisfy the energetic requirements of walrus and found they needed to eat 3,000-4,000 clams or one third of a ringed seal (and a ninth of a bearded seal) daily. No sampled walrus has tested for 100% upper trophic level species, and there has been no difference between males and females sampled, but it is possible that no rogue male has yet been captured and tested.

Still, the question of who are these overwintering walrus remains: the existence of a seal-eating ecotype does not explain why these walrus are remaining in the offshore shelf waters of the Chukchi Sea when most of the ice seals are also down in the Bering Sea (Cameron et al. 2010). Figure 181 shows, at least for bearded seals, that this assumption is also no longer valid. Bearded seals calling activity is persistent and sustained for almost the entire overwinter period throughout the northeastern Chukchi Sea, including the offshore Icy Cape (IC3) mooring site. Fitting with the hunter protocol of killing rogue males to allow the return of more desirable species to the shore, comparison between timing of the walrus and bearded seal calling activity seems to indicate that bearded seals avoid (or become silent) when walrus are present. This observation was first reported in the presence of Atlantic walrus by Cleator and Stirling (1990), who believe that lack of calling means absence of bearded seals, and that competition for prey resources or predator avoidance are both equally likely reasons for bearded seals to move out of an area.

Are overwintering walrus part of the ‘New Normal’ (Wood et al. 2015)? Thinner, less-multi-year, and more fractured sea ice does seem inevitable as the Arctic climate continues to rapidly change. This change may mean either a shift of subadults or adults from summer to winter feeding on the Chukchi shelf, or a shift to a more upper trophic level diet. Or perhaps no shift is taking place at all. Fay (1982) reported a personal communication from J. Burns that ‘solitary animals occasionally overwinter near Pt. Hope’; a seal-eating ecotype may have always existed. It is hard to determine what baseline levels were, since our ability to monitor these species has improved, such as with the use of long-term autonomous passive acoustic recorder moorings. It is therefore critical to continue this monitoring so that trends in timing and distribution can be identified.

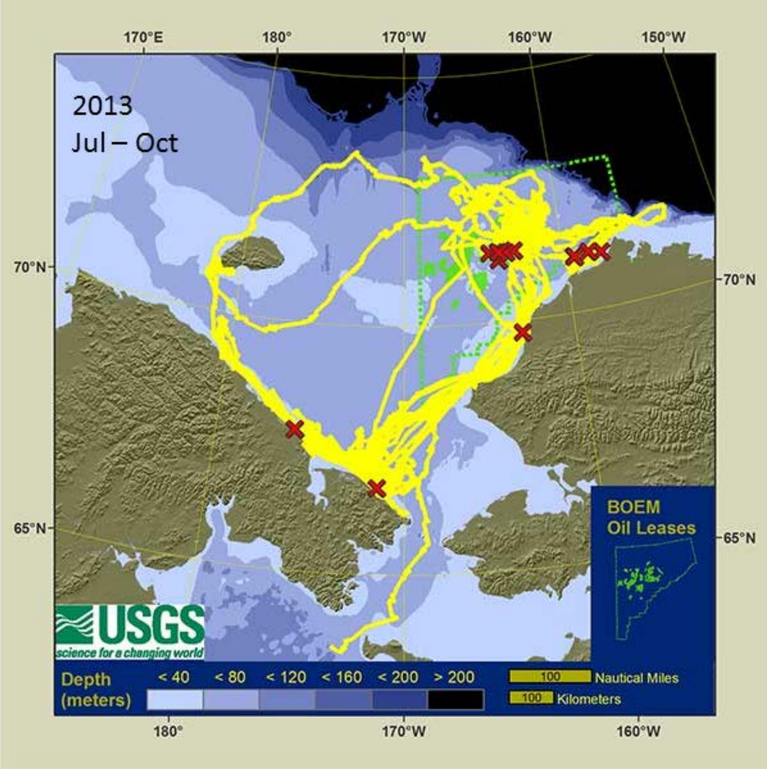


Figure 183. Tracks of 18 satellite tagged walrus (tagging location marked with a red X) between July and October of 2013. Taken from https://alaska.usgs.gov/science/biology/walrus/tracking.html.

5. *Conclusions*

The combined data from the CHAOZ, CHAOZ-X, and ARCWEST studies were able to provide the first evidence of walrus overwintering in the northeastern Chukchi Sea. This calling activity, though sustained at high levels for the first two years of monitoring, decreased in persistence and level throughout the next four years until the 2016-17 season saw its return to high levels. Detections were limited mostly to the offshore Icy Cape mooring location (IC3) at 120 nm off the coast. This overwintering presence was found under 100% ice concentrations, and did not show a correlation with ice thickness for the two years with data. True color satellite imagery, however, shows the presence of a vast network of leads and polynyas that can facilitate passage of the walrus to this offshore area both northward from polynyas on the Chukotka and western Alaskan coast, as well as laterally from Wrangell Island and Herald and Hanna Shoals. Regardless of how they have reached this area, the biggest question that remains to be answered is who these individuals are. They could be subadults that do not need to migrate into the Bering Sea to breed and are using the presence of the non-multiyear fractured and thin ice to reach their preferred bivalve patches. They could also be adults adjusting to a New Normal, increasing their energy reserves by feeding in the off season. Finally, they also could be a seal-eating ecotype that has always prowled the waters of the north.

6. Recommendations

The discovery of overwintering walrus at the offshore Icy Cape mooring site raises more questions than it answers. Fortunately, continuation of long-term passive acoustic monitor will allow trends to be determined about the importance of this location to walrus. Geographic variation in calling has been found for several pinniped species including harbor (Bjørgesæter et al. 2004), bearded (Risch et al. 2007), elephant (Le Boeuf and Petrinovich 1974), and harp (Terhune 1994) seals, and is suggested, albeit with low sample size, for walrus (Sjare et al. 2003). Examination of differences in vocal repertoires among recordings made near the three breeding aggregation sites may allow identification of which individuals are overwintering in this offshore location, or determine whether a fourth dialect exists for a potentially isolated group.

Passive acoustics may also be useful for providing corroborating (or the only) evidence of ice condition. If the ice is thin or fractured enough to support the presence of smaller marine mammals, it can be identified as deteriorated. Finally, identification of the switch in the association with walrus calling activity levels and transport direction between February and March will allow for a substantially smaller, and therefore more tenable, investigation into the mechanisms driving either the open water areas and/or walrus presence.

D. Long-range predictions for the CHAOZ-X environment

Current Situation

High benthic biomass and attendance by walrus during the summer results from the prolonged presence of sea ice in this region (e.g., Dunton et al. 2016). The impact of Hanna Shoal on the rest of the region depends not on average regional patterns, but what happens directly over the shoal. At present, its impact is disproportionate with its physical size, however the future of its impact is uncertain. As stated in our initial CHAOZ report (Berchok et al. 2015), we envision several different scenarios based on our original regional ocean atmosphere circulation model to forecast future conditions in the Chukchi shelf ecosystem. The models predict later arrival of the sea ice to the region as a whole and longer open-water seasons. Although not much changes before 2050 in the ensemble mean predictions for spring, there are episodic early sea-ice retreat events predicted by the models beginning in 2020, only three years from now. Although the models predict a late arrival of sea ice in the fall we focus on the timing of ice retreat in the spring and the importance it has in determining ocean temperatures; an early ice retreat permits greater solar heating and results in warmer sea surface temperatures. An early ice retreat also likely results in an earlier export of chlorophyll to bottom for the region as a whole.

Of primary importance will be conditions that promote or suppress the sustained presence of sea ice over the shoal. As described in this report, it is the prolonged presence of sea ice that creates favorable condition for the production of epontic algae that are eventually delivered to the seafloor. Further, the melting of sea ice helps to establish strong stratification that eventually separates the subsurface plankton from the surface. Last, it is the shallow depths of the shoal that enable sunlight to reach the depths where the sinks have aggregated and allow them to continue to photosynthesize, enabling sustained production throughout the summer until the nutrient reservoir at depth is depleted.

Of secondary importance will be the currents that wash over and around the shoal. Currents are weak and circle the western and northern flanks of the shoal. In addition, the weak currents allow the phytoplankton cells to be retained in a nepheloid layer so that they may eventually become incorporated into the sediments.

In Berchok et al. (2015) we presented two likely scenarios, both determined by wind patterns. In the first scenario, the strong winds persisting from the southwest drive the ice north and out of the Chukchi Sea before significant melting or freshwater intrusion can occur. In the second scenario, ice retreat is due to melting, and not winds, thus creating a strong surface layer of low-salinity water. These two scenarios, and the possible outcomes of each, are discussed below. Figure 184. Schematic of ecosystems and possible future scenarios. Figure 184 is a schematic representing the current conditions in the Chukchi, as well as the two different scenarios. Additionally, the possible effects of these two scenarios on marine mammal species are presented in Table 47.

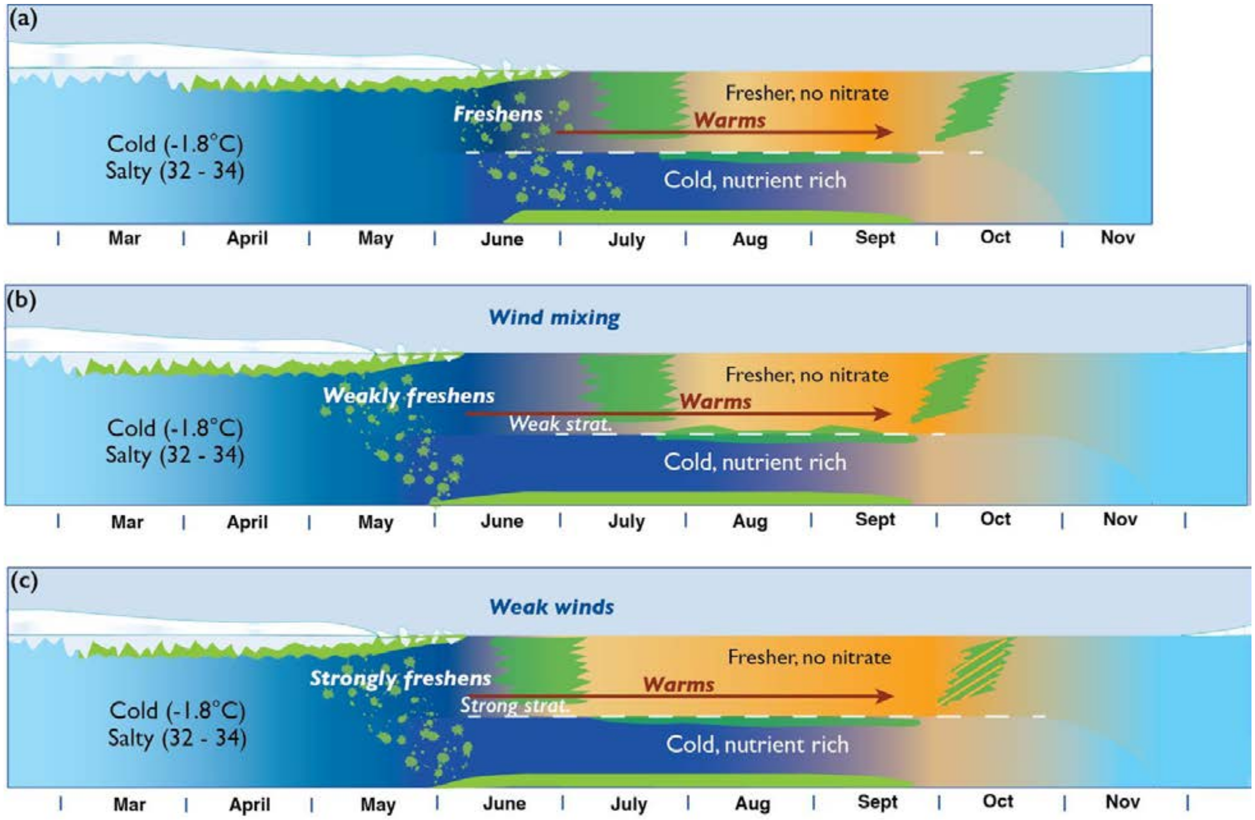


Figure 184. Schematic of ecosystems and possible future scenarios. A) current conditions in the Chukchi Sea. An ice algae bloom occurs under the ice in late winter and early spring. This is exported to the benthos with the melting ice. In summer, a subsurface bloom occurs below the pycnocline. After the retreat of ice and stabilization of the water column, a surface phytoplankton bloom occurs. In the fall, with the mixing of nutrients into the surface a fall phytoplankton bloom can occur. B) Scenario 1. Ice retreat due to wind forcing causes mixing of the water column. C) Scenario 2. Rapid ice melt and weaker winds result in strong stratification (from Berchok et al. 2015).

Scenario 1: Early ice retreat with strong winds and less ice melt

In Scenario 1, strong southwesterly winds successfully push ice off the shelf early in the year. This would shorten the period during which epontic algae rain down onto the seafloor, and thereby would decrease the amount of healthy plankton cells trapped below the pycnocline during the summer. Phytoplankton trapped below the pycnocline would see light levels increase earlier in the year, but total summer production below the pycnocline may decrease due to lower plankton biomass and earlier depletion of nutrients. The latter is due to a weakly stratified water column and frequent mixing of nutrients to the surface. It is uncertain if the amount of primary production within the surface layer (and its subsequent sinking to the seafloor) during the open water period would compensate for the lower production below the pycnocline. The flux of organic material incorporated into sediments that feeds the benthic food web may then decrease.

Scenario 2: Early ice retreat with weak winds and increased local ice melt

In Scenario 2 ice melts in place early in the spring season and creates strong stratification. This again would shorten the period during which epontic algae rain down onto the seafloor and thereby would decrease the amount of phytoplankton biomass trapped below the pycnocline during summer. Some ice algae would continue to be trapped below the pycnocline and see light levels increase earlier in the year, but total summer production below the pycnocline would decrease due to lower plankton biomass. However depletion of nutrients in the surface waters would occur earlier due to stronger stratification of the water column. Primary production in the surface layer during the open water period would exhaust the nutrient supply much earlier (relative to Scenario 1) and would not be able to help compensate for the lower total production below the pycnocline. The flux of organic material incorporated into sediments that feeds the benthic food web may then decrease.

Table 47. Summary of the effects of scenarios 1 and 2 at Hanna Shoal on three benthic feeding marine mammals.

Species	Impacts
Gray Whales	● Early decrease in ice over shoal may increase access to this foraging habitat ● Declining benthic prey availability at Hanna Shoal and other hot spots may result in a shift in foraging strategies, particularly if there is increased availability of pelagic prey
Walrus	● Decreased access to ice over Hanna Shoal feeding grounds; increased haul-outs on shore and increased risk to adult females and calves ● Declining benthic prey availability at Hanna Shoal; regional decline in benthic prey
Bearded Seal	● Decreased access to ice over Hanna Shoal feeding grounds ● Declining benthic prey availability at Hanna Shoal and other hot spots may result in a shift in foraging strategies to take advantage of increased pelagic prey availability.

E. ***Modeling Future Noise Conditions*** *(wind, commercial vessels, drilling rig & ocean tugs) and Influences of Noise Scenarios on Bowhead Whale Acoustic Habitat (71 - 710 Hz)*

1. *Introduction*

There is a reasonably high likelihood that in the coming decade the Arctic acoustic environment will experience significant changes as a result of natural and anthropogenic influences. The primary influences are expected as a result of increases in the levels and occurrences of surface winds and from increases in the types and numbers of anthropogenic activities. Expected increases in anthropogenic activities are primarily driven by the global economics of commercial shipping and offshore energy operations as a result of decreasing ice conditions (http://www.cmts.gov/downloads/CMTS_10-Year_Arctic_Vessel_Projection_Report_1.1.15.pdf). Here we used a combination of projections and reasonable assumptions regarding expected increases in noise from wind and noise from anthropogenic activities as inputs into an acoustic model to estimate aggregate changes in an Arctic acoustic environment in the Chukchi Sea. We used those model results for the acoustic environment to estimate potential influences on the frequency band in which bowhead whales produce calls and songs.

For clarification, the term *acoustic environment* refers to acoustic conditions across the full frequency range of environmental interest, whereas the term *acoustic habitat* refers to only the portion of that acoustic environment utilized by an organism for survival and reproduction. Thus, although the acoustic environment within the Chukchi Sea is the same for beluga and bowhead whales, their acoustic habitats are not the same. By this procedure we calculated differences in potential communication space for calling and singing bowhead whales under a variety of future noise conditions, all referenced to an empirically derived, naturally quiet ambient noise level under open water, low wind conditions. It is important to emphasize several key features of this analytical paradigm. It is not designed to be based on absolute values from physical acoustic models or noise sources. Rather, it is designed to provide a suite of comparative metrics by which to quantify relative differences in future bowhead acoustic habitat. As such, those differences are intended to provide reasonably accurate assessments by which to judge the relative influences of (i.e., contributions from) different types of noise sources under future Arctic scenarios.

2. *Methods*

We applied the Acoustic Ecology Toolbox (AET) to model the potential influences of future noise conditions on the communication space of bowhead whales. We restricted these analyses to a set of nine, 3rd-octave bands spanning the 71 – 708 Hz frequency range; a range in which most of the energy from bowhead calls and songs occurs. The analyses considered noise conditions with the natural factor of wind noise (natural ambient noise under medium and high wind conditions), two anthropogenic noise factors (vessels and drilling operations) and all three natural and anthropogenic noise factors combined (aggregate natural and anthropogenic noise conditions). We consider that all these scenarios represent possible future bowhead acoustic habitat conditions.

Estimates of future bowhead acoustic habitat conditions are calculated relative to a naturally quiet, baseline ambient noise condition computed from CHAOZ empirical data (see

Berchok et al. 2015, Figure 154, page 279). The 5th percentile of the wind – noise distribution data was used to determine a baseline ambient noise condition of 86 dB, also referred to as the naturally quiet ambient noise condition (see Figure 185). We used the noise levels for the 25th and 75th wind speed percentile values to represent medium wind and high wind noise conditions, respectively, resulting in a medium wind speed noise level of 91 dB (5 dB above quiet ambient noise conditions) and a high wind speed noise level of 97 dB (11 dB above quiet ambient noise conditions).

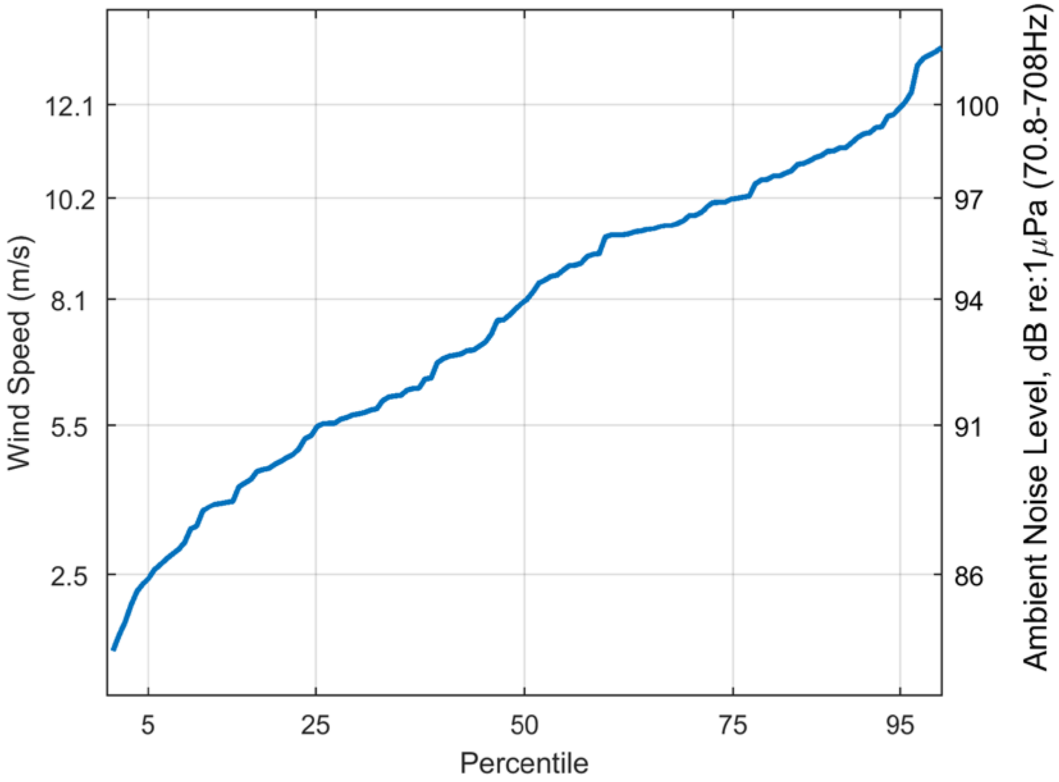


Figure 185. Percentile distribution of wind speed (left) and ambient noise level (right) based on CHAOZ empirical data (see Berchok et al. 2015, Figure 154, Page 279).

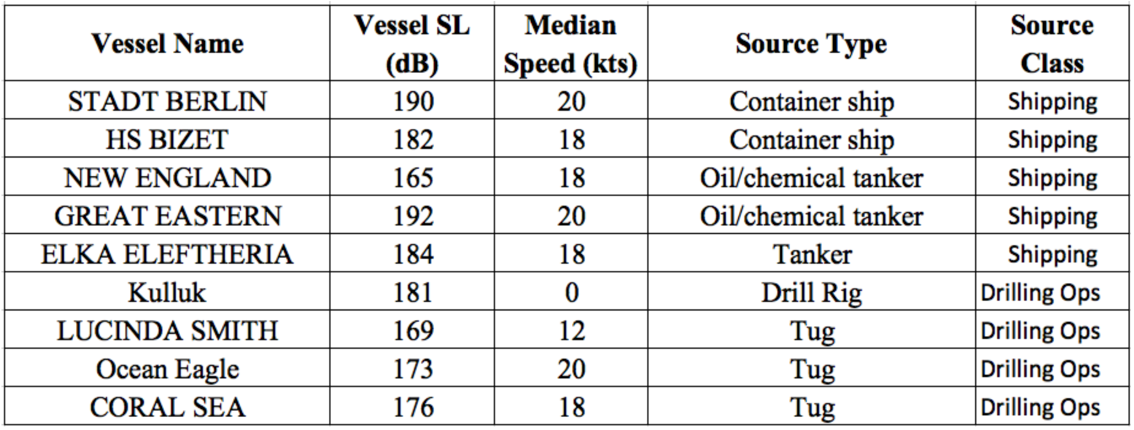
The four future noise condition scenarios, which include two classes of anthropogenic noise sources (Shipping and Drilling Ops) are:

1. Wind only (medium and high wind speeds) scenario: Ambient noise levels in the bowhead acoustic frequency band (71 – 708 Hz) as a result of medium surface wind (noise levels 5 dB higher than the naturally quiet ambient noise condition of 86 dB) and high surface wind conditions (noise levels 11 dB higher than the naturally quiet ambient noise condition of 86 dB).
2. Shipping only: Ambient noise levels in the bowhead acoustic band vary as a result of different numbers and types of commercial ships (we used 5 vessels; 2 container ships and 3 tankers). Basic acoustic characteristics for each of the vessels representing these container and tanker vessel types were based on empirical data obtained from a combination of AIS data and Cornell MARU recorders over a 5-year period in shipping

lanes off Boston. (http://www.listenforwhales.org/Page.aspx?pid=430, see Hatch et al. 2012).

3. Drilling Ops only: Ambient noise levels in the bowhead acoustic band vary as a result of offshore drilling operations (a drill ship with 3 support tugs). The Kulluk drill rig was used as a proxy for a future drilling operation. Basic acoustic characteristics of the drill rig were obtained from Greene (1987), while those for ocean tugs were based on data from shipping lanes off Boston. (http://www.listenforwhales.org/Page.aspx?pid=430).
4. Wind, Shipping & Drilling Ops: Ambient levels in the bowhead acoustic band increase as a result of aggregated noise from wind, shipping traffic, and drilling operations.

Table 48. Listing of anthropogenic noise sources used in acoustic modeling analysis. Source level (in dB) is relative to 1 μPA in the 71-708 Hz frequency band. Median speed is the constant speed at which a vessel moved through the area. Note: The Kulluk was used as a proxy for a potential future drilling rig.



Vessel Name	Vessel SL (dB)	Median Speed (kts)	Source Type	Source Class
STADT BERLIN	190	20	Container ship	Shipping
HS BIZET	182	18	Container ship	Shipping
NEW ENGLAND	165	18	Oil/chemical tanker	Shipping
GREAT EASTERN	192	20	Oil/chemical tanker	Shipping
ELKA ELEFTHERIA	184	18	Tanker	Shipping
Kulluk	181	0	Drill Rig	Drilling Ops
LUCINDA SMITH	169	12	Tug	Drilling Ops
Ocean Eagle	173	20	Tug	Drilling Ops
CORAL SEA	176	18	Tug	Drilling Ops

Changes in future bowhead acoustic habitat conditions as a result of these different scenarios are measured as relative changes in communication space within the 71 – 708 Hz frequency band over a 2-day period (19-20 May 2014) at four sites, every 10 minutes. The analysis model is run for two future wind conditions (medium and high winds), and two different classes of bowhead sounds, calls and songs (Ljungblad et al. 1982; Clark and Johnson 1984), which have predominant energy in the 71-708 Hz frequency band. The 2-day schedule of the shipping and drilling activities is shown in Figure 186. To avoid edge effects in noise modeling runs, the 2 hours at the beginning and the 2 hours at the end of this 48 hr sampling period were not included in model runs. This amounts to 24 10 min samples, yielding a total of 264 x 10 min sample periods in our model analysis.

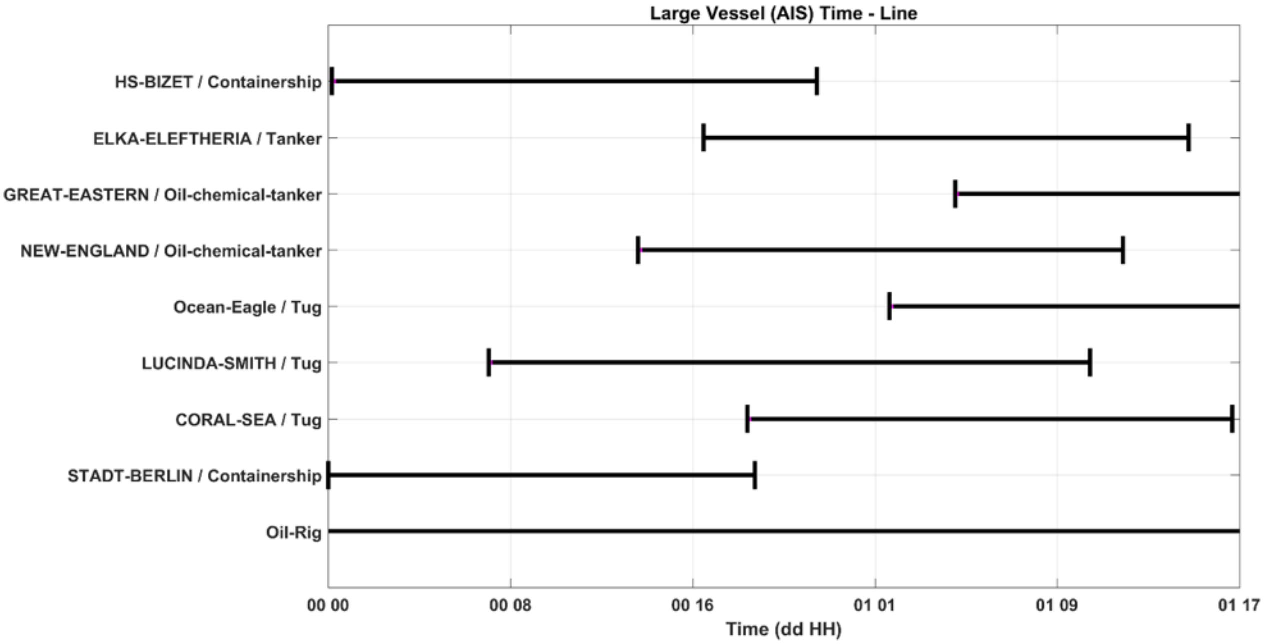


Figure 186. Time chart showing the start times, durations and end times for each type of anthropogenic activity used in the noise model (5 commercial ships, 3 ocean tugs and 1 drill rig) over the 2-day noise model period. Note: The Kulluk was used as a proxy for a potential future drilling rig.

We applied a simple transmission loss algorithm in which we assumed spherical spreading loss [20*Log (range)] out to a range equal to water depth at the source, and a spreading loss of 15*log (range) for ranges greater than water depth at the source (see Greene 1987).

The model was run for each of four sites (Site-01, Site-02, Site-03, and Site-04) located every 25 nm on a line from Wainwright through the drill site that was drilled by Shell’s drilling rig in 2015 (see Figure 187). For this noise model we used the known noise signature from the Kulluk drill rig as a proxy for a drill rig. Each of these sites represents a location at which we modeled changes in the acoustic communication space in the 71-708 Hz frequency band, and results at each of these sites are thus considered proxies for changes in bowhead acoustic habitat.

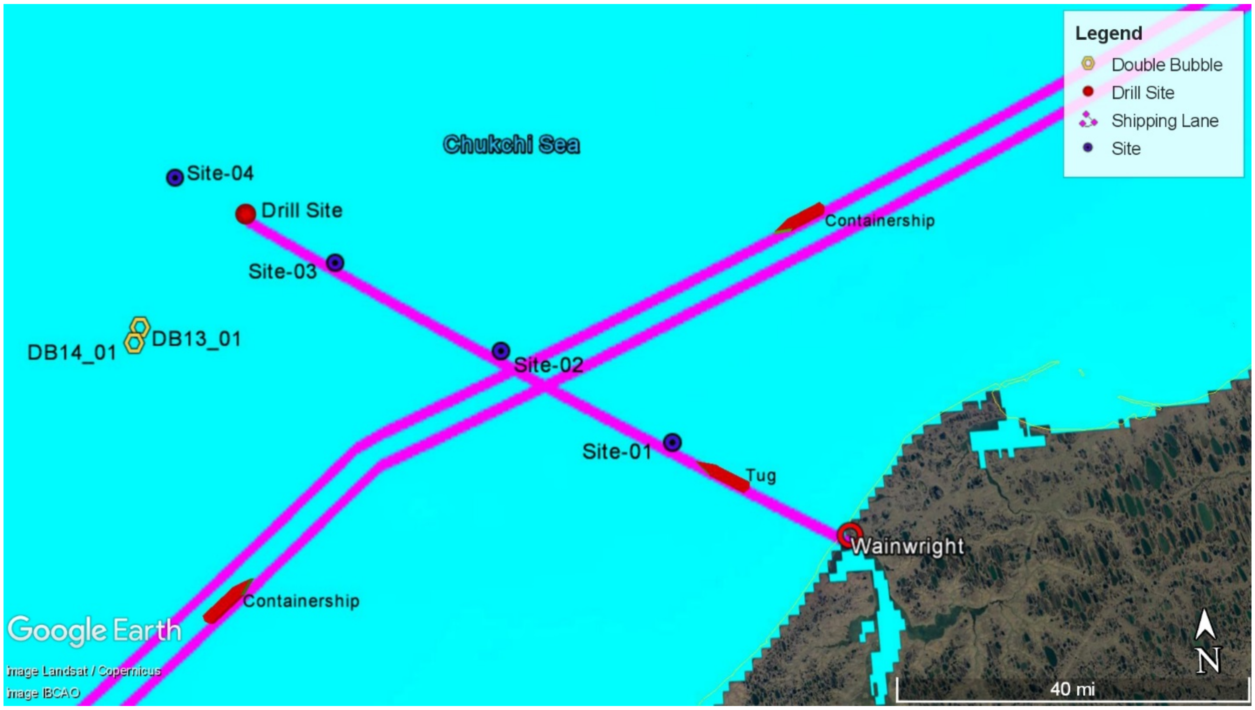


Figure 187. Schematic chart showing the two shipping lanes (a northeast bound lane and a southwest bound lane), four sites (Site-01, Site-02, Site-03, Site-04), the path of support tugs that transit between Wainwright and the Shell drill site, and locations of the two double-bubble recorders (DB13_01 and DB14_01) whose data were used in Section 0.

An example diagram of the acoustic environment as a result of multiple vessels is provided in Figure 188, while Figure 189 is an example diagram showing the area in which the model predicts that the level of a bowhead whale sound (call or song, in dB) would be detectable at Site-01. This area is referred to as the signal excess area. Figure 188 shows sound levels throughout the area surrounding Site-01 (a proxy for the position of a calling or singing bowhead whale), where the sound levels are the aggregate of noises generated by individual vessels (i.e., acoustic footprints). Figure 189 shows the area (blue and white) within which the model predicts a calling bowhead could be heard by another bowhead under these aggregate noise conditions (i.e., SE > 0).

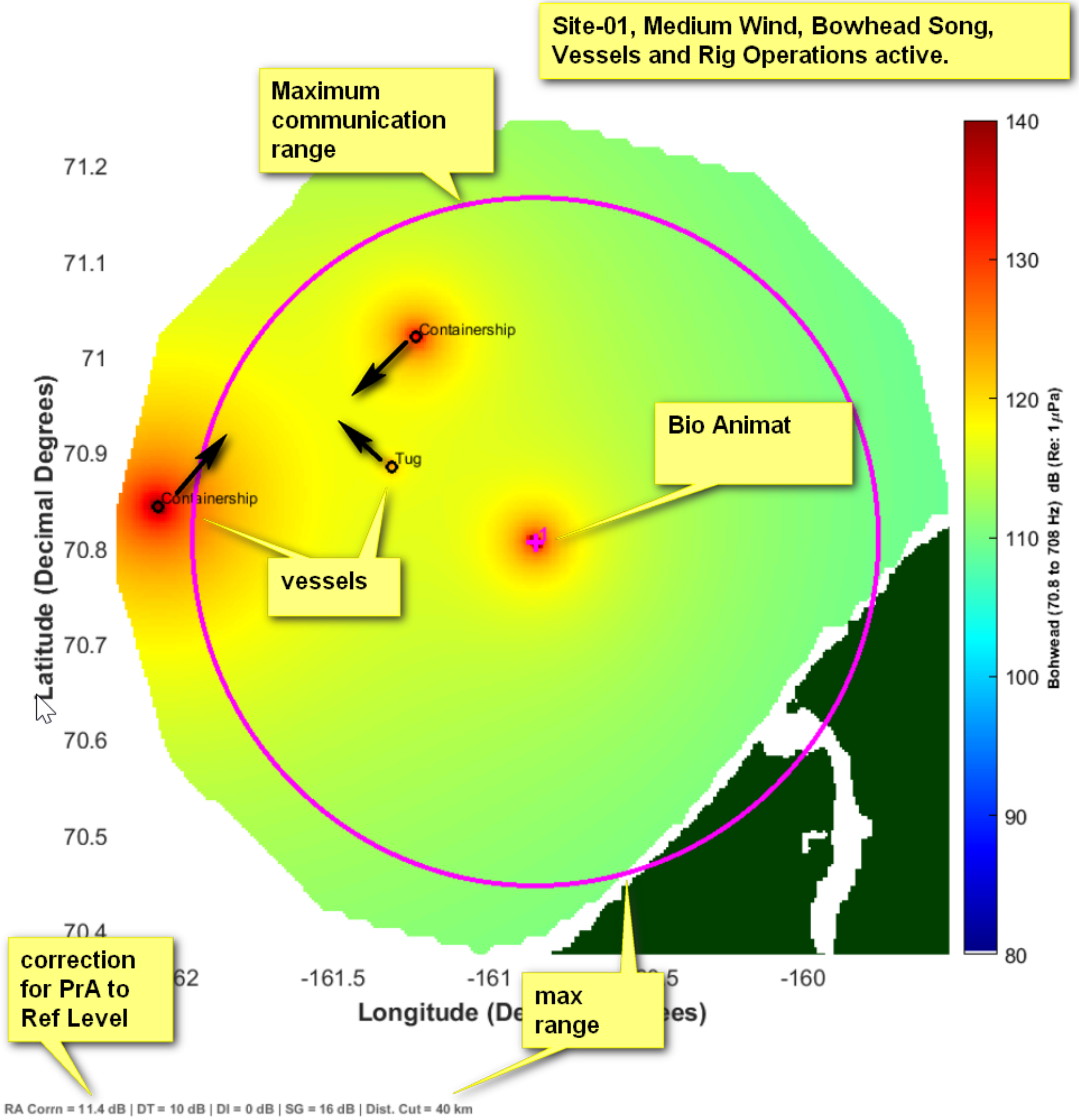


Figure 188. Schematic diagram of the aggregate acoustic environment throughout the area surrounding Site-01 as a result of noise generated by two commercial ships in the shipping lanes and an ocean tug traveling from Wainwright to the Shell drilling rig. Site-01 serves as a proxy for the calling bowhead whale, which has a communication range of 20 km. Note: the term "animat" refers to a modeled animal (Frankel et al. 2002).

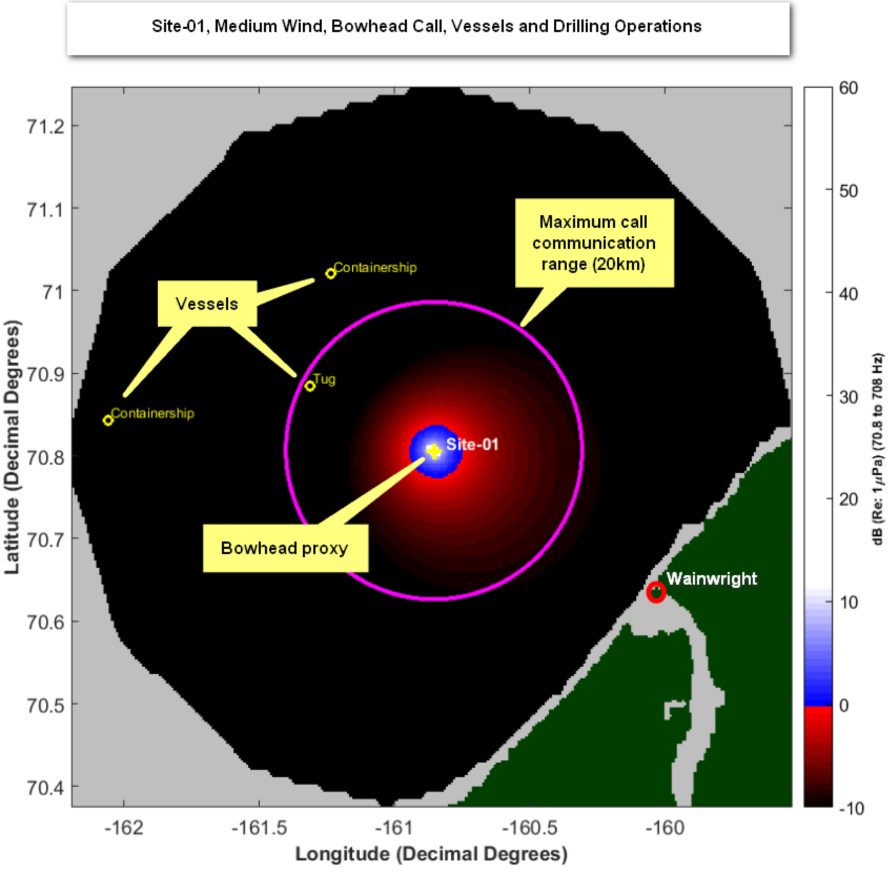


Figure 189. Schematic diagram of the communication space available (blue and white area in which signal excess >0 dB) to a calling bowhead at Site_01 (identical conditions as Figure 188).

For the model, the sound field from the sound aggregation process was computed every 10 minutes throughout a 2-day period under late summer conditions at each of the four sites for the natural noise source (medium and high wind), each of the two types of anthropogenic noise sources (commercial vessels, and drilling operations), and for all three noise types combined. We refer to these three noise types as Wind, Shipping, and Drilling Ops. Each of these different sound fields were combined with the estimated sound field produced by a proxy calling or singing bowhead whale at each of the four sites. They were used to calculate a metric representing the amount of communication space available to the proxy bowhead under the modeled noise condition relative to the whale’s communication space under naturally quiet, baseline ambient noise condition (i.e., without a noise contribution from any of the Wind, Shipping, or Drilling Ops noise sources).

Communication space (CS; re: Clark et al. 2009) values were calculated every 10 mins throughout the 2-day period using bowhead whale acoustic parameter settings (see Table 49) for the four scenarios described above, following the analytical paradigm as initially presented in Clark et al. (2009) and informed by additional analytical considerations as presented in Jensen et al. (2011), Hatch et al. (2012), and Williams et al. (2014). This resulted in 48 model runs (2 bowhead sound types, 2 wind speed conditions, 4 sites, 3 anthropogenic conditions). In Table 49, it is important to note that the recognition differential (RD) is negative because the sum of the directivity index (DI) and processing gain, PG, is greater than the detection threshold (DT). This results in a situation in which signals of interest (calls and songs) can be recognized even when the signal-to-noise ratio (SNR) is greater than the signal's received level. We assumed source levels (SL) of 165 dB and 175 dB for the calls and songs, respectively (Cummings and Holliday 1987).

Table 49. Parameter values for bowhead calls and songs used to calculate estimates of communication space under different noise conditions. SL = source level; DI = directivity index; PG = processing gain; DT = detection threshold; RD = recognition differential.

	SL (dB)	DI (dB)	PG (dB)	DT	RD (dB)	Max Range (km)
Call	165	3	16	10	-9	20
Song	175	3	22	10	-15	40

3. Results

The modeling analyses resulted in 48 model runs, representing estimates of relative changes in communication space and signal excess for all combinations of the two bowhead sound conditions (Call and Song), two wind conditions (Medium Wind and High Wind), three noise activity conditions (Shipping only, Drilling Ops only and Shipping & Drilling Ops) and four bowhead proxy sites.

Basic results are presented in two sets of figures showing the time series of 10-min communication space metrics over a 2-day duration. One set of four figures summarizes results for each of the four sites, and these are referred to as results-by-location figures. A second set of four figures summarizes results for each of the three noise activity conditions, and are referred to as results-by-activity figures. Each of the results-by-location figures (Figures 190-193) consists of a panel for each of the four sites, and each site panel shows communication space data for each of the three noise activity conditions over the 2-day modelling period. Each panel also shows a static line representing communication space under the panel's wind condition, which is assumed to be constant for the 2-day modelling period.

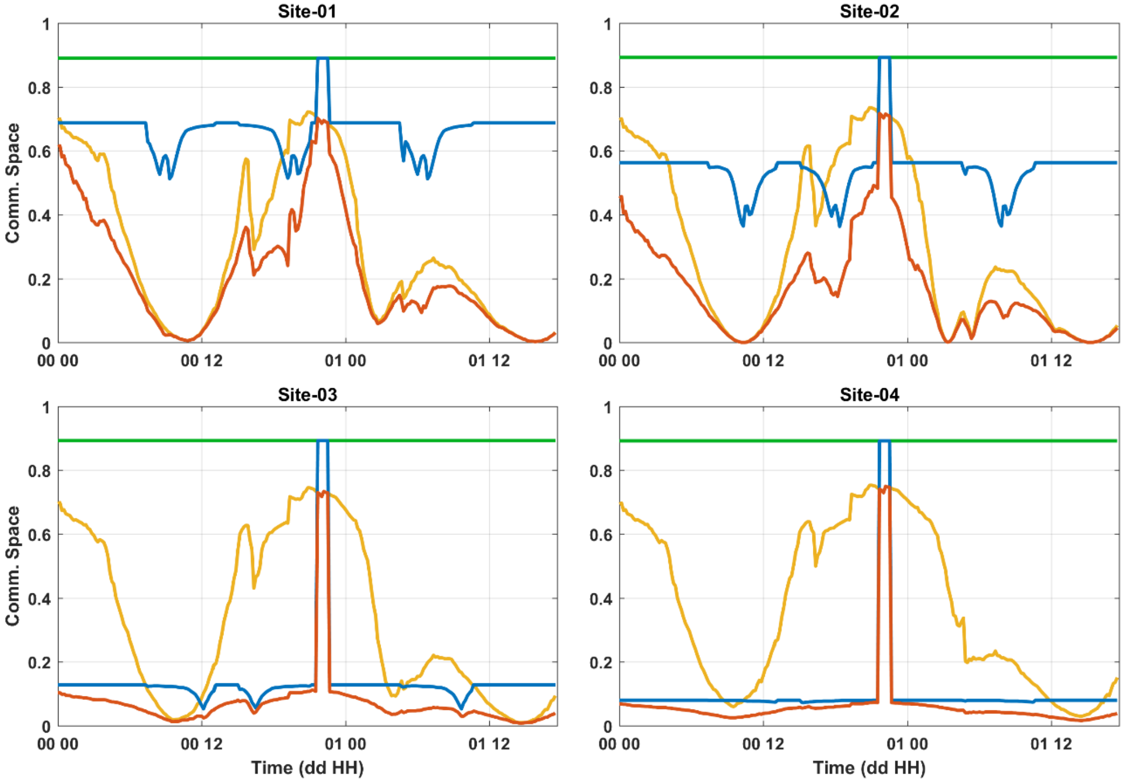


Figure 190. Four-panel results-by-location plot showing the time-varying communication space at each of the four sites for calls, medium wind, and each of the three noise activity conditions (shipping, drilling ops, and shipping & drilling ops). All metrics are relative to the baseline naturally quiet ambient noise condition (86 dB) in the 71-708 HZ frequency band. Green is medium wind, yellow is shipping only, blue is drilling ops only, and red is shipping & drilling ops.

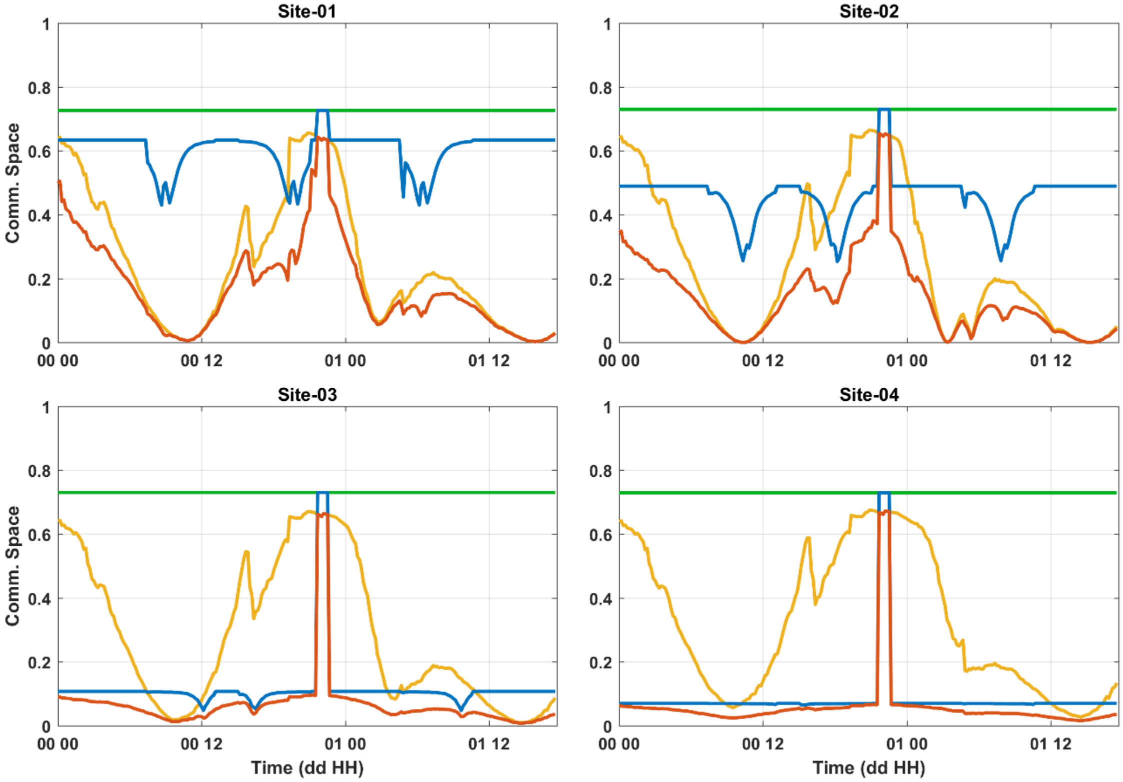


Figure 191. Four-panel results-by-location plot showing the time-varying communication space at each of the four sites for calls, high wind, and each of the three noise activity conditions (shipping, drilling ops, and shipping & drilling ops). All metrics are relative to the baseline naturally quiet ambient noise condition (86 dB) in the 71-708 HZ frequency band. Green is high wind, yellow is shipping only, blue is drilling ops only, and red is shipping & drilling ops.

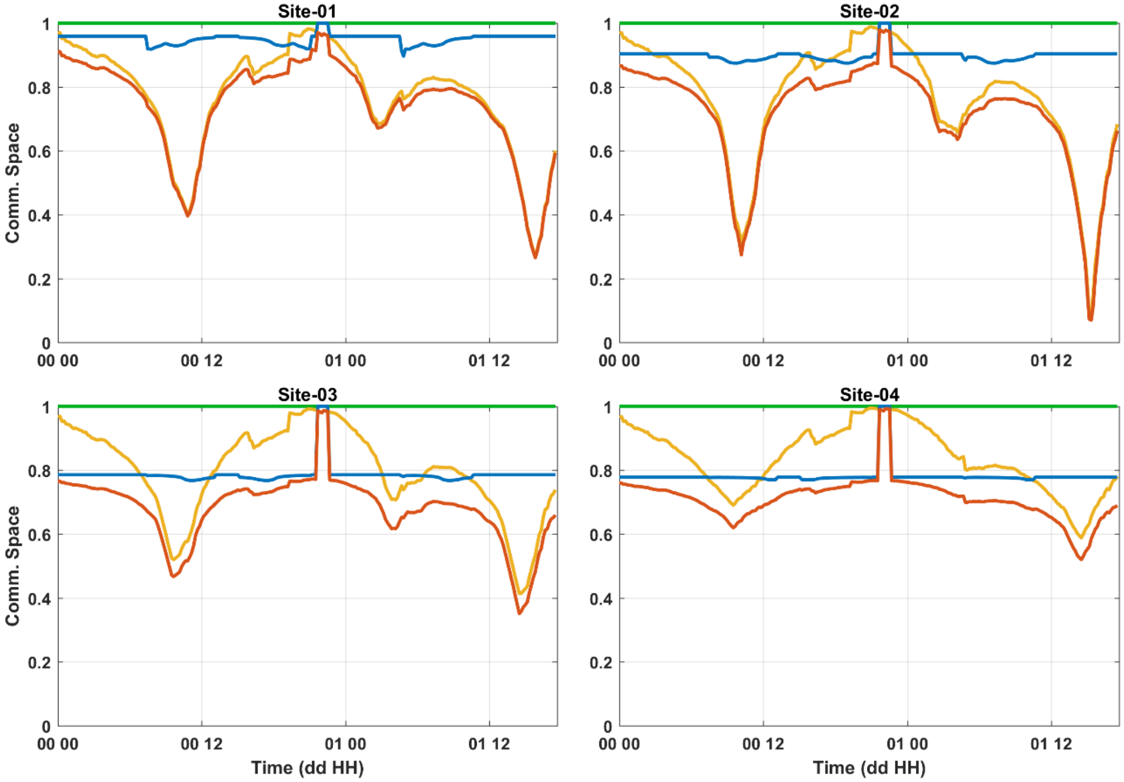


Figure 192. Four-panel results-by-location plot showing the time-varying communication space at each of the four sites for song, medium wind, and each of the three noise activity conditions (shipping, drilling ops, and shipping & drilling ops). All metrics are relative to the baseline naturally quiet ambient noise condition (86 dB) in the 71-708 HZ frequency band. Green is medium wind, yellow is shipping only, blue is drilling ops only, and red is shipping & drilling ops.

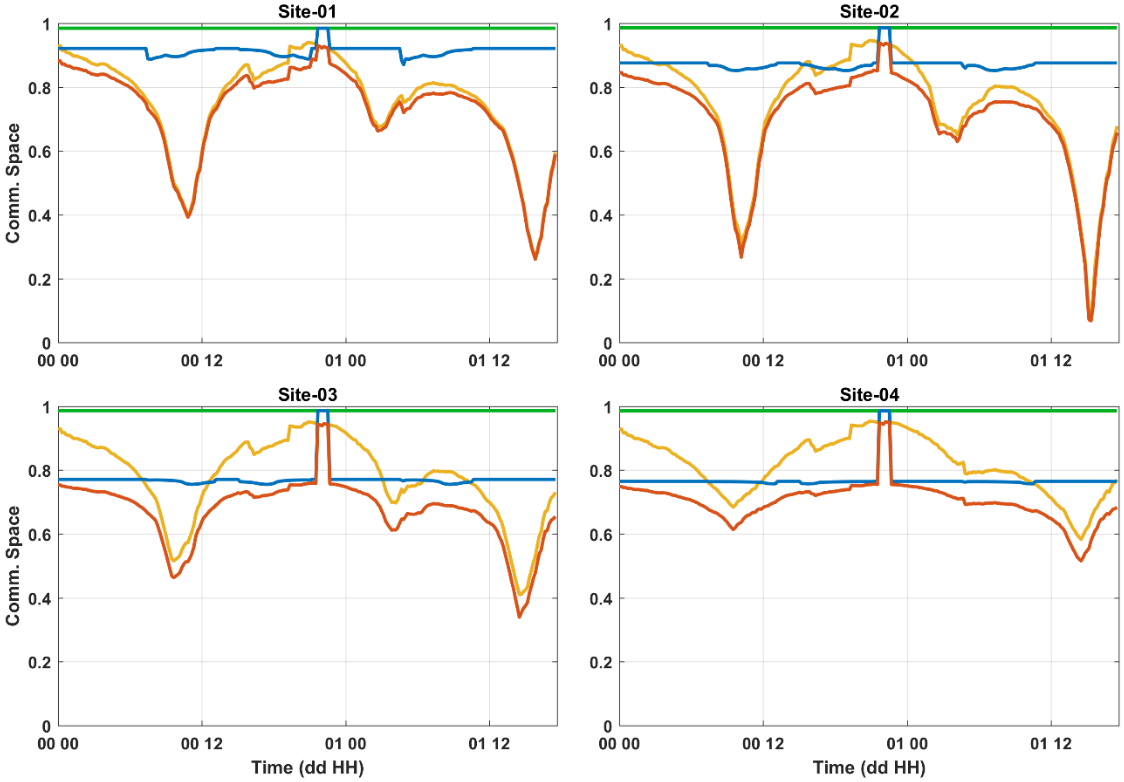


Figure 193. Four-panel results-by-location plot showing the time-varying communication space at each of the four sites for song, high wind, and each of the three noise activity conditions (shipping, drilling ops, and shipping & drilling ops). All metrics are relative to the baseline naturally quiet ambient noise condition (86 dB) in the 71-708 HZ frequency band. Green is high wind, yellow is shipping only, blue is drilling ops only, and red is shipping & drilling ops.

Each of the results-by-activity figures (Figures 194-197) consists of a panel for each of the three noise activity conditions, and each site panel shows communication space data for each of the four sites.

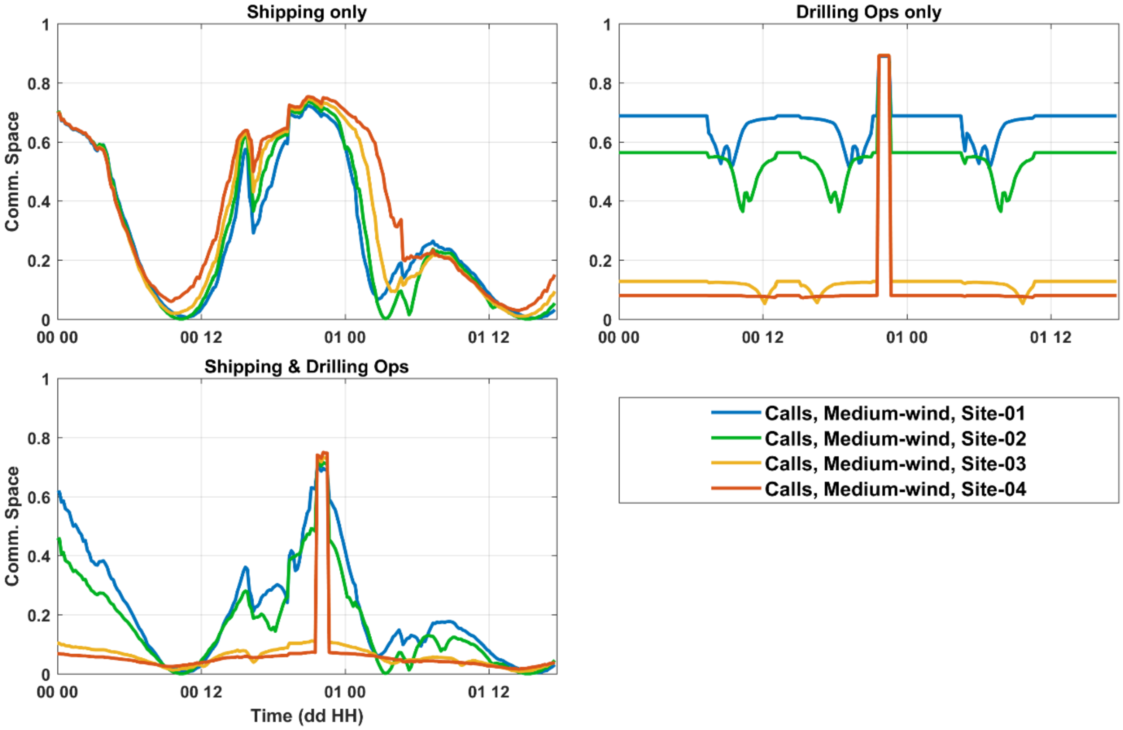


Figure 194. Three-panel results-by-activity plot showing the time-varying communication space for calls, medium wind, and each of the three noise activity conditions (shipping, drilling ops, and shipping & drilling ops). All metrics are relative to the baseline naturally quiet ambient noise condition (86 dB) in the 71-708 HZ frequency band.

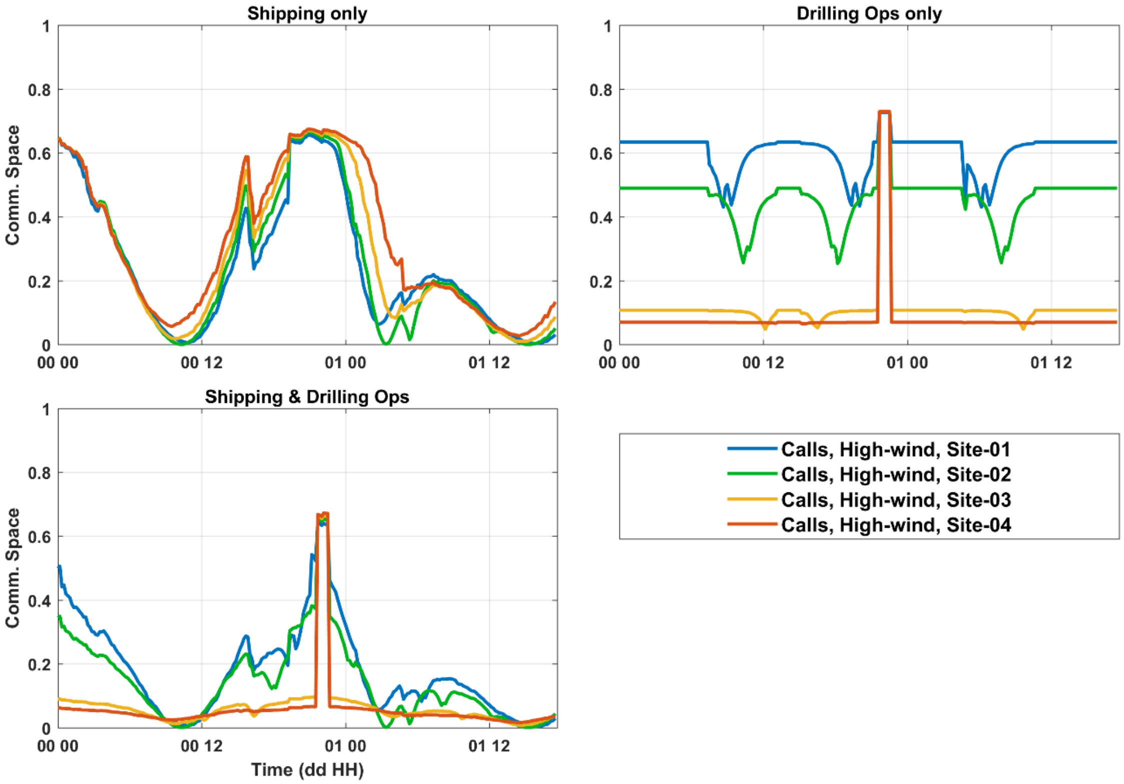


Figure 195. Three-panel results-by-activity plot showing the time-varying communication space for calls, high wind, and each of the three noise activity conditions (shipping, drilling ops, and shipping & drilling ops). All metrics are relative to the baseline naturally quiet ambient noise condition (86 dB) in the 71-708 HZ frequency band.

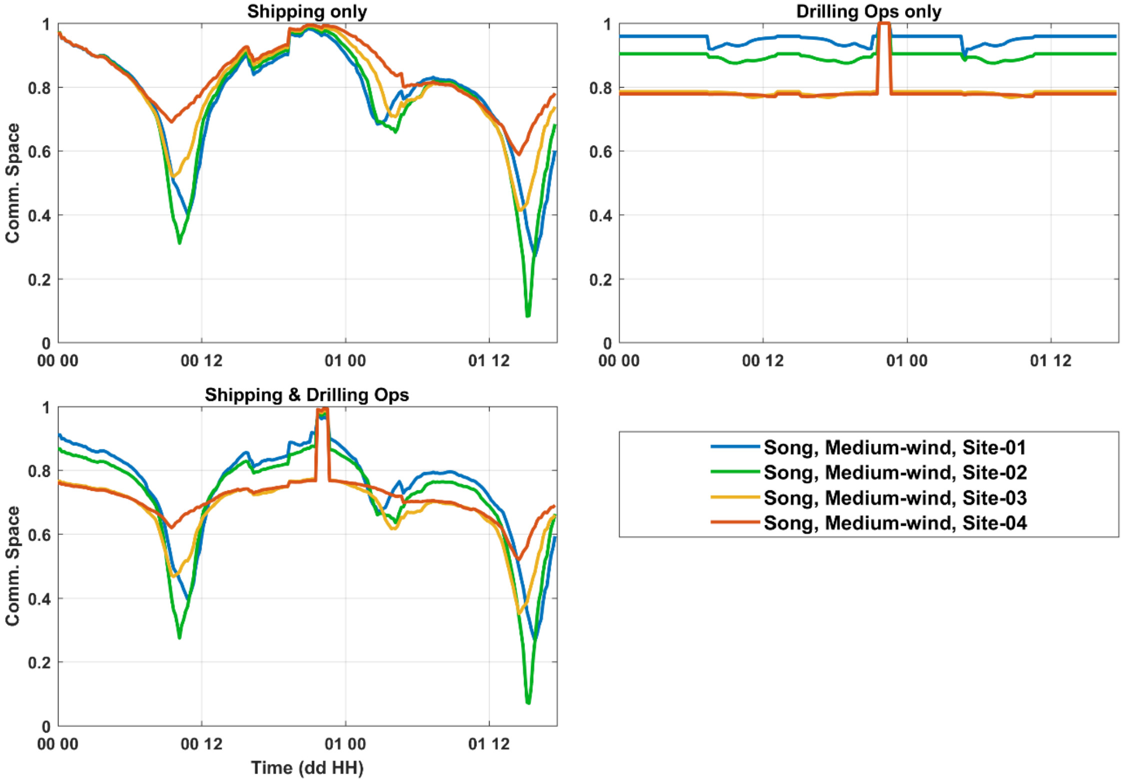


Figure 196. Three-panel results-by-activity plot showing the time-varying communication space for song, medium wind, and each of the three noise activity conditions (shipping, drilling ops, and shipping & drilling ops). All metrics are relative to the baseline naturally quiet ambient noise condition (86 dB) in the 71-708 HZ frequency band.

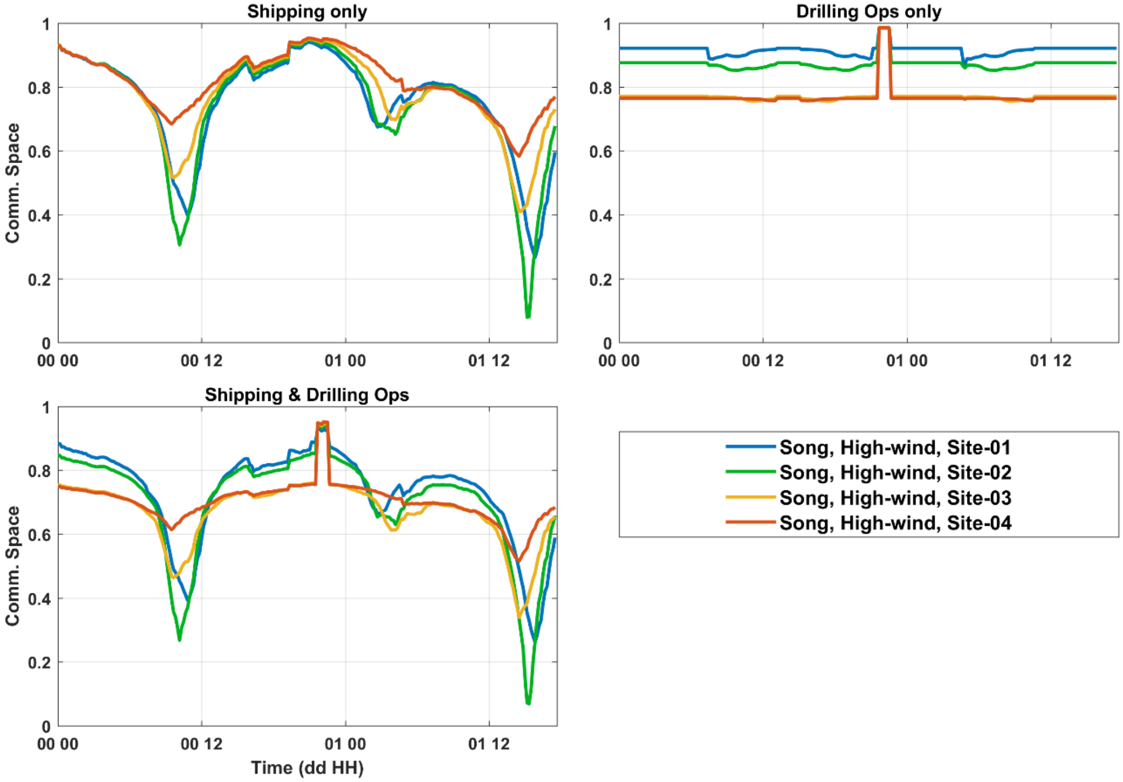
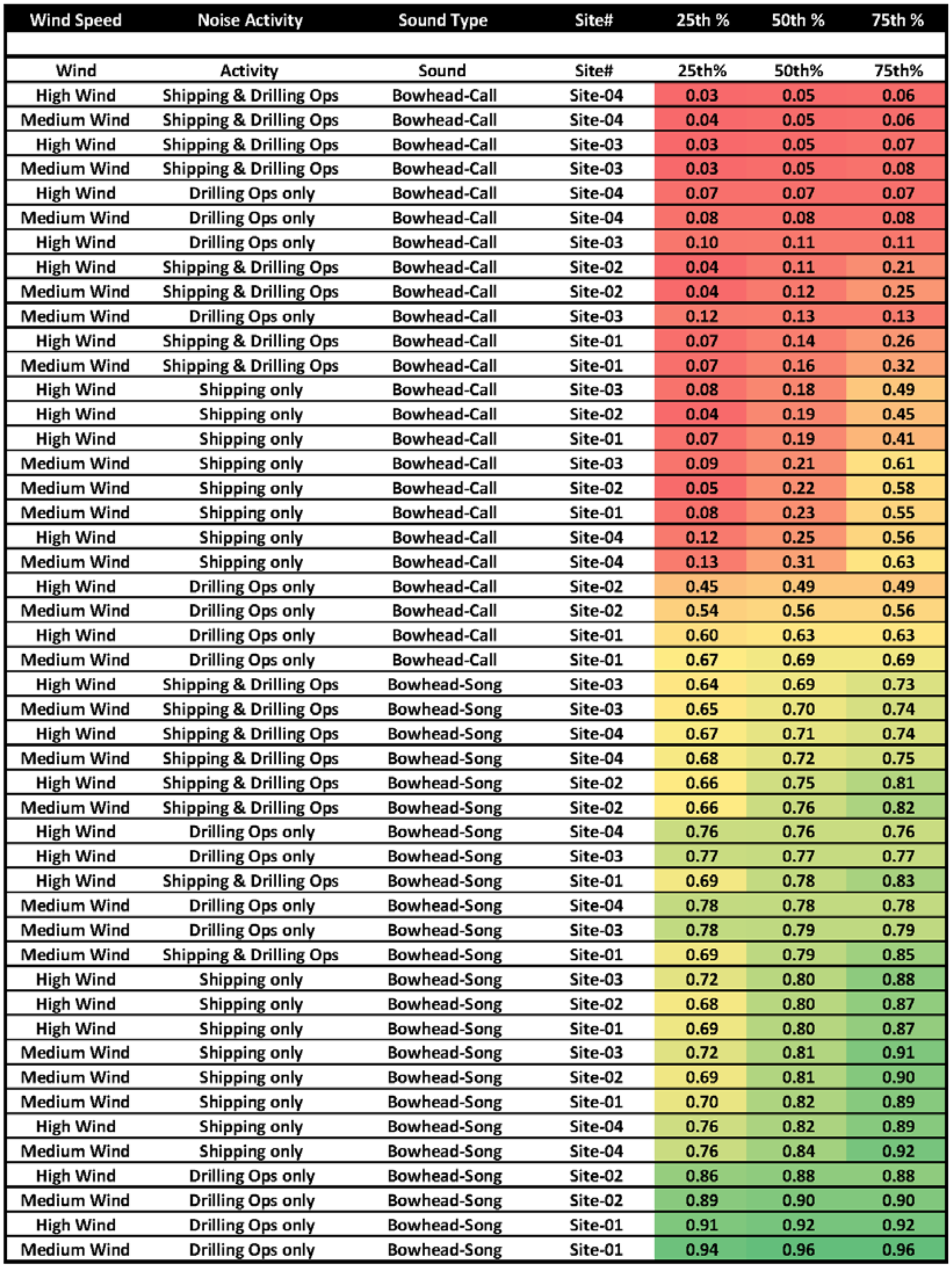


Figure 197. Three-panel results-by-activity plot showing the time-varying communication space for song, high wind, and each of the three noise activity conditions (shipping, drilling ops, and shipping & drilling ops). All metrics are relative to the baseline naturally quiet ambient noise condition (86 dB) in the 71-708 HZ frequency band.

For each of the 48 scenarios we calculated quartile statistics (Table 50, n = 264 10-min samples per scenario).

Table 50. Listing of 25th, 50th, and 75th percentile values for the distributions from each of the 48 communication space model runs. Each run lasted 44 hours and yielded 264 communication space values.



Wind Speed	Noise Activity	Sound Type	Site#	25th %	50th %	75th %
Wind	Activity	Sound	Site#	25th%	50th%	75th%
High Wind	Shipping & Drilling Ops	Bowhead-Call	Site-04	0.03	0.05	0.06
Medium Wind	Shipping & Drilling Ops	Bowhead-Call	Site-04	0.04	0.05	0.06
High Wind	Shipping & Drilling Ops	Bowhead-Call	Site-03	0.03	0.05	0.07
Medium Wind	Shipping & Drilling Ops	Bowhead-Call	Site-03	0.03	0.05	0.08
High Wind	Drilling Ops only	Bowhead-Call	Site-04	0.07	0.07	0.07
Medium Wind	Drilling Ops only	Bowhead-Call	Site-04	0.08	0.08	0.08
High Wind	Drilling Ops only	Bowhead-Call	Site-03	0.10	0.11	0.11
High Wind	Shipping & Drilling Ops	Bowhead-Call	Site-02	0.04	0.11	0.21
Medium Wind	Shipping & Drilling Ops	Bowhead-Call	Site-02	0.04	0.12	0.25
Medium Wind	Drilling Ops only	Bowhead-Call	Site-03	0.12	0.13	0.13
High Wind	Shipping & Drilling Ops	Bowhead-Call	Site-01	0.07	0.14	0.26
Medium Wind	Shipping & Drilling Ops	Bowhead-Call	Site-01	0.07	0.16	0.32
High Wind	Shipping only	Bowhead-Call	Site-03	0.08	0.18	0.49
High Wind	Shipping only	Bowhead-Call	Site-02	0.04	0.19	0.45
High Wind	Shipping only	Bowhead-Call	Site-01	0.07	0.19	0.41
Medium Wind	Shipping only	Bowhead-Call	Site-03	0.09	0.21	0.61
Medium Wind	Shipping only	Bowhead-Call	Site-02	0.05	0.22	0.58
Medium Wind	Shipping only	Bowhead-Call	Site-01	0.08	0.23	0.55
High Wind	Shipping only	Bowhead-Call	Site-04	0.12	0.25	0.56
Medium Wind	Shipping only	Bowhead-Call	Site-04	0.13	0.31	0.63
High Wind	Drilling Ops only	Bowhead-Call	Site-02	0.45	0.49	0.49
Medium Wind	Drilling Ops only	Bowhead-Call	Site-02	0.54	0.56	0.56
High Wind	Drilling Ops only	Bowhead-Call	Site-01	0.60	0.63	0.63
Medium Wind	Drilling Ops only	Bowhead-Call	Site-01	0.67	0.69	0.69
High Wind	Shipping & Drilling Ops	Bowhead-Song	Site-03	0.64	0.69	0.73
Medium Wind	Shipping & Drilling Ops	Bowhead-Song	Site-03	0.65	0.70	0.74
High Wind	Shipping & Drilling Ops	Bowhead-Song	Site-04	0.67	0.71	0.74
Medium Wind	Shipping & Drilling Ops	Bowhead-Song	Site-04	0.68	0.72	0.75
High Wind	Shipping & Drilling Ops	Bowhead-Song	Site-02	0.66	0.75	0.81
Medium Wind	Shipping & Drilling Ops	Bowhead-Song	Site-02	0.66	0.76	0.82
High Wind	Drilling Ops only	Bowhead-Song	Site-04	0.76	0.76	0.76
High Wind	Drilling Ops only	Bowhead-Song	Site-03	0.77	0.77	0.77
High Wind	Shipping & Drilling Ops	Bowhead-Song	Site-01	0.69	0.78	0.83
Medium Wind	Drilling Ops only	Bowhead-Song	Site-04	0.78	0.78	0.78
Medium Wind	Drilling Ops only	Bowhead-Song	Site-03	0.78	0.79	0.79
Medium Wind	Shipping & Drilling Ops	Bowhead-Song	Site-01	0.69	0.79	0.85
High Wind	Shipping only	Bowhead-Song	Site-03	0.72	0.80	0.88
High Wind	Shipping only	Bowhead-Song	Site-02	0.68	0.80	0.87
High Wind	Shipping only	Bowhead-Song	Site-01	0.69	0.80	0.87
Medium Wind	Shipping only	Bowhead-Song	Site-03	0.72	0.81	0.91
Medium Wind	Shipping only	Bowhead-Song	Site-02	0.69	0.81	0.90
Medium Wind	Shipping only	Bowhead-Song	Site-01	0.70	0.82	0.89
High Wind	Shipping only	Bowhead-Song	Site-04	0.76	0.82	0.89
Medium Wind	Shipping only	Bowhead-Song	Site-04	0.76	0.84	0.92
High Wind	Drilling Ops only	Bowhead-Song	Site-02	0.86	0.88	0.88
Medium Wind	Drilling Ops only	Bowhead-Song	Site-02	0.89	0.90	0.90
High Wind	Drilling Ops only	Bowhead-Song	Site-01	0.91	0.92	0.92
Medium Wind	Drilling Ops only	Bowhead-Song	Site-01	0.94	0.96	0.96

Sixteen scenarios were selected to provide a visually-based comparative sense of how the model results for the acoustic environment and the associated signal excess vary as a function of site position, bowhead sound type, wind condition and anthropogenic activity. These 16 example scenarios are based on 10-min samples at each of the four sites, the two bowhead sound conditions (call and song), the two wind conditions (medium and high), and the Shipping &

Drilling Ops condition. We refer to a scenario for the acoustic environment as an acoustic environment scene, and a scenario for the signal excess as a signal excess (SE) scene. Figure 198 shows the pair of scenarios of an acoustic environment scene and a signal excess scene for the same conditions.

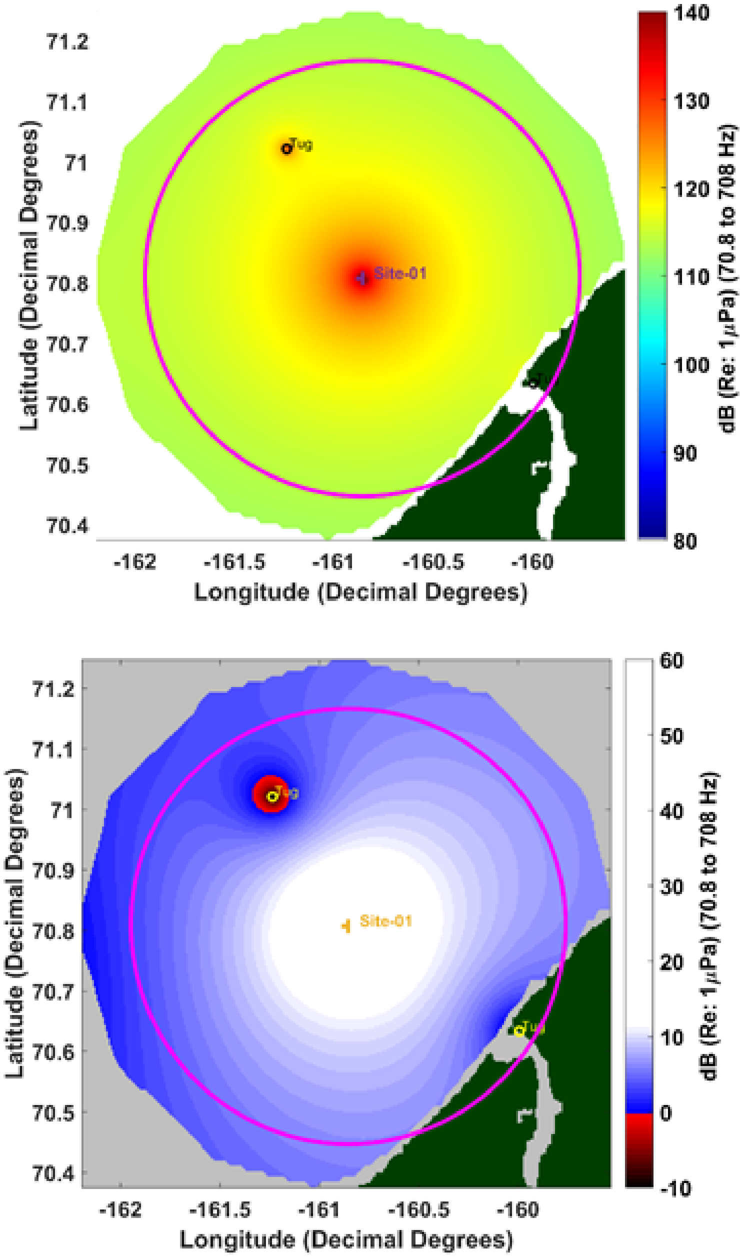


Figure 198. Example of an acoustic environment scene and a signal excess scene under aggregate noise conditions (shipping & drilling ops) for 10-min sample periods in the 71-708 Hz frequency band under bowhead song and high wind condition. The assumed acoustic space in the signal excess scene is shown as a 40 km radius circle. Here we include the acoustic footprints for a representative bowhead song (center of circle), and the acoustic footprints for all shipping & drilling ops activities, although the sites of some of those activities are not located in the scene.

Figure 199 shows all 16 example acoustic environment scenes, and Figure 200 shows the 16 signal excess example scenes. Here we include the acoustic footprints for all Shipping Ops and Drilling Ops activities, although the sites of some of those objects are not located in the scene.

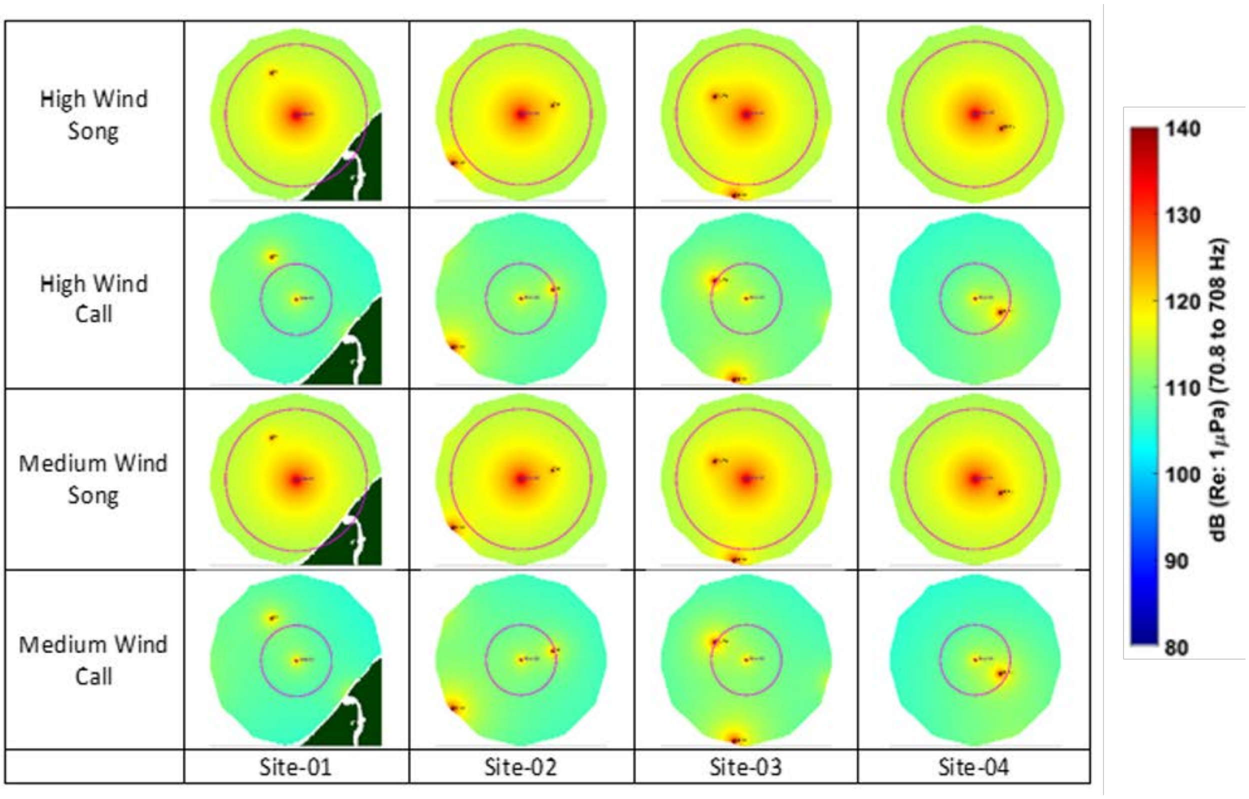


Figure 199. Acoustic environment scenes under aggregate noise conditions (shipping & drilling ops) for 16 10-min sample periods showing bowhead acoustic habitat in the 71-708 Hz frequency band (i.e., bowhead acoustic habitat) for each of the four sites as a function of bowhead sound type (call or song) and wind condition (medium or high). The assumed acoustic spaces over which bowhead calls and songs function are shown as 20 km and 40 km radius circles, respectively. Here we include the acoustic footprints for all shipping & drilling ops activities, although the sites of some of those activities are not located in the scene.

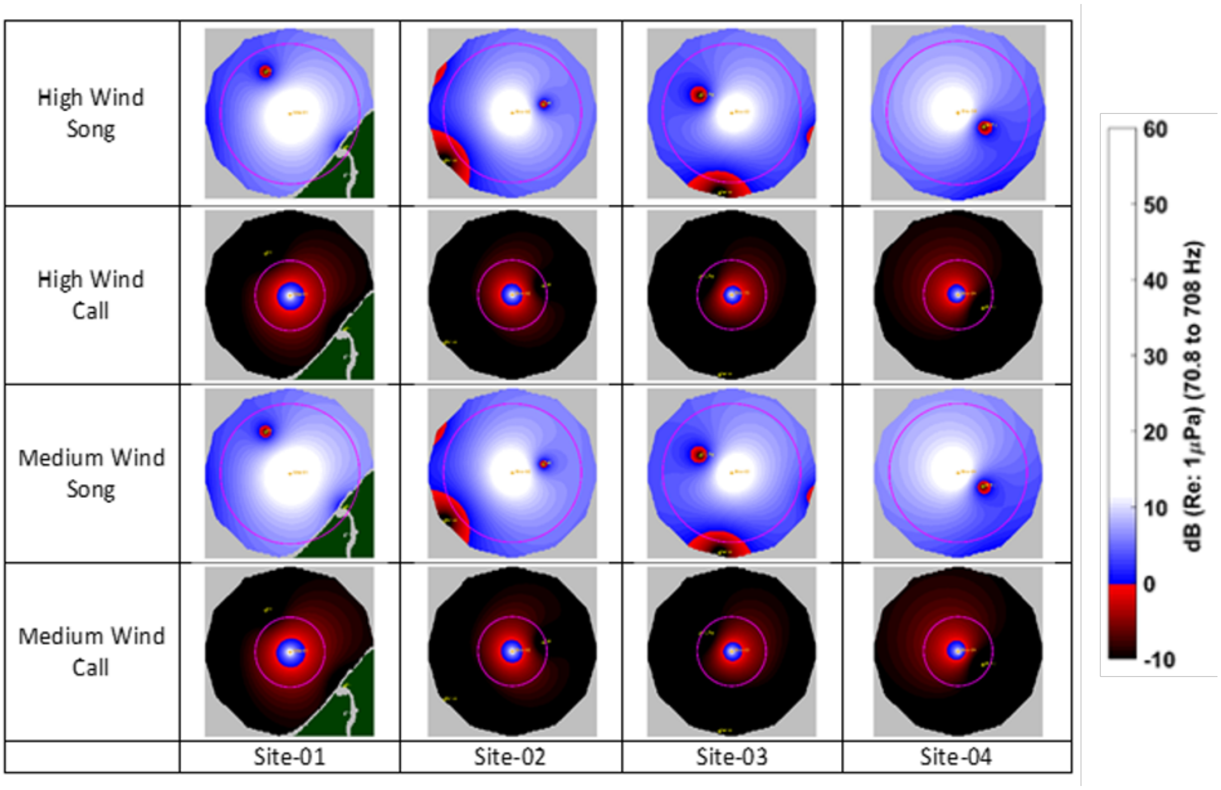


Figure 200. Signal excess scenes under aggregate noise conditions (shipping & drilling ops) for 16 10-min sample periods showing bowhead acoustic habitat in the 71-708 Hz frequency band (i.e., bowhead acoustic habitat) for each of the four sites as a function of bowhead sound type (call or song) and wind condition (medium or high). The assumed acoustic spaces over which bowhead calls and songs function are shown as 20 km and 40 km radius circles, respectively.

In order to explore and compare some of the basic metrics from the 48 model scenarios, we calculated the 5th, 25th, 50th (median), 75th and 90th percentile values from the distribution of each scenario’s communication space measures. The sample size for each was 264: the number of 10-min sample periods within the 44 hour modeling period. The distributions for each of the 48 scenarios were plotted together in order of their lowest to highest median (50th %) communication space values (Figure 201).

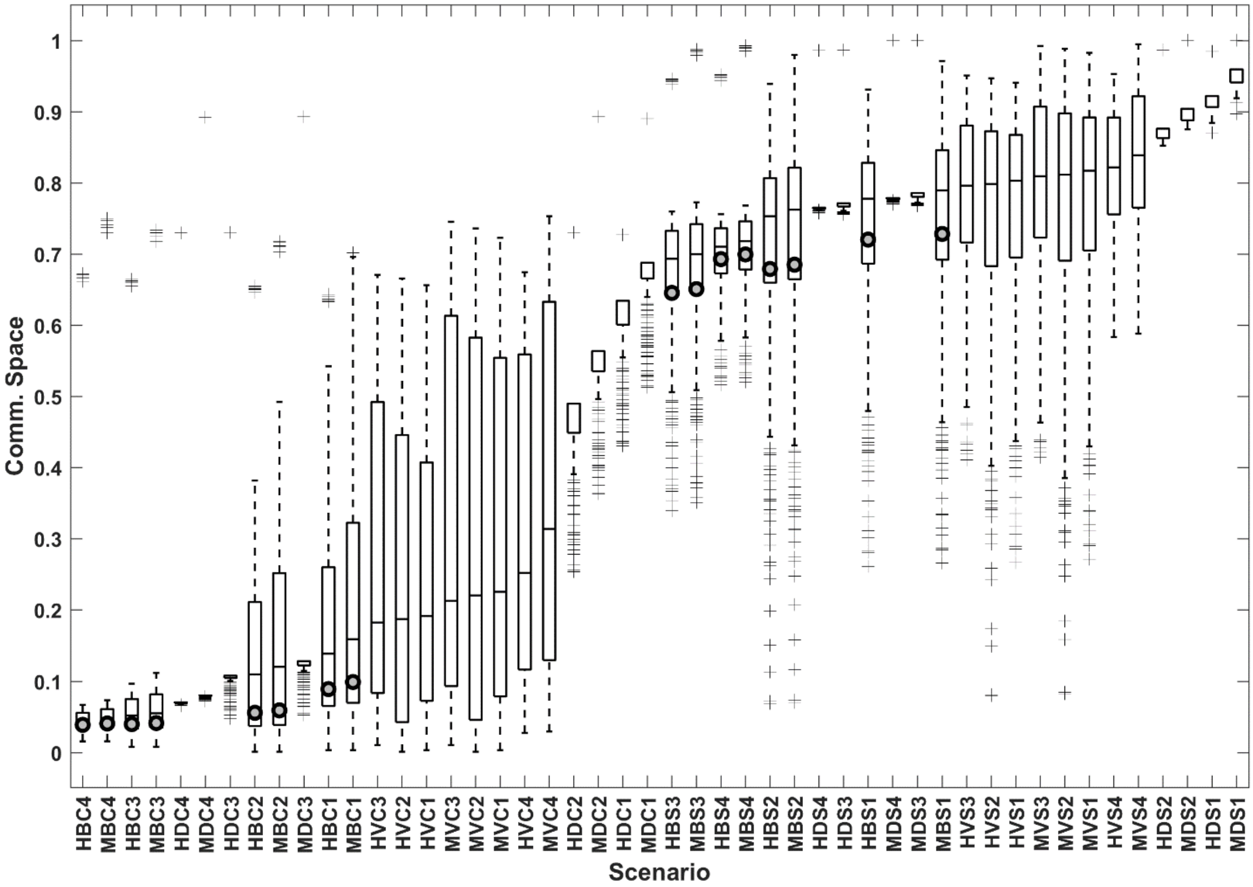


Figure 201. Distribution measures for each of the 48 scenarios. Each scenario is identified with a 4-letter abbreviation (H=high wind, M=medium wind, B=(both) shipping & drilling ops, D=drilling ops, V=(vessel) shipping ops, C=bowhead call, S=bowhead song, 1=Site-01, 2=Site-02, 3=Site-03, 4=Site-04). The circles identify each of the 16 scenarios illustrated in Figure 199 and Figure 200. The position of the circle represents the median communication space value for the 10-min sample from that scenario. The bottom and top edges of the box plot are the 25th % and the 75th %, respectively. The low edge and high edges of the whiskers are the 5th % and 95th %, respectively. The additional extra symbols (e.g., "+", "-", and "1" represent outliers).

4. *Discussion*

The task of modeling future noise conditions by considering future noise from wind, commercial vessel traffic and offshore drilling activities was particularly challenging, but was a fundamental objective of this project and yielded several important results. The analytical tool for conducting these analyses, AET, was developed during the CHAOZ and CHAOZ-X projects.

One can divide the AET process into a physical acoustic stage and a bioacoustic stage. Through multiple and varied applications of the AET in CHAOZ-X and other projects, it is fair to say that the analytical processes (i.e., recipe) for both stages in this exploratory acoustic modeling paradigm are fairly straightforward. However, it is important to note that there are inherent uncertainties, some smaller some larger, in each of the model's analytical steps. In the physical acoustic stage, the type of sound propagation model (e.g., simple propagation model versus range dependent acoustic model) and the empirical fidelity of the model's physical parameters (e.g., seasonal sound velocity profile, ocean substrate) determine most of the uncertainty in the model's results. In the bioacoustic stage, data for the species of concern (e.g., seasonal distribution and density, frequency band, auditory sensitivity) determine most of the uncertainty in the model's results. When considering the combined physical acoustic and bioacoustic stages, the biological uncertainties dominate the model's outcomes.

In these analyses, we deliberately simplified the AET process by considering only the communication space for a low-frequency specialist, the bowhead whale. We assessed changes in bowhead communication space as a function of the frequency band in which most of the energy in its calls and songs occurs and assuming that bowhead acoustic perception in that 71-708 Hz frequency band is relatively uniform. We avoided the challenge of defining a seasonal distribution and density and instead used four sites as proxies for what a bowhead at each site would experience in terms of noise level under 48 scenarios representing different combinations of wind, bowhead sound, anthropogenic and site conditions. All resultant metrics were made relative to an assumed ambient noise condition under a naturally quiet noise condition computed from empirical data collected in the study area.

By this procedure we show relative differences in a simple bioacoustic metric (communication space, CS) that serves as a relative proxy for the area within which a calling or singing bowhead whale can communicate. Eight of the figures provided in the results section (Figures 190-197) are intended to illustrate relative differences in CS as a function of location and as a function of activity. In addition, three figures include 16 snapshots to visualize how an aggregate acoustic noise condition influences CS and signal excess (SE). If one simply scans, or better yet studies these figures one can "see" differences in CS or SE under different noise conditions, but it is difficult to gain a comparative measure of results under all 48 scenarios stacked up. Figure 201 provides that comparative view by showing the distributions of CS values (n = 264) for each of the 48 scenarios, ordered from lowest CS (i.e., greatest loss of communication space) to highest CS (i.e., least loss of communication space).

What Figure 201 shows makes sense, which is a good first-order litmus test for whether or not the simplistic model of a complex problem is useful. At one extreme, in the lower left of Figure 201, distributions represent the seven scenarios with the highest loss of CS (i.e., "worst-case"). These seven have in common the combination of drilling operation and bowhead calling conditions at the two sites closest to the drilling operation (Site-03 and Site-04), and the model predicts very high loss of communication space (> 88%) with very little variation (±1%). At the other extreme, in the upper right of Figure 201, distributions represent the four scenarios with the lowest loss of CS (i.e., "best-case"). These four have in common the combination of no shipping, drilling operation, and bowhead singing conditions at the two sites furthest from the drilling operation (Site-01 and Site-02), and the model predicts the lowest loss of communication space (< 15%) with very little variation (±2%). At either of these extremes, wind condition has a relatively minor influence on CS, while the combination of proximity and drilling operations does.

An obvious feature in the middle portion of Figure 201 is the dramatic shift in communication space as the model shifts from bowhead calling (C) to bowhead singing (S) scenarios. Under all singing scenarios, independent of wind, anthropogenic or site conditions, the loss of communication space is < 27%. This is not surprising because the song condition assumes a 10 dB higher sound level than the call condition and a 6 dB higher value for processing gain, so an overall increase of 16 dB, relative to the calling condition.

Another obvious feature in Figure 201 are the two areas with high levels of variability. Both of these are associated with conditions when vessel noise but no drilling noise are considered. Thus, these scenarios with high levels of variability are a result of vessel movements through the area. These high levels of variability as a result of vessel movement through an area are also apparent in Figures 190-197.

5. Conclusions

One of the most salient conclusions from this modeling exercise is development of fundamental mechanisms for conducting a relative evaluation of combinations of noise factors under a variety of natural and anthropogenic conditions. They provide a logical means by which to assess potential influences of aggregate noise conditions relative to a natural noise condition. In this case, we restricted our model runs to a 2-day period (19-20 May 2014) at four sites using a simple sound propagation model, but such analyses can be readily expanded to longer time periods, a greater number of sites or animats (animats refer to modeled animals, see Frankel et al. 2002). This process follows a standard analytical recipe of convolving sound fields, either from a single source or an aggregate of different sources, with a modeled distribution of animals (i.e., animats). In the modeling exercise here, we did not attempt to judge the biological consequences of the different scenarios, but that step is certainly available for consideration. In summary, the process demonstrated here can serve as a basic mechanism by which agencies can evaluate the relative influences of different aggregate noise conditions on different marine mammals under different behavioral contexts (e.g., communicating, echolocating for food). This ability would be especially valuable for agencies needing to evaluate individual or aggregate impacts from proposed anthropogenic activities on a scale relative to some existing or future ambient noise condition.

6. Recommendations

Given the status and availability of the Acoustic Ecology Toolbox, and the obvious benefits as demonstrated in the outcome of this noise project, the following recommendations are in order:

a) Conduct a modeling exercise that utilizes historic data for a biologically relevant period of time (e.g., fall bowhead migration) and a biologically relevant spatial scale (e.g., eastern Chukchi Sea) for a suite of known conditions (e.g., vessels and drilling operations; can use the Automatic Identification System [AIS]) to compare empirical and predicted noise metrics and compute a predicted assessment of noise scenarios. This exercise would use existing data collected from the various acoustic recorders during the CHAOZ and CHAOZ-X projects and available acoustic data as needed. Vessel track data are available from the AIS, and proxies for vessel noise characteristics are available for similar ships from other regions.

b) Conduct a future noise condition modeling exercise so as to include a biologically relevant period of time (e.g., bowhead migration), a biologically relevant spatial scale (e.g., western Beaufort Sea, eastern Chukchi, Bering Sea) and a suite of reasonable future shipping and offshore energy scenarios.

XII. SUMMARY

A. Overall Summary

This integrative, multi-year study correlated marine mammal distributions with oceanographic parameters and indices of potential prey availability. The technologies utilized allowed us to assess complex trophic interactions and illustrated the benefits of conducting these complex analyses on an annual scale. By including data from the BOEM-funded CHAOZ and ARCWEST datasets, we now have a continuous 5-year dataset with extensive spatial coverage, allowing us to monitor not only the interannual variability in the Arctic, but also document changes to oceanographic and prey parameters, evidenced already in our dataset. A continuation of this dataset will allow us to more fully assess year-round distributions as well as quantify interannual variation, better predict future oceanographic conditions and ecosystem shifts, and evaluate potential impacts of climate change on both lower and upper trophic levels in this rapidly changing environment.

A suite of passive acoustic analysis tools allowed us to characterize seasonal variation in the acoustic environment and the acoustic contributions from different types of sound sources throughout the study areas. These initial results confirm that applying this method to the combined passive acoustic dataset from the CHAOZ and CHAOZ-X projects will provide a comprehensive spatial and temporal characterization of the acoustic environments dominating the monitored regions in the Bering, Chukchi and Beaufort Seas, their key contributing species, and the degree of disturbance caused by vessel and airgun noise.

B. Recommendations for Future Work

The data collected for the CHAOZ-X project demonstrate the utility and benefit of concurrent zooplankton, oceanography, and marine mammal monitoring. These data, combined with those from the BOEM-funded ARCWEST and previously collected for the CHAOZ project, represent the only long-term integrated dataset of its kind from the Chukchi Sea shelf and U.S. Arctic in general. As additional years of data are added, they can be compared with, and then incorporated into, these long-term trends. Given the rate at which the ecosystem is changing, it is imperative that the most current information is available on ecological processes, and their effects on marine mammal spatio-temporal distribution when making management decisions in this region. We therefore recommend continuation of the long-term mooring deployments. With current modifications to the moored TAPS6-NG instruments, we will be able to collect data for a full year, allowing for assessment of trophic interactions on an annual time scale. It will also be possible to establish multi-year patterns in marine mammal distributions as they relate to indices of zooplankton and oceanographic conditions.

We also recommend continuation of the integrated biophysical shipboard surveys conducted during this study. These surveys provide data on the fine-scale vertical resolution of zooplankton abundance as they correlate with oceanographic indices, nutrients, and distribution of marine mammals. To maximize marine mammal detections during shipboard surveys, it is essential to have both passive acoustic monitoring and visual survey components. Since each method is well-suited to particular species, together they provide a more complete picture of marine mammal distribution. In addition, joint passive acoustic/visual survey focal follows enable future calculations of relative abundance. The addition of a benthic ecology component would help to address prey availability for those mammals that feed on benthic epifauna and infauna.

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XV. LIST OF PUBLICATIONS AND PRESENTATIONS

Publications

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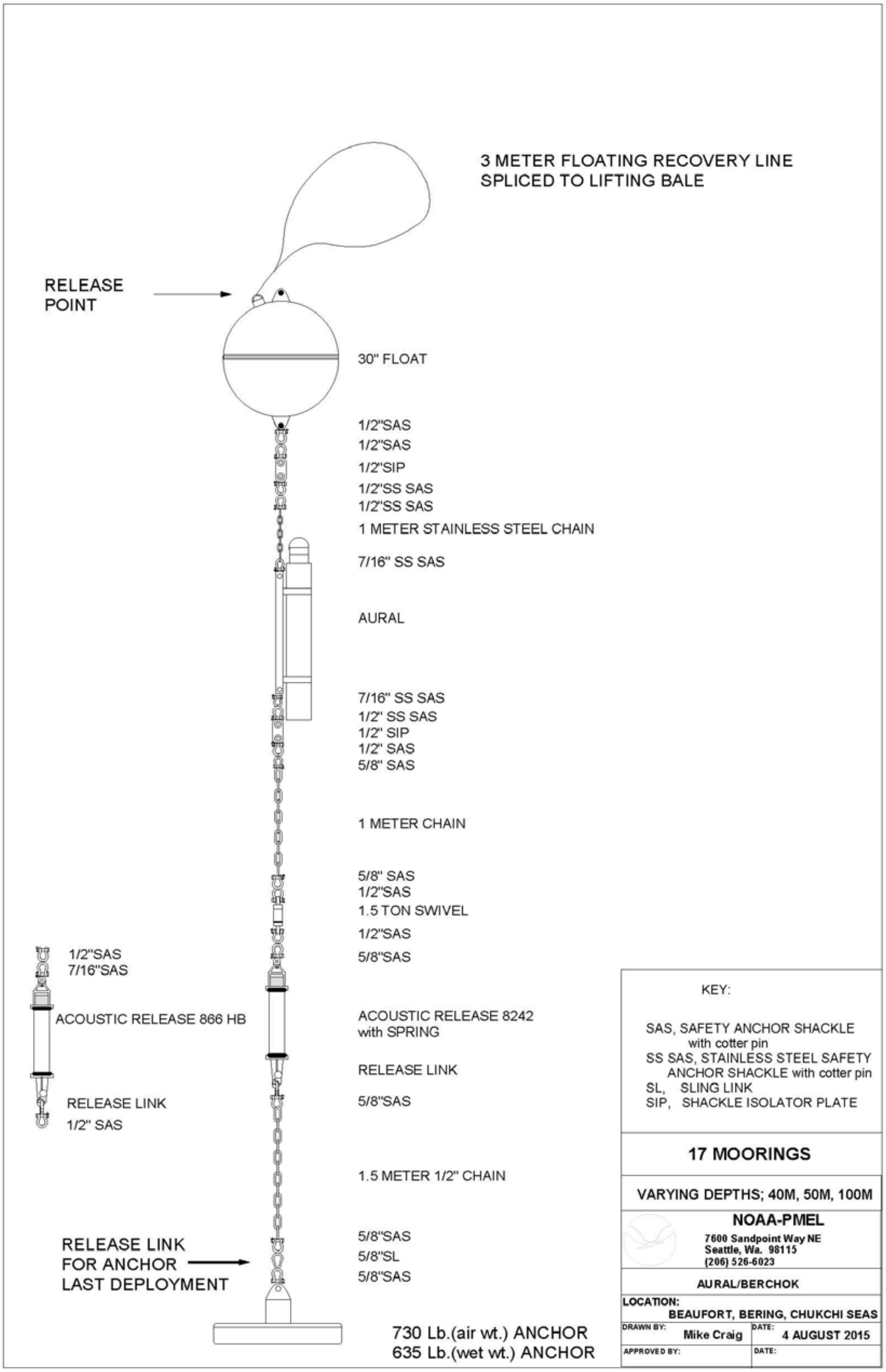
XVI. APPENDICES

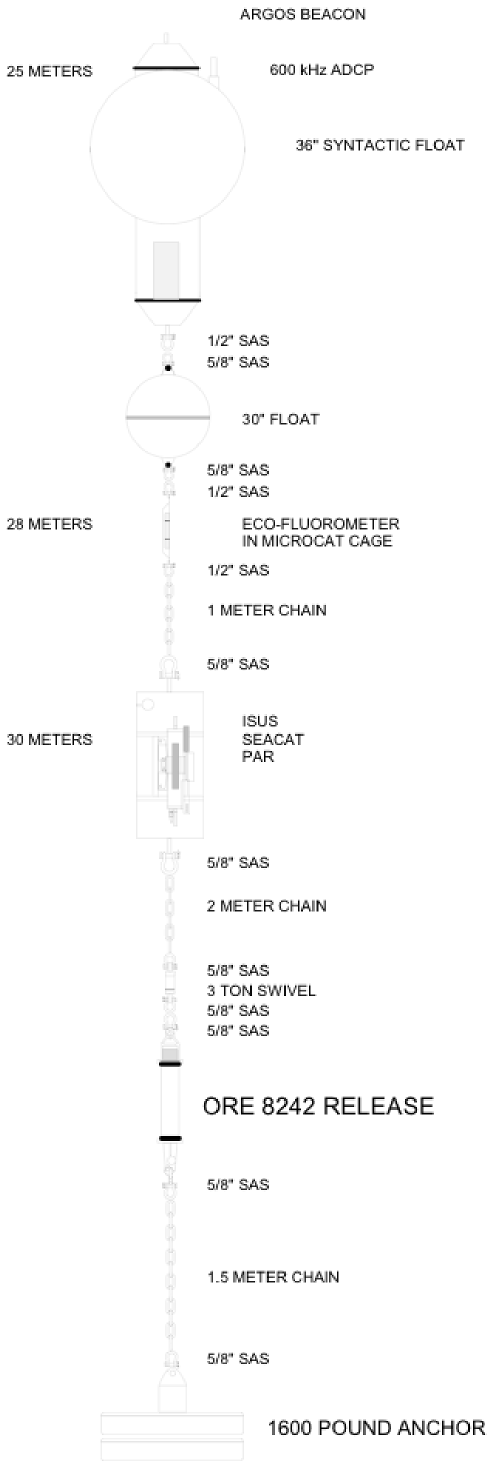
A. Field survey summary table

Year	Start date	End date	Start port location	End port location	Vessel	Captain	Chief Scientist
2013	8/13/2013	9/18/2013	Kodiak, AK	Kodiak, AK	R/V *Aquila*	Kale Garcia	Dr. Catherine Berchok
2014	9/7/2014	10/20/2014	Nome, AK	Dutch Harbor, AK	R/V *Aquila*	Kale Garcia	Dr. Catherine Berchok
2015	8/6/2015	9/4/2015	Kodiak, AK	Dutch Harbor, AK	NOAA ship *Ronald H. Brown*	n/a	Dr. Nancy Kachel/ Dr. Ian Hartwell
2015	9/8/2015	9/28/2015	Nome, AK	Dutch Harbor, AK	R/V *Aquila*	Bruce Greenwood	Dr. Catherine Berchok
2016	9/3/2016	9/29/2016	Nome, AK	Dutch Harbor, AK	R/V *Aquila*	Bruce Greenwood	Dr. Catherine Berchok

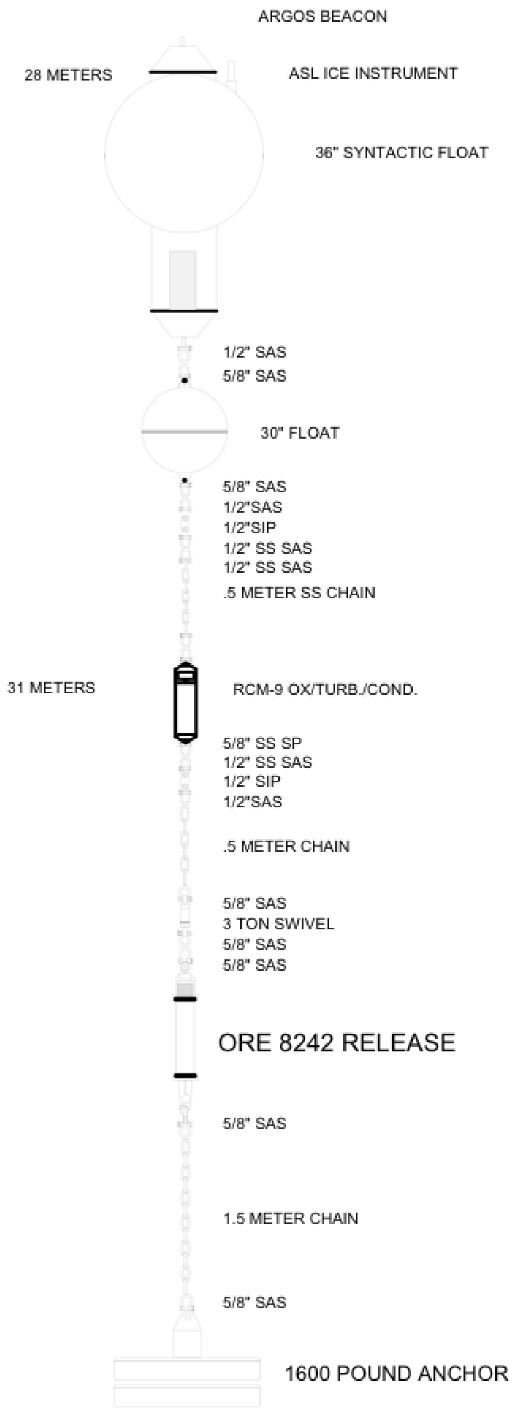
B. Mooring diagrams



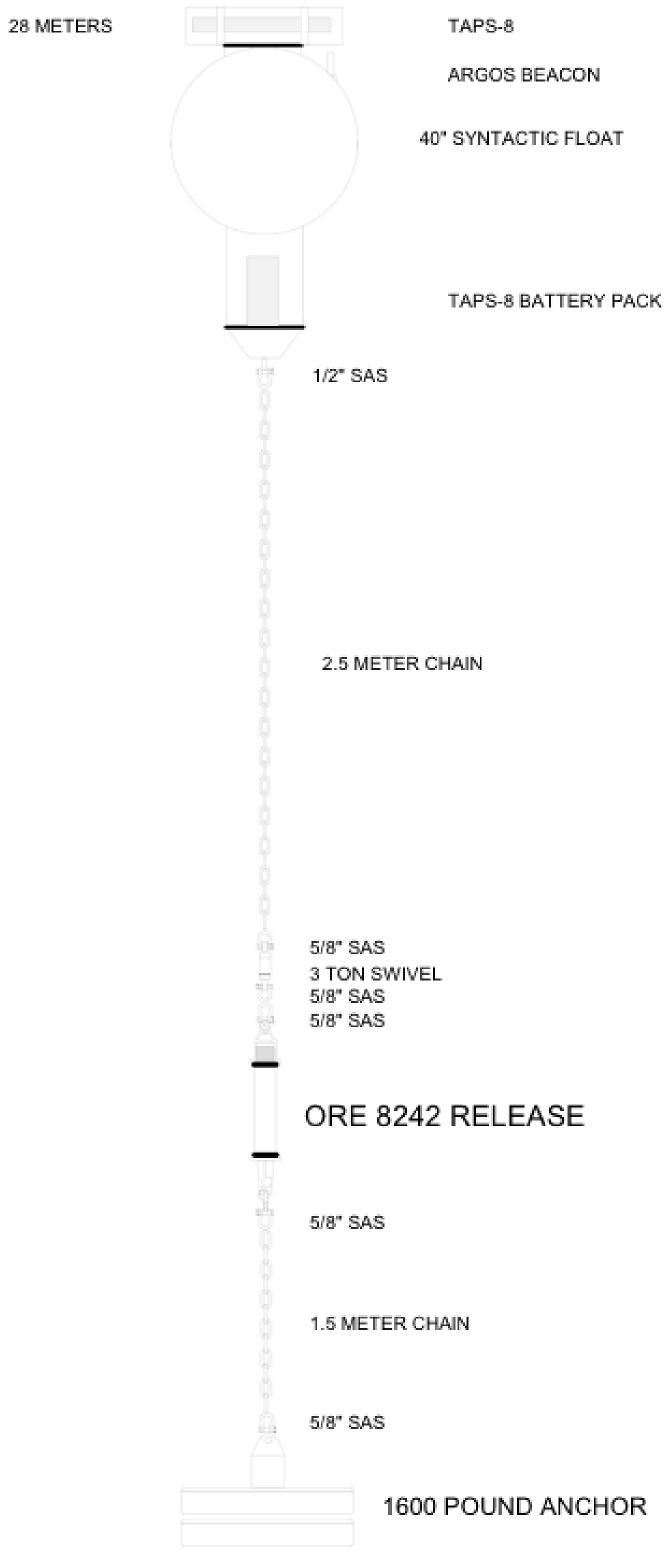
Appendix B. 1. Mooring diagram for passive acoustic recorders.



Appendix B. 2. Mooring design for CKP1A, CKP2A, AND CKP3A. 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).



Appendix B. 3. Mooring design for CKP1A, CKP2A, AND CKP3A. In addition to the ASL ice instrument (measures ice thickness), this mooring contains RCM9 that measures currents at one depth, temperature, oxygen, and turbidity.



Appendix B. 4. Mooring design for the CKT. The TAPS-8 is an instrument that acoustically measures zooplankton biovolume.

C. Long-term passive acoustic data

This appendix lists all the long-term passive acoustic mooring data results. Appendix C. 1 contains the results for all moorings and species/sound sources averaged over year. Appendix C.2 contains the same results, but averaged over all years for each month. Tables Appendix C. 3-16 again contain the same results, but as monthly averages for each year. For all tables, a dash (-) indicates where there was no effort (either no data recordings exist or that species was not analyzed) for that year, month, or day. Also, for Tables Appendix C.1 and C.2, the following abbreviations are used: UnidPin = Unidentified pinniped (this includes all pinniped-type sounds that were not obvious walrus, ribbon seal, or bearded seal), Boing = Minke whale boing call (Rankin and Barlow 2005), Gunshot = gunshot call produced by both North Pacific right whales and bowhead whales (all gunshot calls detected for this study are assumed to be attributed to bowhead whales), DblKnck = double-knock sound. The double-knock sound is a work in progress, it is possible this sound is produced by fish; we have only recently started formally noting its presence.

The following species were not included in Tables Appendix C.1-16: minke whale (non-boing), sperm whale, and right whale; the data were analyzed for these species, but no detections were made. Figures Appendix D.1-3 visualize the data included in Tables Appendix C.3-16. Again, only those species/sound sources that had more than a handful of detections are included here.

Appendix C. 1. Average yearly calling/noise activity 2010-2015 for all detected species/sound sources at all mooring locations. Number of days with calling activity (#), number of days with recordings (Eff), percent of days with calling activity per month (%).

Species	Year	KZ1			PH1			CL1			IC3			IC2			IC1			WT2			HS1			HS2			HS3			WT1			PB1			BF2		
		#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%
Bowhead	2010	-	-	-	-	-	-	-	-	-	60	113	**53**	70	113	**62**	64	113	**57**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	45	103	**44**
Bowhead	2011	-	-	-	-	-	-	-	-	-	40	284	**14**	75	297	**25**	120	298	**40**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	158	363	**44**
Bowhead	2012	64	133	**48**	57	132	**43**	47	131	**36**	82	261	**31**	72	267	**27**	115	363	**32**	61	124	**49**	-	-	-	-	-	-	-	-	-	75	124	**60**	-	-	-	181	334	**54**
Bowhead	2013	134	364	**37**	117	365	**32**	122	365	**33**	97	364	**27**	128	338	**38**	156	365	**43**	58	317	**18**	51	124	**41**	-	-	-	2	64	**3**	177	365	**48**	76	121	**63**	209	363	**58**
Bowhead	2014	157	365	**43**	116	364	**32**	113	364	**31**	84	365	**23**	100	365	**27**	131	365	**36**	40	87	**46**	33	364	**9**	18	89	**20**	62	265	**23**	133	365	**36**	147	364	**40**	156	364	**43**
Bowhead	2015	120	264	**45**	91	264	**34**	86	263	**33**	42	260	**16**	30	256	**12**	79	261	**30**	10	260	**4**	16	259	**6**	15	259	**6**	-	-	-	96	256	**38**	103	257	**40**	130	257	**51**
Beluga	2010	-	-	-	-	-	-	-	-	-	8	113	**7**	23	113	**20**	26	113	**23**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	35	103	**34**
Beluga	2011	-	-	-	-	-	-	-	-	-	19	284	**7**	32	297	**11**	71	298	**24**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	363	**28**
Beluga	2012	25	133	**19**	48	132	**36**	20	131	**15**	30	261	**11**	36	267	**13**	71	363	**20**	2	124	**2**	-	-	-	-	-	-	-	-	-	27	124	**22**	-	-	-	166	334	**50**
Beluga	2013	63	364	**17**	135	365	**37**	33	237	**14**	57	364	**16**	67	338	**20**	86	365	**24**	36	317	**11**	4	124	**3**	-	-	-	12	64	**19**	74	365	**20**	32	121	**26**	174	363	**48**
Beluga	2014	86	365	**24**	118	364	**32**	-	-	-	92	365	**25**	68	365	**19**	100	365	**27**	3	87	**3**	10	364	**3**	3	89	**3**	103	263	**39**	100	364	**27**	93	364	**26**	163	364	**45**
Beluga	2015	48	264	**18**	53	263	**20**	-	-	-	21	260	**8**	30	256	**12**	73	261	**28**	35	260	**13**	15	259	**6**	19	259	**7**	-	-	-	56	250	**22**	55	257	**21**	125	257	**49**
Bearded	2010	-	-	-	-	-	-	-	-	-	26	113	**23**	52	113	**46**	64	113	**57**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	68	103	**66**
Bearded	2011	-	-	-	-	-	-	-	-	-	224	284	**79**	252	297	**85**	258	298	**87**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	225	363	**62**
Bearded	2012	45	133	**34**	74	132	**56**	67	131	**51**	226	261	**87**	226	267	**85**	234	363	**64**	86	124	**69**	-	-	-	-	-	-	-	-	-	74	124	**60**	-	-	-	287	334	**86**
Bearded	2013	221	364	**61**	265	365	**73**	165	237	**70**	223	364	**61**	261	338	**77**	188	365	**52**	228	317	**72**	65	124	**52**	-	-	-	5	64	**8**	253	365	**69**	96	121	**79**	277	363	**76**
Bearded	2014	227	365	**62**	250	364	**69**	-	-	-	203	365	**56**	275	365	**75**	228	365	**62**	68	87	**78**	215	364	**59**	12	89	**13**	151	263	**57**	258	364	**71**	296	364	**81**	247	364	**68**
Bearded	2015	163	264	**62**	163	263	**62**	-	-	-	177	260	**68**	180	256	**70**	176	261	**67**	189	260	**73**	193	259	**75**	181	259	**70**	-	-	-	177	250	**71**	213	257	**83**	215	257	**84**
Walrus	2010	-	-	-	-	-	-	-	-	-	38	113	**34**	20	113	**18**	35	113	**31**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	103	**2**
Walrus	2011	-	-	-	-	-	-	-	-	-	106	284	**37**	76	297	**26**	110	298	**37**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	363	**0**
Walrus	2012	18	133	**14**	13	132	**10**	18	131	**14**	76	261	**29**	21	267	**8**	79	363	**22**	43	124	**35**	-	-	-	-	-	-	-	-	-	1	124	**1**	-	-	-	7	334	**2**
Walrus	2013	109	364	**30**	52	365	**14**	59	365	**16**	81	364	**22**	68	338	**20**	97	365	**27**	122	317	**38**	60	124	**48**	-	-	-	0	64	**0**	50	365	**14**	6	121	**5**	31	363	**9**
Walrus	2014	133	365	**36**	37	364	**10**	55	364	**15**	88	365	**24**	69	365	**19**	85	365	**23**	9	87	**10**	136	364	**37**	15	89	**17**	0	265	**0**	70	365	**19**	83	364	**23**	7	364	**2**
Walrus	2015	131	264	**50**	21	264	**8**	50	263	**19**	45	260	**17**	32	256	**13**	33	261	**13**	94	260	**36**	119	259	**46**	94	259	**36**	-	-	-	43	256	**17**	29	257	**11**	10	257	**4**
Gray	2010	-	-	-	-	-	-	-	-	-	0	113	**0**	1	113	**1**	6	113	**5**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	103	**0**
Gray	2011	-	-	-	-	-	-	-	-	-	0	284	**0**	0	297	**0**	5	298	**2**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	363	**0**
Gray	2012	2	133	**2**	50	132	**38**	5	131	**4**	0	261	**0**	0	267	**0**	13	363	**4**	0	124	**0**	-	-	-	-	-	-	-	-	-	0	124	**0**	-	-	-	0	334	**0**
Gray	2013	17	364	**5**	121	365	**33**	1	365	**0**	0	364	**0**	0	338	**0**	1	365	**0**	0	317	**0**	0	124	**0**	-	-	-	0	64	**0**	0	365	**0**	3	121	**2**	0	363	**0**
Gray	2014	57	365	**16**	128	364	**35**	0	364	**0**	1	365	**0**	0	365	**0**	0	365	**0**	0	87	**0**	1	364	**0**	0	89	**0**	0	265	**0**	1	365	**0**	16	364	**4**	0	364	**0**
Gray	2015	31	264	**12**	57	264	**22**	45	263	**17**	1	260	**0**	0	256	**0**	0	261	**0**	0	260	**0**	0	259	**0**	0	259	**0**	-	-	-	1	256	**0**	49	257	**19**	0	257	**0**
Humpback	2010	-	-	-	-	-	-	-	-	-	0	113	**0**	0	113	**0**	0	113	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	103	**0**
Humpback	2011	-	-	-	-	-	-	-	-	-	0	284	**0**	0	297	**0**	0	298	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	363	**0**
Humpback	2012	50	133	**38**	31	132	**23**	6	131	**5**	0	261	**0**	0	267	**0**	0	363	**0**	0	124	**0**	-	-	-	-	-	-	-	-	-	0	124	**0**	-	-	-	0	334	**0**
Humpback	2013	67	364	**18**	76	365	**21**	11	365	**3**	0	364	**0**	0	338	**0**	0	365	**0**	0	317	**0**	0	124	**0**	-	-	-	0	64	**0**	3	365	**1**	0	121	**0**	0	363	**0**
Humpback	2014	71	365	**19**	18	364	**5**	2	364	**1**	1	365	**0**	0	365	**0**	0	365	**0**	0	87	**0**	0	364	**0**	0	89	**0**	0	265	**0**	1	365	**0**	0	364	**0**	0	364	**0**
Humpback	2015	18	264	**7**	9	264	**3**	25	263	**10**	0	260	**0**	0	256	**0**	0	261	**0**	0	260	**0**	0	259	**0**	0	259	**0**	-	-	-	2	256	**1**	0	257	**0**	0	257	**0**
Gunshot	2010	-	-	-	-	-	-	-	-	-	38	113	**34**	13	113	**12**	13	113	**12**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	103	**0**
Gunshot	2011	-	-	-	-	-	-	-	-	-	20	284	**7**	12	297	**4**	34	298	**11**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	363	**1**
Gunshot	2012	3	133	**2**	32	132	**24**	37	131	**28**	58	261	**22**	36	267	**13**	28	363	**8**	49	124	**40**	-	-	-	-	-	-	-	-	-	34	124	**27**	-	-	-	2	334	**1**
Gunshot	2013	8	364	**2**	51	365	**14**	51	365	**14**	36	364	**10**	12	338	**4**	16	365	**4**	5	317	**2**	1	124	**1**	-	-	-	0	64	**0**	29	365	**8**	12	121	**10**	11	363	**3**
Gunshot	2014	1	365	**0**	58	364	**16**	21	364	**6**	40	365	**11**	30	365	**8**	24	365	**7**	21	87	**24**	5	364	**1**	13	89	**15**	0	265	**0**	17	365	**5**	29	364	**8**	12	364	**3**
Gunshot	2015	0	264	**0**	24	264	**9**	18	263	**7**	52	260	**20**	6	256	**2**	1	261	**0**	6	260	**2**	1	259	**0**	5	259	**2**	-	-	-	6	256	**2**	34	257	**13**	4	257	**2**

Appendix C.1 (cont.). Average yearly calling/noise activity 2010-2015 for all detected species/sound sources at all mooring locations. Number of days with calling activity (#), number of days with recordings (Eff), percent of days with calling activity per month (%).

Species	Year	KZ1			PH1			CL1			IC3			IC2			IC1			WT2			HS1			HS2			HS3			WT1			PB1			BF2		
		#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%
Fin	2010	-	-	-	-	-	-	-	-	-	0	113	0	0	113	0	0	113	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fin	2011	-	-	-	-	-	-	-	-	-	0	284	0	0	297	0	0	298	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fin	2012	-	-	-	51	132	39	27	131	21	0	135	0	0	140	0	0	235	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fin	2013	-	-	-	78	365	21	51	365	14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fin	2014	-	-	-	34	258	13	29	267	11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fin	2015	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ribbon	2010	-	-	-	-	-	-	-	-	-	0	113	0	0	113	0	0	113	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	103	10
Ribbon	2011	-	-	-	-	-	-	-	-	-	0	284	0	0	297	0	1	298	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	25	363	7
Ribbon	2012	3	133	2	29	132	22	20	131	15	4	261	2	3	267	1	1	363	0	1	124	1	0	-	-	-	-	-	-	-	-	3	124	2	-	-	-	22	334	7
Ribbon	2013	0	364	0	10	365	3	0	237	0	2	364	1	8	338	2	4	365	1	5	317	2	2	124	2	-	-	-	4	64	6	3	365	1	1	121	1	48	363	13
Ribbon	2014	0	365	0	0	364	0	-	-	-	4	365	1	3	365	1	5	365	1	0	87	0	0	364	0	0	89	0	13	263	5	1	364	0	0	364	0	13	364	4
Ribbon	2015	7	264	3	2	263	1	-	-	-	0	260	0	0	256	0	0	261	0	0	260	0	0	259	0	0	259	0	-	-	-	0	250	0	1	257	0	0	257	0
Killer	2010	-	-	-	-	-	-	-	-	-	0	113	0	0	113	0	0	113	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	103	0
Killer	2011	-	-	-	-	-	-	-	-	-	0	284	0	0	297	0	4	298	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	363	0
Killer	2012	1	133	1	17	132	13	0	131	0	1	261	0	1	267	0	2	363	1	0	124	0	-	-	-	-	-	-	-	-	-	1	124	1	-	-	-	4	334	1
Killer	2013	29	364	8	39	365	11	0	237	0	0	364	0	0	338	0	2	365	1	2	317	1	0	124	0	-	-	-	0	64	0	0	365	0	7	121	6	2	363	1
Killer	2014	45	365	12	34	364	9	-	-	-	0	365	0	0	365	0	0	365	0	0	87	0	0	364	0	0	89	0	0	263	0	0	364	0	9	364	2	0	364	0
Killer	2015	19	264	7	20	263	8	-	-	-	0	260	0	0	256	0	0	261	0	1	260	0	1	259	0	0	259	0	-	-	-	0	250	0	0	257	0	1	257	0
Boing	2010	-	-	-	-	-	-	-	-	-	0	113	0	0	113	0	0	113	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	103	0
Boing	2011	-	-	-	-	-	-	-	-	-	0	284	0	0	297	0	2	298	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	363	0
Boing	2012	2	133	2	0	132	0	11	131	8	0	261	0	0	267	0	0	363	0	0	124	0	-	-	-	-	-	-	-	-	-	0	124	0	-	-	-	0	334	0
Boing	2013	2	364	1	1	365	0	0	237	0	0	364	0	0	338	0	0	365	0	0	317	0	0	124	0	-	-	-	0	64	0	0	365	0	0	121	0	0	363	0
Boing	2014	0	365	0	1	364	0	-	-	-	0	365	0	0	365	0	0	365	0	0	87	0	0	364	0	0	89	0	0	263	0	0	364	0	0	364	0	0	364	0
Boing	2015	0	264	0	0	263	0	-	-	-	0	260	0	0	256	0	0	261	0	0	260	0	0	259	0	0	259	0	-	-	-	0	250	0	0	257	0	0	257	0
UnidPin	2010	-	-	-	-	-	-	-	-	-	0	113	0	3	113	3	10	113	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	13	103	13
UnidPin	2011	-	-	-	-	-	-	-	-	-	2	284	1	25	297	8	45	298	15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8	363	2
UnidPin	2012	0	133	0	6	132	5	7	131	5	8	261	3	22	267	8	83	363	23	5	124	4	-	-	-	-	-	-	-	-	-	18	124	15	-	-	-	18	334	5
UnidPin	2013	1	364	0	35	365	10	32	365	9	7	364	2	24	338	7	66	365	18	16	317	5	7	124	6	-	-	-	2	64	3	61	365	17	3	121	2	9	363	2
UnidPin	2014	2	365	1	26	364	7	48	364	13	77	365	21	14	365	4	71	365	19	7	87	8	50	364	14	2	89	2	3	265	1	45	365	12	41	364	11	35	364	10
UnidPin	2015	13	264	5	7	264	3	7	263	3	22	260	8	7	256	3	30	261	11	33	260	13	47	259	18	12	259	5	-	-	-	27	256	11	12	257	5	12	257	5
DblKnck	2010	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	103	3
DblKnck	2011	-	-	-	-	-	-	-	-	-	0	125	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	363	0
DblKnck	2012	-	-	-	-	-		12	131	9	0	261	0	-	-	-	2	129	2	2	124	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	211	1
DblKnck	2013	-	-	-	-	-		79	365	22	0	364	0	-	-	-	61	365	17	51	240	21	0	124	0	-	-	-	-	-	-	0	125	0	0	121	0	-	-	-
DblKnck	2014	-	-	-	0	106	0	106	364	29	0	269	0	-	-	-	125	365	34	0	87	0	0	364	0	0	89	0	-	-	-	0	365	0	46	364	13	-	-	-
DblKnck	2015	-	-	-	0	264	0	89	263	34	0	0		-	-	-	47	261	18	45	260	17	35	259	14	38	259	15	-	-	-	0	256	0	34	257	13	-	-	-

Appendix C.1 (cont.). Average yearly calling/noise activity 2010-2015 for all detected species/sound sources at all mooring locations. Number of days with calling activity (#), number of days with recordings (Eff), percent of days with calling activity per month (%).

Species	Year	KZ1			PH1			CL1			IC3			IC2			IC1			WT2			HS1			HS2			HS3			WT1			PB1			BF2		
		#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**
Airgun	2010	-	-	-	-	-	-	-	-	-	20	113	**18**	21	113	**19**	21	113	**19**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	103	**6**
Airgun	2011	-	-	-	-	-	-	-	-	-	21	284	**7**	22	297	**7**	14	298	**5**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	23	363	**6**
Airgun	2012	0	133	**0**	3	132	**2**	7	131	**5**	3	261	**1**	2	267	**1**	2	363	**1**	2	124	**2**	-	-	-	-	-	-	-	-	-	2	124	**2**	-	-	-	50	334	**15**
Airgun	2013	0	364	**0**	6	365	**2**	24	365	**7**	60	364	**16**	53	338	**16**	56	365	**15**	38	317	**12**	46	124	**37**	-	-	-	1	64	**2**	38	365	**10**	34	121	**28**	21	363	**6**
Airgun	2014	0	365	**0**	0	364	**0**	0	364	**0**	4	365	**1**	4	365	**1**	2	365	**1**	5	87	**6**	0	364	**0**	1	89	**1**	6	265	**2**	2	365	**1**	4	364	**1**	20	364	**5**
Airgun	2015	0	264	**0**	0	264	**0**	0	263	**0**	5	260	**2**	0	256	**0**	0	261	**0**	0	260	**0**	0	259	**0**	0	259	**0**	-	-	-	0	256	**0**	2	257	**1**	0	257	**0**
Vessel	2010	-	-	-	-	-	-	-	-	-	0	113	**0**	2	113	**2**	11	113	**10**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	14	103	**14**
Vessel	2011	-	-	-	-	-	-	-	-	-	6	284	**2**	15	297	**5**	5	298	**2**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	15	363	**4**
Vessel	2012	33	133	**25**	27	132	**20**	35	131	**27**	31	261	**12**	67	267	**25**	77	363	**21**	36	124	**29**	-	-	-	-	-	-	-	-	-	42	124	**34**	-	-	-	41	334	**12**
Vessel	2013	61	364	**17**	47	365	**13**	31	365	**8**	30	364	**8**	22	338	**7**	62	365	**17**	7	317	**2**	27	124	**22**	-	-	-	7	64	**11**	46	365	**13**	18	121	**15**	29	363	**8**
Vessel	2014	64	365	**18**	33	364	**9**	18	364	**5**	4	365	**1**	5	365	**1**	31	365	**8**	2	87	**2**	7	364	**2**	2	89	**2**	2	265	**1**	36	365	**10**	82	364	**23**	33	364	**9**
Vessel	2015	58	264	**22**	58	264	**22**	47	263	**18**	29	260	**11**	55	256	**21**	75	261	**29**	15	260	**6**	0	259	**0**	4	259	**2**	-	-	-	58	256	**23**	53	257	**21**	8	257	**3**
Ice	2010	-	-	-	-	-	-	-	-	-	25	113	**22**	34	113	**30**	29	113	**26**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	60	103	**58**
Ice	2011	-	-	-	-	-	-	-	-	-	88	284	**31**	57	297	**19**	109	298	**37**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	194	363	**53**
Ice	2012	23	133	**17**	40	132	**30**	41	131	**31**	110	261	**42**	136	267	**51**	222	363	**61**	54	124	**44**	-	-	-	-	-	-	-	-	-	49	124	**40**	-	-	-	238	334	**71**
Ice	2013	121	364	**33**	130	365	**36**	123	237	**52**	254	364	**70**	238	338	**70**	131	365	**36**	215	317	**68**	64	124	**52**	-	-	-	43	64	**67**	129	365	**35**	40	121	**33**	268	363	**74**
Ice	2014	124	365	**34**	149	364	**41**	-	-	-	244	365	**67**	237	365	**65**	135	365	**37**	56	87	**64**	290	364	**80**	62	89	**70**	183	263	**70**	124	364	**34**	194	364	**53**	262	364	**72**
Ice	2015	106	264	**40**	127	263	**48**	-	-	-	170	260	**65**	177	256	**69**	102	261	**39**	169	260	**65**	141	259	**54**	105	259	**41**	-	-	-	143	250	**57**	145	257	**56**	211	257	**82**

Appendix C.2. Average monthly calling activity 2010-2015 for all detected species/sound sources at all mooring locations. Number of days with calling activity (#), number of days with recordings (Eff), percent of days with calling activity per month (%).

Species	Month	KZ1			PH1			CL1			IC3			IC2			IC1			WT2			HS1			HS2			HS3			WT1			PB1			BF2		
		#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%
Bowhead	Jan	68	93	**73**	46	93	**49**	30	93	**32**	0	155	**0**	4	155	**3**	7	155	**5**	0	62	**0**	0	62	**0**	0	31	**0**	0	31	**0**	4	93	**4**	0	62	**0**	1	155	**1**
Bowhead	Feb	34	84	**40**	12	84	**14**	1	84	**1**	0	141	**0**	0	141	**0**	0	141	**0**	0	56	**0**	0	56	**0**	0	28	**0**	0	28	**0**	1	84	**1**	1	56	**2**	0	141	**0**
Bowhead	Mar	40	93	**43**	20	93	**22**	5	93	**5**	0	155	**0**	2	155	**1**	5	155	**3**	0	62	**0**	0	62	**0**	0	31	**0**	0	31	**0**	0	93	**0**	10	62	**16**	2	155	**1**
Bowhead	Apr	86	90	**96**	78	90	**87**	59	90	**66**	0	150	**0**	7	150	**5**	70	150	**47**	0	60	**0**	0	60	**0**	1	30	**3**	0	30	**0**	67	90	**74**	49	60	**82**	96	150	**64**
Bowhead	May	63	93	**68**	71	93	**76**	91	93	**98**	2	138	**1**	34	143	**24**	138	155	**89**	8	62	**13**	6	62	**10**	2	31	**6**	19	31	**61**	90	93	**97**	58	62	**94**	152	155	**98**
Bowhead	Jun	7	90	**8**	5	90	**6**	22	90	**24**	2	98	**2**	31	111	**28**	70	147	**48**	10	60	**17**	2	60	**3**	3	30	**10**	13	30	**43**	47	90	**52**	37	60	**62**	135	150	**90**
Bowhead	Jul	0	93	**0**	1	93	**1**	3	93	**3**	19	93	**20**	21	93	**23**	53	124	**43**	0	62	**0**	4	62	**6**	0	31	**0**	19	31	**61**	37	93	**40**	38	62	**61**	114	153	**75**
Bowhead	Aug	0	103	**0**	0	103	**0**	0	102	**0**	35	99	**35**	7	74	**9**	9	121	**7**	0	63	**0**	6	64	**9**	1	31	**3**	7	31	**23**	11	95	**12**	17	62	**27**	65	123	**53**
Bowhead	Sep	0	111	**0**	9	110	**8**	0	109	**0**	54	158	**34**	48	154	**31**	31	157	**20**	18	77	**23**	32	76	**42**	8	16	**50**	4	22	**18**	66	103	**64**	40	72	**56**	107	142	**75**
Bowhead	Oct	6	93	**6**	15	93	**16**	17	93	**18**	120	155	**77**	137	155	**88**	108	155	**70**	78	88	**89**	40	61	**66**	17	28	**61**	0	3	**0**	67	93	**72**	44	62	**71**	133	155	**86**
Bowhead	Nov	79	90	**88**	47	90	**52**	76	90	**84**	125	150	**83**	132	150	**88**	125	150	**83**	48	74	**65**	10	60	**17**	1	30	**3**	2	30	**7**	70	90	**78**	22	60	**37**	71	150	**47**
Bowhead	Dec	92	93	**99**	77	93	**83**	64	93	**69**	48	155	**31**	52	155	**34**	49	155	**32**	7	62	**11**	0	62	**0**	0	31	**0**	0	31	**0**	21	93	**23**	10	62	**16**	3	155	**2**
Beluga	Jan	10	93	**11**	20	93	**22**	0	31	**0**	11	155	**7**	5	155	**3**	5	155	**3**	1	62	**2**	1	62	**2**	0	31	**0**	0	31	**0**	2	93	**2**	6	62	**10**	17	155	**11**
Beluga	Feb	7	84	**8**	4	84	**5**	0	28	**0**	5	141	**4**	6	141	**4**	3	141	**2**	2	56	**4**	0	56	**0**	0	28	**0**	2	28	**7**	0	84	**0**	4	56	**7**	1	141	**1**
Beluga	Mar	36	93	**39**	41	93	**44**	3	31	**10**	4	155	**3**	9	155	**6**	13	155	**8**	2	62	**3**	0	62	**0**	0	31	**0**	0	31	**0**	1	93	**1**	5	62	**8**	5	155	**3**
Beluga	Apr	67	90	**74**	71	90	**79**	20	30	**67**	42	150	**28**	60	150	**40**	94	150	**63**	15	60	**25**	5	60	**8**	4	30	**13**	9	30	**30**	52	90	**58**	31	60	**52**	74	150	**49**
Beluga	May	24	93	**26**	62	93	**67**	9	31	**29**	40	138	**29**	59	143	**41**	114	155	**74**	22	62	**35**	9	62	**15**	8	31	**26**	26	31	**84**	66	93	**71**	39	62	**63**	132	155	**85**
Beluga	Jun	1	90	**1**	9	90	**10**	1	30	**3**	22	98	**22**	24	111	**22**	38	147	**26**	15	60	**25**	4	60	**7**	1	30	**3**	5	30	**17**	29	90	**32**	9	60	**15**	62	150	**41**
Beluga	Jul	1	93	**1**	0	93	**0**	0	31	**0**	6	93	**6**	5	93	**5**	9	124	**7**	3	62	**5**	2	62	**3**	4	31	**13**	22	31	**71**	13	89	**15**	21	62	**34**	122	153	**80**
Beluga	Aug	0	103	**0**	0	103	**0**	0	34	**0**	3	99	**3**	2	74	**3**	3	121	**2**	1	63	**2**	0	64	**0**	2	31	**6**	28	31	**90**	4	94	**4**	8	62	**13**	91	123	**74**
Beluga	Sep	1	111	**1**	2	109	**2**	0	30	**0**	2	158	**1**	3	154	**2**	8	157	**5**	1	77	**1**	0	76	**0**	0	16	**0**	11	20	**55**	7	102	**7**	4	72	**6**	78	142	**55**
Beluga	Oct	3	93	**3**	14	93	**15**	0	31	**0**	24	155	**15**	22	155	**14**	53	155	**34**	8	88	**9**	5	61	**8**	3	28	**11**	2	3	**67**	37	93	**40**	26	62	**42**	103	155	**66**
Beluga	Nov	45	90	**50**	85	90	**94**	19	30	**63**	59	150	**39**	51	150	**34**	77	150	**51**	5	74	**7**	2	60	**3**	0	30	**0**	10	30	**33**	42	90	**47**	24	60	**40**	66	150	**44**
Beluga	Dec	27	93	**29**	46	93	**49**	1	31	**3**	9	155	**6**	10	155	**6**	10	155	**6**	1	62	**2**	1	62	**2**	0	31	**0**	0	31	**0**	4	92	**4**	3	62	**5**	12	155	**8**
Bearded	Jan	89	93	**96**	90	93	**97**	25	31	**81**	136	155	**88**	153	155	**99**	143	155	**92**	59	62	**95**	56	62	**90**	26	31	**84**	14	31	**45**	84	93	**90**	58	62	**94**	130	155	**84**
Bearded	Feb	73	84	**87**	81	84	**96**	28	28	**100**	126	141	**89**	139	141	**99**	135	141	**96**	56	56	**100**	56	56	**100**	28	28	**100**	21	28	**75**	84	84	**100**	56	56	**100**	141	141	**100**
Bearded	Mar	93	93	**100**	93	93	**100**	30	31	**97**	149	155	**96**	155	155	**100**	155	155	**100**	62	62	**100**	62	62	**100**	31	31	**100**	25	31	**81**	93	93	**100**	62	62	**100**	154	155	**99**
Bearded	Apr	90	90	**100**	90	90	**100**	30	30	**100**	150	150	**100**	150	150	**100**	150	150	**100**	60	60	**100**	60	60	**100**	29	30	**97**	29	30	**97**	90	90	**100**	60	60	**100**	149	150	**99**
Bearded	May	93	93	**100**	93	93	**100**	31	31	**100**	138	138	**100**	143	143	**100**	155	155	**100**	62	62	**100**	62	62	**100**	31	31	**100**	31	31	**100**	93	93	**100**	62	62	**100**	155	155	**100**
Bearded	Jun	45	90	**50**	46	90	**51**	21	30	**70**	95	98	**97**	111	111	**100**	132	147	**90**	60	60	**100**	60	60	**100**	30	30	**100**	29	30	**97**	88	90	**98**	57	60	**95**	150	150	**100**
Bearded	Jul	0	93	**0**	2	93	**2**	0	31	**0**	4	93	**4**	13	93	**14**	18	124	**15**	3	62	**5**	13	62	**21**	6	31	**19**	2	31	**6**	16	89	**18**	18	62	**29**	58	153	**38**
Bearded	Aug	1	103	**1**	1	103	**1**	0	34	**0**	8	99	**8**	12	74	**16**	11	121	**9**	4	63	**6**	1	64	**2**	0	31	**0**	0	31	**0**	13	94	**14**	33	62	**53**	39	123	**32**
Bearded	Sep	1	111	**1**	6	109	**6**	4	30	**13**	55	158	**35**	57	154	**37**	21	157	**13**	19	77	**25**	14	76	**18**	0	16	**0**	0	20	**0**	43	102	**42**	56	72	**78**	87	142	**61**
Bearded	Oct	69	93	**74**	81	93	**87**	24	31	**77**	60	155	**39**	78	155	**50**	52	155	**34**	66	88	**75**	27	61	**44**	6	28	**21**	0	3	**0**	44	93	**47**	49	62	**79**	77	155	**50**
Bearded	Nov	63	90	**70**	90	90	**100**	24	30	**80**	45	150	**30**	104	150	**69**	64	150	**43**	62	74	**84**	22	60	**37**	1	30	**3**	0	30	**0**	41	90	**46**	42	60	**70**	63	150	**42**
Bearded	Dec	39	93	**42**	79	93	**85**	15	31	**48**	113	155	**73**	131	155	**85**	112	155	**72**	58	62	**94**	40	62	**65**	5	31	**16**	5	31	**16**	73	92	**79**	52	62	**84**	116	155	**75**
Walrus	Jan	40	93	**43**	0	93	**0**	0	93	**0**	26	155	**17**	1	155	**1**	5	155	**3**	0	62	**0**	5	62	**8**	0	31	**0**	0	31	**0**	0	93	**0**	1	62	**2**	1	155	**1**
Walrus	Feb	36	84	**43**	2	84	**2**	1	84	**1**	50	141	**35**	1	141	**1**	6	141	**4**	0	56	**0**	2	56	**4**	0	28	**0**	0	28	**0**	0	84	**0**	3	56	**5**	1	141	**1**
Walrus	Mar	71	93	**76**	7	93	**8**	3	93	**3**	40	155	**26**	2	155	**1**	18	155	**12**	1	62	**2**	3	62	**5**	0	31	**0**	0	31	**0**	1	93	**1**	2	62	**3**	7	155	**5**
Walrus	Apr	57	90	**63**	0	90	**0**	2	90	**2**	23	150	**15**	9	150	**6**	16	150	**11**	0	60	**0**	5	60	**8**	0	30	**0**	0	30	**0**	2	90	**2**	9	60	**15**	3	150	**2**
Walrus	May	81	93	**87**	37	93	**40**	11	93	**12**	11	138	**8**	5	143	**3**	13	155	**8**	0	62	**0**	10	62	**16**	0	31	**0**	0	31	**0**	0	93	**0**	8	62	**13**	2	155	**1**
Walrus	Jun	46	90	**51**	45	90	**50**	74	90	**82**	42	98	**43**	75	111	**68**	99	147	**67**	39	60	**65**	34	60	**57**	18	30	**60**	0	30	**0**	33	90	**37**	26	60	**43**	2	150	**1**
Walrus	Jul	0	93	**0**	3	93	**3**	16	93	**17**	71	93	**76**	54	93	**58**	89	124	**72**	62	62	**100**	62	62	**100**	30	31	**97**	0	31	**0**	55	93	**59**	36	62	**58**	20	153	**13**
Walrus	Aug	3	103	**3**	6	103	**6**	4	102	**4**	34	99	**34**	8	74	**11**	25	121	**21**	62	63	**98**	64	64	**100**	31	31	**100**	0	31	**0**	42	95	**44**	14	62	**23**	12	123	**10**
Walrus	Sep	3	111	**3**	10	110	**9**	31	109	**28**	58	158	**37**	62	154	**40**	80	157	**51**	70	77	**91**	73	76	**96**	15	16	**94**	0	22	**0**	23	103	**22**	7	72	**10**	2	142	**1**
Walrus	Oct	0	93	**0**	7	93	**8**	39	93	**42**	35	155	**23**	43	155	**28**	45	155	**29**	30	88	**34**	32	61	**52**	12	28	**43**	0	3	**0**	5	93	**5**	2	62	**3**	0	155	**0**
Walrus	Nov	9	90	**10**	2	90	**2**	1	90	**1**	12	150	**8**	21	150	**14**	26	150	**17**	4	74	**5**	12	60	**20**	2	30	**7**	0	30	**0**	2	90	**2**	8	60	**13**	2	150	**1**
Walrus	Dec	45	93	**48**	4	93	**4**	0	93	**0**	32	155	**21**	5	155	**3**	17	155	**11**	0	62	**0**	13	62	**21**	1	31	**3**	0	31	**0**	1	93	**1**	2	62	**3**	5	155	**3**

Appendix C.2. (cont.). Average monthly calling activity 2010-2015 for all detected species/sound sources at all mooring locations. Number of days with calling activity (#), number of days with recordings (Eff), percent of days with calling activity per month (%).

Species	Month	KZ1			PH1			CL1			IC3			IC2			IC1			WT2			HS1			HS2			HS3			WT1			PB1			BF2		
		#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%
Gray	Jan	0	93	0	0	93	0	0	93	0	0	155	0	0	155	0	0	155	0	0	62	0	0	62	0	0	31	0	0	31	0	0	93	0	0	62	0	0	155	0
Gray	Feb	0	84	0	0	84	0	0	84	0	0	141	0	0	141	0	0	141	0	0	56	0	0	56	0	0	28	0	0	28	0	0	84	0	0	56	0	0	141	0
Gray	Mar	1	93	1	0	93	0	0	93	0	0	155	0	0	155	0	0	155	0	0	62	0	0	62	0	0	31	0	0	31	0	0	93	0	1	62	2	0	155	0
Gray	Apr	5	90	6	0	90	0	1	90	1	0	150	0	0	150	0	0	150	0	0	60	0	0	60	0	0	30	0	0	30	0	0	90	0	3	60	5	0	150	0
Gray	May	2	93	2	0	93	0	1	93	1	0	138	0	0	143	0	2	155	1	0	62	0	0	62	0	0	31	0	0	31	0	0	93	0	3	62	5	0	155	0
Gray	Jun	34	90	38	31	90	34	10	90	11	0	98	0	0	111	0	3	147	2	0	60	0	0	60	0	0	30	0	0	30	0	0	90	0	5	60	8	0	150	0
Gray	Jul	28	93	30	83	93	89	9	93	10	1	93	1	0	93	0	5	124	4	0	62	0	1	62	2	0	31	0	0	31	0	1	93	1	22	62	35	0	153	0
Gray	Aug	20	103	19	88	103	85	18	102	18	1	99	1	0	74	0	1	121	1	0	63	0	0	64	0	0	31	0	0	31	0	1	95	1	19	62	31	0	123	0
Gray	Sep	10	111	9	88	110	80	10	109	9	0	158	0	0	154	0	2	157	1	0	77	0	0	76	0	0	16	0	0	22	0	0	103	0	11	72	15	0	142	0
Gray	Oct	3	93	3	62	93	67	2	93	2	0	155	0	1	155	1	8	155	5	0	88	0	0	61	0	0	28	0	0	3	0	0	93	0	3	62	5	0	155	0
Gray	Nov	4	90	4	4	90	4	0	90	0	0	150	0	0	150	0	4	150	3	0	74	0	0	60	0	0	30	0	0	30	0	0	90	0	1	60	2	0	150	0
Gray	Dec	0	93	0	0	93	0	0	93	0	0	155	0	0	155	0	0	155	0	0	62	0	0	62	0	0	31	0	0	31	0	0	93	0	0	62	0	0	155	0
Humpback	Jan	0	93	0	0	93	0	0	93	0	0	155	0	0	155	0	0	155	0	0	62	0	0	62	0	0	31	0	0	31	0	0	93	0	0	62	0	0	155	0
Humpback	Feb	0	84	0	0	84	0	0	84	0	0	141	0	0	141	0	0	141	0	0	56	0	0	56	0	0	28	0	0	28	0	0	84	0	0	56	0	0	141	0
Humpback	Mar	0	93	0	0	93	0	0	93	0	0	155	0	0	155	0	0	155	0	0	62	0	0	62	0	0	31	0	0	31	0	0	93	0	0	62	0	0	155	0
Humpback	Apr	0	90	0	0	90	0	0	90	0	0	150	0	0	150	0	0	150	0	0	60	0	0	60	0	0	30	0	0	30	0	0	90	0	0	60	0	0	150	0
Humpback	May	0	93	0	1	93	1	0	93	0	0	138	0	0	143	0	0	155	0	0	62	0	0	62	0	0	31	0	0	31	0	0	93	0	0	62	0	0	155	0
Humpback	Jun	9	90	10	3	90	3	3	90	3	0	98	0	0	111	0	0	147	0	0	60	0	0	60	0	0	30	0	0	30	0	1	90	1	0	60	0	0	150	0
Humpback	Jul	30	93	32	23	93	25	15	93	16	0	93	0	0	93	0	0	124	0	0	62	0	0	62	0	0	31	0	0	31	0	2	93	2	0	62	0	0	153	0
Humpback	Aug	49	103	48	40	103	39	17	102	17	1	99	1	0	74	0	0	121	0	0	63	0	0	64	0	0	31	0	0	31	0	0	95	0	0	62	0	0	123	0
Humpback	Sep	66	111	59	56	110	51	5	109	5	0	158	0	0	154	0	0	157	0	0	77	0	0	76	0	0	16	0	0	22	0	0	103	0	0	72	0	0	142	0
Humpback	Oct	50	93	54	10	93	11	4	93	4	0	155	0	0	155	0	0	155	0	0	88	0	0	61	0	0	28	0	0	3	0	3	93	3	0	62	0	0	155	0
Humpback	Nov	2	90	2	1	90	1	0	90	0	0	150	0	0	150	0	0	150	0	0	74	0	0	60	0	0	30	0	0	30	0	0	90	0	0	60	0	0	150	0
Humpback	Dec	0	93	0	0	93	0	0	93	0	0	155	0	0	155	0	0	155	0	0	62	0	0	62	0	0	31	0	0	31	0	0	93	0	0	62	0	0	155	0
Gunshot	Jan	0	93	0	9	93	10	32	93	34	43	155	28	5	155	3	2	155	1	3	62	5	0	62	0	2	31	6	0	31	0	12	93	13	0	62	0	0	155	0
Gunshot	Feb	0	84	0	0	84	0	8	84	10	16	141	11	0	141	0	0	141	0	0	56	0	0	56	0	0	28	0	0	28	0	3	84	4	1	56	2	0	141	0
Gunshot	Mar	1	93	1	0	93	0	2	93	2	9	155	6	0	155	0	0	155	0	0	62	0	0	62	0	0	31	0	0	31	0	2	93	2	0	62	0	0	155	0
Gunshot	Apr	0	90	0	0	90	0	0	90	0	0	150	0	0	150	0	2	150	1	0	60	0	0	60	0	0	30	0	0	30	0	3	90	3	3	60	5	0	150	0
Gunshot	May	0	93	0	0	93	0	0	93	0	0	138	0	0	143	0	9	155	6	0	62	0	0	62	0	0	31	0	0	31	0	0	93	0	10	62	16	0	155	0
Gunshot	Jun	3	90	3	5	90	6	10	90	11	0	98	0	0	111	0	10	147	7	0	60	0	1	60	2	0	30	0	0	30	0	0	90	0	6	60	10	3	150	2
Gunshot	Jul	2	93	2	21	93	23	11	93	12	12	93	13	1	93	1	7	124	6	3	62	5	0	62	0	3	31	10	0	31	0	7	93	8	14	62	23	8	153	5
Gunshot	Aug	2	103	2	38	103	37	4	102	4	4	99	4	0	74	0	0	121	0	4	63	6	0	64	0	0	31	0	0	31	0	5	95	5	7	62	11	7	123	6
Gunshot	Sep	1	111	1	37	110	34	0	109	0	4	158	3	0	154	0	6	157	4	10	77	13	0	76	0	0	16	0	0	22	0	4	103	4	7	72	10	0	142	0
Gunshot	Oct	1	93	1	23	93	25	3	93	3	16	155	10	4	155	3	7	155	5	4	88	5	2	61	3	3	28	11	0	3	0	4	93	4	4	62	6	0	155	0
Gunshot	Nov	1	90	1	7	90	8	13	90	14	58	150	39	35	150	23	40	150	27	20	74	27	4	60	7	7	30	23	0	30	0	26	90	29	9	60	15	11	150	7
Gunshot	Dec	1	93	1	25	93	27	44	93	47	82	155	53	64	155	41	33	155	21	37	62	60	0	62	0	3	31	10	0	31	0	20	93	22	14	62	23	3	155	2
Fin	Jan	-	-	-	0	62	0	0	62	0	0	62	0	0	62	0	0	62	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fin	Feb	-	-	-	0	56	0	0	56	0	0	57	0	0	57	0	0	57	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fin	Mar	-	-	-	0	62	0	0	62	0	0	62	0	0	62	0	0	62	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fin	Apr	-	-	-	0	60	0	0	60	0	0	60	0	0	60	0	0	60	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fin	May	-	-	-	0	62	0	0	62	0	0	45	0	0	50	0	0	62	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fin	Jun	-	-	-	11	60	18	0	60	0	0	8	0	0	21	0	0	57	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fin	Jul	-	-	-	13	62	21	14	62	23	-	-	-	-	-	-	0	31	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fin	Aug	-	-	-	43	72	60	25	71	35	0	3	0	0	3	0	0	22	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fin	Sep	-	-	-	61	75	81	45	84	54	0	51	0	0	51	0	0	49	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fin	Oct	-	-	-	33	62	53	23	62	37	0	62	0	0	62	0	0	62	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fin	Nov	-	-	-	2	60	3	0	60	0	0	60	0	0	60	0	0	60	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fin	Dec	-	-	-	0	62	0	0	62	0	0	62	0	0	62	0	0	62	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Appendix C.2. (cont.). Average monthly calling activity 2010-2015 for all detected species/sound sources at all mooring locations. Number of days with calling activity (#), number of days with recordings (Eff), percent of days with calling activity per month (%).

Species	Month	KZ1			PH1			CL1			IC3			IC2			IC1			WT2			HS1			HS2			HS3			WT1			PB1			BF2		
		#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**
Ribbon	Jan	0	93	**0**	0	93	**0**	0	31	**0**	0	155	**0**	0	155	**0**	0	155	**0**	0	62	**0**	0	62	**0**	0	31	**0**	0	31	**0**	0	93	**0**	0	62	**0**	0	155	**0**
Ribbon	Feb	0	84	**0**	0	84	**0**	0	28	**0**	0	141	**0**	0	141	**0**	0	141	**0**	0	56	**0**	0	56	**0**	0	28	**0**	0	28	**0**	0	84	**0**	0	56	**0**	0	141	**0**
Ribbon	Mar	0	93	**0**	0	93	**0**	0	31	**0**	0	155	**0**	0	155	**0**	0	155	**0**	0	62	**0**	0	62	**0**	0	31	**0**	0	31	**0**	0	93	**0**	0	62	**0**	0	155	**0**
Ribbon	Apr	0	90	**0**	0	90	**0**	0	30	**0**	0	150	**0**	0	150	**0**	2	150	**1**	0	60	**0**	0	60	**0**	0	30	**0**	2	30	**7**	0	90	**0**	1	60	**2**	0	150	**0**
Ribbon	May	7	93	**8**	2	93	**2**	0	31	**0**	0	138	**0**	0	143	**0**	0	155	**0**	0	62	**0**	0	62	**0**	0	31	**0**	2	31	**6**	0	93	**0**	0	62	**0**	0	155	**0**
Ribbon	Jun	0	90	**0**	0	90	**0**	0	30	**0**	0	98	**0**	0	111	**0**	0	147	**0**	0	60	**0**	0	60	**0**	0	30	**0**	0	30	**0**	0	90	**0**	0	60	**0**	0	150	**0**
Ribbon	Jul	0	93	**0**	0	93	**0**	0	31	**0**	0	93	**0**	0	93	**0**	0	124	**0**	0	62	**0**	0	62	**0**	0	31	**0**	3	31	**10**	0	89	**0**	0	62	**0**	0	153	**0**
Ribbon	Aug	0	103	**0**	0	103	**0**	0	34	**0**	1	99	**1**	0	74	**0**	0	121	**0**	0	63	**0**	0	64	**0**	0	31	**0**	5	31	**16**	0	94	**0**	0	62	**0**	2	123	**2**
Ribbon	Sep	0	111	**0**	0	109	**0**	0	30	**0**	0	158	**0**	0	154	**0**	0	157	**0**	0	77	**0**	0	76	**0**	0	16	**0**	1	20	**5**	0	102	**0**	0	72	**0**	19	142	**13**
Ribbon	Oct	1	93	**1**	5	93	**5**	5	31	**16**	4	155	**3**	3	155	**2**	0	155	**0**	2	88	**2**	2	61	**3**	0	28	**0**	3	3	**100**	3	93	**3**	0	62	**0**	51	155	**33**
Ribbon	Nov	2	90	**2**	30	90	**33**	15	30	**50**	5	150	**3**	10	150	**7**	9	150	**6**	4	74	**5**	0	60	**0**	0	30	**0**	1	30	**3**	4	90	**4**	1	60	**2**	46	150	**31**
Ribbon	Dec	0	93	**0**	4	93	**4**	0	31	**0**	0	155	**0**	1	155	**1**	0	155	**0**	0	62	**0**	0	62	**0**	0	31	**0**	0	31	**0**	0	92	**0**	0	62	**0**	0	155	**0**
Killer	Jan	1	93	**1**	0	93	**0**	0	31	**0**	0	155	**0**	0	155	**0**	0	155	**0**	0	62	**0**	0	62	**0**	0	31	**0**	0	31	**0**	0	93	**0**	0	62	**0**	0	155	**0**
Killer	Feb	0	84	**0**	0	84	**0**	0	28	**0**	0	141	**0**	0	141	**0**	0	141	**0**	0	56	**0**	0	56	**0**	0	28	**0**	0	28	**0**	0	84	**0**	0	56	**0**	0	141	**0**
Killer	Mar	0	93	**0**	0	93	**0**	0	31	**0**	0	155	**0**	0	155	**0**	0	155	**0**	0	62	**0**	0	62	**0**	0	31	**0**	0	31	**0**	0	93	**0**	0	62	**0**	0	155	**0**
Killer	Apr	0	90	**0**	0	90	**0**	0	30	**0**	0	150	**0**	1	150	**1**	0	150	**0**	1	60	**2**	0	60	**0**	0	30	**0**	0	30	**0**	0	90	**0**	0	60	**0**	2	150	**1**
Killer	May	0	93	**0**	0	93	**0**	0	31	**0**	0	138	**0**	0	143	**0**	1	155	**1**	0	62	**0**	0	62	**0**	0	31	**0**	0	31	**0**	0	93	**0**	1	62	**2**	0	155	**0**
Killer	Jun	21	90	**23**	23	90	**26**	0	30	**0**	0	98	**0**	0	111	**0**	1	147	**1**	1	60	**2**	0	60	**0**	0	30	**0**	0	30	**0**	0	90	**0**	0	60	**0**	1	150	**1**
Killer	Jul	16	93	**17**	33	93	**35**	0	31	**0**	0	93	**0**	0	93	**0**	0	124	**0**	1	62	**2**	0	62	**0**	0	31	**0**	0	31	**0**	0	89	**0**	3	62	**5**	1	153	**1**
Killer	Aug	21	103	**20**	25	103	**24**	0	34	**0**	0	99	**0**	0	74	**0**	0	121	**0**	0	63	**0**	1	64	**2**	0	31	**0**	0	31	**0**	0	94	**0**	0	62	**0**	0	123	**0**
Killer	Sep	17	111	**15**	24	109	**22**	0	30	**0**	1	158	**1**	0	154	**0**	1	157	**1**	0	77	**0**	0	76	**0**	0	16	**0**	0	20	**0**	1	102	**1**	1	72	**1**	1	142	**1**
Killer	Oct	10	93	**11**	3	93	**3**	0	31	**0**	0	155	**0**	0	155	**0**	3	155	**2**	0	88	**0**	0	61	**0**	0	28	**0**	0	3	**0**	0	93	**0**	4	62	**6**	2	155	**1**
Killer	Nov	8	90	**9**	2	90	**2**	0	30	**0**	0	150	**0**	0	150	**0**	2	150	**1**	0	74	**0**	0	60	**0**	0	30	**0**	0	30	**0**	0	90	**0**	7	60	**12**	0	150	**0**
Killer	Dec	0	93	**0**	0	93	**0**	0	31	**0**	0	155	**0**	0	155	**0**	0	155	**0**	0	62	**0**	0	62	**0**	0	31	**0**	0	31	**0**	0	92	**0**	0	62	**0**	0	155	**0**
Boing	Jan	0	93	**0**	0	93	**0**	0	31	**0**	0	155	**0**	0	155	**0**	0	155	**0**	0	62	**0**	0	62	**0**	0	31	**0**	0	31	**0**	0	93	**0**	0	62	**0**	0	155	**0**
Boing	Feb	0	84	**0**	0	84	**0**	0	28	**0**	0	141	**0**	0	141	**0**	0	141	**0**	0	56	**0**	0	56	**0**	0	28	**0**	0	28	**0**	0	84	**0**	0	56	**0**	0	141	**0**
Boing	Mar	1	93	**1**	0	93	**0**	0	31	**0**	0	155	**0**	0	155	**0**	0	155	**0**	0	62	**0**	0	62	**0**	0	31	**0**	0	31	**0**	0	93	**0**	0	62	**0**	0	155	**0**
Boing	Apr	0	90	**0**	0	90	**0**	0	30	**0**	0	150	**0**	0	150	**0**	0	150	**0**	0	60	**0**	0	60	**0**	0	30	**0**	0	30	**0**	0	90	**0**	0	60	**0**	0	150	**0**
Boing	May	0	93	**0**	0	93	**0**	0	31	**0**	0	138	**0**	0	143	**0**	0	155	**0**	0	62	**0**	0	62	**0**	0	31	**0**	0	31	**0**	0	93	**0**	0	62	**0**	0	155	**0**
Boing	Jun	0	90	**0**	0	90	**0**	0	30	**0**	0	98	**0**	0	111	**0**	0	147	**0**	0	60	**0**	0	60	**0**	0	30	**0**	0	30	**0**	0	90	**0**	0	60	**0**	0	150	**0**
Boing	Jul	0	93	**0**	0	93	**0**	0	31	**0**	0	93	**0**	0	93	**0**	0	124	**0**	0	62	**0**	0	62	**0**	0	31	**0**	0	31	**0**	0	89	**0**	0	62	**0**	0	153	**0**
Boing	Aug	0	103	**0**	0	103	**0**	0	34	**0**	0	99	**0**	0	74	**0**	0	121	**0**	0	63	**0**	0	64	**0**	0	31	**0**	0	31	**0**	0	94	**0**	0	62	**0**	0	123	**0**
Boing	Sep	0	111	**0**	0	109	**0**	0	30	**0**	0	158	**0**	0	154	**0**	0	157	**0**	0	77	**0**	0	76	**0**	0	16	**0**	0	20	**0**	0	102	**0**	0	72	**0**	0	142	**0**
Boing	Oct	2	93	**2**	1	93	**1**	9	31	**29**	0	155	**0**	0	155	**0**	2	155	**1**	0	88	**0**	0	61	**0**	0	28	**0**	0	3	**0**	0	93	**0**	0	62	**0**	0	155	**0**
Boing	Nov	1	90	**1**	1	90	**1**	2	30	**7**	0	150	**0**	0	150	**0**	0	150	**0**	0	74	**0**	0	60	**0**	0	30	**0**	0	30	**0**	0	90	**0**	0	60	**0**	0	150	**0**
Boing	Dec	0	93	**0**	0	93	**0**	0	31	**0**	0	155	**0**	0	155	**0**	0	155	**0**	0	62	**0**	0	62	**0**	0	31	**0**	0	31	**0**	0	92	**0**	0	62	**0**	0	155	**0**
UnidPin	Jan	0	93	**0**	2	93	**2**	5	93	**5**	4	155	**3**	4	155	**3**	22	155	**14**	2	62	**3**	4	62	**6**	0	31	**0**	0	31	**0**	3	93	**3**	1	62	**2**	12	155	**8**
UnidPin	Feb	1	84	**1**	9	84	**11**	10	84	**12**	10	141	**7**	1	141	**1**	15	141	**11**	7	56	**13**	10	56	**18**	0	28	**0**	0	28	**0**	2	84	**2**	3	56	**5**	4	141	**3**
UnidPin	Mar	2	93	**2**	19	93	**20**	21	93	**23**	14	155	**9**	8	155	**5**	46	155	**30**	8	62	**13**	20	62	**32**	1	31	**3**	1	31	**3**	20	93	**22**	9	62	**15**	14	155	**9**
UnidPin	Apr	10	90	**11**	28	90	**31**	29	90	**32**	32	150	**21**	24	150	**16**	71	150	**47**	19	60	**32**	23	60	**38**	4	30	**13**	2	30	**7**	28	90	**31**	19	60	**32**	11	150	**7**
UnidPin	May	1	93	**1**	6	93	**6**	14	93	**15**	31	138	**22**	30	143	**21**	73	155	**47**	11	62	**18**	29	62	**47**	5	31	**16**	0	31	**0**	28	93	**30**	16	62	**26**	25	155	**16**
UnidPin	Jun	1	90	**1**	1	90	**1**	0	90	**0**	7	98	**7**	8	111	**7**	26	147	**18**	2	60	**3**	8	60	**13**	1	30	**3**	0	30	**0**	13	90	**14**	1	60	**2**	0	150	**0**
UnidPin	Jul	0	93	**0**	0	93	**0**	0	93	**0**	0	93	**0**	0	93	**0**	3	124	**2**	0	62	**0**	3	62	**5**	1	31	**3**	0	31	**0**	9	93	**10**	1	62	**2**	3	153	**2**
UnidPin	Aug	1	103	**1**	0	103	**0**	3	102	**3**	0	99	**0**	2	74	**3**	2	121	**2**	0	63	**0**	0	64	**0**	0	31	**0**	0	31	**0**	3	95	**3**	2	62	**3**	1	123	**1**
UnidPin	Sep	0	111	**0**	0	110	**0**	1	109	**1**	0	158	**0**	4	154	**3**	7	157	**4**	0	77	**0**	2	76	**3**	0	16	**0**	0	22	**0**	1	103	**1**	0	72	**0**	0	142	**0**
UnidPin	Oct	0	93	**0**	2	93	**2**	4	93	**4**	1	155	**1**	2	155	**1**	5	155	**3**	0	88	**0**	1	61	**2**	1	28	**4**	0	3	**0**	3	93	**3**	0	62	**0**	2	155	**1**
UnidPin	Nov	0	90	**0**	5	90	**6**	2	90	**2**	3	150	**2**	9	150	**6**	14	150	**9**	6	74	**8**	1	60	**2**	1	30	**3**	1	30	**3**	22	90	**24**	2	60	**3**	10	150	**7**
UnidPin	Dec	0	93	**0**	2	93	**2**	5	93	**5**	14	155	**9**	3	155	**2**	21	155	**14**	6	62	**10**	3	62	**5**	0	31	**0**	1	31	**3**	19	93	**20**	2	62	**3**	13	155	**8**

Appendix C.2. (cont.). Average monthly calling activity 2010-2015 for all detected species/sound sources at all mooring locations. Number of days with calling activity (#), number of days with recordings (Eff), percent of days with calling activity per month (%).

Species	Month	KZ1			PH1			CL1			IC3			IC2			IC1			WT2			HS1			HS2			HS3			WT1			PB1			BF2		
		#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%
DblKnck	Jan	-	-	-	0	31	0	16	93	17	0	93	0	-	-	-	13	93	14	0	62	0	0	62	0	0	31	0	-	-	-	0	62	0	2	62	3	1	62	2
DblKnck	Feb	-	-	-	0	28	0	50	84	60	0	85	0	-	-	-	21	84	25	5	56	9	0	56	0	0	28	0	-	-	-	0	56	0	2	56	4	0	57	0
DblKnck	Mar	-	-	-	0	31	0	60	93	65	0	93	0	-	-	-	37	93	40	2	62	3	0	62	0	4	31	13	-	-	-	0	62	0	7	62	11	0	62	0
DblKnck	Apr	-	-	-	0	30	0	68	90	76	0	90	0	-	-	-	59	90	66	31	60	52	9	60	15	7	30	23	-	-	-	0	60	0	30	60	50	1	60	2
DblKnck	May	-	-	-	0	31	0	62	93	67	0	76	0	-	-	-	73	93	78	51	62	82	21	62	34	23	31	74	-	-	-	0	62	0	36	62	58	2	62	3
DblKnck	Jun	-	-	-	0	30	0	2	90	2	0	60	0	-	-	-	14	90	16	7	60	12	5	60	8	4	30	13	-	-	-	0	60	0	2	60	3	0	60	0
DblKnck	Jul	-	-	-	0	31	0	0	93	0	0	62	0	-	-	-	0	93	0	0	62	0	0	62	0	0	31	0	-	-	-	0	62	0	0	62	0	0	60	0
DblKnck	Aug	-	-	-	0	31	0	0	102	0	0	68	0	-	-	-	0	100	0	0	61	0	0	64	0	0	31	0	-	-	-	0	65	0	0	62	0	0	29	0
DblKnck	Sep	-	-	-	0	35	0	0	109	0	0	116	0	-	-	-	0	108	0	0	47	0	0	76	0	0	16	0	-	-	-	0	73	0	0	72	0	0	41	0
DblKnck	Oct	-	-	-	0	31	0	0	93	0	0	93	0	-	-	-	0	93	0	0	57	0	0	61	0	0	28	0	-	-	-	0	62	0	0	62	0	0	62	0
DblKnck	Nov	-	-	-	0	30	0	12	90	13	0	90	0	-	-	-	8	90	9	2	60	3	0	60	0	0	30	0	-	-	-	0	60	0	0	60	0	0	60	0
DblKnck	Dec	-	-	-	0	31	0	16	93	17	0	93	0	-	-	-	10	93	11	0	62	0	0	62	0	0	31	0	-	-	-	0	62	0	1	62	2	3	62	5
Airgun	Jan	0	93	0	0	93	0	0	93	0	0	155	0	0	155	0	0	155	0	0	62	0	0	62	0	0	31	0	0	31	0	0	93	0	0	62	0	0	155	0
Airgun	Feb	0	84	0	0	84	0	0	84	0	0	141	0	0	141	0	0	141	0	0	56	0	0	56	0	0	28	0	0	28	0	0	84	0	0	56	0	0	141	0
Airgun	Mar	0	93	0	0	93	0	0	93	0	0	155	0	0	155	0	0	155	0	0	62	0	0	62	0	0	31	0	0	31	0	0	93	0	0	62	0	0	155	0
Airgun	Apr	0	90	0	0	90	0	0	90	0	0	150	0	0	150	0	0	150	0	0	60	0	0	60	0	0	30	0	0	30	0	0	90	0	1	60	2	0	150	0
Airgun	May	0	93	0	0	93	0	0	93	0	0	138	0	0	143	0	0	155	0	0	62	0	0	62	0	0	31	0	0	31	0	0	93	0	0	62	0	0	155	0
Airgun	Jun	0	90	0	0	90	0	0	90	0	0	98	0	0	111	0	0	147	0	0	60	0	0	60	0	0	30	0	0	30	0	0	90	0	1	60	2	0	150	0
Airgun	Jul	0	93	0	0	93	0	0	93	0	7	93	8	9	93	10	6	124	5	0	62	0	0	62	0	0	31	0	0	31	0	0	93	0	0	62	0	0	153	0
Airgun	Aug	0	103	0	2	103	2	7	102	7	16	99	16	6	74	8	9	121	7	0	63	0	0	64	0	0	31	0	0	31	0	2	95	2	3	62	5	5	123	4
Airgun	Sep	0	111	0	1	110	1	7	109	6	58	158	37	56	154	36	52	157	33	16	77	21	23	76	30	0	16	0	6	22	27	19	103	18	15	72	21	80	142	56
Airgun	Oct	0	93	0	5	93	5	15	93	16	29	155	19	28	155	18	25	155	16	25	88	28	23	61	38	1	28	4	1	3	33	20	93	22	20	62	32	28	155	18
Airgun	Nov	0	90	0	1	90	1	2	90	2	3	150	2	3	150	2	3	150	2	4	74	5	0	60	0	0	30	0	0	30	0	1	90	1	0	60	0	7	150	5
Airgun	Dec	0	93	0	0	93	0	0	93	0	0	155	0	0	155	0	0	155	0	0	62	0	0	62	0	0	31	0	0	31	0	0	93	0	0	62	0	0	155	0
Vessel	Jan	0	93	0	1	93	1	0	93	0	0	155	0	0	155	0	0	155	0	0	62	0	0	62	0	0	31	0	0	31	0	0	93	0	0	62	0	0	155	0
Vessel	Feb	0	84	0	0	84	0	0	84	0	0	141	0	4	141	3	0	141	0	0	56	0	0	56	0	0	28	0	0	28	0	0	84	0	0	56	0	1	141	1
Vessel	Mar	0	93	0	0	93	0	0	93	0	0	155	0	0	155	0	0	155	0	0	62	0	0	62	0	0	31	0	0	31	0	0	93	0	0	62	0	0	155	0
Vessel	Apr	1	90	1	0	90	0	0	90	0	0	150	0	0	150	0	0	150	0	0	60	0	0	60	0	0	30	0	0	30	0	1	90	1	13	60	22	0	150	0
Vessel	May	0	93	0	0	93	0	0	93	0	0	138	0	0	143	0	0	155	0	0	62	0	0	62	0	0	31	0	0	31	0	0	93	0	20	62	32	0	155	0
Vessel	Jun	8	90	9	1	90	1	3	90	3	0	98	0	2	111	2	4	147	3	0	60	0	0	60	0	0	30	0	0	30	0	1	90	1	13	60	22	16	150	11
Vessel	Jul	63	93	68	45	93	48	29	93	31	7	93	8	15	93	16	37	124	30	0	62	0	0	62	0	0	31	0	0	31	0	20	93	22	28	62	45	9	153	6
Vessel	Aug	66	103	64	57	103	55	46	102	45	31	99	31	30	74	41	75	121	62	5	63	8	2	64	3	3	31	10	0	31	0	61	95	64	38	62	61	24	123	20
Vessel	Sep	53	111	48	44	110	40	34	109	31	38	158	24	67	154	44	86	157	55	21	77	27	21	76	28	1	16	6	2	22	9	63	103	61	34	72	47	41	142	29
Vessel	Oct	21	93	23	11	93	12	12	93	13	19	155	12	32	155	21	43	155	28	23	88	26	11	61	18	2	28	7	0	3	0	25	93	27	5	62	8	38	155	25
Vessel	Nov	4	90	4	6	90	7	7	90	8	5	150	3	16	150	11	16	150	11	11	74	15	0	60	0	0	30	0	7	30	23	11	90	12	2	60	3	10	150	7
Vessel	Dec	0	93	0	0	93	0	0	93	0	0	155	0	0	155	0	0	155	0	0	62	0	0	62	0	0	31	0	0	31	0	0	93	0	0	62	0	1	155	1
Ice	Jan	74	93	80	81	93	87	31	31	100	131	155	85	120	155	77	131	155	85	60	62	97	55	62	89	21	31	68	29	31	94	76	93	82	45	62	73	153	155	99
Ice	Feb	74	84	88	70	84	83	27	28	96	118	141	84	117	141	83	116	141	82	55	56	98	53	56	95	21	28	75	25	28	89	75	84	89	44	56	79	139	141	99
Ice	Mar	79	93	85	86	93	92	24	31	77	103	155	66	111	155	72	121	155	78	57	62	92	58	62	94	23	31	74	29	31	94	64	93	69	50	62	81	125	155	81
Ice	Apr	74	90	82	71	90	79	25	30	83	86	150	57	111	150	74	104	150	69	56	60	93	52	60	87	19	30	63	24	30	80	49	90	54	47	60	78	133	150	89
Ice	May	15	93	16	50	93	54	11	31	35	96	138	70	93	143	65	39	155	25	50	62	81	56	62	90	7	31	23	20	31	65	36	93	39	49	62	79	121	155	78
Ice	Jun	0	90	0	3	90	3	5	30	17	90	98	92	86	111	77	22	147	15	58	60	97	41	60	68	11	30	37	28	30	93	24	90	27	39	60	65	142	150	95
Ice	Jul	1	93	1	0	93	0	0	31	0	48	93	52	38	93	41	19	124	15	35	62	56	35	62	56	3	31	10	22	31	71	4	89	4	15	62	24	133	153	87
Ice	Aug	0	103	0	0	103	0	0	34	0	19	99	19	1	74	1	0	121	0	8	63	13	28	64	44	0	31	0	6	31	19	0	94	0	1	62	2	22	123	18
Ice	Sep	0	111	0	0	109	0	0	30	0	1	158	1	0	154	0	0	157	0	1	77	1	3	76	4	0	16	0	0	20	0	0	102	0	0	72	0	3	142	2
Ice	Oct	0	93	0	0	93	0	0	31	0	4	155	3	1	155	1	0	155	0	1	88	1	1	61	2	6	28	21	1	3	33	0	93	0	0	62	0	4	155	3
Ice	Nov	5	90	6	15	90	17	10	30	33	63	150	42	68	150	45	44	150	29	52	74	70	53	60	88	27	30	90	18	30	60	44	90	49	32	60	53	107	150	71
Ice	Dec	52	93	56	70	93	75	31	31	100	132	155	85	133	155	86	132	155	85	61	62	98	60	62	97	29	31	94	24	31	77	73	92	79	57	62	92	151	155	97

Appendix C.3. Bowhead whale monthly calling activity 2010-2015 across all mooring locations. Number of days with calling activity (#), number of days with recordings (Eff), percent of days with calling activity per month (%).

Year	Month	KZ1			PH1			CL1			IC3			IC2			IC1			WT2			HS1			HS2			HS3			WT1			PB1			BF2		
		#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**
2010	9	-	-	-	-	-	-	-	-	-	4	21	**19**	9	21	**43**	8	21	**38**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11	11	**100**
2010	10	-	-	-	-	-	-	-	-	-	20	31	**65**	25	31	**81**	20	31	**65**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	26	31	**84**
2010	11	-	-	-	-	-	-	-	-	-	24	30	**80**	21	30	**70**	24	30	**80**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8	30	**27**
2010	12	-	-	-	-	-	-	-	-	-	12	31	**39**	15	31	**48**	12	31	**39**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	1	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	2	-	-	-	-	-	-	-	-	-	0	28	**0**	0	28	**0**	0	28	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	28	**0**
2011	3	-	-	-	-	-	-	-	-	-	0	31	**0**	1	31	**3**	5	31	**16**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	31	**6**
2011	4	-	-	-	-	-	-	-	-	-	0	30	**0**	3	30	**10**	14	30	**47**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	21	30	**70**
2011	5	-	-	-	-	-	-	-	-	-	0	31	**0**	3	31	**10**	31	31	**100**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	28	31	**90**
2011	6	-	-	-	-	-	-	-	-	-	0	8	**0**	7	21	**33**	13	27	**48**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	24	30	**80**
2011	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8	31	**26**
2011	8	-	-	-	-	-	-	-	-	-	0	3	**0**	1	3	**33**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	29	**31**
2011	9	-	-	-	-	-	-	-	-	-	2	30	**7**	4	30	**13**	4	28	**14**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	21	30	**70**
2011	10	-	-	-	-	-	-	-	-	-	13	31	**42**	25	31	**81**	25	31	**81**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	28	31	**90**
2011	11	-	-	-	-	-	-	-	-	-	23	30	**77**	30	30	**100**	27	30	**90**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	17	30	**57**
2011	12	-	-	-	-	-	-	-	-	-	2	31	**6**	1	31	**3**	1	31	**3**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2012	1	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	31	**3**
2012	2	-	-	-	-	-	-	-	-	-	0	29	**0**	0	29	**0**	0	29	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	29	**0**
2012	3	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2012	4	-	-	-	-	-	-	-	-	-	0	30	**0**	3	30	**10**	17	30	**57**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	13	30	**43**
2012	5	-	-	-	-	-	-	-	-	-	0	14	**0**	1	19	**5**	22	31	**71**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	31	31	**100**
2012	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12	30	**40**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	24	30	**80**
2012	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	18	31	**58**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	24	29	**83**
2012	8	0	11	**0**	0	10	**0**	0	9	**0**	4	4	**100**	0	5	**0**	5	28	**18**	0	2	**0**	-	-	-	-	-	-	-	-	-	0	2	**0**	-	-	-	1	1	**100**
2012	9	0	30	**0**	4	30	**13**	0	30	**0**	19	30	**63**	9	30	**30**	0	30	**0**	7	30	**23**	-	-	-	-	-	-	-	-	-	25	30	**83**	-	-	-	30	30	**100**
2012	10	3	31	**10**	14	31	**45**	14	31	**45**	31	31	**100**	28	31	**90**	8	31	**26**	31	31	**100**	-	-	-	-	-	-	-	-	-	18	31	**58**	-	-	-	28	31	**90**
2012	11	30	30	**100**	24	30	**80**	30	30	**100**	28	30	**93**	29	30	**97**	28	30	**93**	23	30	**77**	-	-	-	-	-	-	-	-	-	29	30	**97**	-	-	-	26	30	**87**
2012	12	31	31	**100**	15	31	**48**	3	31	**10**	0	31	**0**	2	31	**6**	5	31	**16**	0	31	**0**	-	-	-	-	-	-	-	-	-	3	31	**10**	-	-	-	3	31	**10**
2013	1	14	31	**45**	2	31	**6**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	1	31	**3**	-	-	-	0	31	**0**
2013	2	2	28	**7**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	-	-	-	-	-	-	-	-	-	1	28	**4**	-	-	-	0	28	**0**
2013	3	9	31	**29**	2	31	**6**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	0	31	**0**
2013	4	29	30	**97**	22	30	**73**	17	30	**57**	0	30	**0**	0	30	**0**	13	30	**43**	0	30	**0**	-	-	-	-	-	-	-	-	-	13	30	**43**	-	-	-	16	30	**53**
2013	5	20	31	**65**	30	31	**97**	30	31	**97**	0	31	**0**	13	31	**42**	30	31	**97**	8	31	**26**	-	-	-	-	-	-	-	-	-	30	31	**97**	-	-	-	31	31	**100**
2013	6	0	30	**0**	3	30	**10**	13	30	**43**	0	30	**0**	15	30	**50**	15	30	**50**	9	30	**30**	-	-	-	-	-	-	-	-	-	22	30	**73**	-	-	-	30	30	**100**
2013	7	0	31	**0**	1	31	**3**	2	31	**6**	2	31	**6**	5	31	**16**	7	31	**23**	0	31	**0**	-	-	-	-	-	-	-	-	-	5	31	**16**	-	-	-	26	31	**84**
2013	8	0	30	**0**	0	31	**0**	0	31	**0**	12	30	**40**	1	4	**25**	2	31	**6**	0	30	**0**	1	2	**50**	-	-	-	-	-	-	7	31	**23**	-	-	-	27	31	**87**
2013	9	0	30	**0**	5	30	**17**	0	30	**0**	8	30	**27**	13	30	**43**	8	30	**27**	2	30	**7**	15	30	**50**	-	-	-	-	-	-	26	30	**87**	22	29	**76**	28	28	**100**
2013	10	3	31	**10**	1	31	**3**	1	31	**3**	26	31	**84**	29	31	**94**	29	31	**94**	26	31	**84**	26	31	**84**	-	-	-	0	3	**0**	31	31	**100**	28	31	**90**	31	31	**100**
2013	11	26	30	**87**	20	30	**67**	28	30	**93**	26	30	**87**	30	30	**100**	29	30	**97**	13	14	**93**	9	30	**30**	-	-	-	2	30	**7**	26	30	**87**	17	30	**57**	20	30	**67**
2013	12	31	31	**100**	31	31	**100**	31	31	**100**	23	31	**74**	22	31	**71**	23	31	**74**	-	-	-	0	31	**0**	-	-	-	0	31	**0**	15	31	**48**	9	31	**29**	0	31	**0**
2014	1	23	31	**74**	19	31	**61**	7	31	**23**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**
2014	2	13	28	**46**	10	28	**36**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	-	-	-	0	28	**0**	-	-	-	0	28	**0**	0	28	**0**	1	28	**4**	0	28	**0**
2014	3	6	31	**19**	4	31	**13**	0	31	**0**	0	31	**0**	1	31	**3**	0	31	**0**	-	-	-	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	5	31	**16**	0	31	**0**
2014	4	28	30	**93**	27	30	**90**	17	30	**57**	0	30	**0**	0	30	**0**	7	30	**23**	-	-	-	0	30	**0**	-	-	-	0	30	**0**	24	30	**80**	21	30	**70**	22	30	**73**
2014	5	27	31	**87**	20	31	**65**	31	31	**100**	1	31	**3**	9	31	**29**	30	31	**97**	-	-	-	4	31	**13**	-	-	-	19	31	**61**	29	31	**94**	29	31	**94**	31	31	**100**
2014	6	7	30	**23**	2	30	**7**	8	30	**27**	2	30	**7**	3	30	**10**	10	30	**33**	-	-	-	0	30	**0**	-	-	-	13	30	**43**	11	30	**37**	21	30	**70**	30	30	**100**
2014	7	0	31	**0**	0	31	**0**	0	31	**0**	6	31	**19**	7	31	**23**	20	31	**65**	-	-	-	3	31	**10**	-	-	-	19	31	**61**	18	31	**58**	24	31	**77**	26	31	**84**
2014	8	0	31	**0**	0	31	**0**	0	31	**0**	2	31	**6**	5	31	**16**	2	31	**6**	-	-	-	1	31	**3**	-	-	-	7	31	**23**	2	31	**6**	11	31	**35**	17	31	**55**
2014	9	0	30	**0**	0	29	**0**	0	29	**0**	8	30	**27**	11	30	**37**	11	30	**37**	-	-	-	10	30	**33**	-	-	-	4	22	**18**	13	30	**43**	13	29	**45**	10	29	**34**
2014	10	0	31	**0**	0	31	**0**	2	31	**6**	30	31	**97**	30	31	**97**	26	31	**84**	21	26	**81**	14	30	**47**	17	28	**61**	-	-	-	18	31	**58**	16	31	**52**	20	31	**65**
2014	11	23	30	**77**	3	30	**10**	18	30	**60**	24	30	**80**	22	30	**73**	17	30	**57**	12	30	**40**	1	30	**3**	1	30	**3**	-	-	-	15	30	**50**	5	30	**17**	0	30	**0**
2014	12	30	31	**97**	31	31	**100**	30	31	**97**	11	31	**35**	12	31	**39**	8	31	**26**	7	31	**23**	0	31	**0**	0	31	**0**	-	-	-	3	31	**10**	1	31	**3**	0	31	**0**
2015	1	31	31	**100**	25	31	**81**	23	31	**74**	0	31	**0**	4	31	**13**	7	31	**23**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	3	31	**10**	0	31	**0**	0	31	**0**
2015	2	19	28	**68**	2	28	**7**	1	28	**4**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	-	-	-	0	28	**0**	0	28	**0**	0	28	**0**
2015	3	25	31	**81**	14	31	**45**	5	31	**16**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	5	31	**16**	0	31	**0**
2015	4	29	30	**97**	29	30	**97**	25	30	**83**	0	30	**0**	1	30	**3**	19	30	**63**	0	30	**0**	0	30	**0**	1	30	**3**	-	-	-	30	30	**100**	28	30	**93**	24	30	**80**
2015	5	16	31	**52**	21	31	**68**	30	31	**97**	1	31	**3**	8	31	**26**	25	31	**81**	0	31	**0**	2	31	**6**	2	31	**6**	-	-	-	31	31	**100**	29	31	**94**	31	31	**100**
2015	6	0	30	**0**	0	30	**0**	1	30	**3**	0	30	**0**	6	30	**20**	20	30	**67**	1	30	**3**	2	30	**7**	3	30	**10**	-	-	-	14	30	**47**	16	30	**53**	27	30	**90**
2015	7	0	31	**0**	0	31	**0**	1	31	**3**	11	31	**35**	9	31	**29**	8	31	**26**	0	31	**0**	1	31	**3**	0	31	**0**	-	-	-	14	31	**45**	14	31	**45**	30	31	**97**
2015	8	0	31	**0**	0	31	**0**	0	31	**0**	17	31	**55**	0	31	**0**	0	31	**0**	0	31	**0**	4	31	**13**	1	31	**3**	-	-	-	2	31	**6**	6	31	**19**	11	31	**35**
2015	9	0	21	**0**	0	21	**0**	0	20	**0**	13	17	**76**	2	13	**15**	0	18	**0**	9	17	**53**	7	16	**44**	8	16	**50**	-	-	-	2	13	**15**	5	14	**36**	7	14	**50**

Appendix C.4. Beluga whale monthly calling activity 2010-2015 across all mooring locations. Number of days with calling activity (#), number of days with recordings (Eff), percent of days with calling activity per month (%).

Year	Month	KZ1			PH1			CL1			IC3			IC2			IC1			WT2			HS1			HS2			HS3			WT1			PB1			BF2		
		#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%
2010	9	-	-	-	-	-	-	-	-	-	0	21	**0**	0	21	**0**	2	21	**10**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	11	**9**
2010	10	-	-	-	-	-	-	-	-	-	0	31	**0**	1	31	**3**	5	31	**16**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	21	31	**68**
2010	11	-	-	-	-	-	-	-	-	-	6	30	**20**	14	30	**47**	18	30	**60**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	13	30	**43**
2010	12	-	-	-	-	-	-	-	-	-	2	31	**6**	8	31	**26**	1	31	**3**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	1	-	-	-	-	-	-	-	-	-	0	31	**0**	3	31	**10**	2	31	**6**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	2	-	-	-	-	-	-	-	-	-	0	28	**0**	0	28	**0**	0	28	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	28	**0**
2011	3	-	-	-	-	-	-	-	-	-	0	31	**0**	9	31	**29**	3	31	**10**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	4	-	-	-	-	-	-	-	-	-	9	30	**30**	5	30	**17**	10	30	**33**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	30	**20**
2011	5	-	-	-	-	-	-	-	-	-	0	31	**0**	2	31	**6**	20	31	**65**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	19	31	**61**
2011	6	-	-	-	-	-	-	-	-	-	0	8	**0**	1	21	**5**	5	27	**19**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	30	**10**
2011	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	31	**19**
2011	8	-	-	-	-	-	-	-	-	-	0	3	**0**	0	3	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	29	**34**
2011	9	-	-	-	-	-	-	-	-	-	0	30	**0**	0	30	**0**	0	28	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20	30	**67**
2011	10	-	-	-	-	-	-	-	-	-	2	31	**6**	3	31	**10**	11	31	**35**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	22	31	**71**
2011	11	-	-	-	-	-	-	-	-	-	8	30	**27**	8	30	**27**	17	30	**57**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	13	30	**43**
2011	12	-	-	-	-	-	-	-	-	-	0	31	**0**	1	31	**3**	3	31	**10**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	31	**3**
2012	1	-	-	-	-	-	-	-	-	-	3	31	**10**	1	31	**3**	1	31	**3**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	31	**6**
2012	2	-	-	-	-	-	-	-	-	-	2	29	**7**	0	29	**0**	1	29	**3**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	29	**3**
2012	3	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	1	31	**3**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	31	**6**
2012	4	-	-	-	-	-	-	-	-	-	7	30	**23**	12	30	**40**	18	30	**60**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	18	30	**60**
2012	5	-	-	-	-	-	-	-	-	-	3	14	**21**	12	19	**63**	22	31	**71**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	28	31	**90**
2012	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	30	**10**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	18	30	**60**
2012	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	31	**13**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	26	29	**90**
2012	8	0	11	**0**	0	10	**0**	0	9	**0**	0	4	**0**	0	5	**0**	0	28	**0**	0	2	**0**	-	-	-	-	-	-	-	-	-	0	2	**0**	-	-	-	0	1	**0**
2012	9	0	30	**0**	2	30	**7**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	-	-	-	0	30	**0**	-	-	-	17	30	**57**
2012	10	3	31	**10**	6	31	**19**	0	31	**0**	3	31	**10**	2	31	**6**	3	31	**10**	1	31	**3**	-	-	-	-	-	-	-	-	-	7	31	**23**	-	-	-	21	31	**68**
2012	11	21	30	**70**	29	30	**97**	19	30	**63**	12	30	**40**	8	30	**27**	17	30	**57**	1	30	**3**	-	-	-	-	-	-	-	-	-	19	30	**63**	-	-	-	23	30	**77**
2012	12	1	31	**3**	11	31	**35**	1	31	**3**	0	31	**0**	1	31	**3**	1	31	**3**	0	31	**0**	-	-	-	-	-	-	-	-	-	1	31	**3**	-	-	-	10	31	**32**
2013	1	3	31	**10**	10	31	**32**	0	31	**0**	5	31	**16**	1	31	**3**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	2	31	**6**	-	-	-	15	31	**48**
2013	2	0	28	**0**	1	28	**4**	0	28	**0**	2	28	**7**	6	28	**21**	1	28	**4**	1	28	**4**	-	-	-	-	-	-	-	-	-	0	28	**0**	-	-	-	0	28	**0**
2013	3	15	31	**48**	14	31	**45**	3	31	**10**	3	31	**10**	0	31	**0**	3	31	**10**	0	31	**0**	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	3	31	**10**
2013	4	18	30	**60**	23	30	**77**	20	30	**67**	10	30	**33**	16	30	**53**	22	30	**73**	9	30	**30**	-	-	-	-	-	-	-	-	-	12	30	**40**	-	-	-	13	30	**43**
2013	5	9	31	**29**	28	31	**90**	9	31	**29**	9	31	**29**	14	31	**45**	23	31	**74**	13	31	**42**	-	-	-	-	-	-	-	-	-	21	31	**68**	-	-	-	27	31	**87**
2013	6	0	30	**0**	9	30	**30**	1	30	**3**	4	30	**13**	12	30	**40**	4	30	**13**	4	30	**13**	-	-	-	-	-	-	-	-	-	10	30	**33**	-	-	-	11	30	**37**
2013	7	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	2	31	**6**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	1	31	**3**	-	-	-	29	31	**94**
2013	8	0	30	**0**	0	31	**0**	0	31	**0**	1	30	**3**	0	4	**0**	2	31	**6**	0	30	**0**	0	2	**0**	-	-	-	-	-	-	1	31	**3**	-	-	-	30	31	**97**
2013	9	0	30	**0**	0	30	**0**	0	30	**0**	1	30	**3**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	0	30	**0**	0	29	**0**	13	28	**46**
2013	10	0	31	**0**	3	31	**10**	0	31	**0**	5	31	**16**	9	31	**29**	13	31	**42**	6	31	**19**	2	31	**6**	-	-	-	2	3	**67**	18	31	**58**	15	31	**48**	26	31	**84**
2013	11	8	30	**27**	27	30	**90**	8	30	**27**	13	30	**43**	7	30	**23**	13	30	**43**	3	14	**21**	1	30	**3**	-	-	-	10	30	**33**	8	30	**27**	15	30	**50**	7	30	**23**
2013	12	10	31	**32**	20	31	**65**	1	31	**3**	4	31	**13**	0	31	**0**	5	31	**16**	-	-	-	1	31	**3**	-	-	-	0	31	**0**	1	31	**3**	2	31	**6**	0	31	**0**
2014	1	2	31	**6**	6	31	**19**	0	31	**0**	2	31	**6**	0	31	**0**	1	31	**3**	-	-	-	1	31	**3**	-	-	-	0	31	**0**	0	31	**0**	2	31	**6**	0	31	**0**
2014	2	5	28	**18**	2	28	**7**	0	28	**0**	1	28	**4**	0	28	**0**	0	28	**0**	-	-	-	0	28	**0**	-	-	-	2	28	**7**	0	28	**0**	3	28	**11**	0	28	**0**
2014	3	13	31	**42**	14	31	**45**	2	31	**6**	1	31	**3**	0	31	**0**	1	31	**3**	-	-	-	0	31	**0**	-	-	-	0	31	**0**	1	31	**3**	4	31	**13**	0	31	**0**
2014	4	24	30	**80**	27	30	**90**	28	30	**93**	10	30	**33**	13	30	**43**	21	30	**70**	-	-	-	0	30	**0**	-	-	-	9	30	**30**	23	30	**77**	18	30	**60**	19	30	**63**
2014	5	8	31	**26**	20	31	**65**	17	31	**55**	23	31	**74**	19	31	**61**	25	31	**81**	-	-	-	3	31	**10**	-	-	-	26	31	**84**	20	31	**65**	17	31	**55**	29	31	**94**
2014	6	1	30	**3**	0	30	**0**	1	30	**3**	12	30	**40**	8	30	**27**	10	30	**33**	-	-	-	1	30	**3**	-	-	-	5	30	**17**	7	30	**23**	5	30	**17**	15	30	**50**
2014	7	0	31	**0**	0	31	**0**	0	31	**0**	3	31	**10**	2	31	**6**	2	31	**6**	-	-	-	1	31	**3**	-	-	-	22	31	**71**	10	31	**32**	16	31	**52**	30	31	**97**
2014	8	0	31	**0**	0	31	**0**	0	31	**0**	2	31	**6**	2	31	**6**	1	31	**3**	-	-	-	0	31	**0**	-	-	-	28	31	**90**	3	31	**10**	4	31	**13**	28	31	**90**
2014	9	0	30	**0**	0	29	**0**	0	29	**0**	1	30	**3**	3	30	**10**	6	30	**20**	-	-	-	0	30	**0**	-	-	-	11	20	**55**	7	30	**23**	3	29	**10**	18	29	**62**
2014	10	0	31	**0**	5	31	**16**	0	31	**0**	14	31	**45**	7	31	**23**	21	31	**68**	1	26	**4**	3	30	**10**	3	28	**11**	-	-	-	12	31	**39**	11	31	**35**	13	31	**42**
2014	11	15	30	**50**	29	30	**97**	3	30	**10**	20	30	**67**	14	30	**47**	12	30	**40**	1	30	**3**	1	30	**3**	0	30	**0**	-	-	-	15	30	**50**	9	30	**30**	10	30	**33**
2014	12	17	31	**55**	15	31	**48**	0	31	**0**	3	31	**10**	0	31	**0**	0	31	**0**	1	31	**3**	0	31	**0**	0	31	**0**	-	-	-	2	30	**7**	1	31	**3**	1	31	**3**
2015	1	9	31	**29**	4	31	**13**	0	31	**0**	1	31	**3**	0	31	**0**	1	31	**3**	1	31	**3**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	4	31	**13**	0	31	**0**
2015	2	8	28	**29**	1	28	**4**	0	28	**0**	0	28	**0**	0	28	**0**	1	28	**4**	1	28	**4**	0	28	**0**	0	28	**0**	-	-	-	0	28	**0**	1	28	**4**	0	28	**0**
2015	3	10	31	**32**	13	31	**42**	1	31	**3**	0	31	**0**	0	31	**0**	5	31	**16**	2	31	**6**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	1	31	**3**	0	31	**0**
2015	4	25	30	**83**	21	30	**70**	18	30	**60**	6	30	**20**	14	30	**47**	23	30	**77**	6	30	**20**	5	30	**17**	4	30	**13**	-	-	-	17	30	**57**	13	30	**43**	18	30	**60**
2015	5	7	31	**23**	14	31	**45**	11	31	**35**	5	31	**16**	12	31	**39**	24	31	**77**	9	31	**29**	6	31	**19**	8	31	**26**	-	-	-	25	31	**81**	22	31	**71**	29	31	**94**
2015	6	0	30	**0**	0	30	**0**	1	30	**3**	6	30	**20**	3	30	**10**	16	30	**53**	11	30	**37**	3	30	**10**	1	30	**3**	-	-	-	12	30	**40**	4	30	**13**	15	30	**50**
2015	7	1	31	**3**	0	31	**0**	0	31	**0**	3	31	**10**	1	31	**3**	3	31	**10**	3	31	**10**	1	31	**3**	4	31	**13**	-	-	-	2	27	**7**	5	31	**16**	31	31	**100**
2015	8	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	1	31	**3**	0	31	**0**	2	31	**6**	-	-	-	0	30	**0**	4	31	**13**	23	31	**74**
2015	9	0	21	**0**	0	20	**0**	0	11	**0**	0	17	**0**	0	13	**0**	0	18	**0**	1	17	**6**	0	16	**0**	0	16	**0**	-	-	-	0	12	**0**	1	14	**7**	9	14	**64**

Appendix C.5. Bearded seal monthly calling activity 2010-2015 across all mooring locations. Number of days with calling activity (#), number of days with recordings (Eff), percent of days with calling activity per month (%).

Year	Month	KZ1			PH1			CL1			IC3			IC2			IC1			WT2			HS1			HS2			HS3			WT1			PB1			BF2		
		#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%
2010	9	-	-	-	-	-	-	-	-	-	0	21	0	0	21	0	3	21	14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8	11	73
2010	10	-	-	-	-	-	-	-	-	-	7	31	23	1	31	3	18	31	58	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	21	31	68
2010	11	-	-	-	-	-	-	-	-	-	5	30	17	23	30	77	17	30	57	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12	30	40
2010	12	-	-	-	-	-	-	-	-	-	14	31	45	28	31	90	26	31	84	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	27	31	87
2011	1	-	-	-	-	-	-	-	-	-	18	31	58	31	31	100	29	31	94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	26	31	84
2011	2	-	-	-	-	-	-	-	-	-	14	28	50	26	28	93	28	28	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	28	28	100
2011	3	-	-	-	-	-	-	-	-	-	30	31	97	31	31	100	31	31	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	30	31	97
2011	4	-	-	-	-	-	-	-	-	-	30	30	100	30	30	100	30	30	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	29	30	97
2011	5	-	-	-	-	-	-	-	-	-	31	31	100	31	31	100	31	31	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	31	31	100
2011	6	-	-	-	-	-	-	-	-	-	8	8	100	21	21	100	27	27	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	30	30	100
2011	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	31	13
2011	8	-	-	-	-	-	-	-	-	-	2	3	67	1	3	33	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	29	0
2011	9	-	-	-	-	-	-	-	-	-	28	30	93	10	30	33	9	28	32	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	15	30	50
2011	10	-	-	-	-	-	-	-	-	-	18	31	58	20	31	65	25	31	81	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	14	31	45
2011	11	-	-	-	-	-	-	-	-	-	14	30	47	21	30	70	23	30	77	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	30	33
2011	12	-	-	-	-	-	-	-	-	-	31	31	100	30	31	97	25	31	81	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8	31	26
2012	1	-	-	-	-	-	-	-	-	-	30	31	97	31	31	100	31	31	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	29	31	94
2012	2	-	-	-	-	-	-	-	-	-	29	29	100	29	29	100	28	29	97	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	29	29	100
2012	3	-	-	-	-	-	-	-	-	-	26	31	84	31	31	100	31	31	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	31	31	100
2012	4	-	-	-	-	-	-	-	-	-	30	30	100	30	30	100	30	30	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	30	30	100
2012	5	-	-	-	-	-	-	-	-	-	14	14	100	19	19	100	31	31	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	31	31	100
2012	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	26	30	87	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	30	30	100
2012	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	13	31	42	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	17	29	59
2012	8	1	11	9	0	10	0	0	9	0	3	4	75	0	5	0	7	28	25	0	2	0	-	-	-	-	-	-	-	-	-	0	2	0	-	-	-	0	1	0
2012	9	0	30	0	0	30	0	4	30	13	24	30	80	11	30	37	0	30	0	6	30	20	-	-	-	-	-	-	-	-	-	11	30	37	-	-	-	22	30	73
2012	10	23	31	74	22	31	71	24	31	77	23	31	74	16	31	52	0	31	0	27	31	87	-	-	-	-	-	-	-	-	-	12	31	39	-	-	-	17	31	55
2012	11	20	30	67	30	30	100	24	30	80	18	30	60	28	30	93	6	30	20	25	30	83	-	-	-	-	-	-	-	-	-	20	30	67	-	-	-	20	30	67
2012	12	1	31	3	22	31	71	15	31	48	29	31	94	31	31	100	31	31	100	28	31	90	-	-	-	-	-	-	-	-	-	31	31	100	-	-	-	31	31	100
2013	1	29	31	94	31	31	100	25	31	81	31	31	100	31	31	100	23	31	74	28	31	90	-	-	-	-	-	-	-	-	-	26	31	84	-	-	-	28	31	90
2013	2	26	28	93	27	28	96	28	28	100	28	28	100	28	28	100	24	28	86	28	28	100	-	-	-	-	-	-	-	-	-	28	28	100	-	-	-	28	28	100
2013	3	31	31	100	31	31	100	30	31	97	31	31	100	31	31	100	31	31	100	31	31	100	-	-	-	-	-	-	-	-	-	31	31	100	-	-	-	31	31	100
2013	4	30	30	100	30	30	100	30	30	100	30	30	100	30	30	100	30	30	100	30	30	100	-	-	-	-	-	-	-	-	-	30	30	100	-	-	-	30	30	100
2013	5	31	31	100	31	31	100	31	31	100	31	31	100	31	31	100	31	31	100	31	31	100	-	-	-	-	-	-	-	-	-	31	31	100	-	-	-	31	31	100
2013	6	19	30	63	19	30	63	21	30	70	29	30	97	30	30	100	25	30	83	30	30	100	-	-	-	-	-	-	-	-	-	30	30	100	-	-	-	30	30	100
2013	7	0	31	0	2	31	6	0	31	0	2	31	6	5	31	16	0	31	0	3	31	10	-	-	-	-	-	-	-	-	-	6	31	19	-	-	-	16	31	52
2013	8	0	30	0	1	31	3	0	25	0	2	30	7	1	4	25	0	31	0	2	30	7	0	2	0	-	-	-	-	-	-	4	31	13	-	-	-	5	31	16
2013	9	0	30	0	1	30	3	-	-	-	1	30	3	15	30	50	0	30	0	7	30	23	6	30	20	-	-	-	-	-	-	14	30	47	22	29	76	20	28	71
2013	10	26	31	84	31	31	100	-	-	-	12	31	39	23	31	74	3	31	10	28	31	90	20	31	65	-	-	-	0	3	0	23	31	74	29	31	94	19	31	61
2013	11	15	30	50	30	30	100	-	-	-	5	30	17	15	30	50	5	30	17	10	14	71	16	30	53	-	-	-	0	30	0	8	30	27	20	30	67	11	30	37
2013	12	14	31	45	31	31	100	-	-	-	21	31	68	21	31	68	16	31	52	-	-	-	23	31	74	-	-	-	5	31	16	22	31	71	25	31	81	28	31	90
2014	1	30	31	97	28	31	90	-	-	-	30	31	97	31	31	100	31	31	100	-	-	-	25	31	81	-	-	-	14	31	45	30	31	97	28	31	90	20	31	65
2014	2	19	28	68	26	28	93	-	-	-	28	28	100	28	28	100	28	28	100	-	-	-	28	28	##	-	-	-	21	28	75	28	28	100	28	28	##	28	28	100
2014	3	31	31	100	31	31	100	-	-	-	31	31	100	31	31	100	31	31	100	-	-	-	31	31	##	-	-	-	25	31	81	31	31	100	31	31	##	31	31	100
2014	4	30	30	100	30	30	100	-	-	-	30	30	100	30	30	100	30	30	100	-	-	-	30	30	##	-	-	-	29	30	97	30	30	100	30	30	##	30	30	100
2014	5	31	31	100	31	31	100	-	-	-	31	31	100	31	31	100	31	31	100	-	-	-	31	31	##	-	-	-	31	31	##	31	31	100	31	31	##	31	31	100
2014	6	13	30	43	15	30	50	-	-	-	30	30	100	30	30	100	26	30	87	-	-	-	30	30	##	-	-	-	29	30	97	30	30	100	30	30	##	30	30	100
2014	7	0	31	0	0	31	0	-	-	-	2	31	6	7	31	23	5	31	16	-	-	-	5	31	16	-	-	-	2	31	6	9	31	29	8	31	26	9	31	29
2014	8	0	31	0	0	31	0	-	-	-	0	31	0	10	31	32	4	31	13	-	-	-	0	31	0	-	-	-	0	31	0	9	31	29	18	31	58	15	31	48
2014	9	1	30	3	5	29	17	-	-	-	0	30	0	21	30	70	9	30	30	-	-	-	5	30	17	-	-	-	0	20	0	18	30	60	23	29	79	15	29	52
2014	10	20	31	65	28	31	90	-	-	-	0	31	0	18	31	58	6	31	19	11	26	42	7	30	23	6	28	21	-	-	-	9	31	29	20	31	65	6	31	19
2014	11	28	30	93	30	30	100	-	-	-	3	30	10	17	30	57	13	30	43	27	30	90	6	30	20	1	30	3	-	-	-	13	30	43	22	30	73	10	30	33
2014	12	24	31	77	26	31	84	-	-	-	18	31	58	21	31	68	14	31	45	30	31	97	17	31	55	5	31	16	-	-	-	20	30	67	27	31	87	22	31	71
2015	1	30	31	97	31	31	100	-	-	-	27	31	87	29	31	94	29	31	94	31	31	100	31	31	##	26	31	84	-	-	-	28	31	90	30	31	97	27	31	87
2015	2	28	28	100	28	28	100	-	-	-	27	28	96	28	28	100	27	28	96	28	28	100	28	28	##	28	28	##	-	-	-	28	28	100	28	28	##	28	28	100
2015	3	31	31	100	31	31	100	-	-	-	31	31	100	31	31	100	31	31	100	31	31	100	31	31	##	31	31	##	-	-	-	31	31	100	31	31	##	31	31	100
2015	4	30	30	100	30	30	100	-	-	-	30	30	100	30	30	100	30	30	100	30	30	100	30	30	##	29	30	97	-	-	-	30	30	100	30	30	##	30	30	100
2015	5	31	31	100	31	31	100	-	-	-	31	31	100	31	31	100	31	31	100	31	31	100	31	31	##	31	31	##	-	-	-	31	31	100	31	31	##	31	31	100
2015	6	13	30	43	12	30	40	-	-	-	28	30	93	30	30	100	28	30	93	30	30	100	30	30	##	30	30	##	-	-	-	28	30	93	27	30	90	30	30	100
2015	7	0	31	0	0	31	0	-	-	-	0	31	0	1	31	3	0	31	0	0	31	0	8	31	26	6	31	19	-	-	-	1	27	4	10	31	32	12	31	39
2015	8	0	31	0	0	31	0	-	-	-	1	31	3	0	31	0	0	31	0	2	31	6	1	31	3	0	31	0	-	-	-	0	30	0	15	31	48	19	31	61
2015	9	0	21	0	0	20	0	-	-	-	2	17	12	0	13	0	0	18	0	6	17	35	3	16	19	0	16	0	-	-	-	0	12	0	11	14	79	7	14	50

Appendix C.6. Walrus monthly calling activity 2010-2015 across all mooring locations. Number of days with calling activity (#), number of days with recordings (Eff), percent of days with calling activity per month (%).

Year	Month	KZ1			PH1			CL1			IC3			IC2			IC1			WT2			HS1			HS2			HS3			WT1			PB1			BF2		
		#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%
2010	9	-	-	-	-	-	-	-	-	-	10	21	48	12	21	57	13	21	62	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	11	0
2010	10	-	-	-	-	-	-	-	-	-	6	31	19	7	31	23	8	31	26	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	0
2010	11	-	-	-	-	-	-	-	-	-	1	30	3	1	30	3	7	30	23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	30	3
2010	12	-	-	-	-	-	-	-	-	-	21	31	68	0	31	0	7	31	23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	31	3
2011	1	-	-	-	-	-	-	-	-	-	13	31	42	1	31	3	5	31	16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	0
2011	2	-	-	-	-	-	-	-	-	-	19	28	68	0	28	0	1	28	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	28	0
2011	3	-	-	-	-	-	-	-	-	-	12	31	39	0	31	0	5	31	16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	0
2011	4	-	-	-	-	-	-	-	-	-	16	30	53	1	30	3	13	30	43	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	0
2011	5	-	-	-	-	-	-	-	-	-	5	31	16	1	31	3	11	31	35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	0
2011	6	-	-	-	-	-	-	-	-	-	4	8	50	17	21	81	20	27	74	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	0
2011	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	0
2011	8	-	-	-	-	-	-	-	-	-	3	3	100	3	3	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	29	0
2011	9	-	-	-	-	-	-	-	-	-	14	30	47	23	30	77	27	28	96	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	0
2011	10	-	-	-	-	-	-	-	-	-	9	31	29	16	31	52	19	31	61	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	0
2011	11	-	-	-	-	-	-	-	-	-	6	30	20	11	30	37	7	30	23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	0
2011	12	-	-	-	-	-	-	-	-	-	5	31	16	3	31	10	2	31	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	0
2012	1	-	-	-	-	-	-	-	-	-	8	31	26	0	31	0	0	31	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	0
2012	2	-	-	-	-	-	-	-	-	-	22	29	76	0	29	0	3	29	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	29	0
2012	3	-	-	-	-	-	-	-	-	-	24	31	77	2	31	6	3	31	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	0
2012	4	-	-	-	-	-	-	-	-	-	7	30	23	8	30	27	2	30	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	0
2012	5	-	-	-	-	-	-	-	-	-	4	14	29	1	19	5	2	31	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	0
2012	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12	30	40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	0
2012	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	29	31	94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	29	7
2012	8	0	11	0	1	10	10	0	9	0	1	4	25	0	5	0	4	28	14	2	2	100	-	-	-	-	-	-	-	-	-	0	2	0	-	-	-	0	1	0
2012	9	0	30	0	5	30	17	5	30	17	9	30	30	9	30	30	7	30	23	30	30	100	-	-	-	-	-	-	-	-	-	1	30	3	-	-	-	2	30	7
2012	10	0	31	0	6	31	19	13	31	42	1	31	3	1	31	3	3	31	10	11	31	35	-	-	-	-	-	-	-	-	-	0	31	0	-	-	-	0	31	0
2012	11	5	30	17	0	30	0	0	30	0	0	30	0	0	30	0	7	30	23	0	30	0	-	-	-	-	-	-	-	-	-	0	30	0	-	-	-	1	30	3
2012	12	13	31	42	1	31	3	0	31	0	0	31	0	0	31	0	7	31	23	0	31	0	-	-	-	-	-	-	-	-	-	0	31	0	-	-	-	2	31	6
2013	1	2	31	6	0	31	0	0	31	0	1	31	3	0	31	0	0	31	0	0	31	0	-	-	-	-	-	-	-	-	-	0	31	0	-	-	-	1	31	3
2013	2	8	28	29	2	28	7	0	28	0	6	28	21	0	28	0	2	28	7	0	28	0	-	-	-	-	-	-	-	-	-	0	28	0	-	-	-	1	28	4
2013	3	20	31	65	2	31	6	0	31	0	2	31	6	0	31	0	9	31	29	1	31	3	-	-	-	-	-	-	-	-	-	1	31	3	-	-	-	6	31	19
2013	4	15	30	50	0	30	0	1	30	3	0	30	0	0	30	0	1	30	3	0	30	0	-	-	-	-	-	-	-	-	-	2	30	7	-	-	-	3	30	10
2013	5	24	31	77	12	31	39	0	31	0	2	31	6	2	31	6	0	31	0	0	31	0	-	-	-	-	-	-	-	-	-	0	31	0	-	-	-	1	31	3
2013	6	22	30	73	24	30	80	23	30	77	4	30	13	18	30	60	22	30	73	18	30	60	-	-	-	-	-	-	-	-	-	3	30	10	-	-	-	1	30	3
2013	7	0	31	0	3	31	10	12	31	39	22	31	71	22	31	71	24	31	77	31	31	100	-	-	-	-	-	-	-	-	-	18	31	58	-	-	-	6	31	19
2013	8	0	30	0	1	31	3	0	31	0	10	30	33	1	4	25	7	31	23	29	30	97	2	2	##	-	-	-	-	-	-	15	31	48	-	-	-	10	31	32
2013	9	0	30	0	3	30	10	7	30	23	12	30	40	10	30	33	17	30	57	29	30	97	29	30	97	-	-	-	-	-	-	8	30	27	1	29	3	0	28	0
2013	10	0	31	0	1	31	3	16	31	52	14	31	45	13	31	42	14	31	45	13	31	42	17	31	55	-	-	-	0	3	0	2	31	6	1	31	3	0	31	0
2013	11	1	30	3	2	30	7	0	30	0	5	30	17	2	30	7	1	30	3	1	14	7	7	30	23	-	-	-	0	30	0	0	30	0	2	30	7	0	30	0
2013	12	17	31	55	2	31	6	0	31	0	3	31	10	0	31	0	0	31	0	-	-	-	5	31	16	-	-	-	0	31	0	1	31	3	2	31	6	2	31	6
2014	1	10	31	32	0	31	0	0	31	0	4	31	13	0	31	0	0	31	0	-	-	-	0	31	0	-	-	-	0	31	0	0	31	0	1	31	3	0	31	0
2014	2	13	28	46	0	28	0	1	28	4	3	28	11	0	28	0	0	28	0	-	-	-	1	28	4	-	-	-	0	28	0	0	28	0	3	28	11	0	28	0
2014	3	23	31	74	3	31	10	1	31	3	0	31	0	0	31	0	0	31	0	-	-	-	0	31	0	-	-	-	0	31	0	0	31	0	2	31	6	1	31	3
2014	4	24	30	80	0	30	0	0	30	0	0	30	0	0	30	0	0	30	0	-	-	-	0	30	0	-	-	-	0	30	0	0	30	0	9	30	30	0	30	0
2014	5	26	31	84	20	31	65	3	31	10	0	31	0	1	31	3	0	31	0	-	-	-	2	31	6	-	-	-	0	31	0	0	31	0	8	31	26	1	31	3
2014	6	17	30	57	12	30	40	27	30	90	18	30	60	18	30	60	22	30	73	-	-	-	14	30	47	-	-	-	0	30	0	12	30	40	14	30	47	1	30	3
2014	7	0	31	0	0	31	0	0	31	0	31	31	100	25	31	81	28	31	90	-	-	-	31	31	##	-	-	-	0	31	0	27	31	87	24	31	77	3	31	10
2014	8	1	31	3	0	31	0	0	31	0	12	31	39	2	31	6	13	31	42	-	-	-	31	31	##	-	-	-	0	31	0	13	31	42	10	31	32	1	31	3
2014	9	1	30	3	1	29	3	12	29	41	12	30	40	8	30	27	16	30	53	-	-	-	29	30	97	-	-	-	0	22	0	13	30	43	5	29	17	0	29	0
2014	10	0	31	0	0	31	0	10	31	32	5	31	16	6	31	19	1	31	3	6	26	23	15	30	50	12	28	43	-	-	-	3	31	10	1	31	3	0	31	0
2014	11	3	30	10	0	30	0	1	30	3	0	30	0	7	30	23	4	30	13	3	30	10	5	30	17	2	30	7	-	-	-	2	30	7	6	30	20	0	30	0
2014	12	15	31	48	1	31	3	0	31	0	3	31	10	2	31	6	1	31	3	0	31	0	8	31	26	1	31	3	-	-	-	0	31	0	0	31	0	0	31	0
2015	1	28	31	90	0	31	0	0	31	0	0	31	0	0	31	0	0	31	0	0	31	0	5	31	16	0	31	0	-	-	-	0	31	0	0	31	0	0	31	0
2015	2	15	28	54	0	28	0	0	28	0	0	28	0	1	28	4	0	28	0	0	28	0	1	28	4	0	28	0	-	-	-	0	28	0	0	28	0	0	28	0
2015	3	28	31	90	2	31	6	2	31	6	2	31	6	0	31	0	1	31	3	0	31	0	3	31	10	0	31	0	-	-	-	0	31	0	0	31	0	0	31	0
2015	4	18	30	60	0	30	0	1	30	3	0	30	0	0	30	0	0	30	0	0	30	0	5	30	17	0	30	0	-	-	-	0	30	0	0	30	0	0	30	0
2015	5	31	31	100	5	31	16	8	31	26	0	31	0	0	31	0	0	31	0	0	31	0	8	31	26	0	31	0	-	-	-	0	31	0	0	31	0	0	31	0
2015	6	7	30	23	9	30	30	24	30	80	16	30	53	22	30	73	23	30	77	21	30	70	20	30	67	18	30	60	-	-	-	18	30	60	12	30	40	0	30	0
2015	7	0	31	0	0	31	0	4	31	13	18	31	58	7	31	23	8	31	26	31	31	100	31	31	##	30	31	97	-	-	-	10	31	32	12	31	39	9	31	29
2015	8	2	31	6	4	31	13	4	31	13	8	31	26	2	31	6	1	31	3	31	31	100	31	31	##	31	31	##	-	-	-	14	31	45	4	31	13	1	31	3
2015	9	2	21	10	1	21	5	7	20	35	1	17	6	0	13	0	0	18	0	11	17	65	15	16	94	15	16	94	-	-	-	1	13	8	1	14	7	0	14	0

Appendix C.7. Gray whale monthly calling activity 2010-2015 across all mooring locations. Number of days with calling activity (#), number of days with recordings (Eff), percent of days with calling activity per month (%).

Year	Month	KZ1			PH1			CL1			IC3			IC2			IC1			WT2			HS1			HS2			HS3			WT1			PB1			BF2		
		#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%
2010	9	-	-	-	-	-	-	-	-	-	0	21	**0**	0	21	**0**	0	21	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	11	**0**
2010	10	-	-	-	-	-	-	-	-	-	0	31	**0**	1	31	**3**	5	31	**16**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2010	11	-	-	-	-	-	-	-	-	-	0	30	**0**	0	30	**0**	1	30	**3**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2010	12	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	1	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	2	-	-	-	-	-	-	-	-	-	0	28	**0**	0	28	**0**	0	28	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	28	**0**
2011	3	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	4	-	-	-	-	-	-	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2011	5	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	6	-	-	-	-	-	-	-	-	-	0	8	**0**	0	21	**0**	0	27	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2011	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	8	-	-	-	-	-	-	-	-	-	0	3	**0**	0	3	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	29	**0**
2011	9	-	-	-	-	-	-	-	-	-	0	30	**0**	0	30	**0**	1	28	**4**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2011	10	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	1	31	**3**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	11	-	-	-	-	-	-	-	-	-	0	30	**0**	0	30	**0**	3	30	**10**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2011	12	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2012	1	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2012	2	-	-	-	-	-	-	-	-	-	0	29	**0**	0	29	**0**	0	29	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	29	**0**
2012	3	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2012	4	-	-	-	-	-	-	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2012	5	-	-	-	-	-	-	-	-	-	0	14	**0**	0	19	**0**	2	31	**6**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2012	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	30	**10**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2012	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	31	**16**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	29	**0**
2012	8	0	11	**0**	9	10	**90**	1	9	**11**	0	4	**0**	0	5	**0**	0	28	**0**	0	2	**0**	-	-	-	-	-	-	-	-	-	0	2	**0**	-	-	-	0	1	**0**
2012	9	0	30	**0**	24	30	**80**	2	30	**7**	0	30	**0**	0	30	**0**	1	30	**3**	0	30	**0**	-	-	-	-	-	-	-	-	-	0	30	**0**	-	-	-	0	30	**0**
2012	10	0	31	**0**	16	31	**52**	2	31	**6**	0	31	**0**	0	31	**0**	2	31	**6**	0	31	**0**	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	0	31	**0**
2012	11	2	30	**7**	1	30	**3**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	-	-	-	0	30	**0**	-	-	-	0	30	**0**
2012	12	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	0	31	**0**
2013	1	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	0	31	**0**
2013	2	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	-	-	-	-	-	-	-	-	-	0	28	**0**	-	-	-	0	28	**0**
2013	3	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	0	31	**0**
2013	4	0	30	**0**	0	30	**0**	1	30	**3**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	-	-	-	0	30	**0**	-	-	-	0	30	**0**
2013	5	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	0	31	**0**
2013	6	6	30	**20**	9	30	**30**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	-	-	-	0	30	**0**	-	-	-	0	30	**0**
2013	7	8	31	**26**	27	31	**87**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	0	31	**0**
2013	8	2	30	**7**	30	31	**97**	0	31	**0**	0	30	**0**	0	4	**0**	1	31	**3**	0	30	**0**	0	2	**0**	-	-	-	-	-	-	0	31	**0**	-	-	-	0	31	**0**
2013	9	0	30	**0**	30	30	**100**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	0	30	**0**	1	29	**3**	0	28	**0**
2013	10	0	31	**0**	24	31	**77**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	3	**0**	0	31	**0**	1	31	**3**	0	31	**0**
2013	11	1	30	**3**	1	30	**3**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	14	**0**	0	30	**0**	-	-	-	0	30	**0**	0	30	**0**	1	30	**3**	0	30	**0**
2013	12	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**
2014	1	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**
2014	2	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	-	-	-	0	28	**0**	-	-	-	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**
2014	3	1	31	**3**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	1	31	**3**	0	31	**0**
2014	4	4	30	**13**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	-	-	-	0	30	**0**	0	30	**0**	3	30	**10**	0	30	**0**
2014	5	1	31	**3**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	3	31	**10**	0	31	**0**
2014	6	17	30	**57**	14	30	**47**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	-	-	-	0	30	**0**	0	30	**0**	5	30	**17**	0	30	**0**
2014	7	13	31	**42**	31	31	**100**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	1	31	**3**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**
2014	8	11	31	**35**	31	31	**100**	0	31	**0**	1	31	**3**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	-	-	-	0	31	**0**	1	31	**3**	1	31	**3**	0	31	**0**
2014	9	6	30	**20**	28	29	**97**	0	29	**0**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	-	-	-	0	22	**0**	0	30	**0**	1	29	**3**	0	29	**0**
2014	10	3	31	**10**	22	31	**71**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	26	**0**	0	30	**0**	0	28	**0**	-	-	-	0	31	**0**	2	31	**6**	0	31	**0**
2014	11	1	30	**3**	2	30	**7**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**
2014	12	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**
2015	1	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**
2015	2	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	-	-	-	0	28	**0**	0	28	**0**	0	28	**0**
2015	3	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**
2015	4	1	30	**3**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**
2015	5	1	31	**3**	0	31	**0**	1	31	**3**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**
2015	6	11	30	**37**	8	30	**27**	10	30	**33**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**
2015	7	7	31	**23**	25	31	**81**	9	31	**29**	1	31	**3**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	1	31	**3**	22	31	**71**	0	31	**0**
2015	8	7	31	**23**	18	31	**58**	17	31	**55**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	18	31	**58**	0	31	**0**
2015	9	4	21	**19**	6	21	**29**	8	20	**40**	0	17	**0**	0	13	**0**	0	18	**0**	0	17	**0**	0	16	**0**	0	16	**0**	-	-	-	0	13	**0**	9	14	**64**	0	14	**0**

Appendix C.8. Humpback whale monthly calling activity 2010-2015 across all mooring locations. Number of days with calling activity (#), number of days with recordings (Eff), percent of days with calling activity per month (%).

Year	Month	KZ1			PH1			CL1			IC3			IC2			IC1			WT2			HS1			HS2			HS3			WT1			PB1			BF2		
		#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%
2010	9	-	-	-	-	-	-	-	-	-	0	21	**0**	0	21	**0**	0	21	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	11	**0**
2010	10	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2010	11	-	-	-	-	-	-	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2010	12	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	1	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	2	-	-	-	-	-	-	-	-	-	0	28	**0**	0	28	**0**	0	28	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	28	**0**
2011	3	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	4	-	-	-	-	-	-	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2011	5	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	6	-	-	-	-	-	-	-	-	-	0	8	**0**	0	21	**0**	0	27	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2011	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	8	-	-	-	-	-	-	-	-	-	0	3	**0**	0	3	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	29	**0**
2011	9	-	-	-	-	-	-	-	-	-	0	30	**0**	0	30	**0**	0	28	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2011	10	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	11	-	-	-	-	-	-	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2011	12	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2012	1	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2012	2	-	-	-	-	-	-	-	-	-	0	29	**0**	0	29	**0**	0	29	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	29	**0**
2012	3	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2012	4	-	-	-	-	-	-	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2012	5	-	-	-	-	-	-	-	-	-	0	14	**0**	0	19	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2012	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2012	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	29	**0**
2012	8	8	11	**73**	8	10	**80**	0	9	**0**	0	4	**0**	0	5	**0**	0	28	**0**	0	2	**0**	-	-	-	-	-	-	-	-	-	0	2	**0**	-	-	-	0	1	**0**
2012	9	20	30	**67**	21	30	**70**	3	30	**10**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	-	-	-	0	30	**0**	-	-	-	0	30	**0**
2012	10	21	31	**68**	2	31	**6**	3	31	**10**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	0	31	**0**
2012	11	1	30	**3**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	-	-	-	0	30	**0**	-	-	-	0	30	**0**
2012	12	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	0	31	**0**
2013	1	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	0	31	**0**
2013	2	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	-	-	-	-	-	-	-	-	-	0	28	**0**	-	-	-	0	28	**0**
2013	3	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	0	31	**0**
2013	4	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	-	-	-	0	30	**0**	-	-	-	0	30	**0**
2013	5	0	31	**0**	1	31	**3**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	0	31	**0**
2013	6	1	30	**3**	2	30	**7**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	-	-	-	0	30	**0**	-	-	-	0	30	**0**
2013	7	19	31	**61**	21	31	**68**	5	31	**16**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	0	31	**0**
2013	8	25	30	**83**	21	31	**68**	4	31	**13**	0	30	**0**	0	4	**0**	0	31	**0**	0	30	**0**	0	2	**0**	-	-	-	-	-	-	0	31	**0**	-	-	-	0	31	**0**
2013	9	15	30	**50**	27	30	**90**	1	30	**3**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	0	30	**0**	0	29	**0**	0	28	**0**
2013	10	7	31	**23**	4	31	**13**	1	31	**3**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	3	**0**	3	31	**10**	0	31	**0**	0	31	**0**
2013	11	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	14	**0**	0	30	**0**	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**
2013	12	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**
2014	1	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**
2014	2	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	-	-	-	0	28	**0**	-	-	-	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**
2014	3	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**
2014	4	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**
2014	5	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**
2014	6	7	30	**23**	0	30	**0**	1	30	**3**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	-	-	-	0	30	**0**	1	30	**3**	0	30	**0**	0	30	**0**
2014	7	9	31	**29**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**
2014	8	11	31	**35**	6	31	**19**	1	31	**3**	1	31	**3**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**
2014	9	21	30	**70**	7	29	**24**	0	29	**0**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	-	-	-	0	22	**0**	0	30	**0**	0	29	**0**	0	29	**0**
2014	10	22	31	**71**	4	31	**13**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	26	**0**	0	30	**0**	0	28	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**
2014	11	1	30	**3**	1	30	**3**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**
2014	12	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**
2015	1	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**
2015	2	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	-	-	-	0	28	**0**	0	28	**0**	0	28	**0**
2015	3	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**
2015	4	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**
2015	5	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**
2015	6	1	30	**3**	1	30	**3**	2	30	**7**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**
2015	7	2	31	**6**	2	31	**6**	10	31	**32**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	2	31	**6**	0	31	**0**	0	31	**0**
2015	8	5	31	**16**	5	31	**16**	12	31	**39**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**
2015	9	10	21	**48**	1	21	**5**	1	20	**5**	0	17	**0**	0	13	**0**	0	18	**0**	0	17	**0**	0	16	**0**	0	16	**0**	-	-	-	0	13	**0**	0	14	**0**	0	14	**0**

Appendix C.9. Killer whale monthly calling activity 2010-2015 across all mooring locations. Number of days with calling activity (#), number of days with recordings (Eff), percent of days with calling activity per month (%).

Year	Month	KZ1			PH1			CL1			IC3			IC2			IC1			WT2			HS1			HS2			HS3			WT1			PB1			BF2		
		#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%
2010	9	-	-	-	-	-	-	-	-	-	0	21	**0**	0	21	**0**	0	21	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	11	**0**
2010	10	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2010	11	-	-	-	-	-	-	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2010	12	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	1	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	2	-	-	-	-	-	-	-	-	-	0	28	**0**	0	28	**0**	0	28	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	28	**0**
2011	3	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	4	-	-	-	-	-	-	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2011	5	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	6	-	-	-	-	-	-	-	-	-	0	8	**0**	0	21	**0**	0	27	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2011	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	8	-	-	-	-	-	-	-	-	-	0	3	**0**	0	3	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	29	**0**
2011	9	-	-	-	-	-	-	-	-	-	0	30	**0**	0	30	**0**	1	28	**4**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2011	10	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	3	31	**10**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	11	-	-	-	-	-	-	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2011	12	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2012	1	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2012	2	-	-	-	-	-	-	-	-	-	0	29	**0**	0	29	**0**	0	29	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	29	**0**
2012	3	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2012	4	-	-	-	-	-	-	-	-	-	0	30	**0**	1	30	**3**	0	30	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	30	**3**
2012	5	-	-	-	-	-	-	-	-	-	0	14	**0**	0	19	**0**	1	31	**3**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2012	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	30	**3**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2012	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	29	**0**
2012	8	0	11	**0**	5	10	**50**	0	9	**0**	0	4	**0**	0	5	**0**	0	28	**0**	0	2	**0**	-	-	-	-	-	-	-	-	-	0	2	**0**	-	-	-	0	1	**0**
2012	9	0	30	**0**	9	30	**30**	0	30	**0**	1	30	**3**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	-	-	-	1	30	**3**	-	-	-	1	30	**3**
2012	10	1	31	**3**	3	31	**10**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	2	31	**6**
2012	11	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	-	-	-	0	30	**0**	-	-	-	0	30	**0**
2012	12	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	0	31	**0**
2013	1	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	0	31	**0**
2013	2	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	-	-	-	-	-	-	-	-	-	0	28	**0**	-	-	-	0	28	**0**
2013	3	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	0	31	**0**
2013	4	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	1	30	**3**	-	-	-	-	-	-	-	-	-	0	30	**0**	-	-	-	0	30	**0**
2013	5	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	0	31	**0**
2013	6	2	30	**7**	7	30	**23**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	1	30	**3**	-	-	-	-	-	-	-	-	-	0	30	**0**	-	-	-	1	30	**3**
2013	7	6	31	**19**	16	31	**52**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	1	31	**3**
2013	8	2	30	**7**	8	31	**26**	0	25	**0**	0	30	**0**	0	4	**0**	0	31	**0**	0	30	**0**	0	2	**0**	-	-	-	-	-	-	0	31	**0**	-	-	-	0	31	**0**
2013	9	11	30	**37**	8	30	**27**	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	0	30	**0**	0	29	**0**	0	28	**0**
2013	10	4	31	**13**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	3	**0**	0	31	**0**	2	31	**6**	0	31	**0**
2013	11	4	30	**13**	0	30	**0**	-	-	-	0	30	**0**	0	30	**0**	2	30	**7**	0	14	**0**	0	30	**0**	-	-	-	0	30	**0**	0	30	**0**	5	30	**17**	0	30	**0**
2013	12	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**
2014	1	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**
2014	2	0	28	**0**	0	28	**0**	-	-	-	0	28	**0**	0	28	**0**	0	28	**0**	-	-	-	0	28	**0**	-	-	-	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**
2014	3	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**
2014	4	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**
2014	5	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	1	31	**3**	0	31	**0**
2014	6	12	30	**40**	9	30	**30**	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**
2014	7	6	31	**19**	11	31	**35**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	3	31	**10**	0	31	**0**
2014	8	12	31	**39**	5	31	**16**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**
2014	9	6	30	**20**	7	29	**24**	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	-	-	-	0	20	**0**	0	30	**0**	1	29	**3**	0	29	**0**
2014	10	5	31	**16**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	0	26	**0**	0	30	**0**	0	28	**0**	-	-	-	0	31	**0**	2	31	**6**	0	31	**0**
2014	11	4	30	**13**	2	30	**7**	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	2	30	**7**	0	30	**0**
2014	12	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	30	**0**	0	31	**0**	0	31	**0**
2015	1	1	31	**3**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**
2015	2	0	28	**0**	0	28	**0**	-	-	-	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	-	-	-	0	28	**0**	0	28	**0**	0	28	**0**
2015	3	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**
2015	4	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	0	30	**0**	1	30	**3**
2015	5	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**
2015	6	7	30	**23**	7	30	**23**	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**
2015	7	4	31	**13**	6	31	**19**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	1	31	**3**	0	31	**0**	0	31	**0**	-	-	-	0	27	**0**	0	31	**0**	0	31	**0**
2015	8	7	31	**23**	7	31	**23**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	1	31	**3**	0	31	**0**	-	-	-	0	30	**0**	0	31	**0**	0	31	**0**
2015	9	0	21	**0**	0	20	**0**	-	-	-	0	17	**0**	0	13	**0**	0	18	**0**	0	17	**0**	0	16	**0**	0	16	**0**	-	-	-	0	12	**0**	0	14	**0**	0	14	**0**

Appendix C.10. Ribbon seal monthly calling activity 2010-2015 across all mooring locations. Number of days with calling activity (#), number of days with recordings (Eff), percent of days with calling activity per month (%).

Year	Month	KZ1			PH1			CL1			IC3			IC2			IC1			WT2			HS1			HS2			HS3			WT1			PB1			BF2		
		#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%
2010	9	-	-	-	-	-	-	-	-	-	0	21	**0**	0	21	**0**	0	21	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	11	**0**
2010	10	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	31	**29**
2010	11	-	-	-	-	-	-	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	30	**3**
2010	12	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	1	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	2	-	-	-	-	-	-	-	-	-	0	28	**0**	0	28	**0**	0	28	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	28	**0**
2011	3	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	4	-	-	-	-	-	-	-	-	-	0	30	**0**	0	30	**0**	1	30	**3**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2011	5	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	6	-	-	-	-	-	-	-	-	-	0	8	**0**	0	21	**0**	0	27	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2011	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	8	-	-	-	-	-	-	-	-	-	0	3	**0**	0	3	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	29	**0**
2011	9	-	-	-	-	-	-	-	-	-	0	30	**0**	0	30	**0**	0	28	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	30	**10**
2011	10	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	31	**32**
2011	11	-	-	-	-	-	-	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12	30	**40**
2011	12	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2012	1	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2012	2	-	-	-	-	-	-	-	-	-	0	29	**0**	0	29	**0**	0	29	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	29	**0**
2012	3	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2012	4	-	-	-	-	-	-	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2012	5	-	-	-	-	-	-	-	-	-	0	14	**0**	0	19	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2012	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2012	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	29	**0**
2012	8	0	11	**0**	0	10	**0**	0	9	**0**	0	4	**0**	0	5	**0**	0	28	**0**	0	2	**0**	-	-	-	-	-	-	-	-	-	0	2	**0**	-	-	-	0	1	**0**
2012	9	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	-	-	-	0	30	**0**	-	-	-	2	30	**7**
2012	10	1	31	**3**	4	31	**13**	5	31	**16**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	1	31	**3**
2012	11	2	30	**7**	25	30	**83**	15	30	**50**	4	30	**13**	2	30	**7**	1	30	**3**	1	30	**3**	-	-	-	-	-	-	-	-	-	3	30	**10**	-	-	-	19	30	**63**
2012	12	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	1	31	**3**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	0	31	**0**
2013	1	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	0	31	**0**
2013	2	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	-	-	-	-	-	-	-	-	-	0	28	**0**	-	-	-	0	28	**0**
2013	3	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	0	31	**0**
2013	4	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	1	30	**3**	0	30	**0**	-	-	-	-	-	-	-	-	-	0	30	**0**	-	-	-	0	30	**0**
2013	5	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	0	31	**0**
2013	6	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	-	-	-	0	30	**0**	-	-	-	0	30	**0**
2013	7	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	0	31	**0**
2013	8	0	30	**0**	0	31	**0**	0	25	**0**	1	30	**3**	0	4	**0**	0	31	**0**	0	30	**0**	0	2	**0**	-	-	-	-	-	-	0	31	**0**	-	-	-	0	31	**0**
2013	9	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	0	30	**0**	0	29	**0**	9	28	**32**
2013	10	0	31	**0**	1	31	**3**	-	-	-	1	31	**3**	2	31	**6**	0	31	**0**	2	31	**6**	2	31	**6**	-	-	-	3	3	**##**	2	31	**6**	0	31	**0**	27	31	**87**
2013	11	0	30	**0**	5	30	**17**	-	-	-	0	30	**0**	6	30	**20**	3	30	**10**	3	14	**21**	0	30	**0**	-	-	-	1	30	**3**	1	30	**3**	1	30	**3**	12	30	**40**
2013	12	0	31	**0**	4	31	**13**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**
2014	1	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**
2014	2	0	28	**0**	0	28	**0**	-	-	-	0	28	**0**	0	28	**0**	0	28	**0**	-	-	-	0	28	**0**	-	-	-	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**
2014	3	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**
2014	4	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	-	-	-	2	30	**7**	0	30	**0**	0	30	**0**	0	30	**0**
2014	5	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	-	-	-	2	31	**6**	0	31	**0**	0	31	**0**	0	31	**0**
2014	6	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**
2014	7	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	-	-	-	3	31	**10**	0	31	**0**	0	31	**0**	0	31	**0**
2014	8	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	-	-	-	5	31	**16**	0	31	**0**	0	31	**0**	2	31	**6**
2014	9	0	30	**0**	0	29	**0**	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	-	-	-	1	20	**5**	0	30	**0**	0	29	**0**	5	29	**17**
2014	10	0	31	**0**	0	31	**0**	-	-	-	3	31	**10**	1	31	**3**	0	31	**0**	0	26	**0**	0	30	**0**	0	28	**0**	-	-	-	1	31	**3**	0	31	**0**	4	31	**13**
2014	11	0	30	**0**	0	30	**0**	-	-	-	1	30	**3**	2	30	**7**	5	30	**17**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	0	30	**0**	2	30	**7**
2014	12	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	30	**0**	0	31	**0**	0	31	**0**
2015	1	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**
2015	2	0	28	**0**	0	28	**0**	-	-	-	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	-	-	-	0	28	**0**	0	28	**0**	0	28	**0**
2015	3	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**
2015	4	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	1	30	**3**	0	30	**0**
2015	5	7	31	**23**	2	31	**6**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**
2015	6	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**
2015	7	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	27	**0**	0	31	**0**	0	31	**0**
2015	8	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	30	**0**	0	31	**0**	0	31	**0**
2015	9	0	21	**0**	0	20	**0**	-	-	-	0	17	**0**	0	13	**0**	0	18	**0**	0	17	**0**	0	16	**0**	0	16	**0**	-	-	-	0	12	**0**	0	14	**0**	0	14	**0**

Appendix C.11. Unidentified pinniped monthly calling activity 2010-2015 across all mooring locations. Number of days with calling activity (#), number of days with recordings (Eff), percent of days with calling activity per month (%).

Year	Month	KZ1			PH1			CL1			IC3			IC2			IC1			WT2			HS1			HS2			HS3			WT1			PB1			BF2		
		#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%
2010	9	-	-	-	-	-	-	-	-	-	0	21	**0**	0	21	**0**	4	21	**19**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	11	**0**
2010	10	-	-	-	-	-	-	-	-	-	0	31	**0**	2	31	**6**	5	31	**16**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	31	**6**
2010	11	-	-	-	-	-	-	-	-	-	0	30	**0**	0	30	**0**	1	30	**3**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	30	**10**
2010	12	-	-	-	-	-	-	-	-	-	0	31	**0**	1	31	**3**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8	31	**26**
2011	1	-	-	-	-	-	-	-	-	-	1	31	**3**	0	31	**0**	3	31	**10**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	31	**16**
2011	2	-	-	-	-	-	-	-	-	-	0	28	**0**	0	28	**0**	3	28	**11**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	28	**0**
2011	3	-	-	-	-	-	-	-	-	-	0	31	**0**	2	31	**6**	3	31	**10**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	31	**3**
2011	4	-	-	-	-	-	-	-	-	-	0	30	**0**	2	30	**7**	4	30	**13**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2011	5	-	-	-	-	-	-	-	-	-	0	31	**0**	8	31	**26**	11	31	**35**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	6	-	-	-	-	-	-	-	-	-	0	8	**0**	4	21	**19**	2	27	**7**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2011	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	8	-	-	-	-	-	-	-	-	-	0	3	**0**	2	3	**67**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	29	**0**
2011	9	-	-	-	-	-	-	-	-	-	0	30	**0**	3	30	**10**	3	28	**11**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2011	10	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	11	-	-	-	-	-	-	-	-	-	1	30	**3**	4	30	**13**	9	30	**30**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	30	**7**
2011	12	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	7	31	**23**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2012	1	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	8	31	**26**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	31	**3**
2012	2	-	-	-	-	-	-	-	-	-	0	29	**0**	0	29	**0**	1	29	**3**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	29	**0**
2012	3	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	12	31	**39**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2012	4	-	-	-	-	-	-	-	-	-	4	30	**13**	6	30	**20**	10	30	**33**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	30	**3**
2012	5	-	-	-	-	-	-	-	-	-	0	14	**0**	9	19	**47**	20	31	**65**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7	31	**23**
2012	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	14	30	**47**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2012	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	31	**10**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	29	**3**
2012	8	0	11	**0**	0	10	**0**	0	9	**0**	0	4	**0**	0	5	**0**	1	28	**4**	0	2	**0**	-	-	-	-	-	-	-	-	-	0	2	**0**	-	-	-	0	1	**0**
2012	9	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	1	30	**3**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	-	-	-	0	30	**0**	-	-	-	0	30	**0**
2012	10	0	31	**0**	0	31	**0**	3	31	**10**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	0	31	**0**
2012	11	0	30	**0**	4	30	**13**	2	30	**7**	0	30	**0**	5	30	**17**	4	30	**13**	3	30	**10**	-	-	-	-	-	-	-	-	-	13	30	**43**	-	-	-	5	30	**17**
2012	12	0	31	**0**	2	31	**6**	2	31	**6**	4	31	**13**	1	31	**3**	10	31	**32**	2	31	**6**	-	-	-	-	-	-	-	-	-	5	31	**16**	-	-	-	3	31	**10**
2013	1	0	31	**0**	1	31	**3**	3	31	**10**	2	31	**6**	1	31	**3**	2	31	**6**	1	31	**3**	-	-	-	-	-	-	-	-	-	1	31	**3**	-	-	-	3	31	**10**
2013	2	0	28	**0**	5	28	**18**	5	28	**18**	0	28	**0**	0	28	**0**	1	28	**4**	6	28	**21**	-	-	-	-	-	-	-	-	-	0	28	**0**	-	-	-	1	28	**4**
2013	3	0	31	**0**	7	31	**23**	4	31	**13**	0	31	**0**	1	31	**3**	7	31	**23**	0	31	**0**	-	-	-	-	-	-	-	-	-	1	31	**3**	-	-	-	2	31	**6**
2013	4	1	30	**3**	14	30	**47**	8	30	**27**	1	30	**3**	8	30	**27**	25	30	**83**	6	30	**20**	-	-	-	-	-	-	-	-	-	9	30	**30**	-	-	-	0	30	**0**
2013	5	0	31	**0**	6	31	**19**	7	31	**23**	0	31	**0**	11	31	**35**	25	31	**81**	2	31	**6**	-	-	-	-	-	-	-	-	-	18	31	**58**	-	-	-	3	31	**10**
2013	6	0	30	**0**	1	30	**3**	0	30	**0**	0	30	**0**	2	30	**7**	3	30	**10**	1	30	**3**	-	-	-	-	-	-	-	-	-	11	30	**37**	-	-	-	0	30	**0**
2013	7	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	8	31	**26**	-	-	-	0	31	**0**
2013	8	0	30	**0**	0	31	**0**	1	31	**3**	0	30	**0**	0	4	**0**	1	31	**3**	0	30	**0**	0	2	**0**	-	-	-	-	-	-	3	31	**10**	-	-	-	0	31	**0**
2013	9	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	2	30	**7**	-	-	-	-	-	-	1	30	**3**	0	29	**0**	0	28	**0**
2013	10	0	31	**0**	1	31	**3**	1	31	**3**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	1	31	**3**	-	-	-	0	3	**0**	2	31	**6**	0	31	**0**	0	31	**0**
2013	11	0	30	**0**	0	30	**0**	0	30	**0**	1	30	**3**	0	30	**0**	0	30	**0**	0	14	**0**	1	30	**3**	-	-	-	1	30	**3**	0	30	**0**	2	30	**7**	0	30	**0**
2013	12	0	31	**0**	0	31	**0**	3	31	**10**	3	31	**10**	1	31	**3**	2	31	**6**	-	-	-	3	31	**10**	-	-	-	1	31	**3**	7	31	**23**	1	31	**3**	0	31	**0**
2014	1	0	31	**0**	1	31	**3**	2	31	**6**	0	31	**0**	1	31	**3**	5	31	**16**	-	-	-	3	31	**10**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	3	31	**10**
2014	2	1	28	**4**	0	28	**0**	5	28	**18**	7	28	**25**	0	28	**0**	9	28	**32**	-	-	-	10	28	**36**	-	-	-	0	28	**0**	2	28	**7**	3	28	**11**	2	28	**7**
2014	3	0	31	**0**	11	31	**35**	17	31	**55**	5	31	**16**	4	31	**13**	15	31	**48**	-	-	-	9	31	**29**	-	-	-	1	31	**3**	2	31	**6**	5	31	**16**	8	31	**26**
2014	4	0	30	**0**	12	30	**40**	17	30	**57**	25	30	**83**	7	30	**23**	20	30	**67**	-	-	-	9	30	**30**	-	-	-	2	30	**7**	14	30	**47**	18	30	**60**	9	30	**30**
2014	5	0	31	**0**	0	31	**0**	6	31	**19**	25	31	**81**	1	31	**3**	13	31	**42**	-	-	-	16	31	**52**	-	-	-	0	31	**0**	8	31	**26**	13	31	**42**	10	31	**32**
2014	6	1	30	**3**	0	30	**0**	0	30	**0**	6	30	**20**	1	30	**3**	7	30	**23**	-	-	-	3	30	**10**	-	-	-	0	30	**0**	1	30	**3**	0	30	**0**	0	30	**0**
2014	7	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	-	-	-	0	31	**0**	1	31	**3**	0	31	**0**	0	31	**0**
2014	8	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	1	31	**3**	1	31	**3**
2014	9	0	30	**0**	0	29	**0**	1	29	**3**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	-	-	-	0	22	**0**	0	30	**0**	0	29	**0**	0	29	**0**
2014	10	0	31	**0**	1	31	**3**	0	31	**0**	1	31	**3**	0	31	**0**	0	31	**0**	0	26	**0**	0	30	**0**	1	28	**4**	-	-	-	1	31	**3**	0	31	**0**	0	31	**0**
2014	11	0	30	**0**	1	30	**3**	0	30	**0**	1	30	**3**	0	30	**0**	0	30	**0**	3	30	**10**	0	30	**0**	1	30	**3**	-	-	-	9	30	**30**	0	30	**0**	0	30	**0**
2014	12	0	31	**0**	0	31	**0**	0	31	**0**	7	31	**23**	0	31	**0**	2	31	**6**	4	31	**13**	0	31	**0**	0	31	**0**	-	-	-	7	31	**23**	1	31	**3**	2	31	**6**
2015	1	0	31	**0**	0	31	**0**	0	31	**0**	1	31	**3**	2	31	**6**	4	31	**13**	1	31	**3**	1	31	**3**	0	31	**0**	-	-	-	2	31	**6**	1	31	**3**	0	31	**0**
2015	2	0	28	**0**	4	28	**14**	0	28	**0**	3	28	**11**	1	28	**4**	1	28	**4**	1	28	**4**	0	28	**0**	0	28	**0**	-	-	-	0	28	**0**	0	28	**0**	1	28	**4**
2015	3	2	31	**6**	1	31	**3**	0	31	**0**	9	31	**29**	1	31	**3**	9	31	**29**	8	31	**26**	11	31	**35**	1	31	**3**	-	-	-	17	31	**55**	4	31	**13**	3	31	**10**
2015	4	9	30	**30**	2	30	**7**	4	30	**13**	2	30	**7**	1	30	**3**	12	30	**40**	13	30	**43**	14	30	**47**	4	30	**13**	-	-	-	5	30	**17**	1	30	**3**	1	30	**3**
2015	5	1	31	**3**	0	31	**0**	1	31	**3**	6	31	**19**	1	31	**3**	4	31	**13**	9	31	**29**	13	31	**42**	5	31	**16**	-	-	-	2	31	**6**	3	31	**10**	5	31	**16**
2015	6	0	30	**0**	0	30	**0**	0	30	**0**	1	30	**3**	1	30	**3**	0	30	**0**	1	30	**3**	5	30	**17**	1	30	**3**	-	-	-	1	30	**3**	1	30	**3**	0	30	**0**
2015	7	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	3	31	**10**	1	31	**3**	-	-	-	0	31	**0**	1	31	**3**	2	31	**6**
2015	8	1	31	**3**	0	31	**0**	2	31	**6**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	1	31	**3**	0	31	**0**
2015	9	0	21	**0**	0	21	**0**	0	20	**0**	0	17	**0**	0	13	**0**	0	18	**0**	0	17	**0**	0	16	**0**	0	16	**0**	-	-	-	0	13	**0**	0	14	**0**	0	14	**0**

Appendix C.12. Fin whale monthly calling activity 2010-2015 across all mooring locations. Number of days with calling activity (#), number of days with recordings (Eff), percent of days with calling activity per month (%). Note most moorings have not been analyzed yet for fin whales.

Year	Month	KZ1			PH1			CL1			IC3			IC2			IC1			WT2			HS1			HS2			HS3			WT1			PB1			BF2		
		#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**
2010	9	-	-	-	-	-	-	-	-	-	0	21	**0**	0	21	**0**	0	21	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2010	10	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2010	11	-	-	-	-	-	-	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2010	12	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2011	1	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2011	2	-	-	-	-	-	-	-	-	-	0	28	**0**	0	28	**0**	0	28	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2011	3	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2011	4	-	-	-	-	-	-	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2011	5	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2011	6	-	-	-	-	-	-	-	-	-	0	8	**0**	0	21	**0**	0	27	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2011	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2011	8	-	-	-	-	-	-	-	-	-	0	3	**0**	0	3	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2011	9	-	-	-	-	-	-	-	-	-	0	30	**0**	0	30	**0**	0	28	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2011	10	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2011	11	-	-	-	-	-	-	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2011	12	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2012	1	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2012	2	-	-	-	-	-	-	-	-	-	0	29	**0**	0	29	**0**	0	29	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2012	3	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2012	4	-	-	-	-	-	-	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2012	5	-	-	-	-	-	-	-	-	-	0	14	**0**	0	19	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2012	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2012	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2012	8	-	-	-	10	10	**100**	1	9	**11**	-	-	-	-	-	-	0	22	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2012	9	-	-	-	30	30	**100**	15	30	**50**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2012	10	-	-	-	11	31	**35**	11	31	**35**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2012	11	-	-	-	0	30	**0**	0	30	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2012	12	-	-	-	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2013	1	-	-	-	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2013	2	-	-	-	0	28	**0**	0	28	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2013	3	-	-	-	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2013	4	-	-	-	0	30	**0**	0	30	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2013	5	-	-	-	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2013	6	-	-	-	6	30	**20**	0	30	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2013	7	-	-	-	7	31	**23**	8	31	**26**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2013	8	-	-	-	15	31	**48**	14	31	**45**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2013	9	-	-	-	26	30	**87**	17	30	**57**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2013	10	-	-	-	22	31	**71**	12	31	**39**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2013	11	-	-	-	2	30	**7**	0	30	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2013	12	-	-	-	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2014	1	-	-	-	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2014	2	-	-	-	0	28	**0**	0	28	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2014	3	-	-	-	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2014	4	-	-	-	0	30	**0**	0	30	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2014	5	-	-	-	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2014	6	-	-	-	5	30	**17**	0	30	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2014	7	-	-	-	6	31	**19**	6	31	**19**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2014	8	-	-	-	18	31	**58**	10	31	**32**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2014	9	-	-	-	5	15	**33**	13	24	**54**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2014	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2014	11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2014	12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2015	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2015	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2015	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2015	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2015	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2015	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2015	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2015	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2015	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Appendix C.13. Vessel noise activity 2010-2015 across all mooring locations. Number of days with calling activity (#), number of days with recordings (Eff), percent of days with calling activity per month (%).

Year	Month	KZ1			PH1			CL1			IC3			IC2			IC1			WT2			HS1			HS2			HS3			WT1			PB1			BF2		
		#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%
2010	9	-	-	-	-	-	-	-	-	-	0	21	**0**	0	21	**0**	3	21	**14**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	11	**55**
2010	10	-	-	-	-	-	-	-	-	-	0	31	**0**	2	31	**6**	7	31	**23**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8	31	**26**
2010	11	-	-	-	-	-	-	-	-	-	0	30	**0**	0	30	**0**	1	30	**3**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2010	12	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	1	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	2	-	-	-	-	-	-	-	-	-	0	28	**0**	4	28	**14**	0	28	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	28	**4**
2011	3	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	4	-	-	-	-	-	-	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2011	5	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	6	-	-	-	-	-	-	-	-	-	0	8	**0**	0	21	**0**	0	27	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2011	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	8	-	-	-	-	-	-	-	-	-	2	3	**67**	1	3	**33**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	29	**3**
2011	9	-	-	-	-	-	-	-	-	-	3	30	**10**	7	30	**23**	4	28	**14**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	30	**7**
2011	10	-	-	-	-	-	-	-	-	-	1	31	**3**	0	31	**0**	1	31	**3**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	31	**29**
2011	11	-	-	-	-	-	-	-	-	-	0	30	**0**	3	30	**10**	0	30	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	30	**3**
2011	12	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	31	**3**
2012	1	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2012	2	-	-	-	-	-	-	-	-	-	0	29	**0**	0	29	**0**	0	29	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	29	**0**
2012	3	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2012	4	-	-	-	-	-	-	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2012	5	-	-	-	-	-	-	-	-	-	0	14	**0**	0	19	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2012	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	30	**7**
2012	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	29	**0**
2012	8	8	11	**73**	5	10	**50**	5	9	**56**	2	4	**50**	2	5	**40**	7	28	**25**	0	2	**0**	-	-	-	-	-	-	-	-	-	1	2	**50**	-	-	-	1	1	**100**
2012	9	15	30	**50**	10	30	**33**	12	30	**40**	17	30	**57**	28	30	**93**	29	30	**97**	7	30	**23**	-	-	-	-	-	-	-	-	-	17	30	**57**	-	-	-	12	30	**40**
2012	10	7	31	**23**	6	31	**19**	11	31	**35**	7	31	**23**	24	31	**77**	26	31	**84**	18	31	**58**	-	-	-	-	-	-	-	-	-	13	31	**42**	-	-	-	17	31	**55**
2012	11	3	30	**10**	6	30	**20**	7	30	**23**	5	30	**17**	13	30	**43**	15	30	**50**	11	30	**37**	-	-	-	-	-	-	-	-	-	11	30	**37**	-	-	-	9	30	**30**
2012	12	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	0	31	**0**
2013	1	0	31	**0**	1	31	**3**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	0	31	**0**
2013	2	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	-	-	-	-	-	-	-	-	-	0	28	**0**	-	-	-	0	28	**0**
2013	3	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	0	31	**0**
2013	4	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	-	-	-	1	30	**3**	-	-	-	0	30	**0**
2013	5	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	0	31	**0**
2013	6	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	1	30	**3**	0	30	**0**	-	-	-	-	-	-	-	-	-	0	30	**0**	-	-	-	5	30	**17**
2013	7	19	31	**61**	16	31	**52**	8	31	**26**	1	31	**3**	0	31	**0**	9	31	**29**	0	31	**0**	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	5	31	**16**
2013	8	17	30	**57**	14	31	**45**	14	31	**45**	8	30	**27**	2	4	**50**	25	31	**81**	1	30	**3**	2	2	**##**	-	-	-	-	-	-	20	31	**65**	-	-	-	5	31	**16**
2013	9	17	30	**57**	12	30	**40**	9	30	**30**	10	30	**33**	18	30	**60**	22	30	**73**	3	30	**10**	17	30	**57**	-	-	-	-	-	-	19	30	**63**	15	29	**52**	10	28	**36**
2013	10	8	31	**26**	4	31	**13**	0	31	**0**	11	31	**35**	2	31	**6**	5	31	**16**	3	31	**10**	8	31	**26**	-	-	-	0	3	**0**	6	31	**19**	3	31	**10**	4	31	**13**
2013	11	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	14	**0**	0	30	**0**	-	-	-	7	30	**23**	0	30	**0**	0	30	**0**	0	30	**0**
2013	12	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**
2014	1	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**
2014	2	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	-	-	-	0	28	**0**	-	-	-	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**
2014	3	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**
2014	4	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	-	-	-	0	30	**0**	0	30	**0**	12	30	**40**	0	30	**0**
2014	5	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	20	31	**65**	0	31	**0**
2014	6	6	30	**20**	0	30	**0**	1	30	**3**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	-	-	-	0	30	**0**	0	30	**0**	13	30	**43**	9	30	**30**
2014	7	24	31	**77**	11	31	**35**	7	31	**23**	0	31	**0**	0	31	**0**	3	31	**10**	-	-	-	0	31	**0**	-	-	-	0	31	**0**	2	31	**6**	11	31	**35**	4	31	**13**
2014	8	17	31	**55**	13	31	**42**	6	31	**19**	4	31	**13**	0	31	**0**	14	31	**45**	-	-	-	0	31	**0**	-	-	-	0	31	**0**	14	31	**45**	13	31	**42**	11	31	**35**
2014	9	10	30	**33**	8	29	**28**	3	29	**10**	0	30	**0**	1	30	**3**	10	30	**33**	-	-	-	4	30	**13**	-	-	-	2	22	**9**	14	30	**47**	9	29	**31**	9	29	**31**
2014	10	6	31	**19**	1	31	**3**	1	31	**3**	0	31	**0**	4	31	**13**	4	31	**13**	2	26	**8**	3	30	**10**	2	28	**7**	-	-	-	6	31	**19**	2	31	**6**	0	31	**0**
2014	11	1	30	**3**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	2	30	**7**	0	30	**0**
2014	12	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**
2015	1	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**
2015	2	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	-	-	-	0	28	**0**	0	28	**0**	0	28	**0**
2015	3	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**
2015	4	1	30	**3**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	1	30	**3**	0	30	**0**
2015	5	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**
2015	6	2	30	**7**	1	30	**3**	2	30	**7**	0	30	**0**	2	30	**7**	3	30	**10**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	1	30	**3**	0	30	**0**	0	30	**0**
2015	7	20	31	**65**	18	31	**58**	14	31	**45**	6	31	**19**	15	31	**48**	25	31	**81**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	18	31	**58**	17	31	**55**	0	31	**0**
2015	8	24	31	**77**	25	31	**81**	21	31	**68**	15	31	**48**	25	31	**81**	29	31	**94**	4	31	**13**	0	31	**0**	3	31	**10**	-	-	-	26	31	**84**	25	31	**81**	6	31	**19**
2015	9	11	21	**52**	14	21	**67**	10	20	**50**	8	17	**47**	13	13	**100**	18	18	**100**	11	17	**65**	0	16	**0**	1	16	**6**	-	-	-	13	13	**100**	10	14	**71**	2	14	**14**

Appendix C.14. Airgun noise activity 2010-2015 across all mooring locations. Number of days with calling activity (#), number of days with recordings (Eff), percent of days with calling activity per month (%).

Year	Month	KZ1			PH1			CL1			IC3			IC2			IC1			WT2			HS1			HS2			HS3			WT1			PB1			BF2		
		#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**
2010	9	-	-	-	-	-	-	-	-	-	20	21	**95**	20	21	**95**	20	21	**95**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	11	**36**
2010	10	-	-	-	-	-	-	-	-	-	0	31	**0**	1	31	**3**	1	31	**3**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	31	**6**
2010	11	-	-	-	-	-	-	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2010	12	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	1	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	2	-	-	-	-	-	-	-	-	-	0	28	**0**	0	28	**0**	0	28	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	28	**0**
2011	3	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	4	-	-	-	-	-	-	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2011	5	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	6	-	-	-	-	-	-	-	-	-	0	8	**0**	0	21	**0**	0	27	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2011	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	8	-	-	-	-	-	-	-	-	-	3	3	**100**	3	3	**100**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	29	**10**
2011	9	-	-	-	-	-	-	-	-	-	14	30	**47**	14	30	**47**	11	28	**39**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	16	30	**53**
2011	10	-	-	-	-	-	-	-	-	-	4	31	**13**	5	31	**16**	3	31	**10**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	31	**13**
2011	11	-	-	-	-	-	-	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2011	12	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2012	1	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2012	2	-	-	-	-	-	-	-	-	-	0	29	**0**	0	29	**0**	0	29	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	29	**0**
2012	3	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2012	4	-	-	-	-	-	-	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2012	5	-	-	-	-	-	-	-	-	-	0	14	**0**	0	19	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2012	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2012	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	29	**0**
2012	8	0	11	**0**	2	10	**20**	5	9	**56**	0	4	**0**	0	5	**0**	0	28	**0**	0	2	**0**	-	-	-	-	-	-	-	-	-	0	2	**0**	-	-	-	1	1	**100**
2012	9	0	30	**0**	0	30	**0**	0	30	**0**	1	30	**3**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	-	-	-	1	30	**3**	-	-	-	30	30	**100**
2012	10	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	1	31	**3**	-	-	-	12	31	**39**
2012	11	0	30	**0**	1	30	**3**	2	30	**7**	2	30	**7**	2	30	**7**	2	30	**7**	2	30	**7**	-	-	-	-	-	-	-	-	-	0	30	**0**	-	-	-	7	30	**23**
2012	12	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	0	31	**0**
2013	1	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	0	31	**0**
2013	2	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	-	-	-	-	-	-	-	-	-	0	28	**0**	-	-	-	0	28	**0**
2013	3	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	0	31	**0**
2013	4	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	-	-	-	0	30	**0**	-	-	-	0	30	**0**
2013	5	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	0	31	**0**
2013	6	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	-	-	-	-	-	-	0	30	**0**	-	-	-	0	30	**0**
2013	7	0	31	**0**	0	31	**0**	0	31	**0**	7	31	**23**	9	31	**29**	6	31	**19**	0	31	**0**	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	0	31	**0**
2013	8	0	30	**0**	0	31	**0**	2	31	**6**	9	30	**30**	3	4	**75**	9	31	**29**	0	30	**0**	0	2	**0**	-	-	-	-	-	-	2	31	**6**	-	-	-	0	31	**0**
2013	9	0	30	**0**	1	30	**3**	7	30	**23**	22	30	**73**	22	30	**73**	21	30	**70**	16	30	**53**	23	30	**77**	-	-	-	-	-	-	18	30	**60**	15	29	**52**	12	28	**43**
2013	10	0	31	**0**	5	31	**16**	15	31	**48**	22	31	**71**	19	31	**61**	20	31	**65**	22	31	**71**	23	31	**74**	-	-	-	1	3	**33**	18	31	**58**	19	31	**61**	9	31	**29**
2013	11	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	14	**0**	0	30	**0**	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**
2013	12	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**
2014	1	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**
2014	2	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	-	-	-	0	28	**0**	-	-	-	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**
2014	3	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**
2014	4	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	-	-	-	0	30	**0**	0	30	**0**	1	30	**3**	0	30	**0**
2014	5	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**
2014	6	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	-	-	-	0	30	**0**	0	30	**0**	1	30	**3**	0	30	**0**
2014	7	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**
2014	8	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	1	31	**3**	1	31	**3**
2014	9	0	30	**0**	0	29	**0**	0	29	**0**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	-	-	-	6	22	**27**	0	30	**0**	0	29	**0**	18	29	**62**
2014	10	0	31	**0**	0	31	**0**	0	31	**0**	3	31	**10**	3	31	**10**	1	31	**3**	3	26	**12**	0	30	**0**	1	28	**4**	-	-	-	1	31	**3**	1	31	**3**	1	31	**3**
2014	11	0	30	**0**	0	30	**0**	0	30	**0**	1	30	**3**	1	30	**3**	1	30	**3**	2	30	**7**	0	30	**0**	0	30	**0**	-	-	-	1	30	**3**	0	30	**0**	0	30	**0**
2014	12	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**
2015	1	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**
2015	2	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	0	28	**0**	-	-	-	0	28	**0**	0	28	**0**	0	28	**0**
2015	3	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**
2015	4	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**
2015	5	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**
2015	6	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**
2015	7	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**
2015	8	0	31	**0**	0	31	**0**	0	31	**0**	4	31	**13**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	2	31	**6**	0	31	**0**
2015	9	0	21	**0**	0	21	**0**	0	20	**0**	1	17	**6**	0	13	**0**	0	18	**0**	0	17	**0**	0	16	**0**	0	16	**0**	-	-	-	0	13	**0**	0	14	**0**	0	14	**0**

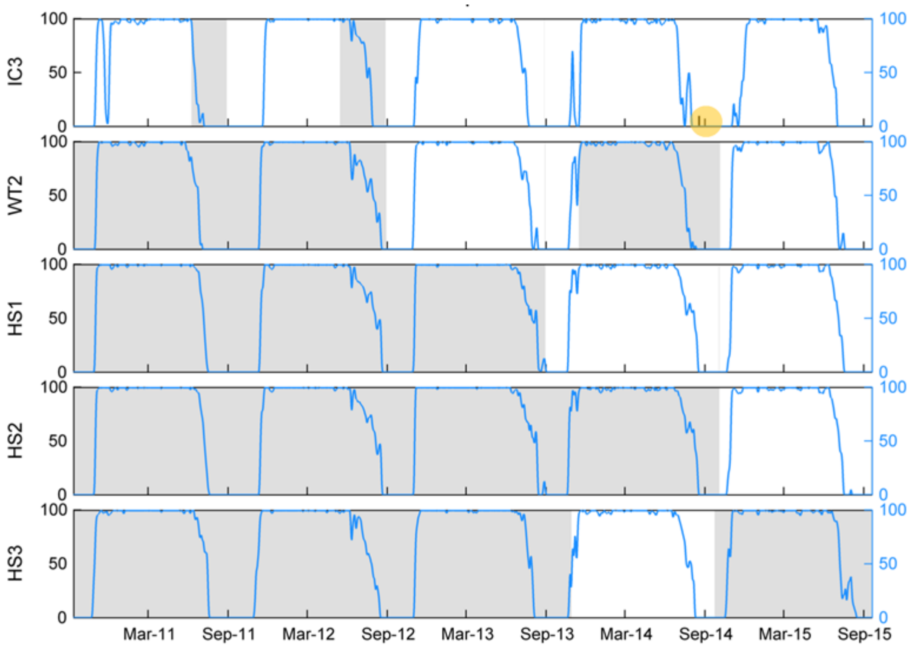
Appendix C.15. Ice noise activity 2010-2015 across all mooring locations. Number of days with calling activity (#), number of days with recordings (Eff), percent of days with calling activity per month (%).

Year	Month	KZ1			PH1			CL1			IC3			IC2			IC1			WT2			HS1			HS2			HS3			WT1			PB1			BF2		
		#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**	#	Eff	**%**
2010	9	-	-	-	-	-	-	-	-	-	0	21	**0**	0	21	**0**	0	21	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	11	**0**
2010	10	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	31	**3**
2010	11	-	-	-	-	-	-	-	-	-	8	30	**27**	15	30	**50**	8	30	**27**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	28	30	**93**
2010	12	-	-	-	-	-	-	-	-	-	17	31	**55**	19	31	**61**	21	31	**68**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	31	31	**100**
2011	1	-	-	-	-	-	-	-	-	-	19	31	**61**	8	31	**26**	19	31	**61**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	30	31	**97**
2011	2	-	-	-	-	-	-	-	-	-	19	28	**68**	11	28	**39**	15	28	**54**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	28	28	**100**
2011	3	-	-	-	-	-	-	-	-	-	7	31	**23**	2	31	**6**	12	31	**39**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	14	31	**45**
2011	4	-	-	-	-	-	-	-	-	-	4	30	**13**	0	30	**0**	16	30	**53**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	18	30	**60**
2011	5	-	-	-	-	-	-	-	-	-	0	31	**0**	0	31	**0**	6	31	**19**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11	31	**35**
2011	6	-	-	-	-	-	-	-	-	-	0	8	**0**	0	21	**0**	0	27	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	24	30	**80**
2011	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	15	31	**48**
2011	8	-	-	-	-	-	-	-	-	-	0	3	**0**	0	3	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	29	**0**
2011	9	-	-	-	-	-	-	-	-	-	0	30	**0**	0	30	**0**	0	28	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	30	**7**
2011	10	-	-	-	-	-	-	-	-	-	3	31	**10**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	11	-	-	-	-	-	-	-	-	-	9	30	**30**	8	30	**27**	10	30	**33**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	22	30	**73**
2011	12	-	-	-	-	-	-	-	-	-	27	31	**87**	28	31	**90**	31	31	**100**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	30	31	**97**
2012	1	-	-	-	-	-	-	-	-	-	21	31	**68**	20	31	**65**	31	31	**100**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	30	31	**97**
2012	2	-	-	-	-	-	-	-	-	-	21	29	**72**	23	29	**79**	28	29	**97**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	29	29	**100**
2012	3	-	-	-	-	-	-	-	-	-	9	31	**29**	16	31	**52**	31	31	**100**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	23	31	**74**
2012	4	-	-	-	-	-	-	-	-	-	9	30	**30**	21	30	**70**	27	30	**90**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	29	30	**97**
2012	5	-	-	-	-	-	-	-	-	-	3	14	**21**	2	19	**11**	27	31	**87**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	27	31	**87**
2012	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	21	30	**70**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	28	30	**93**
2012	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	19	31	**61**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	26	29	**90**
2012	8	0	11	**0**	0	10	**0**	0	9	**0**	0	4	**0**	0	5	**0**	0	28	**0**	0	2	**0**	-	-	-	-	-	-	-	-	-	0	2	**0**	-	-	-	0	1	**0**
2012	9	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	0	30	**0**	1	30	**3**	-	-	-	-	-	-	-	-	-	0	30	**0**	-	-	-	0	30	**0**
2012	10	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	0	31	**0**
2012	11	4	30	**13**	10	30	**33**	10	30	**33**	19	30	**63**	23	30	**77**	9	30	**30**	22	30	**73**	-	-	-	-	-	-	-	-	-	20	30	**67**	-	-	-	18	30	**60**
2012	12	19	31	**61**	30	31	**97**	31	31	**100**	28	31	**90**	31	31	**100**	29	31	**94**	31	31	**100**	-	-	-	-	-	-	-	-	-	29	31	**94**	-	-	-	28	31	**90**
2013	1	22	31	**71**	25	31	**81**	31	31	**100**	31	31	**100**	31	31	**100**	24	31	**77**	31	31	**100**	-	-	-	-	-	-	-	-	-	25	31	**81**	-	-	-	31	31	**100**
2013	2	26	28	**93**	22	28	**79**	27	28	**96**	26	28	**93**	28	28	**100**	27	28	**96**	27	28	**96**	-	-	-	-	-	-	-	-	-	28	28	**100**	-	-	-	28	28	**100**
2013	3	26	31	**84**	28	31	**90**	24	31	**77**	29	31	**94**	31	31	**100**	28	31	**90**	30	31	**97**	-	-	-	-	-	-	-	-	-	26	31	**84**	-	-	-	31	31	**100**
2013	4	26	30	**87**	23	30	**77**	25	30	**83**	29	30	**97**	30	30	**100**	19	30	**63**	30	30	**100**	-	-	-	-	-	-	-	-	-	12	30	**40**	-	-	-	30	30	**100**
2013	5	7	31	**23**	13	31	**42**	11	31	**35**	31	31	**100**	31	31	**100**	3	31	**10**	26	31	**84**	-	-	-	-	-	-	-	-	-	3	31	**10**	-	-	-	30	31	**97**
2013	6	0	30	**0**	0	30	**0**	5	30	**17**	30	30	**100**	30	30	**100**	0	30	**0**	28	30	**93**	-	-	-	-	-	-	-	-	-	0	30	**0**	-	-	-	30	30	**100**
2013	7	1	31	**3**	0	31	**0**	0	31	**0**	22	31	**71**	20	31	**65**	0	31	**0**	30	31	**97**	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	30	31	**97**
2013	8	0	30	**0**	0	31	**0**	0	25	**0**	12	30	**40**	0	4	**0**	0	31	**0**	8	30	**27**	2	2	**##**	-	-	-	-	-	-	0	31	**0**	-	-	-	12	31	**39**
2013	9	0	30	**0**	0	30	**0**	-	-	-	1	30	**3**	0	30	**0**	0	30	**0**	0	30	**0**	3	30	**10**	-	-	-	-	-	-	0	30	**0**	0	29	**0**	1	28	**4**
2013	10	0	31	**0**	0	31	**0**	-	-	-	1	31	**3**	1	31	**3**	0	31	**0**	1	31	**3**	0	31	**0**	-	-	-	1	3	**33**	0	31	**0**	0	31	**0**	0	31	**0**
2013	11	0	30	**0**	3	30	**10**	-	-	-	13	30	**43**	10	30	**33**	8	30	**27**	4	14	**29**	28	30	**93**	-	-	-	18	30	**60**	13	30	**43**	14	30	**47**	14	30	**47**
2013	12	13	31	**42**	16	31	**52**	-	-	-	29	31	**94**	26	31	**84**	22	31	**71**	-	-	-	31	31	**##**	-	-	-	24	31	**77**	22	31	**71**	26	31	**84**	31	31	**100**
2014	1	28	31	**90**	29	31	**94**	-	-	-	29	31	**94**	30	31	**97**	26	31	**84**	-	-	-	31	31	**##**	-	-	-	29	31	**94**	27	31	**87**	19	31	**61**	31	31	**100**
2014	2	22	28	**79**	24	28	**86**	-	-	-	27	28	**96**	27	28	**96**	22	28	**79**	-	-	-	25	28	**89**	-	-	-	25	28	**89**	23	28	**82**	22	28	**79**	28	28	**100**
2014	3	28	31	**90**	29	31	**94**	-	-	-	30	31	**97**	31	31	**100**	25	31	**81**	-	-	-	31	31	**##**	-	-	-	29	31	**94**	21	31	**68**	24	31	**77**	28	31	**90**
2014	4	22	30	**73**	27	30	**90**	-	-	-	22	30	**73**	30	30	**100**	22	30	**73**	-	-	-	30	30	**##**	-	-	-	24	30	**80**	12	30	**40**	20	30	**67**	26	30	**87**
2014	5	3	31	**10**	13	31	**42**	-	-	-	31	31	**100**	29	31	**94**	2	31	**6**	-	-	-	31	31	**##**	-	-	-	20	31	**65**	3	31	**10**	24	31	**77**	23	31	**74**
2014	6	0	30	**0**	1	30	**3**	-	-	-	30	30	**100**	30	30	**100**	0	30	**0**	-	-	-	30	30	**##**	-	-	-	28	30	**93**	2	30	**7**	20	30	**67**	30	30	**100**
2014	7	0	31	**0**	0	31	**0**	-	-	-	24	31	**77**	18	31	**58**	0	31	**0**	-	-	-	31	31	**##**	-	-	-	22	31	**71**	3	31	**10**	15	31	**48**	31	31	**100**
2014	8	0	31	**0**	0	31	**0**	-	-	-	6	31	**19**	1	31	**3**	0	31	**0**	-	-	-	26	31	**84**	-	-	-	6	31	**19**	0	31	**0**	1	31	**3**	6	31	**19**
2014	9	0	30	**0**	0	29	**0**	-	-	-	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	-	-	-	0	20	**0**	0	30	**0**	0	29	**0**	0	29	**0**
2014	10	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	0	26	**0**	1	30	**3**	6	28	**21**	-	-	-	0	31	**0**	0	31	**0**	3	31	**10**
2014	11	1	30	**3**	2	30	**7**	-	-	-	14	30	**47**	12	30	**40**	9	30	**30**	26	30	**87**	25	30	**83**	27	30	**90**	-	-	-	11	30	**37**	18	30	**60**	25	30	**83**
2014	12	20	31	**65**	24	31	**77**	-	-	-	31	31	**100**	29	31	**94**	29	31	**94**	30	31	**97**	29	31	**94**	29	31	**94**	-	-	-	22	30	**73**	31	31	**##**	31	31	**100**
2015	1	24	31	**77**	27	31	**87**	-	-	-	31	31	**100**	31	31	**100**	31	31	**100**	29	31	**94**	24	31	**77**	21	31	**68**	-	-	-	24	31	**77**	26	31	**84**	31	31	**100**
2015	2	26	28	**93**	24	28	**86**	-	-	-	25	28	**89**	28	28	**100**	24	28	**86**	28	28	**100**	28	28	**##**	21	28	**75**	-	-	-	24	28	**86**	22	28	**79**	26	28	**93**
2015	3	25	31	**81**	29	31	**94**	-	-	-	28	31	**90**	31	31	**100**	25	31	**81**	27	31	**87**	27	31	**87**	23	31	**74**	-	-	-	17	31	**55**	26	31	**84**	29	31	**94**
2015	4	26	30	**87**	21	30	**70**	-	-	-	22	30	**73**	30	30	**100**	20	30	**67**	26	30	**87**	22	30	**73**	19	30	**63**	-	-	-	25	30	**83**	27	30	**90**	30	30	**100**
2015	5	5	31	**16**	24	31	**77**	-	-	-	31	31	**100**	31	31	**100**	1	31	**3**	24	31	**77**	25	31	**81**	7	31	**23**	-	-	-	30	31	**97**	25	31	**81**	30	31	**97**
2015	6	0	30	**0**	2	30	**7**	-	-	-	30	30	**100**	26	30	**87**	1	30	**3**	30	30	**100**	11	30	**37**	11	30	**37**	-	-	-	22	30	**73**	19	30	**63**	30	30	**100**
2015	7	0	31	**0**	0	31	**0**	-	-	-	2	31	**6**	0	31	**0**	0	31	**0**	5	31	**16**	4	31	**13**	3	31	**10**	-	-	-	1	27	**4**	0	31	**0**	31	31	**100**
2015	8	0	31	**0**	0	31	**0**	-	-	-	1	31	**3**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	30	**0**	0	31	**0**	4	31	**13**
2015	9	0	21	**0**	0	20	**0**	-	-	-	0	17	**0**	0	13	**0**	0	18	**0**	0	17	**0**	0	16	**0**	0	16	**0**	-	-	-	0	12	**0**	0	14	**0**	0	14	**0**

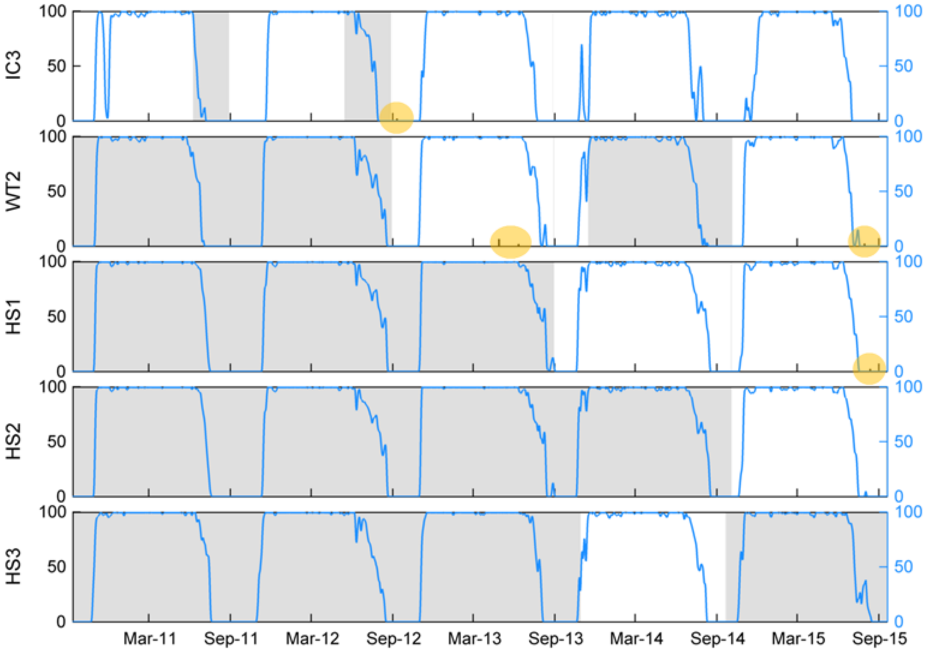
Appendix C.16. Double knock activity 2010-2015 across all mooring locations. Number of days with calling activity (#), number of days with recordings (Eff), percent of days with calling activity per month (%). Note: this sound type is a recent addition to our analysis and not all mooring locations have results.

Year	Month	KZ1			PH1			CL1			IC3			IC2			IC1			WT2			HS1			HS2			HS3			WT1			PB1			BF2		
		#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%
2010	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	11	**0**
2010	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2010	11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2010	12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	31	**10**
2011	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	31	**3**
2011	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	28	**0**
2011	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2011	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2011	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	8	-	-	-	-	-	-	-	-	-	0	3	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	29	**0**
2011	9	-	-	-	-	-	-	-	-	-	0	30	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2011	10	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2011	11	-	-	-	-	-	-	-	-	-	0	30	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2011	12	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2012	1	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2012	2	-	-	-	-	-	-	-	-	-	0	29	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	29	**0**
2012	3	-	-	-	-	-	-	-	-	-	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	31	**0**
2012	4	-	-	-	-	-	-	-	-	-	0	30	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	30	**3**
2012	5	-	-	-	-	-	-	-	-	-	0	14	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	31	**6**
2012	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	30	**0**
2012	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	29	**0**
2012	8	-	-	-	-	-	-	0	9	**0**	0	4	**0**	-	-	-	0	7	**0**	0	2	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**0**
2012	9	-	-	-	-	-	-	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	0	30	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**0**
2012	10	-	-	-	-	-	-	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**0**
2012	11	-	-	-	-	-	-	7	30	**23**	0	30	**0**	-	-	-	2	30	**7**	2	30	**7**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**0**
2012	12	-	-	-	-	-	-	5	31	**16**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**0**
2013	1	-	-	-	-	-	-	2	31	**6**	0	31	**0**	-	-	-	1	31	**3**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**0**
2013	2	-	-	-	-	-	-	9	28	**32**	0	28	**0**	-	-	-	1	28	**4**	5	28	**18**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**0**
2013	3	-	-	-	-	-	-	15	31	**48**	0	31	**0**	-	-	-	2	31	**6**	1	31	**3**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**0**
2013	4	-	-	-	-	-	-	20	30	**67**	0	30	**0**	-	-	-	17	30	**57**	16	30	**53**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**0**
2013	5	-	-	-	-	-	-	16	31	**52**	0	31	**0**	-	-	-	24	31	**77**	25	31	**81**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**0**
2013	6	-	-	-	-	-	-	2	30	**7**	0	30	**0**	-	-	-	4	30	**13**	4	30	**13**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**0**
2013	7	-	-	-	-	-	-	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**0**
2013	8	-	-	-	-	-	-	0	31	**0**	0	30	**0**	-	-	-	0	31	**0**	0	28	**0**	0	2	**0**	-	-	-	-	-	-	0	3	**0**	-	-	-	-	-	**0**
2013	9	-	-	-	-	-	-	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	-	-	-	0	30	**0**	-	-	-	-	-	-	0	30	**0**	0	29	**0**	-	-	**0**
2013	10	-	-	-	-	-	-	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	-	-	-	0	31	**0**	-	-	-	-	-	-	0	31	**0**	0	31	**0**	-	-	**0**
2013	11	-	-	-	-	-	-	4	30	**13**	0	30	**0**	-	-	-	3	30	**10**	-	-	-	0	30	**0**	-	-	-	-	-	-	0	30	**0**	0	30	**0**	-	-	**0**
2013	12	-	-	-	-	-	-	11	31	**35**	0	31	**0**	-	-	-	9	31	**29**	-	-	-	0	31	**0**	-	-	-	-	-	-	0	31	**0**	0	31	**0**	-	-	**0**
2014	1	-	-	-	-	-	-	8	31	**26**	0	31	**0**	-	-	-	11	31	**35**	-	-	-	0	31	**0**	-	-	-	-	-	-	0	31	**0**	0	31	**0**	-	-	**0**
2014	2	-	-	-	-	-	-	21	28	**75**	0	28	**0**	-	-	-	17	28	**61**	-	-	-	0	28	**0**	-	-	-	-	-	-	0	28	**0**	0	28	**0**	-	-	**0**
2014	3	-	-	-	-	-	-	25	31	**81**	0	31	**0**	-	-	-	24	31	**77**	-	-	-	0	31	**0**	-	-	-	-	-	-	0	31	**0**	4	31	**13**	-	-	**0**
2014	4	-	-	-	-	-	-	30	30	**100**	0	30	**0**	-	-	-	30	30	**100**	-	-	-	0	30	**0**	-	-	-	-	-	-	0	30	**0**	18	30	**60**	-	-	**0**
2014	5	-	-	-	-	-	-	21	31	**68**	0	31	**0**	-	-	-	30	31	**97**	-	-	-	0	31	**0**	-	-	-	-	-	-	0	31	**0**	22	31	**71**	-	-	**0**
2014	6	-	-	-	-	-	-	0	30	**0**	0	30	**0**	-	-	-	9	30	**30**	-	-	-	0	30	**0**	-	-	-	-	-	-	0	30	**0**	1	30	**3**	-	-	**0**
2014	7	-	-	-	-	-	-	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	-	-	-	0	31	**0**	-	-	-	-	-	-	0	31	**0**	0	31	**0**	-	-	**0**
2014	8	-	-	-	-	-	-	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	-	-	-	0	31	**0**	-	-	-	-	-	-	0	31	**0**	0	31	**0**	-	-	**0**
2014	9	-	-	-	0	14	**0**	0	29	**0**	0	26	**0**	-	-	-	0	30	**0**	-	-	-	0	30	**0**	-	-	-	-	-	-	0	30	**0**	0	29	**0**	-	-	**0**
2014	10	-	-	-	0	31	**0**	0	31	**0**	-	-	-	-	-	-	0	31	**0**	0	26	**0**	0	30	**0**	0	28	**0**	-	-	-	0	31	**0**	0	31	**0**	-	-	**0**
2014	11	-	-	-	0	30	**0**	1	30	**3**	-	-	-	-	-	-	3	30	**10**	0	30	**0**	0	30	**0**	0	30	**0**	-	-	-	0	30	**0**	0	30	**0**	-	-	**0**
2014	12	-	-	-	0	31	**0**	0	31	**0**	-	-	-	-	-	-	1	31	**3**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	1	31	**3**	-	-	**0**
2015	1	-	-	-	0	31	**0**	6	31	**19**	-	-	-	-	-	-	1	31	**3**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	2	31	**6**	-	-	**0**
2015	2	-	-	-	0	28	**0**	20	28	**71**	-	-	-	-	-	-	3	28	**11**	0	28	**0**	0	28	**0**	0	28	**0**	-	-	-	0	28	**0**	2	28	**7**	-	-	**0**
2015	3	-	-	-	0	31	**0**	20	31	**65**	-	-	-	-	-	-	11	31	**35**	1	31	**3**	0	31	**0**	4	31	**13**	-	-	-	0	31	**0**	3	31	**10**	-	-	**0**
2015	4	-	-	-	0	30	**0**	18	30	**60**	-	-	-	-	-	-	12	30	**40**	15	30	**50**	9	30	**30**	7	30	**23**	-	-	-	0	30	**0**	12	30	**40**	-	-	**0**
2015	5	-	-	-	0	31	**0**	25	31	**81**	-	-	-	-	-	-	19	31	**61**	26	31	**84**	21	31	**68**	23	31	**74**	-	-	-	0	31	**0**	14	31	**45**	-	-	**0**
2015	6	-	-	-	0	30	**0**	0	30	**0**	-	-	-	-	-	-	1	30	**3**	3	30	**10**	5	30	**17**	4	30	**13**	-	-	-	0	30	**0**	1	30	**3**	-	-	**0**
2015	7	-	-	-	0	31	**0**	0	31	**0**	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	-	-	**0**
2015	8	-	-	-	0	31	**0**	0	31	**0**	-	-	-	-	-	-	0	31	**0**	0	31	**0**	0	31	**0**	0	31	**0**	-	-	-	0	31	**0**	0	31	**0**	-	-	**0**
2015	9	-	-	-	0	21	**0**	0	20	**0**	-	-	-	-	-	-	0	18	**0**	0	17	**0**	0	16	**0**	0	16	**0**	-	-	-	0	13	**0**	0	14	**0**	-	-	**0**

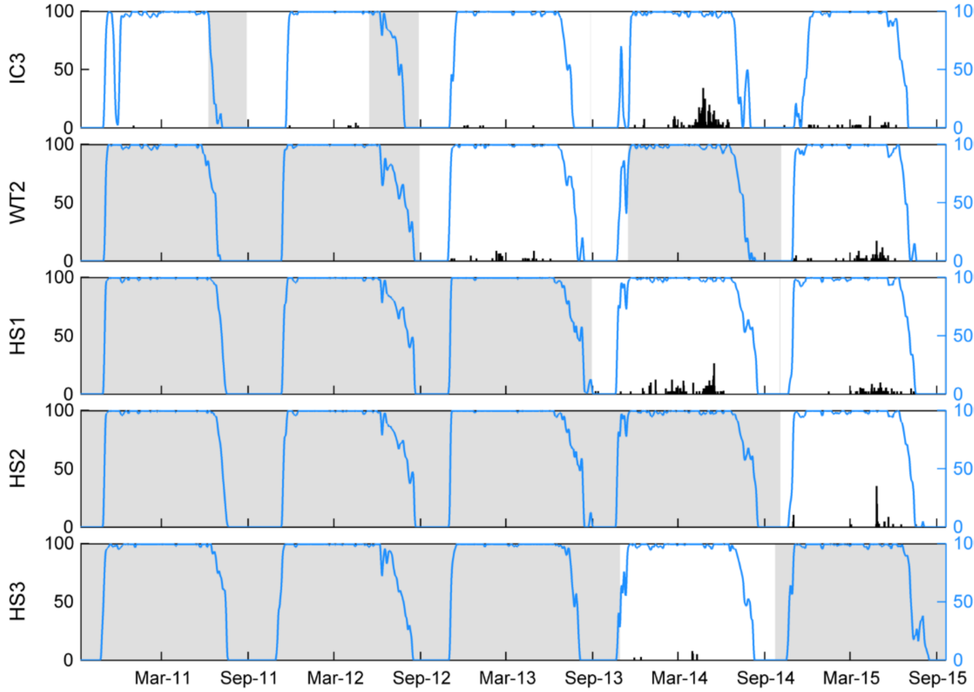
D. Additional long-term passive acoustics calling activity plots.



Appendix D.1. Humpback whale calling activity (presented as the percentage of ten-minute time intervals with calls) for the five CHAOZ-X locations (see Figure 3A), 2012-2015. Blue line indicates percent ice cover (zero-phase, three-day moving average). Gray shading = no data. Yellow ovals highlight days with calling activity.

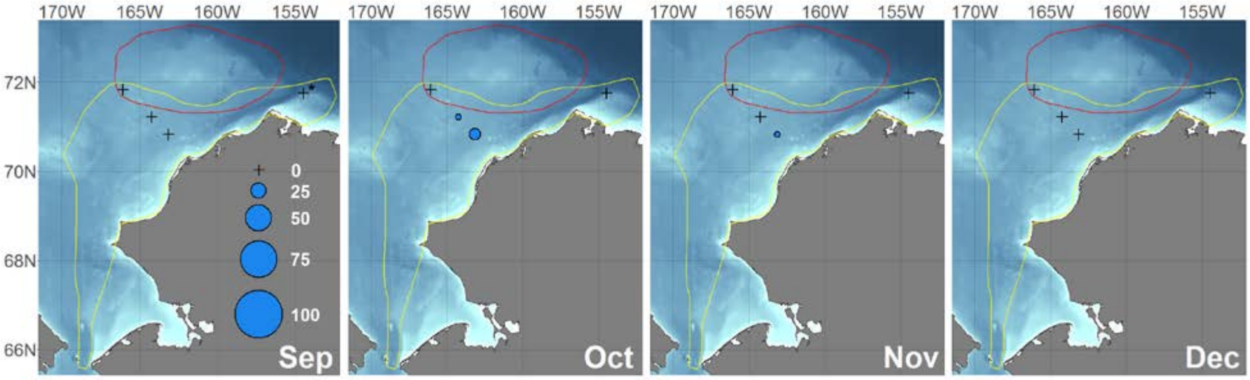


Appendix D.2. Killer whale calling activity (presented as the percentage of ten-minute time intervals with calls) for the five CHAOZ-X locations (see Figure 3A), 2012-2015. Blue line indicates percent ice cover (zero-phase, three-day moving average). Gray shading = no data. Yellow ovals highlight days with calling activity.

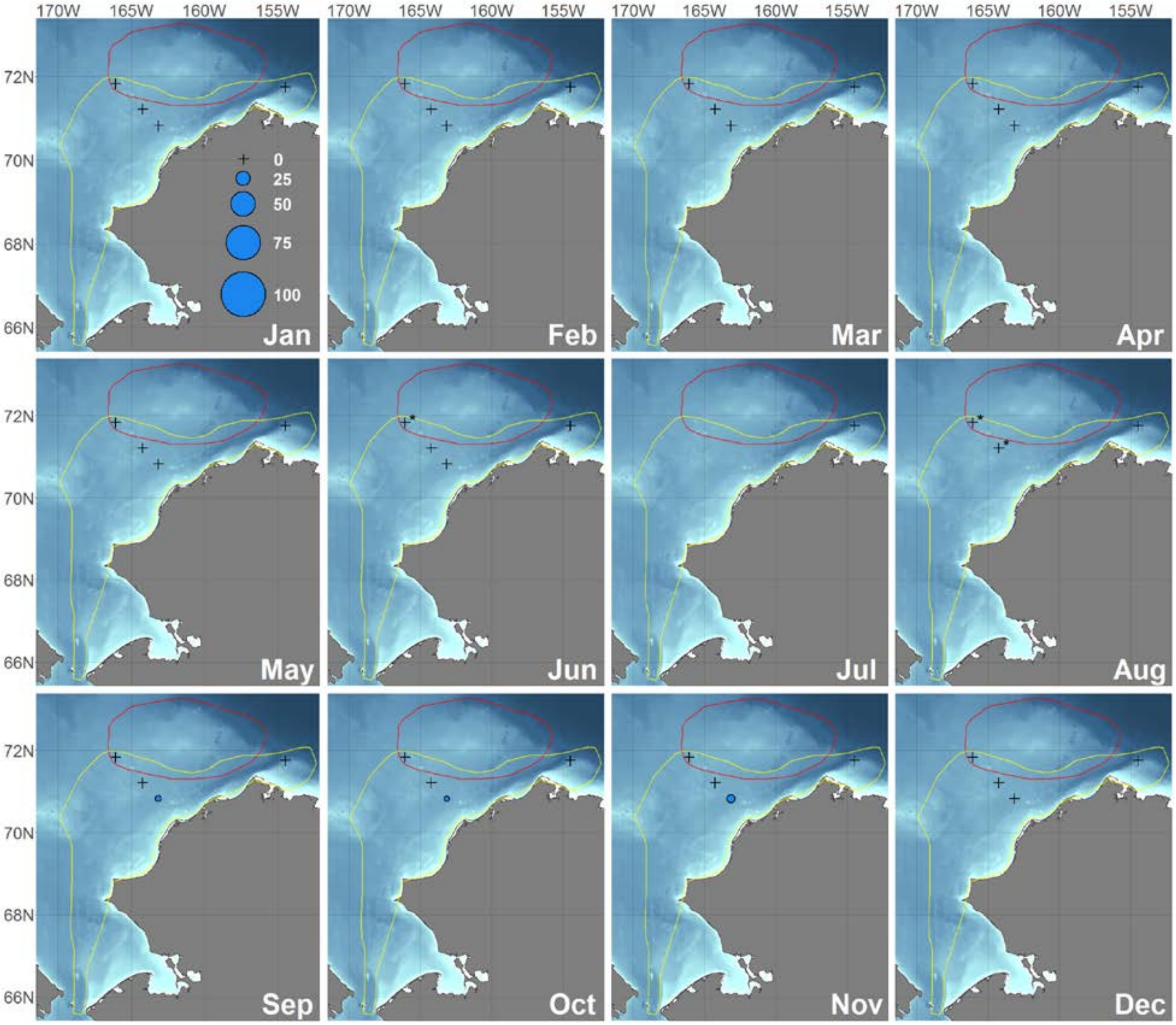


Appendix D.3. Unidentified pinniped calling activity (presented as the percentage of ten-minute time intervals with calls) for the five CHAOZ-X locations (see Figure 3A), 2012-2015. Blue line indicates percent ice cover (zero-phase, three-day moving average). Gray shading = no data.

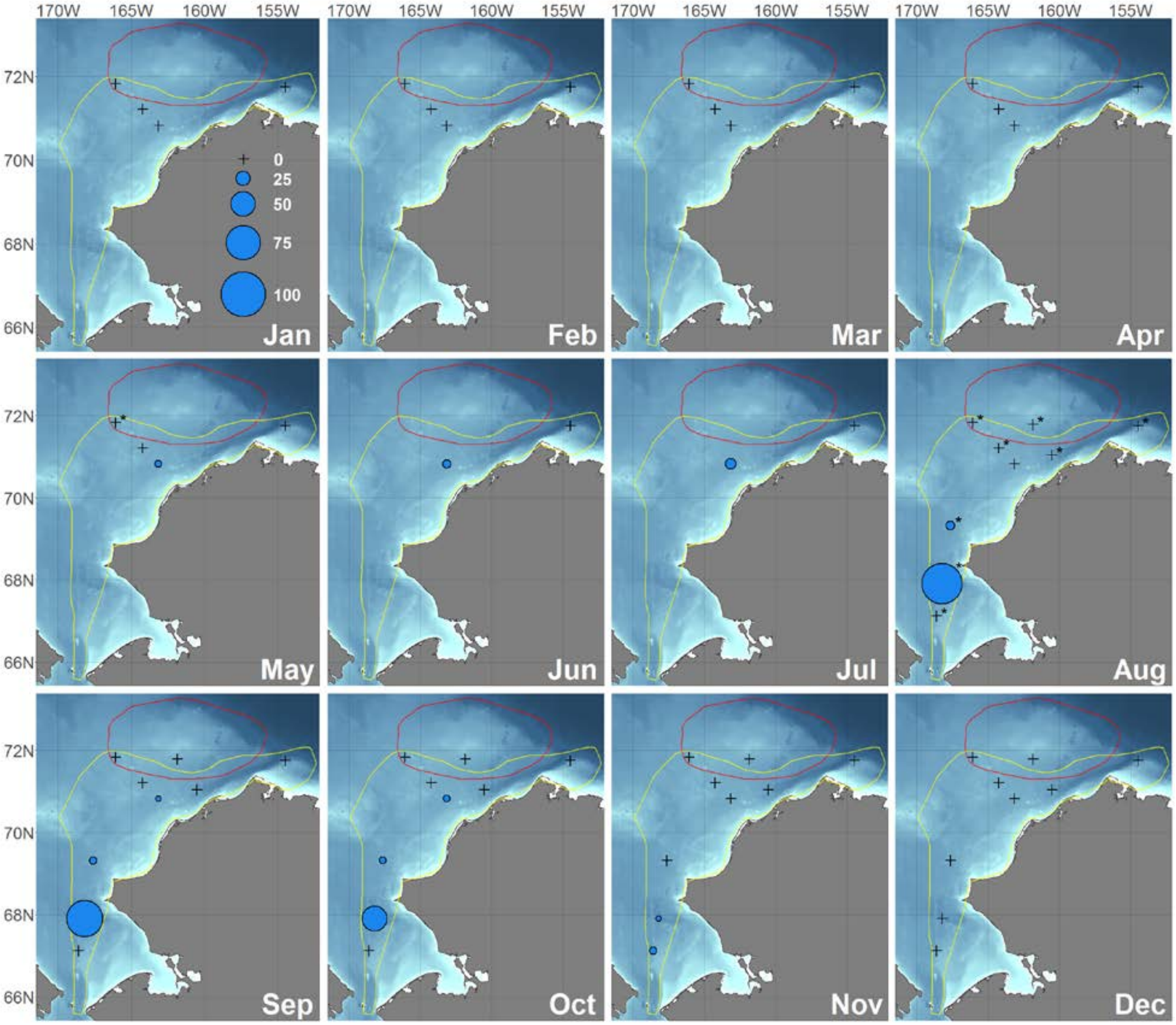
E. Additional passive acoustic monthly calling distribution maps



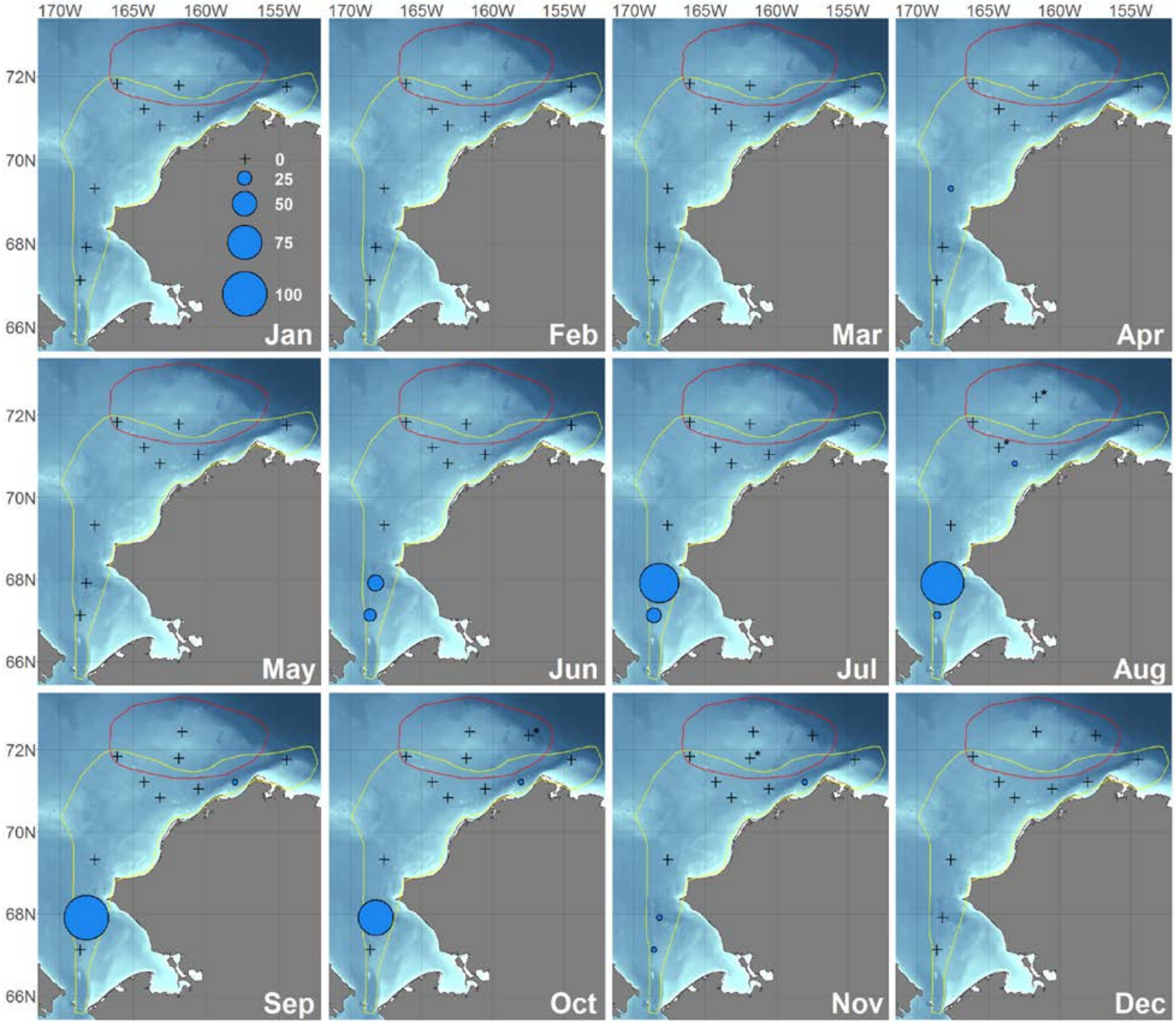
Appendix E.1 Gray whale calling distribution 2010. Graduated scale in the September panel indicates % of days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.7 for numbers used to generate figure.



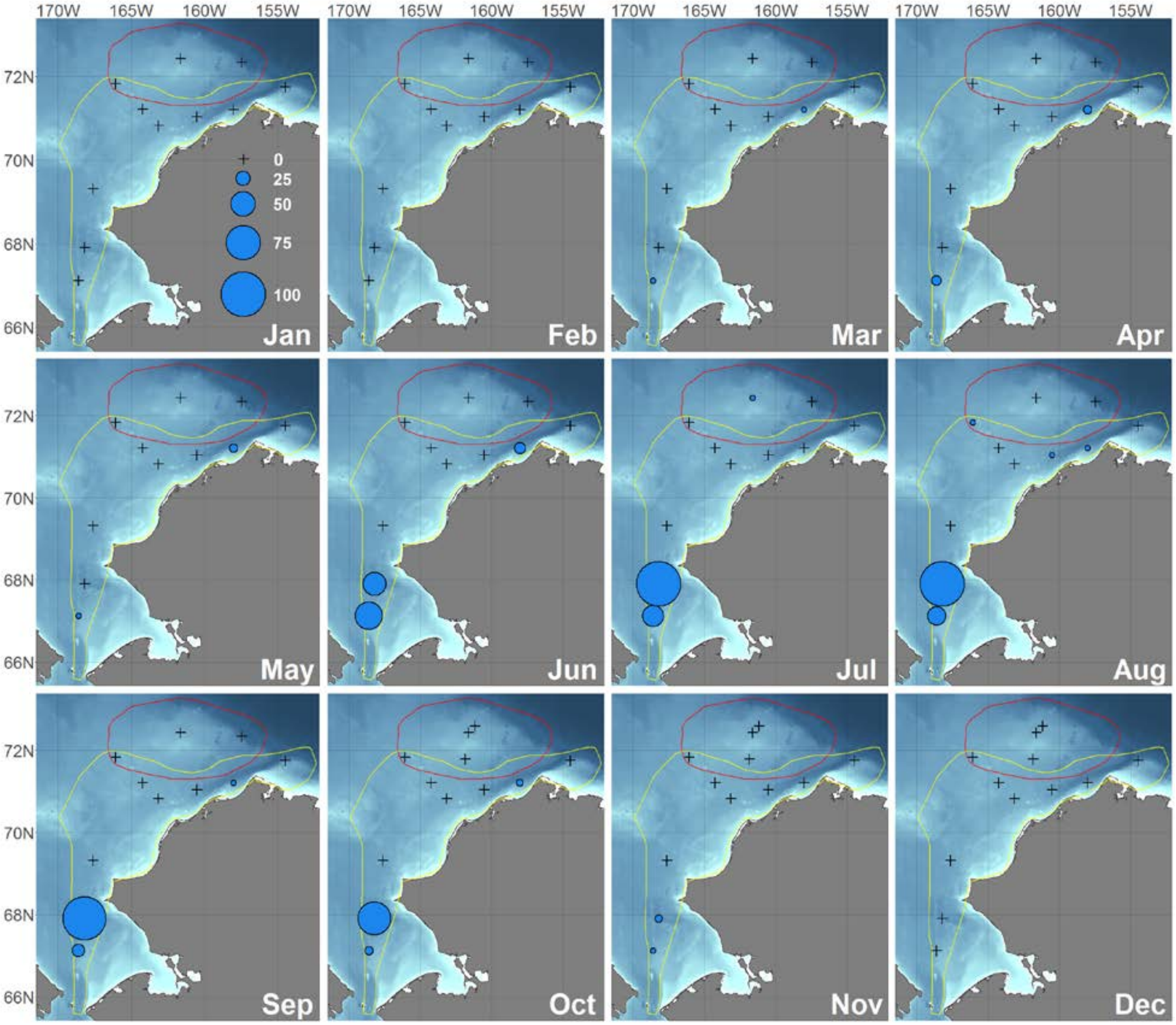
Appendix E.2. Gray whale calling distribution 2011. Graduated scale in the January panel indicates % of days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.7 for numbers used to generate figure.



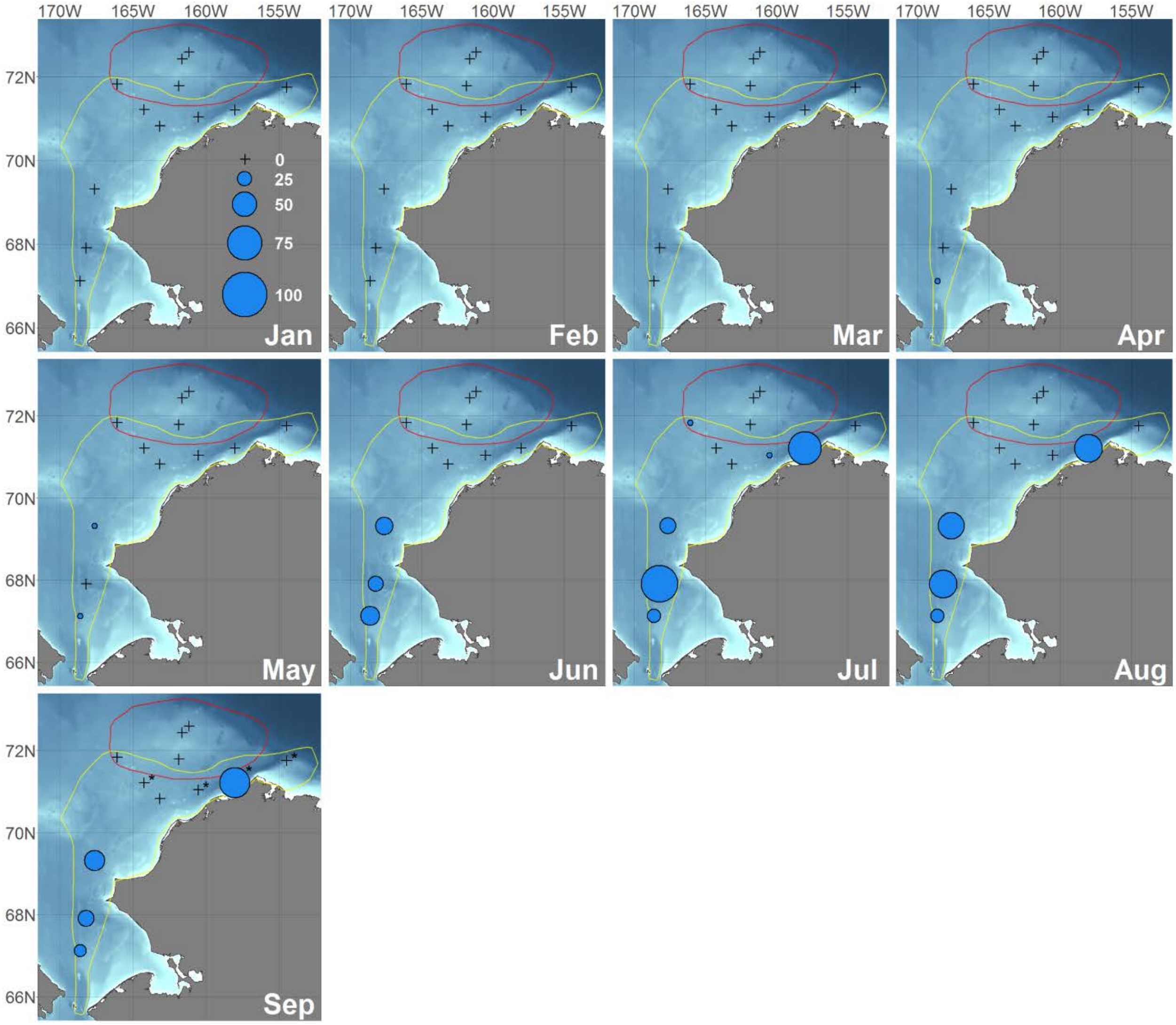
Appendix E.3. Gray whale calling distribution 2012. Graduated scale in the January panel indicates % of days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.7 for numbers used to generate figure.



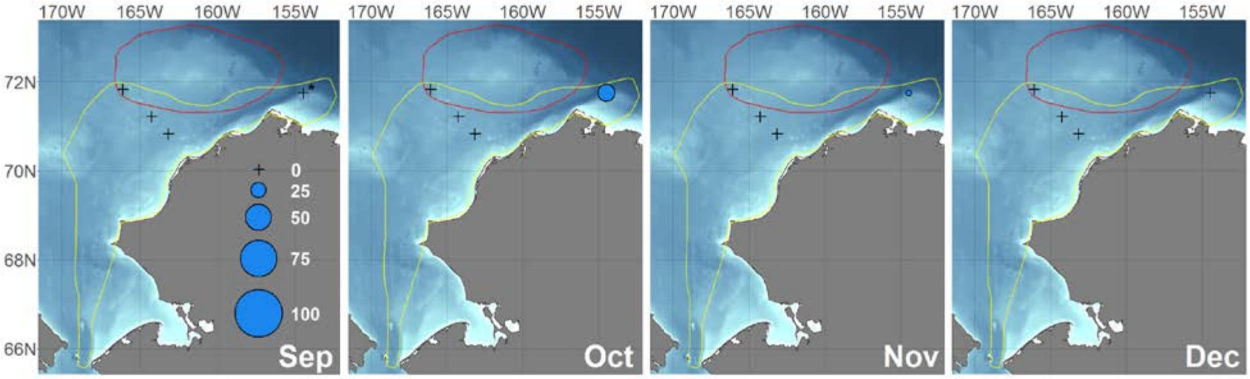
Appendix E.4. Gray whale calling distribution 2013. Graduated scale in the January panel indicates % of days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.7 for numbers used to generate figure.



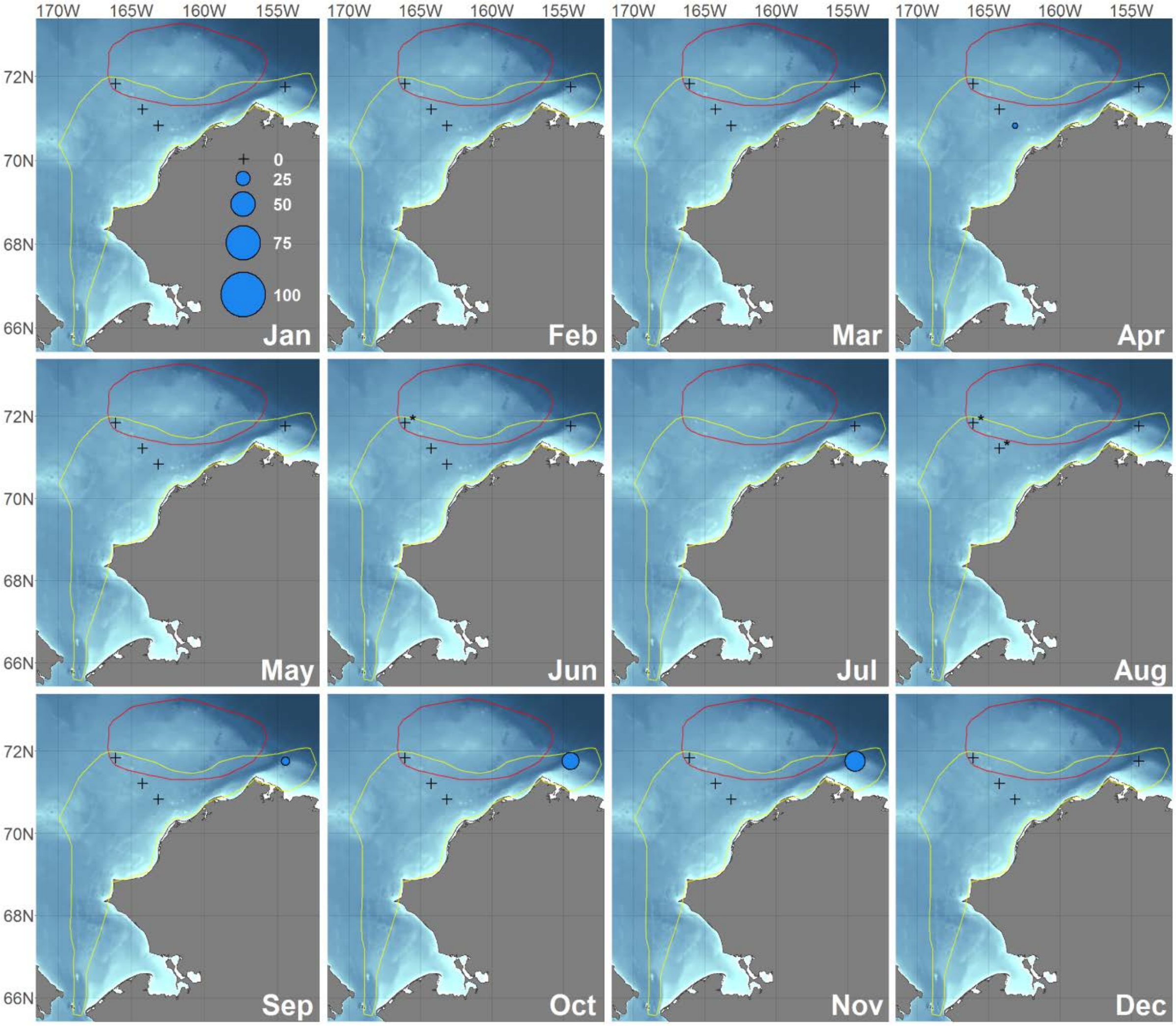
Appendix E.5. Gray whale calling distribution 2014. Graduated scale in the January panel indicates % of days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.7 for numbers used to generate figure.



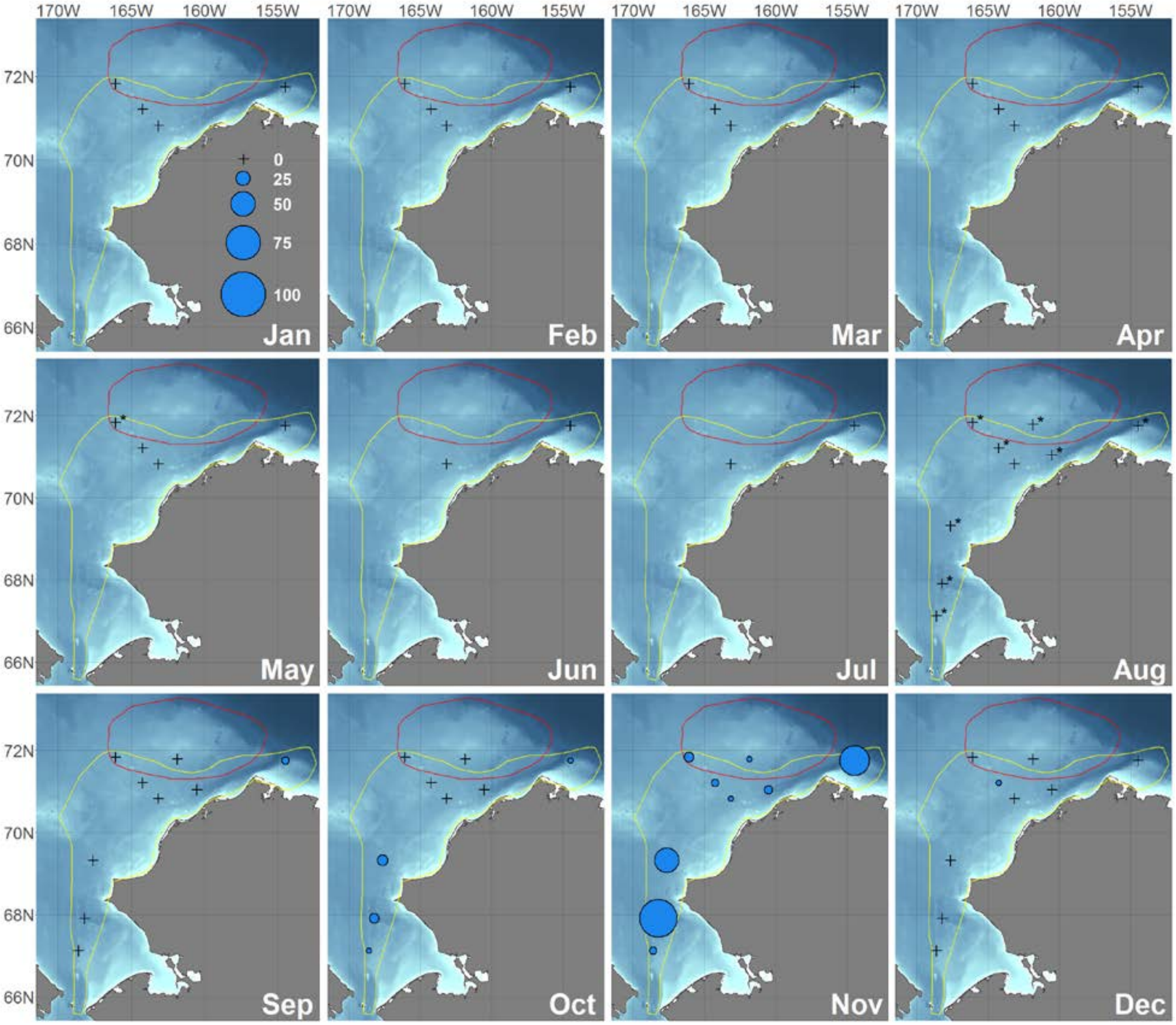
Appendix E.6. Gray whale calling distribution 2015. Graduated scale in the January panel indicates % of days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.7 for numbers used to generate figure.



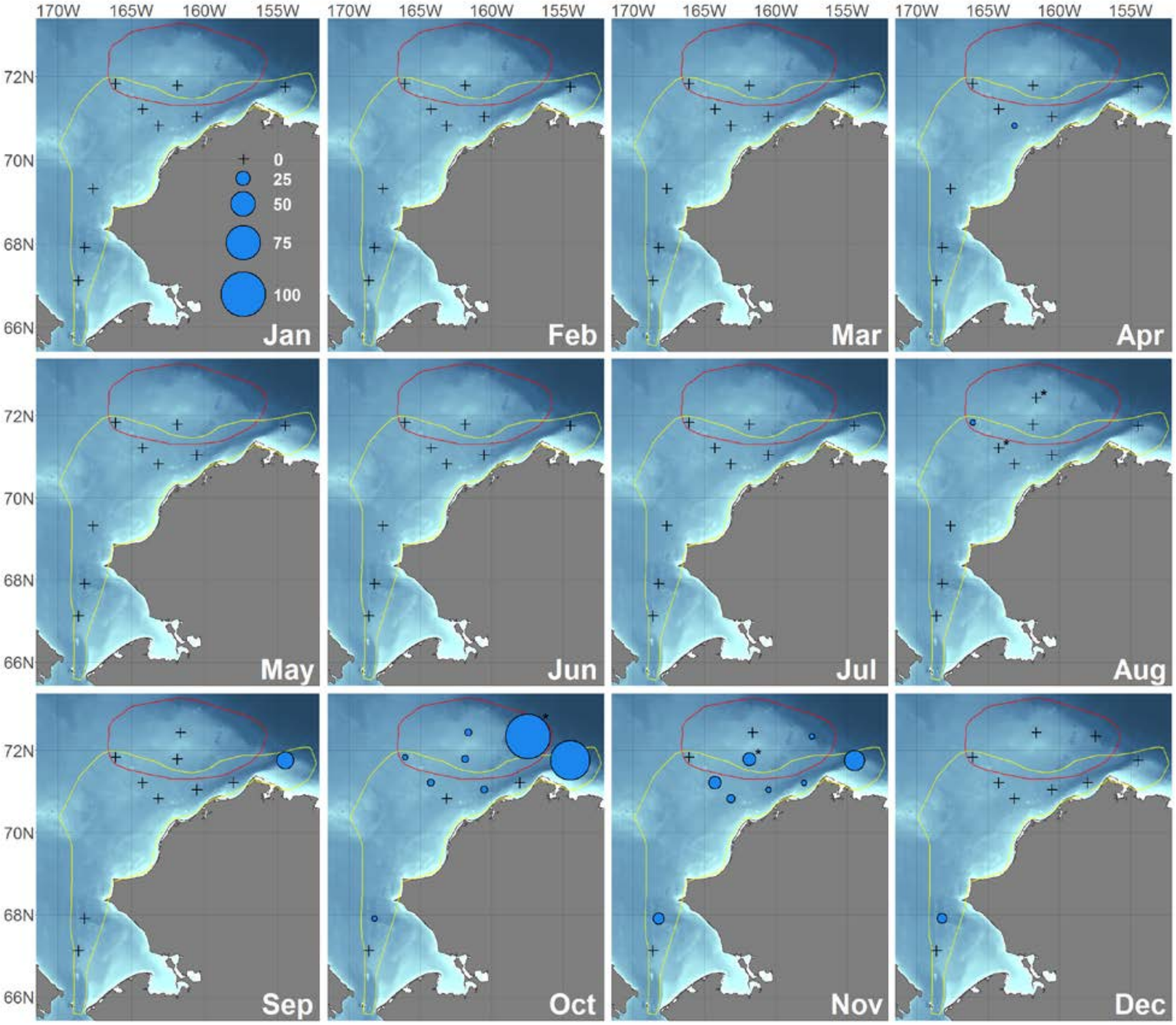
Appendix E.7. Ribbon seal calling distribution 2010. Graduated scale in the September panel indicates % of days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.10 for numbers used to generate figure.



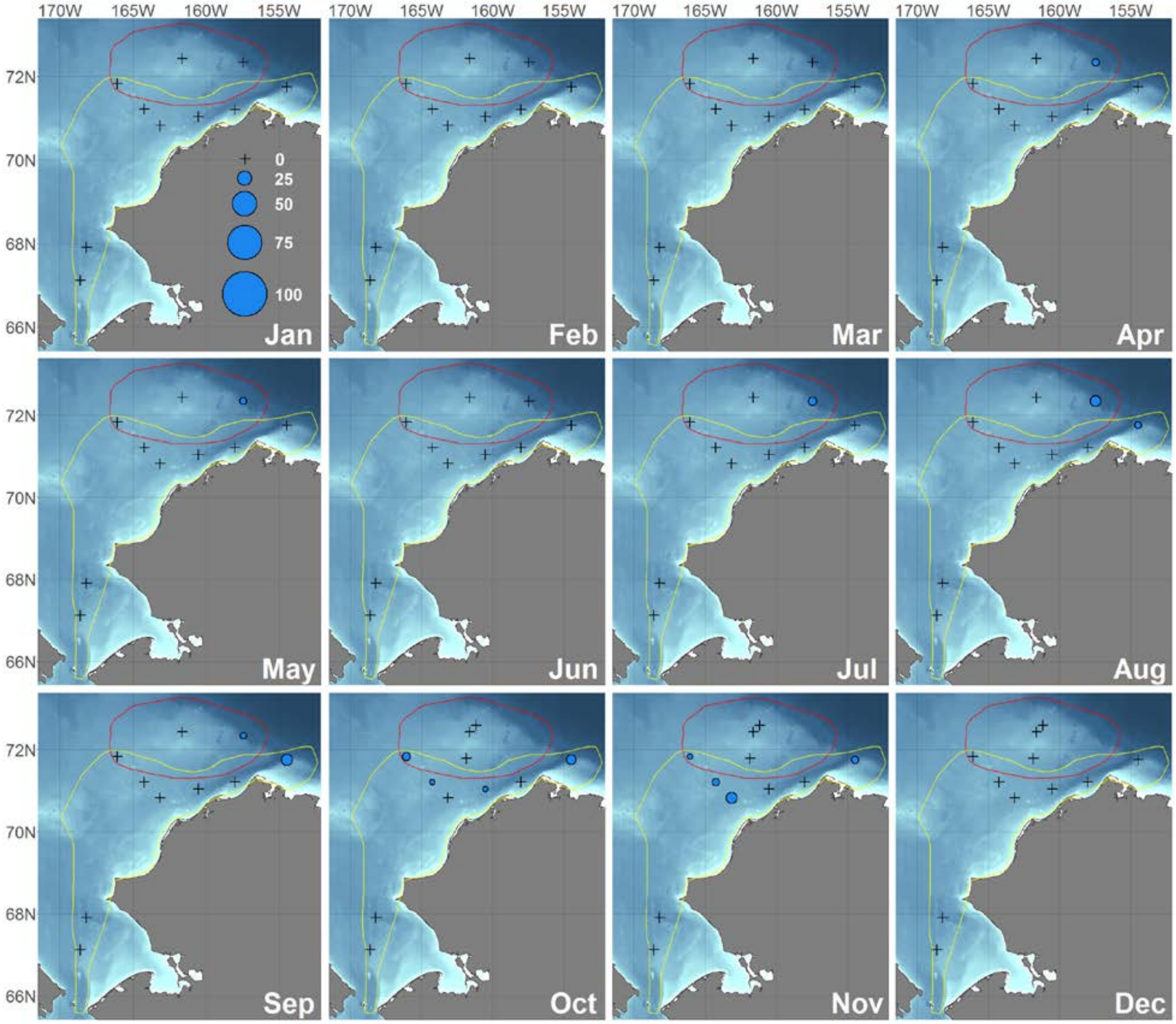
Appendix E.8. Ribbon seal calling distribution 2011. Graduated scale in the January panel indicates % of days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.10 for numbers used to generate figure.



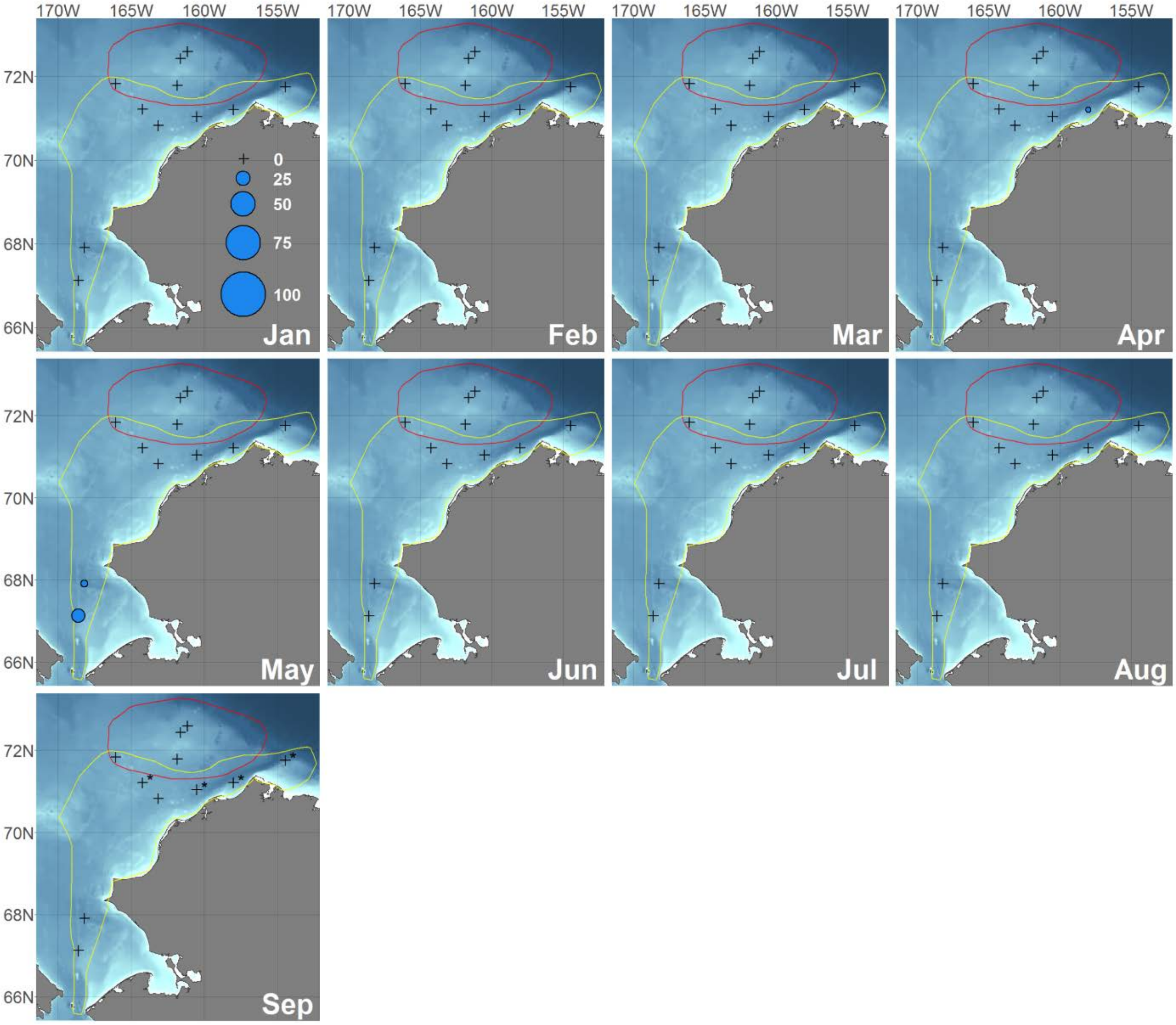
Appendix E.9. Ribbon seal calling distribution 2012. Graduated scale in the January panel indicates % of days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.10 for numbers used to generate figure.



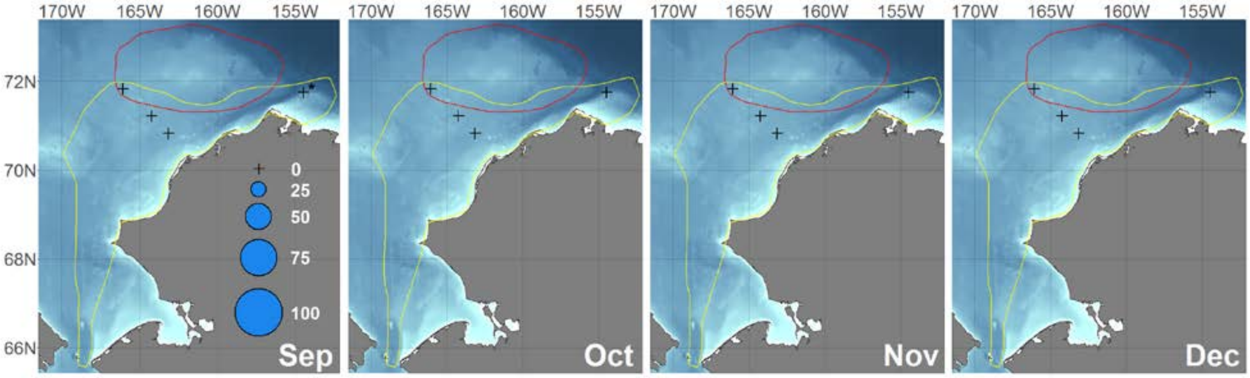
Appendix E.10. Ribbon seal calling distribution 2013. Graduated scale in the January panel indicates % of days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.10 for numbers used to generate figure.



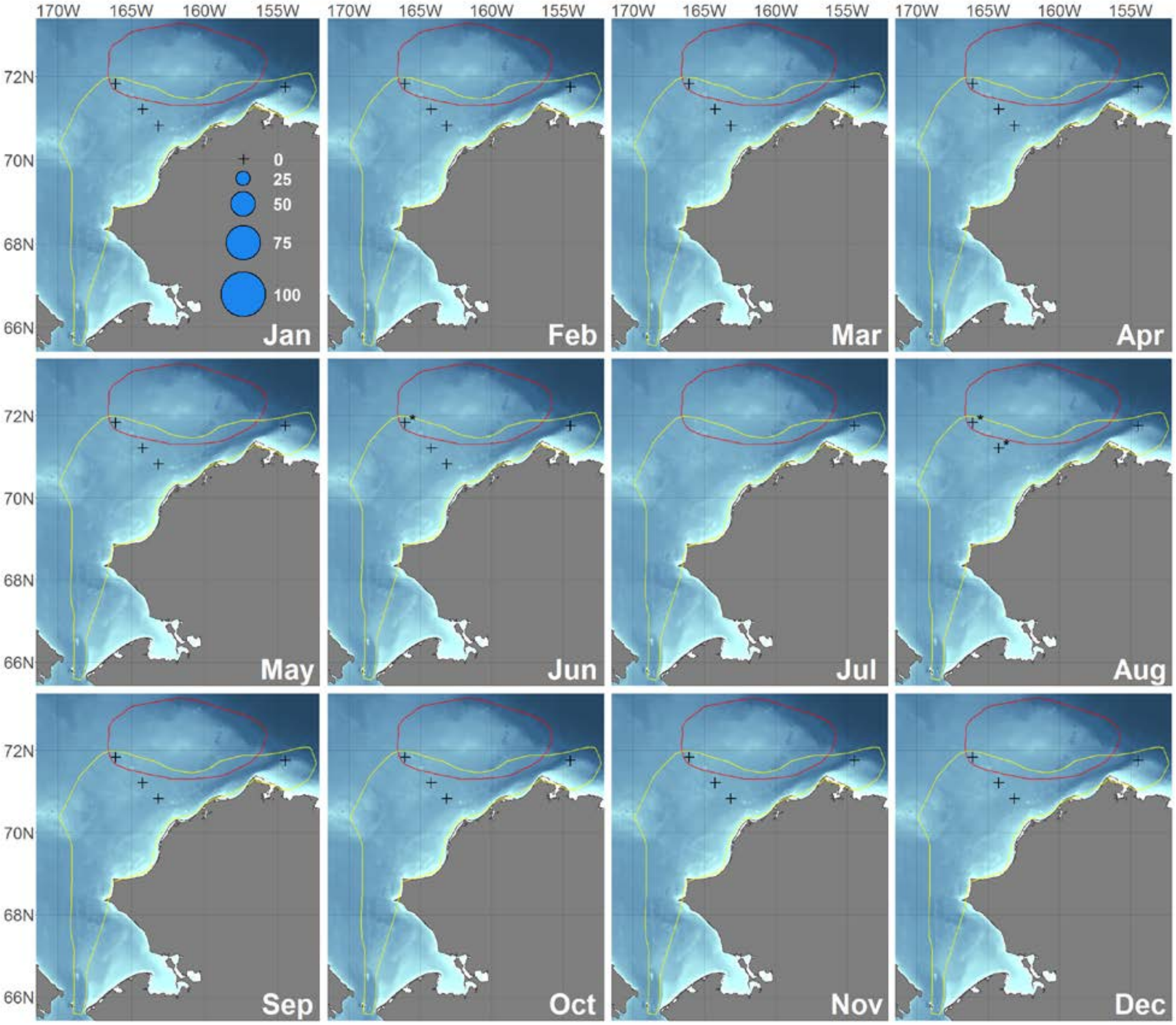
Appendix E.11. Ribbon seal calling distribution 2014. Graduated scale in the January panel indicates % of days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.10 for numbers used to generate figure.



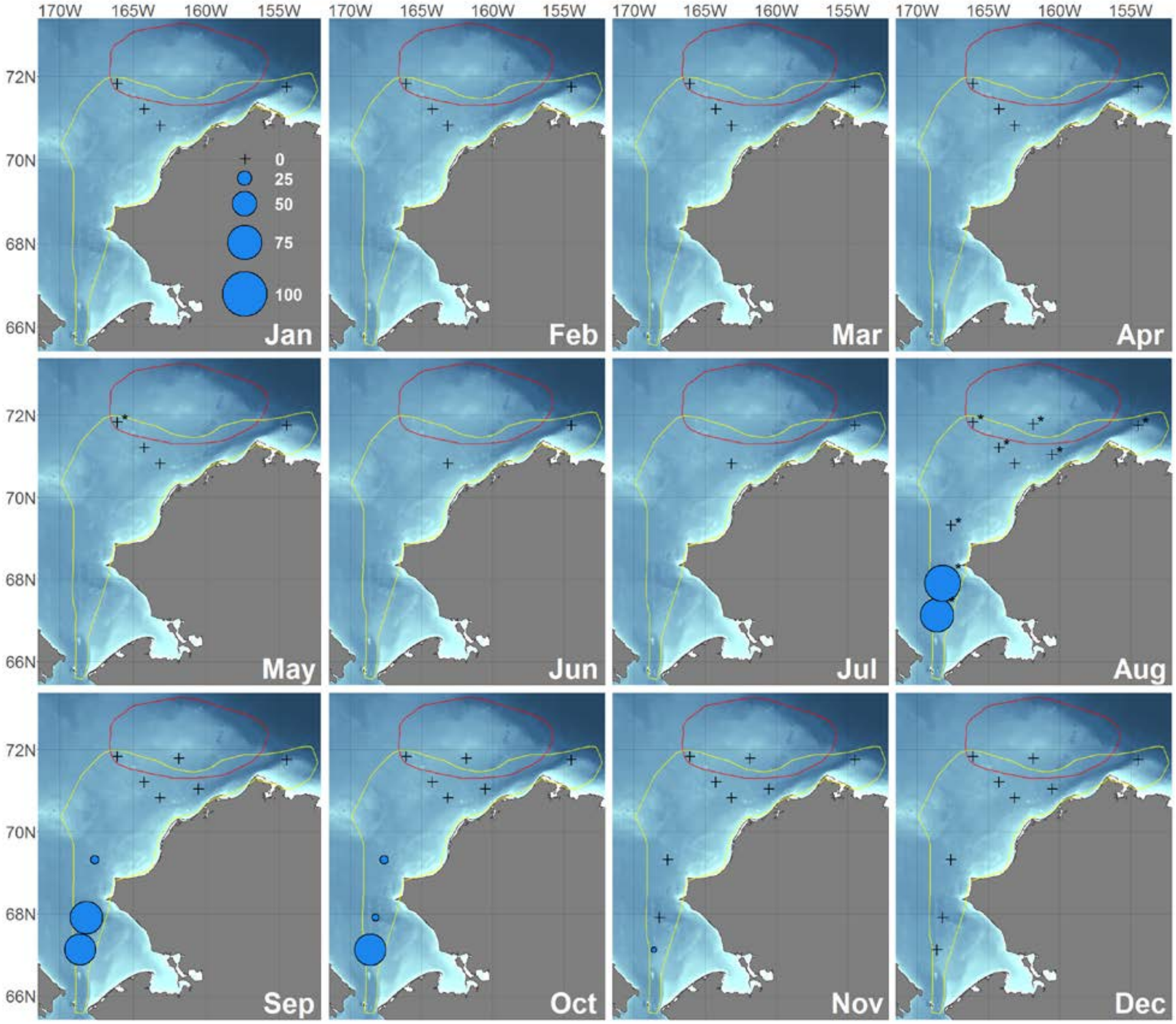
Appendix E.12. Ribbon seal calling distribution 2015. Graduated scale in the January panel indicates % of days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.10 for numbers used to generate figure.



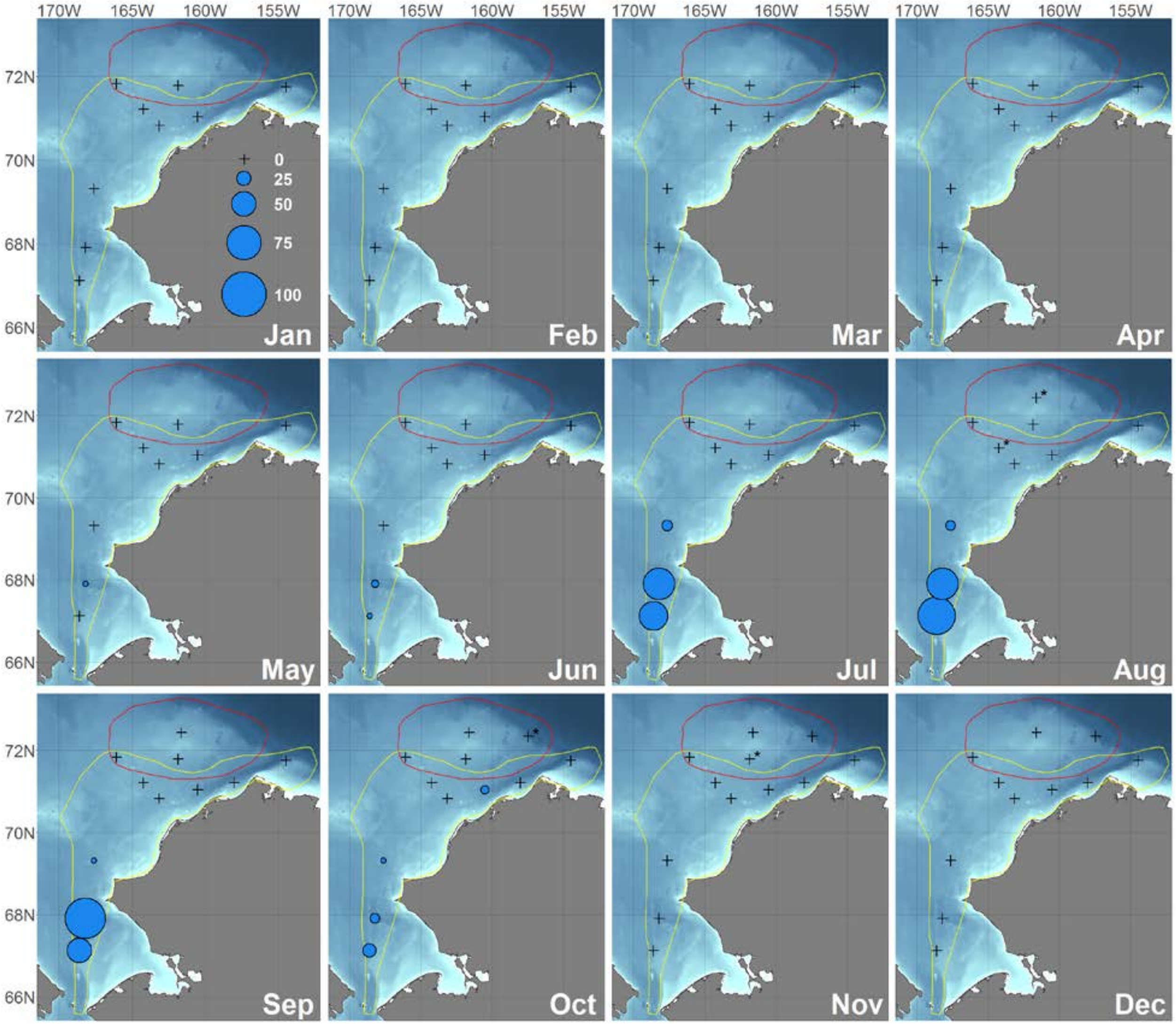
Appendix E.13. Humpback whale calling distribution 2010. Graduated scale in the September panel indicates % of days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.8 for numbers used to generate figure.



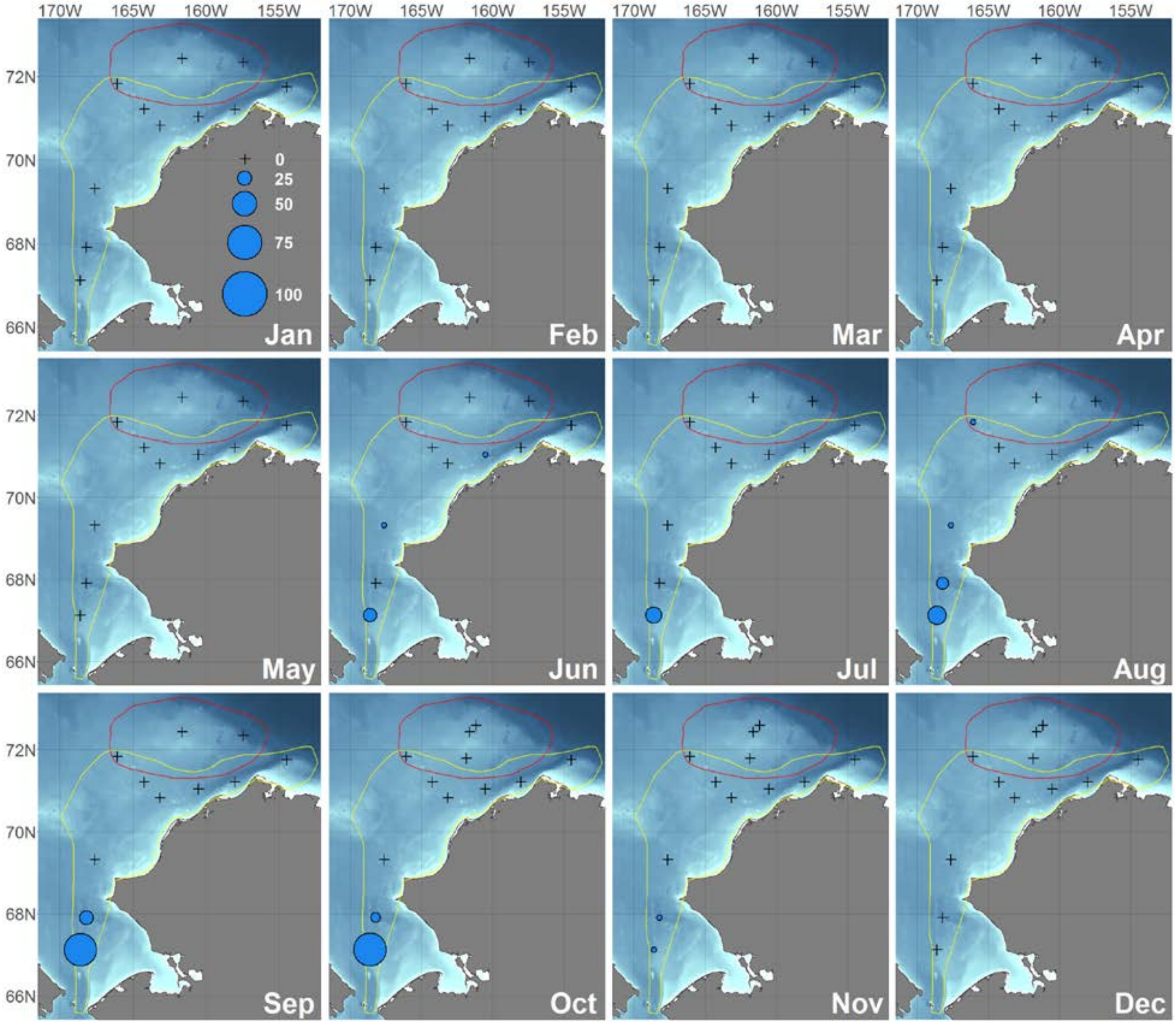
Appendix E.14. Humpback whale calling distribution 2011. Graduated scale in the January panel indicates % of days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.8 for numbers used to generate figure.



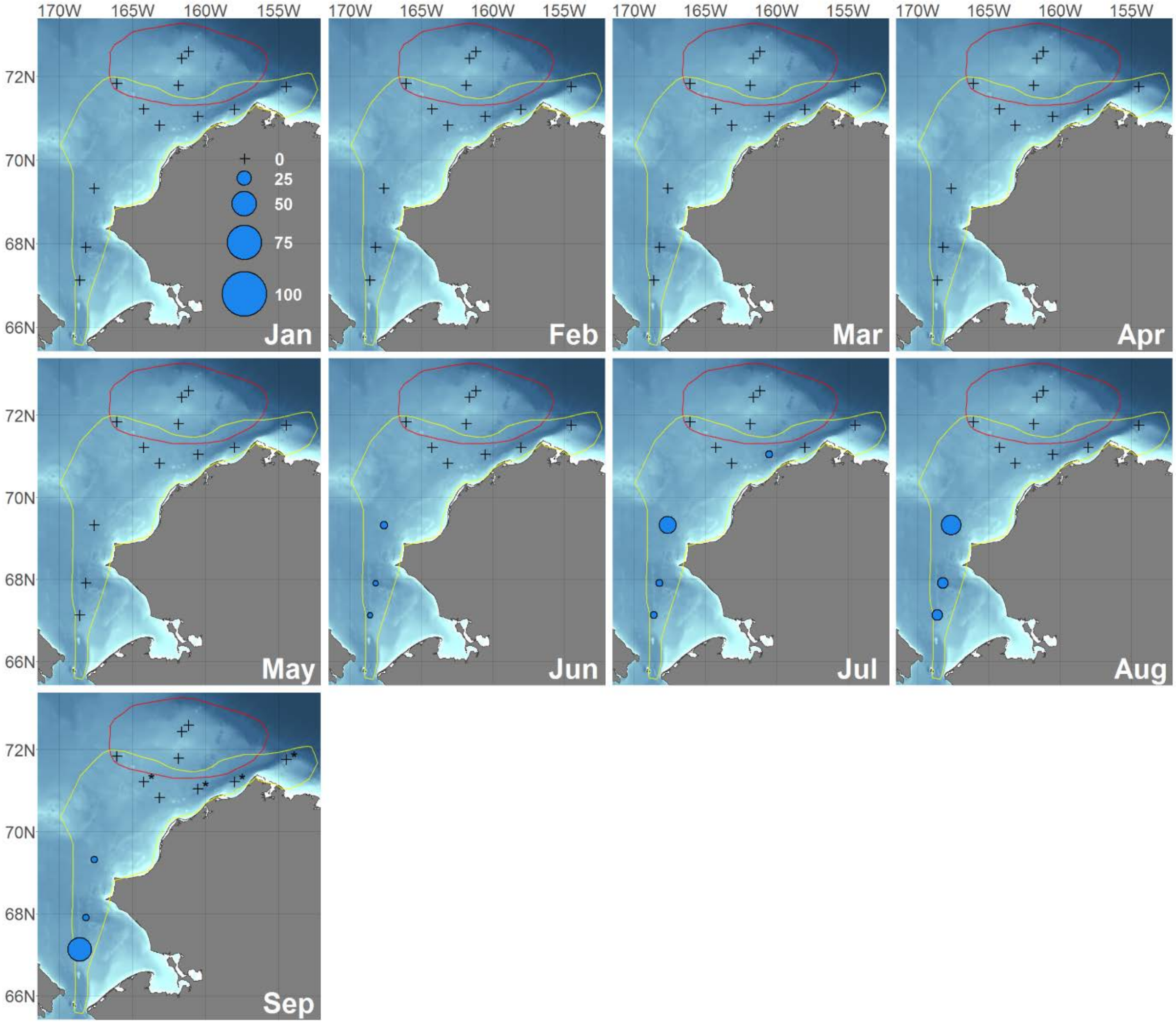
Appendix E.15. Humpback whale calling distribution 2012. Graduated scale in the January panel indicates % of days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.8 for numbers used to generate figure.



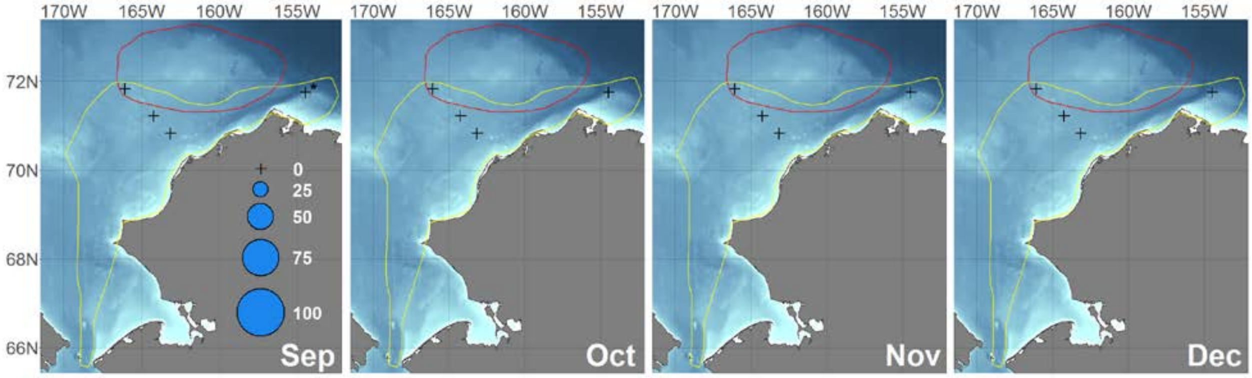
Appendix E.16. Humpback whale calling distribution 2013. Graduated scale in the January panel indicates % of days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.8 for numbers used to generate figure.



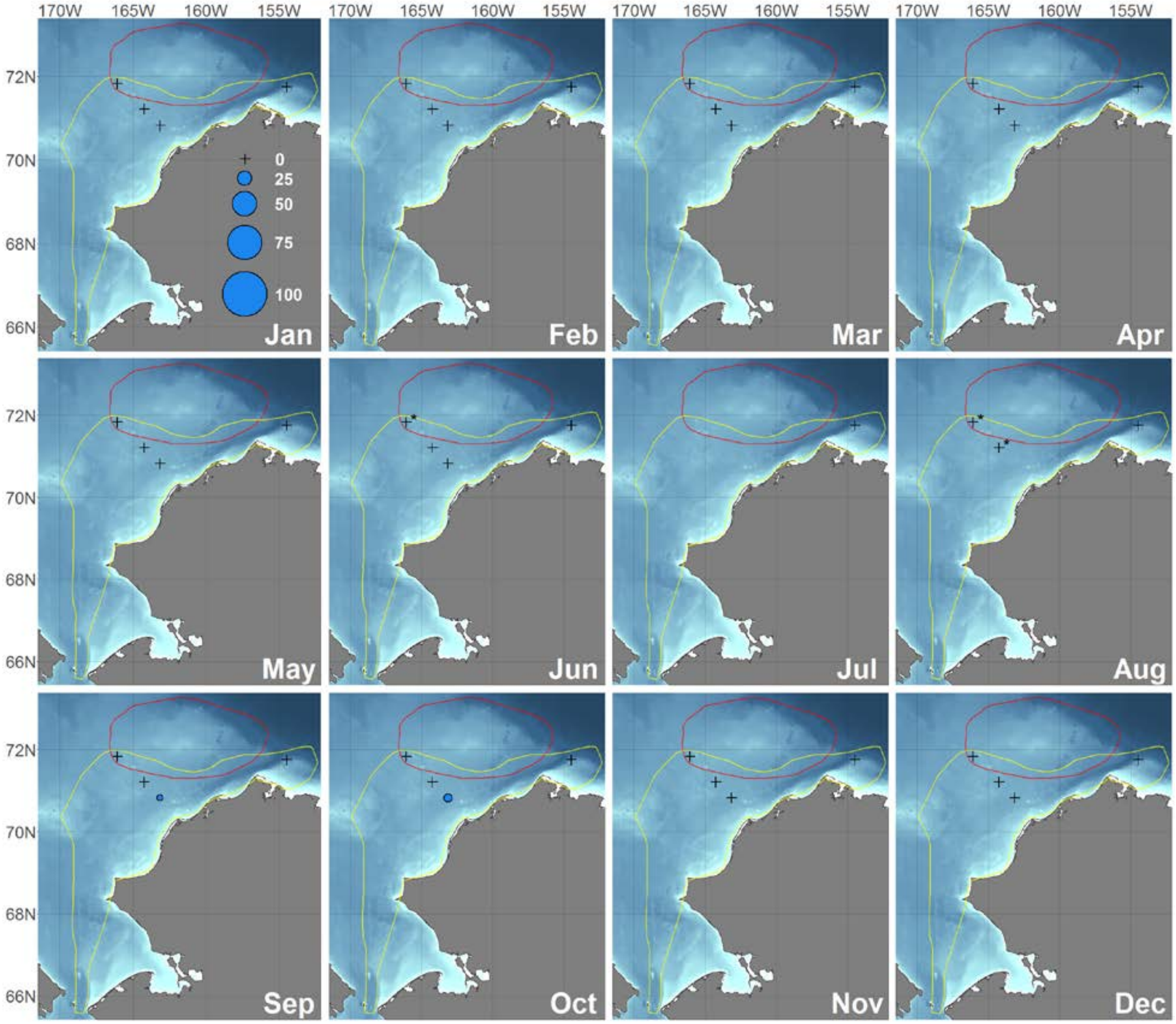
Appendix E.17. Humpback whale calling distribution 2014. Graduated scale in the January panel indicates % of days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.8 for numbers used to generate figure.



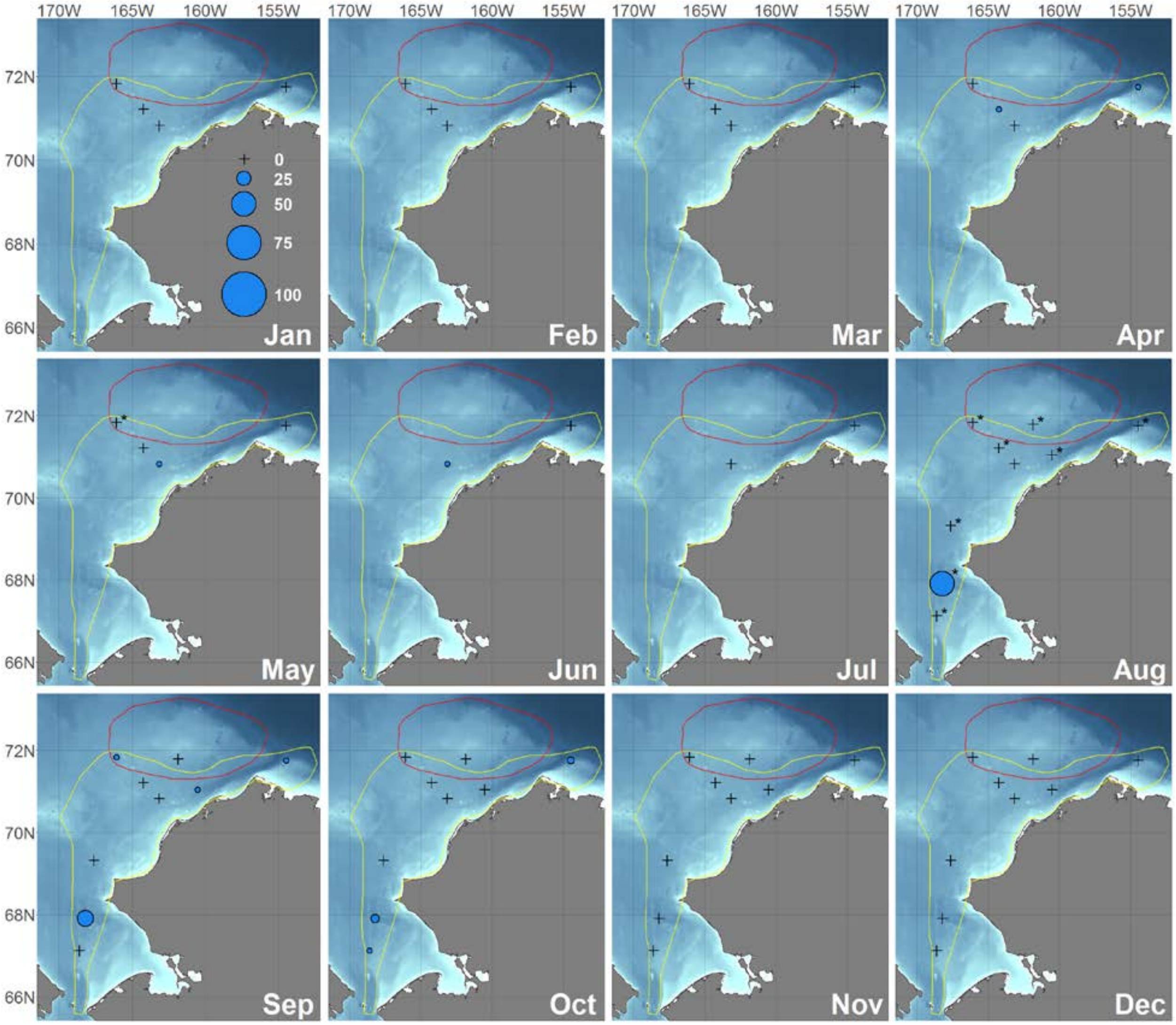
Appendix E.18. Humpback whale calling distribution 2015. Graduated scale in the January panel indicates % of days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.8 for numbers used to generate figure.



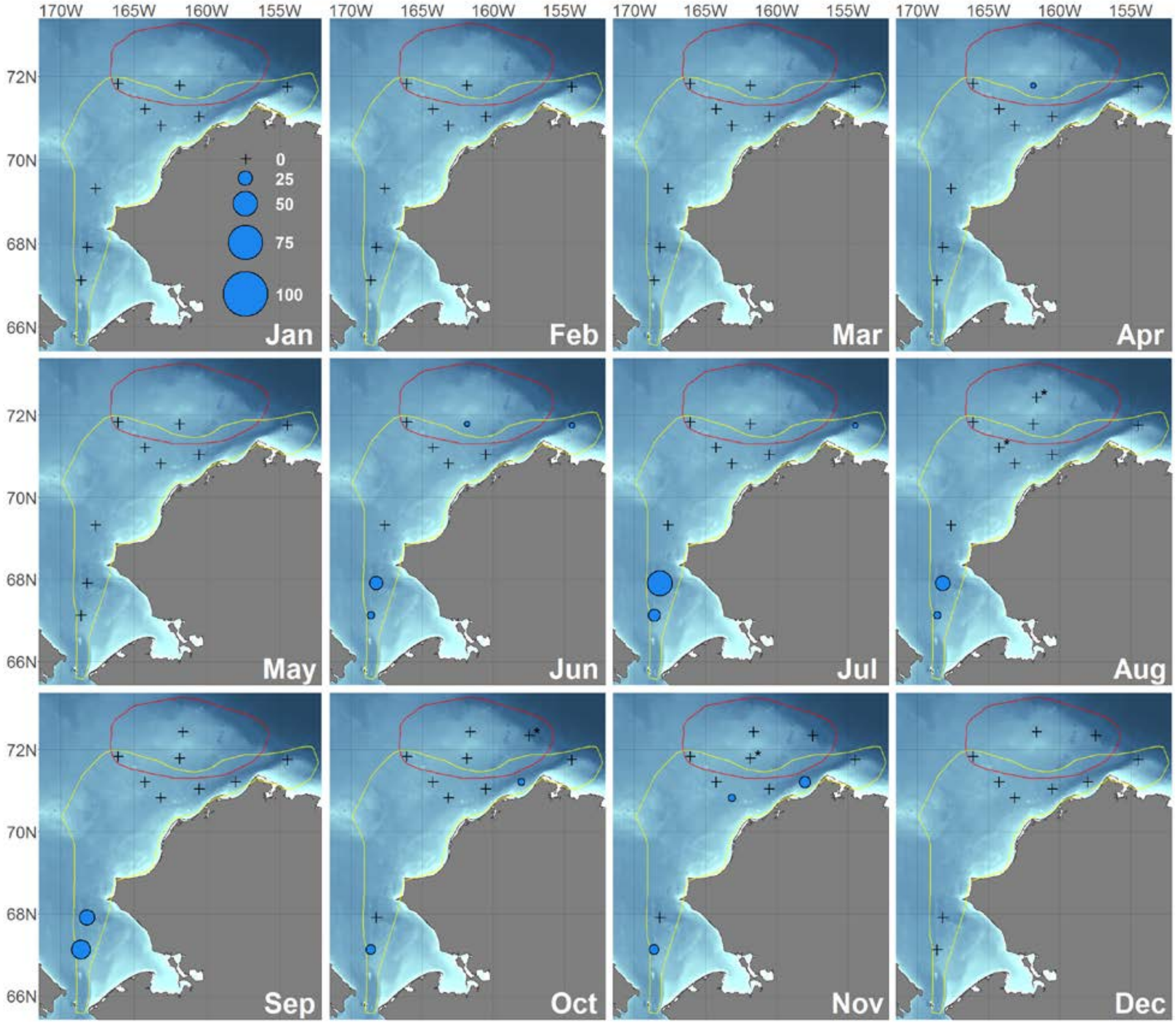
Appendix E.19. Killer whale calling distribution 2010. Graduated scale in the September panel indicates % of days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.9 for numbers used to generate figure.



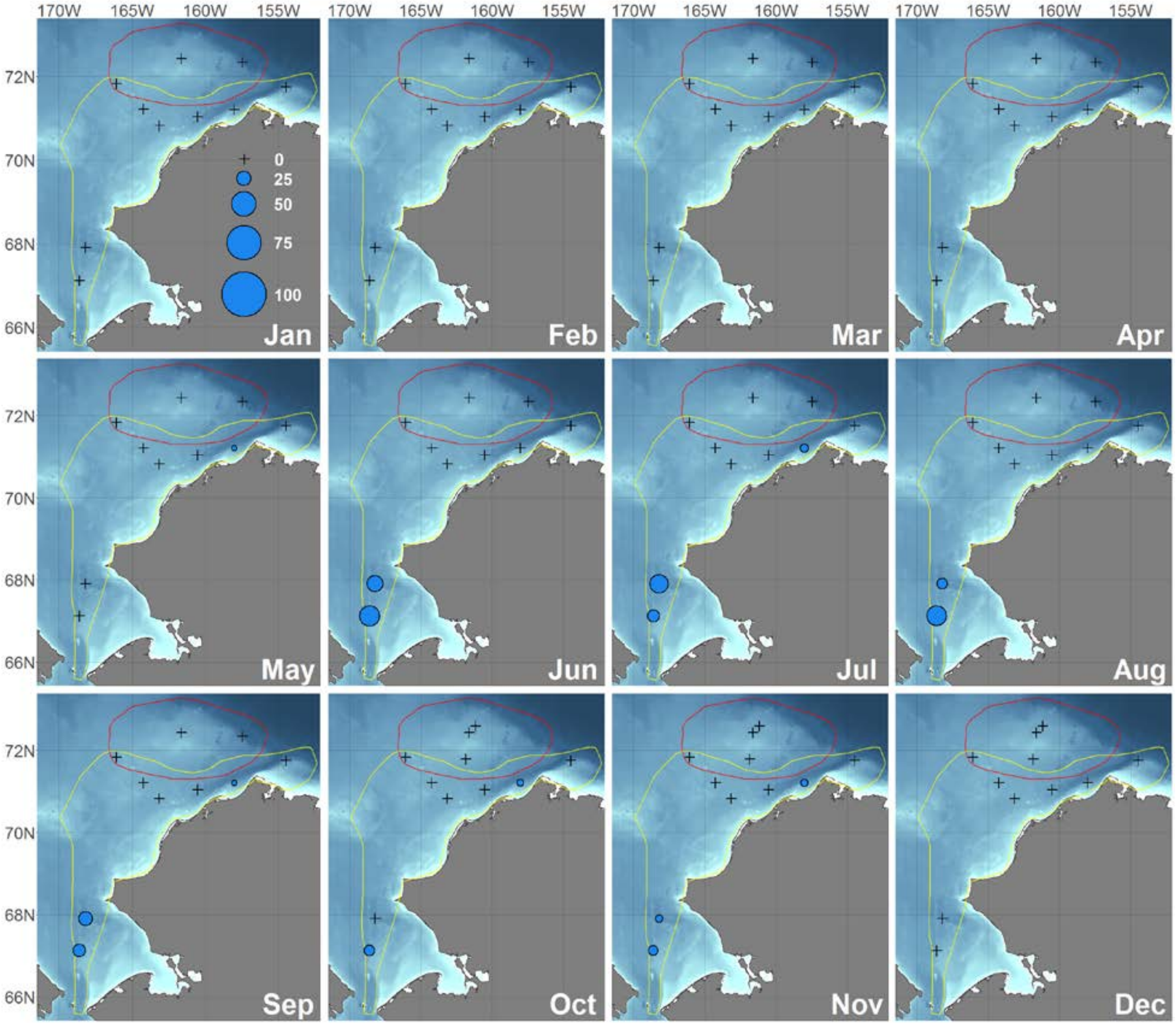
Appendix E.20. Killer whale calling distribution 2011. Graduated scale in the January panel indicates % of days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.9 for numbers used to generate figure.



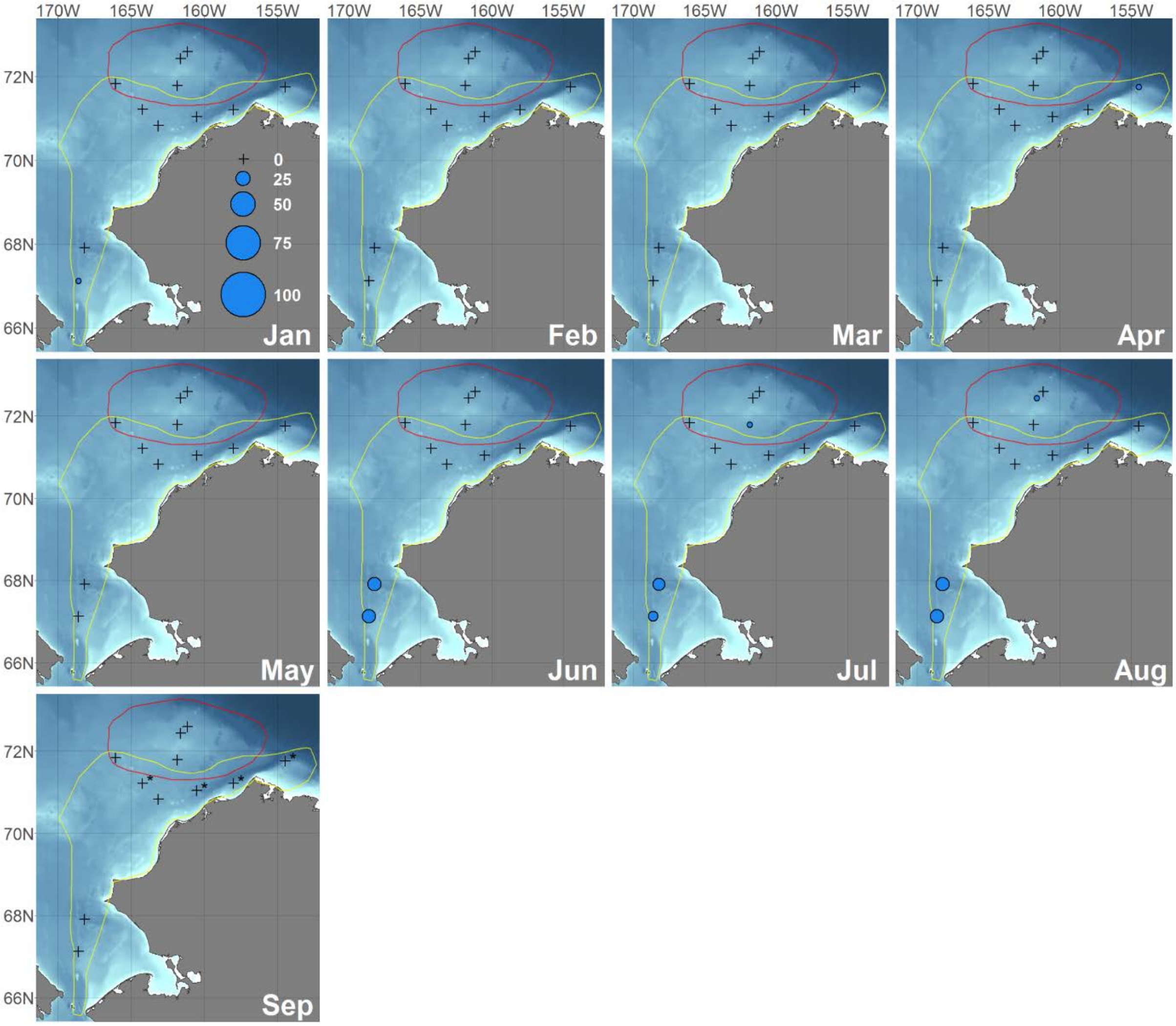
Appendix E.21. Killer whale calling distribution 2012. Graduated scale in the January panel indicates % of days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.9 for numbers used to generate figure.



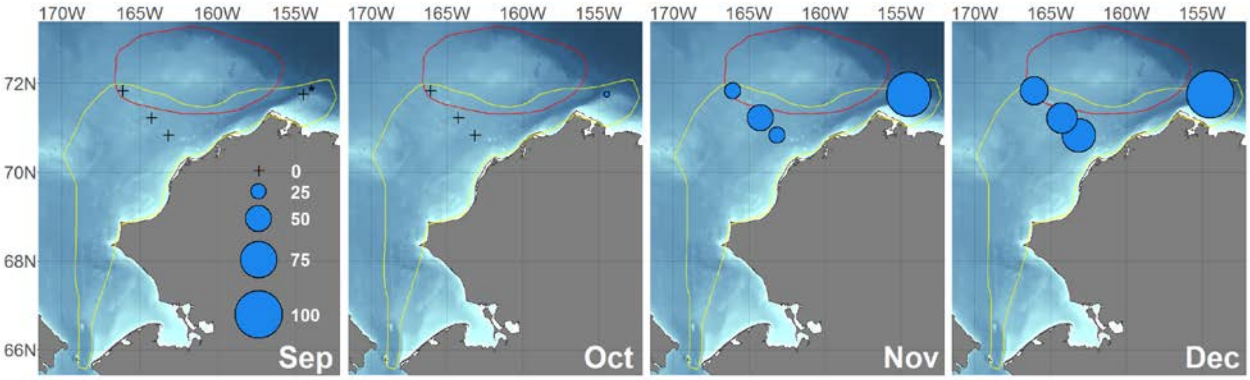
Appendix E.22. Killer whale calling distribution 2013. Graduated scale in the January panel indicates % of days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.9 for numbers used to generate figure.



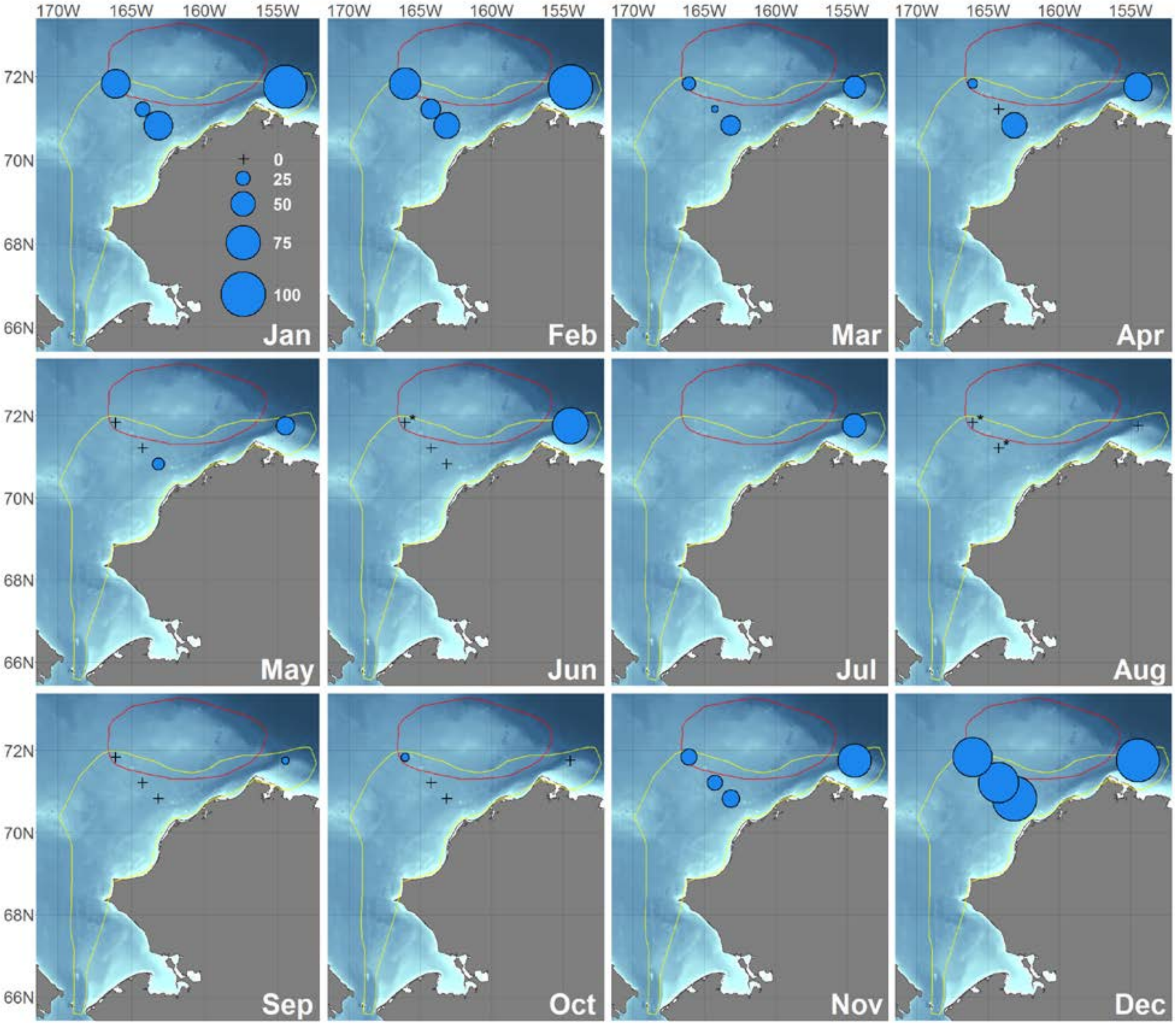
Appendix E.23. Killer whale calling distribution 2014. Graduated scale in the January panel indicates % of days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.9 for numbers used to generate figure.



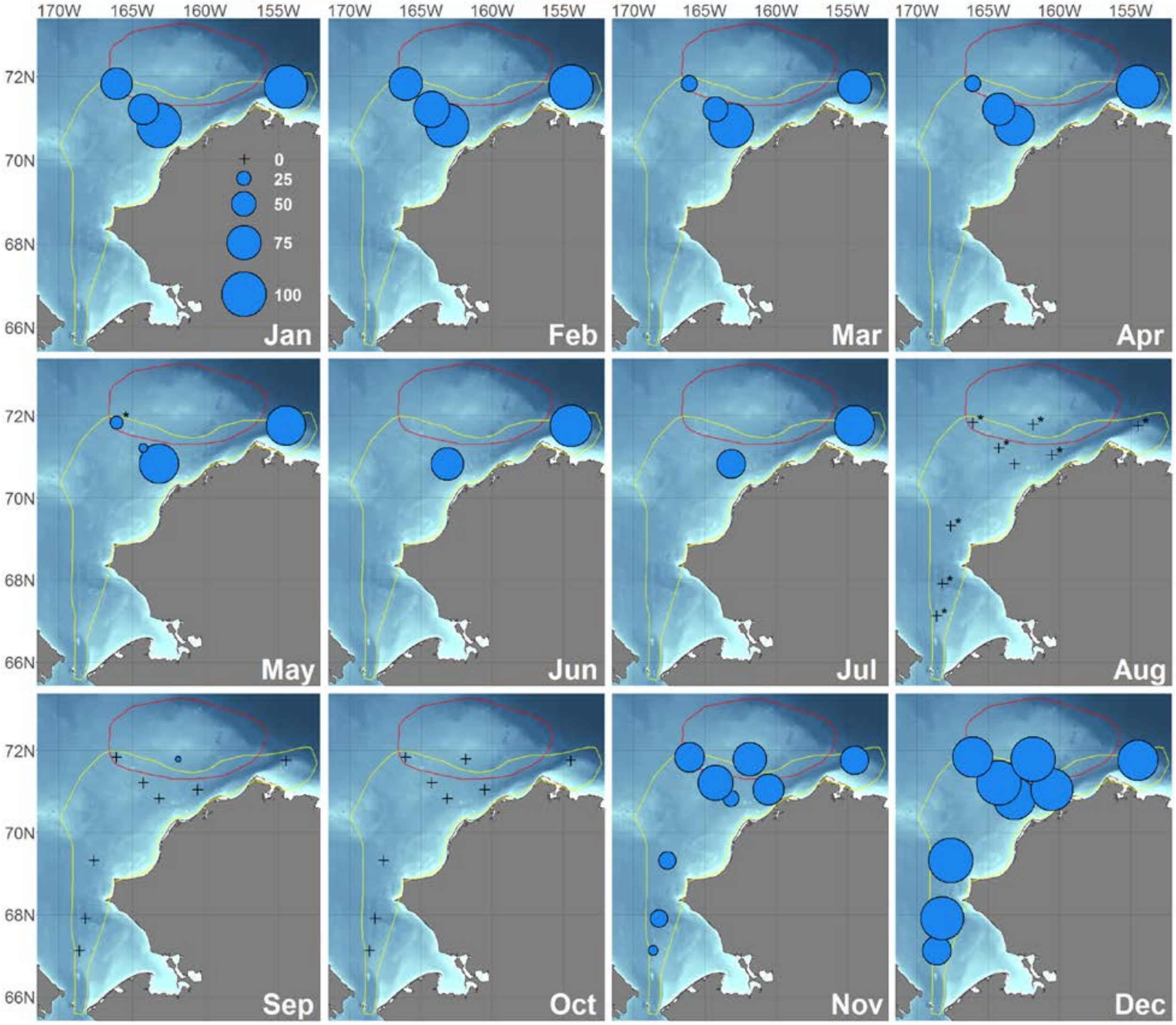
Appendix E.24. Killer whale calling distribution 2015. Graduated scale in the January panel indicates % of days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.9 for numbers used to generate figure.



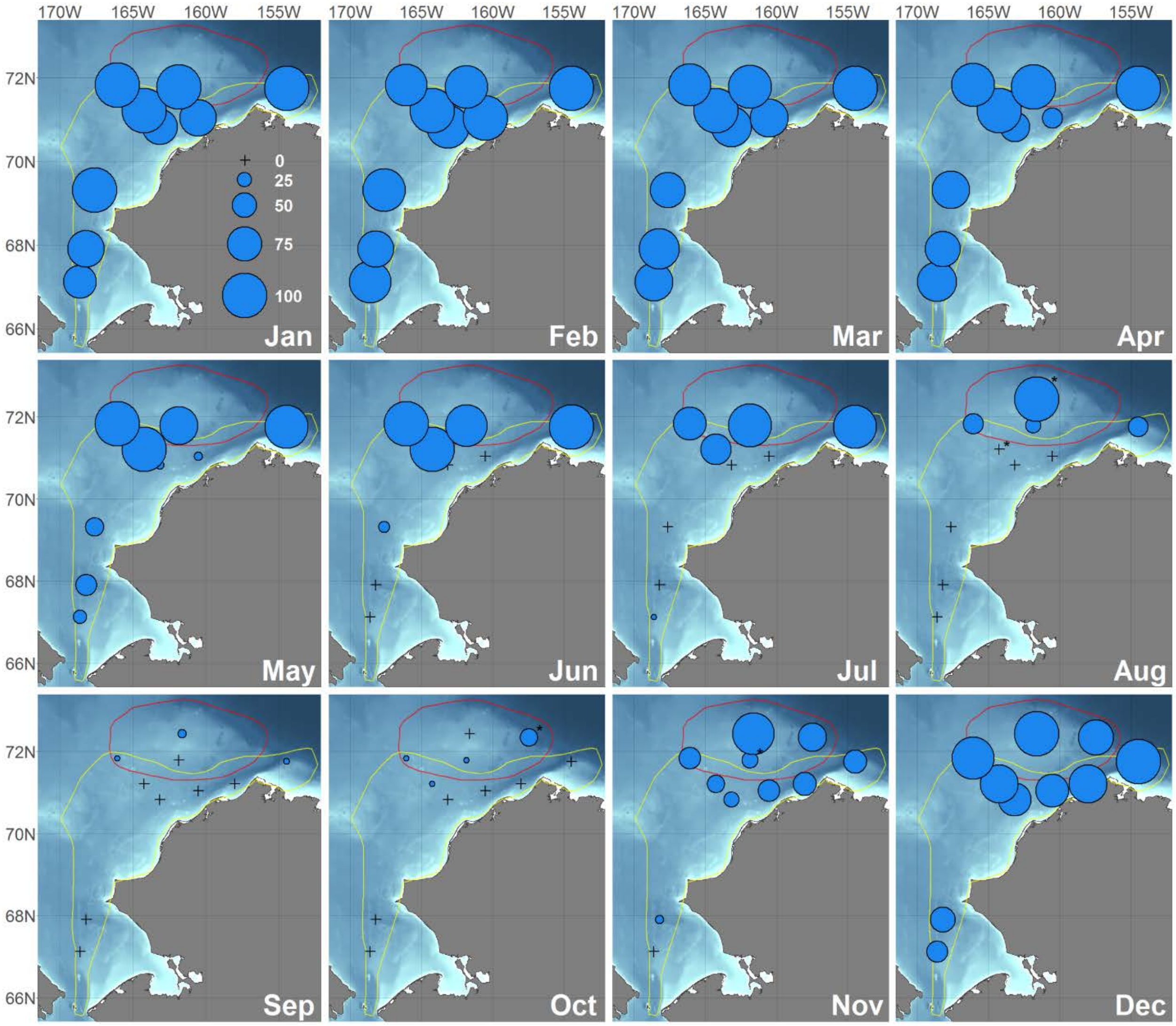
Appendix E.25. Ice noise distribution 2010. Graduated scale in the September panel indicates % of days per month with ice noise. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.15 for numbers used to generate figure.



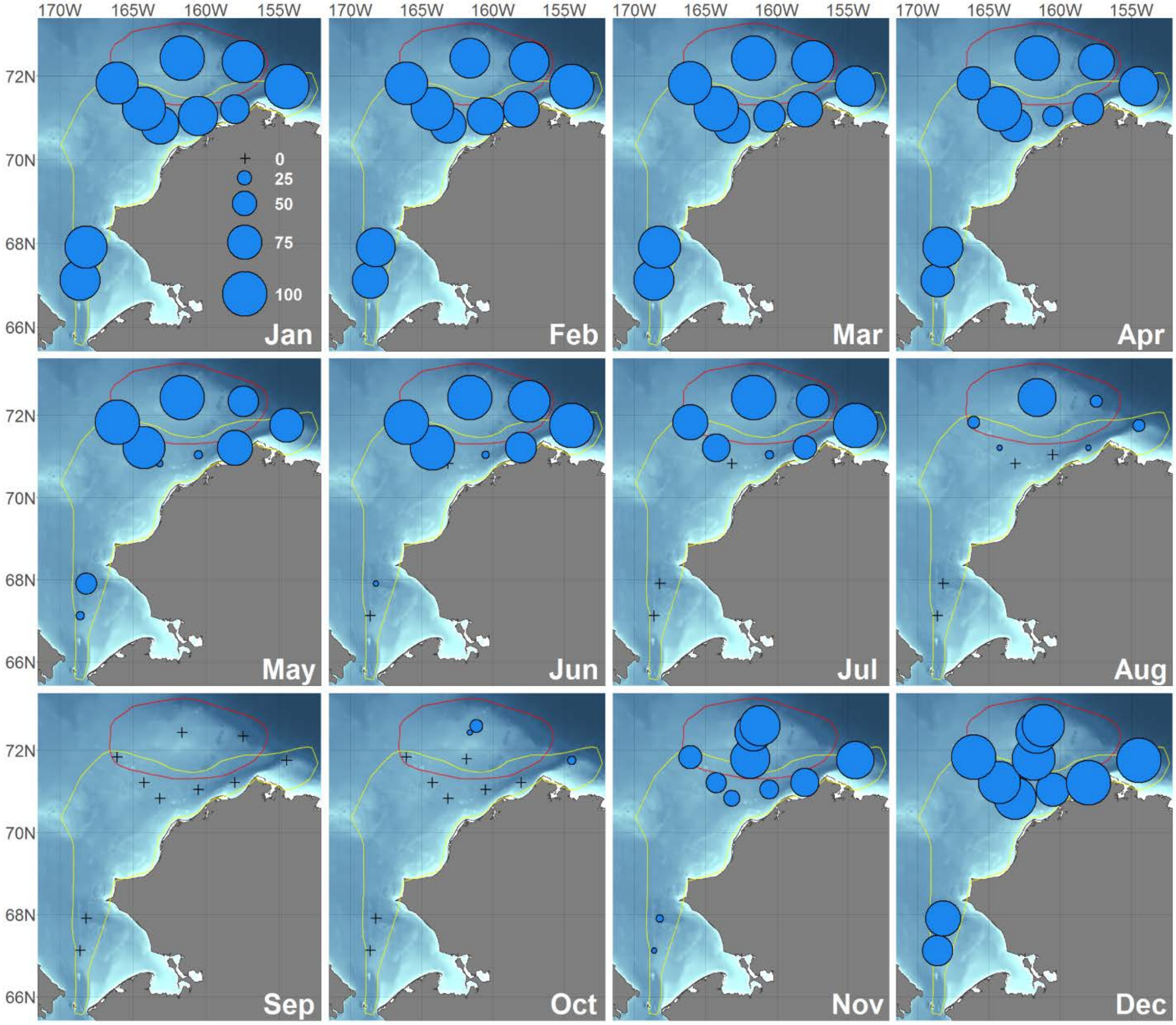
Appendix E.26. Ice noise distribution 2011. Graduated scale in the January panel indicates % of days per month with ice noise. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.15 for numbers used to generate figure.



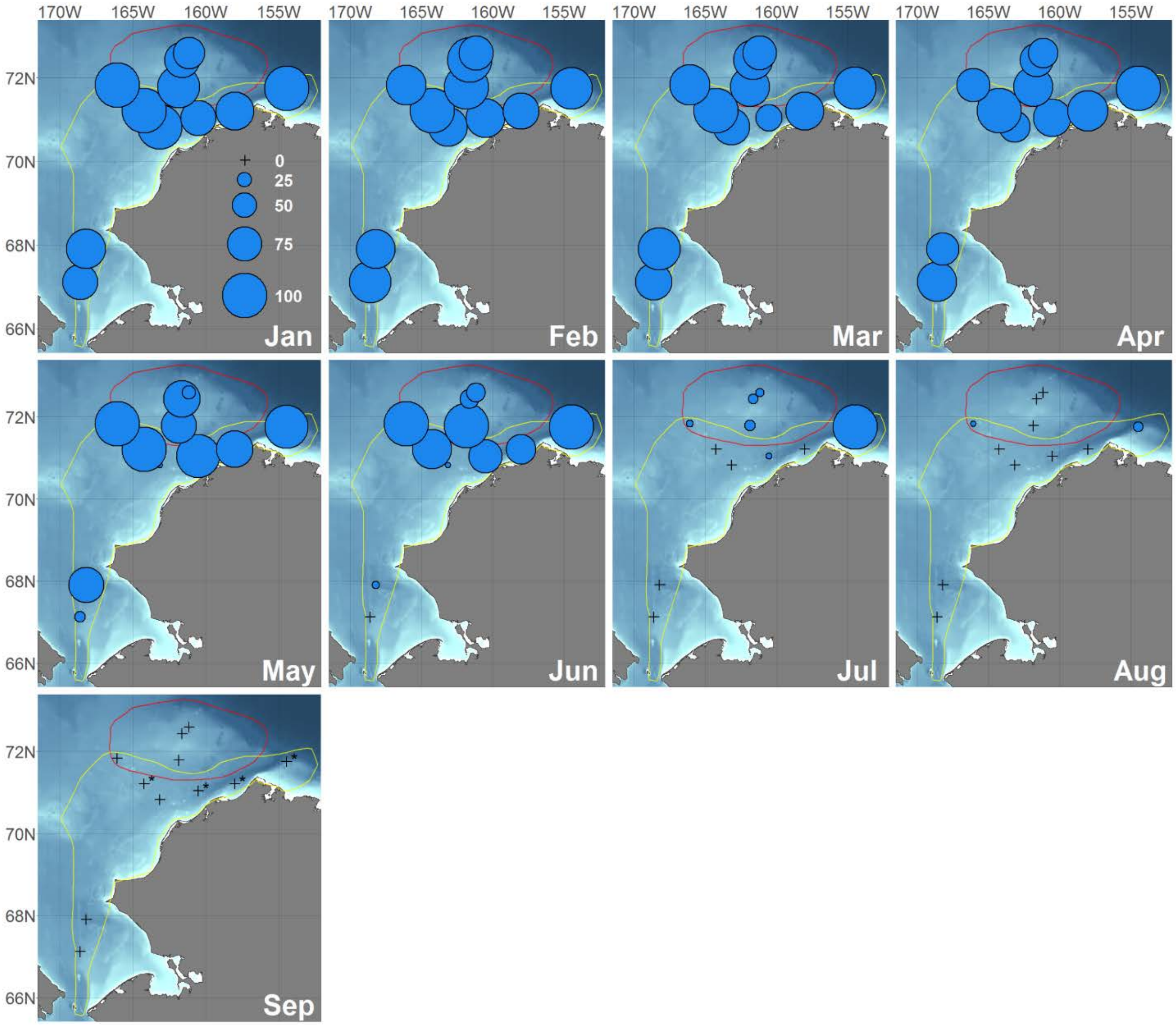
Appendix E.27. Ice noise distribution 2012. Graduated scale in the January panel indicates % of days per month with ice noise. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.15 for numbers used to generate figure.



Appendix E.28. Ice noise distribution 2013. Graduated scale in the January panel indicates % of days per month with ice noise. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.15 for numbers used to generate figure.



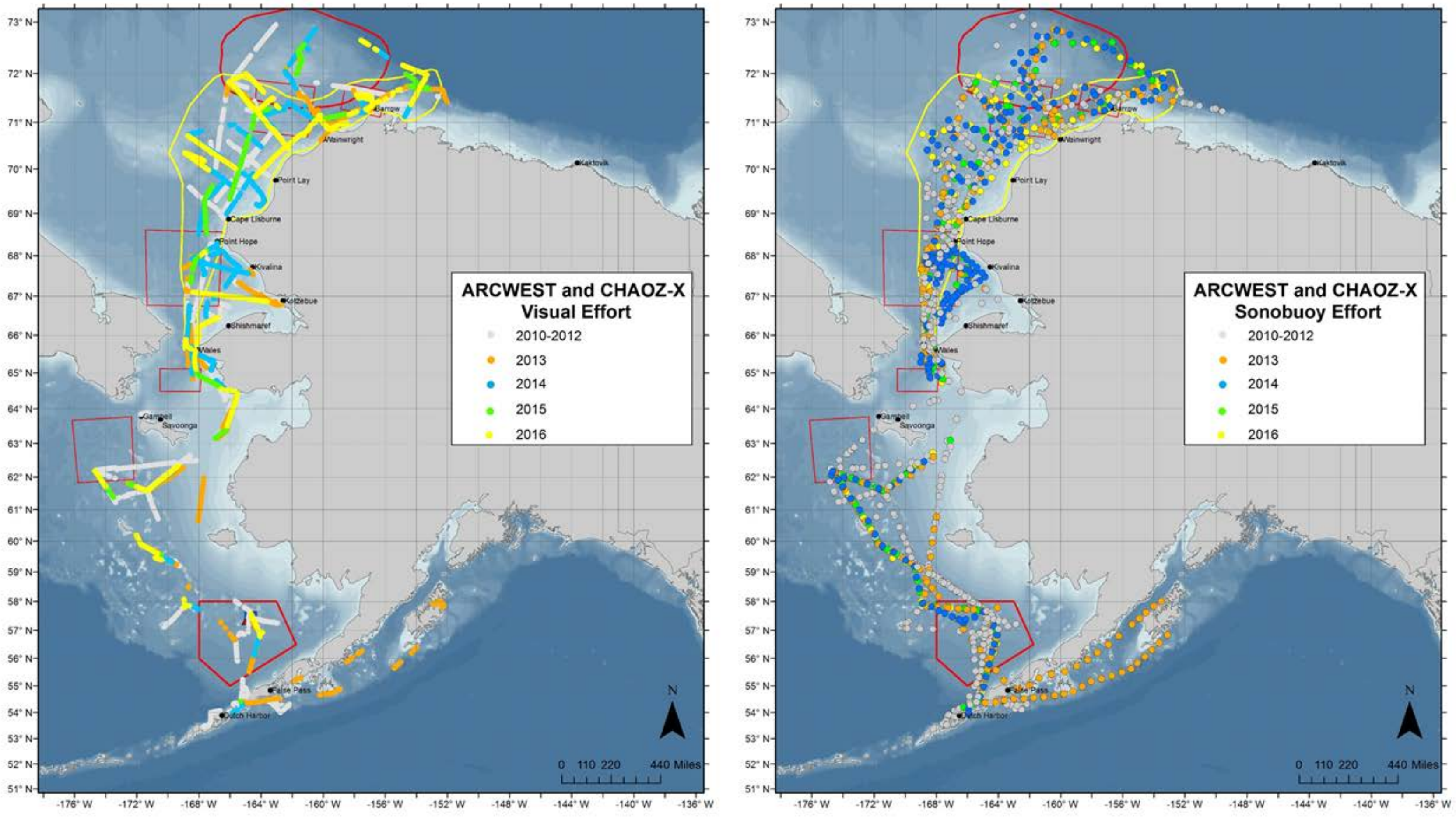
Appendix E.29. Ice noise distribution 2014. Graduated scale in the January panel indicates % of days per month with ice noise. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.15 for numbers used to generate figure.



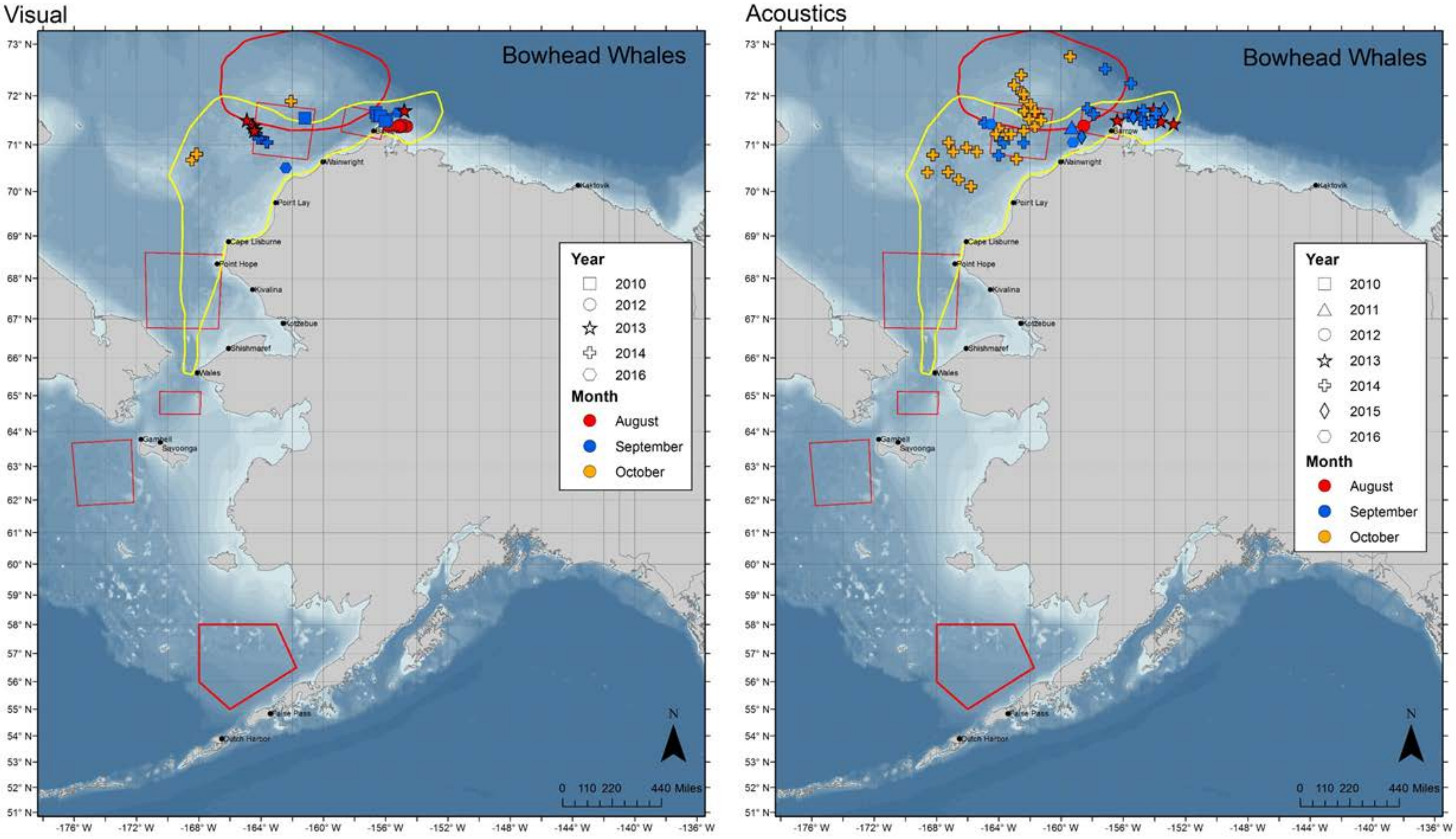
Appendix E.30. Ice noise distribution 2015. Graduated scale in the January panel indicates % of days per month with ice noise. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C.15 for numbers used to generate figure.

F. Sonobuoy and visual survey data

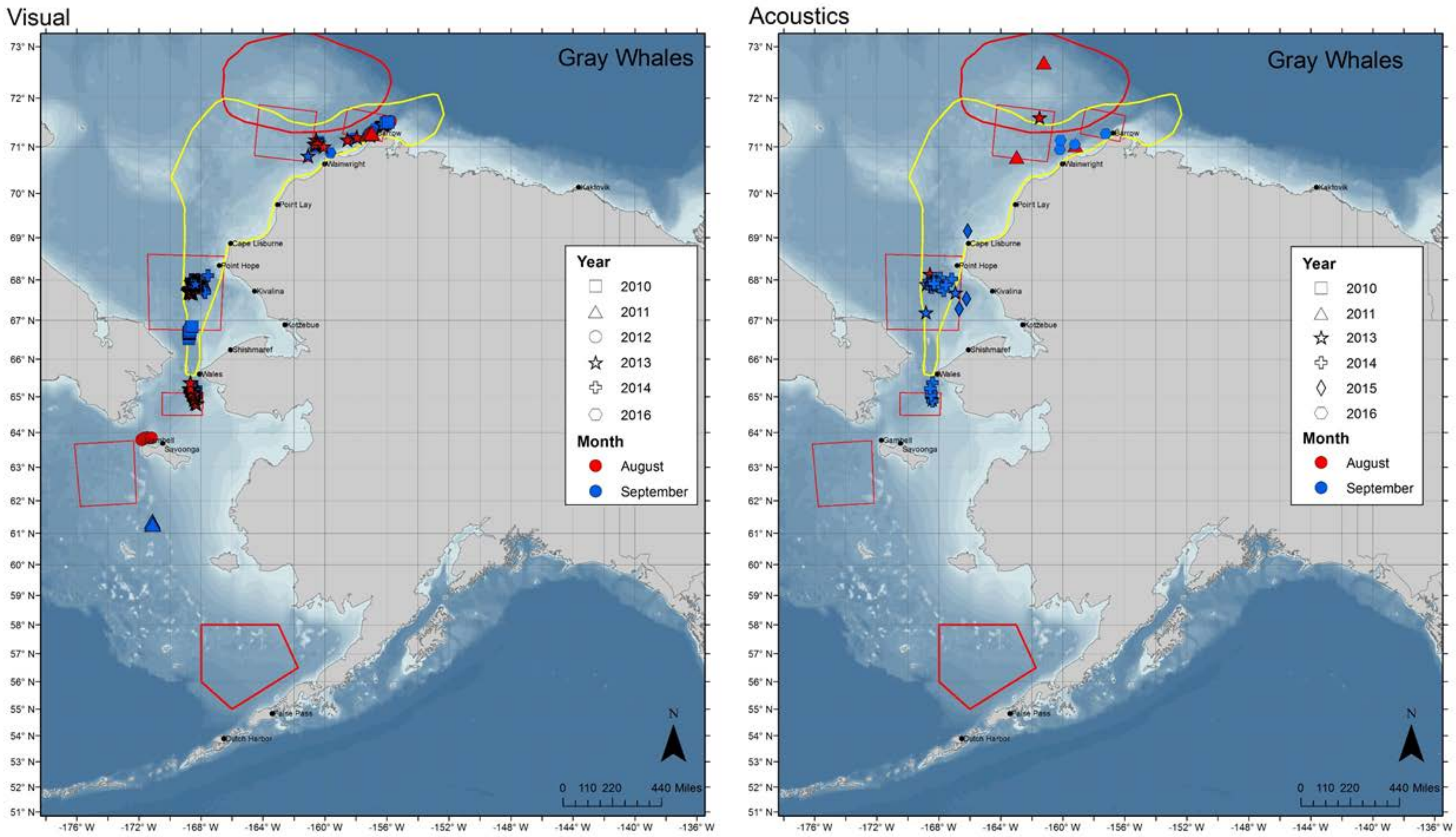
Visual sightings (left) and acoustic detections (right) of each species in the Bering, Chukchi, and Beaufort Seas by month for 2010-2016. DBO regions outlined in red.



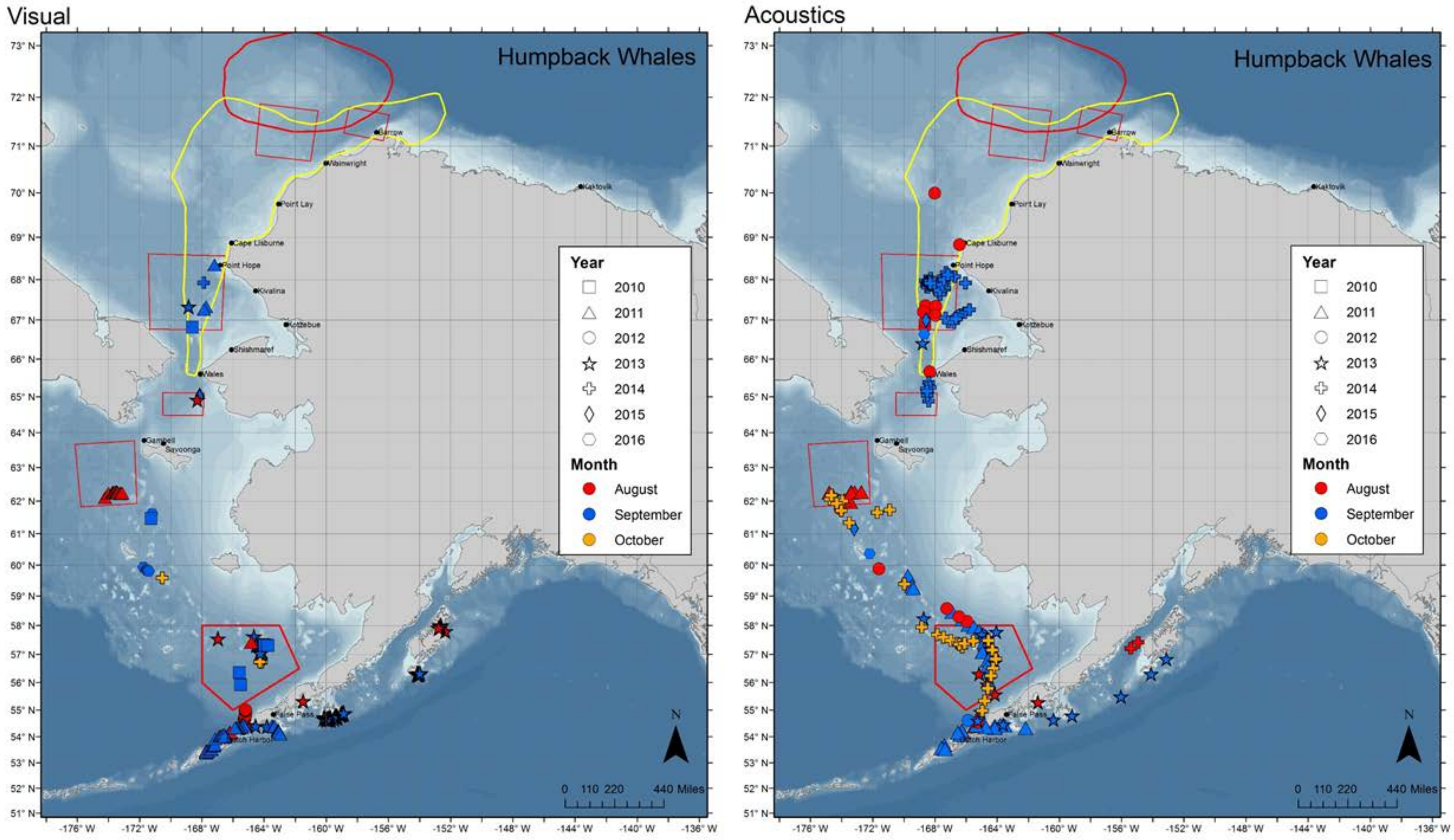
Appendix F.1. Summary of total visual and sonobuoy effort, 2010-2016.



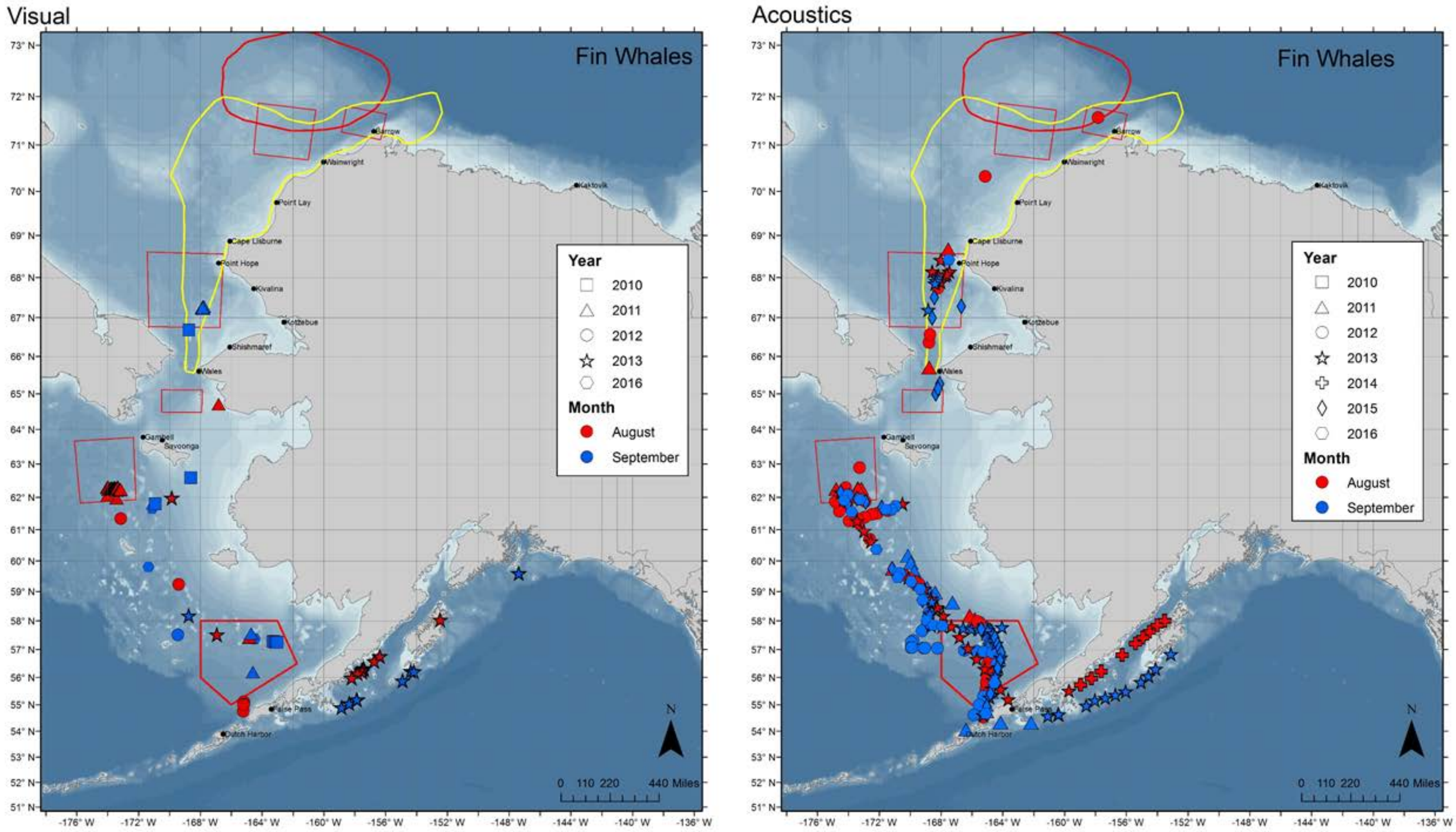
Appendix F. 2. Bowhead whale sightings and acoustic detections, 2010-2016.



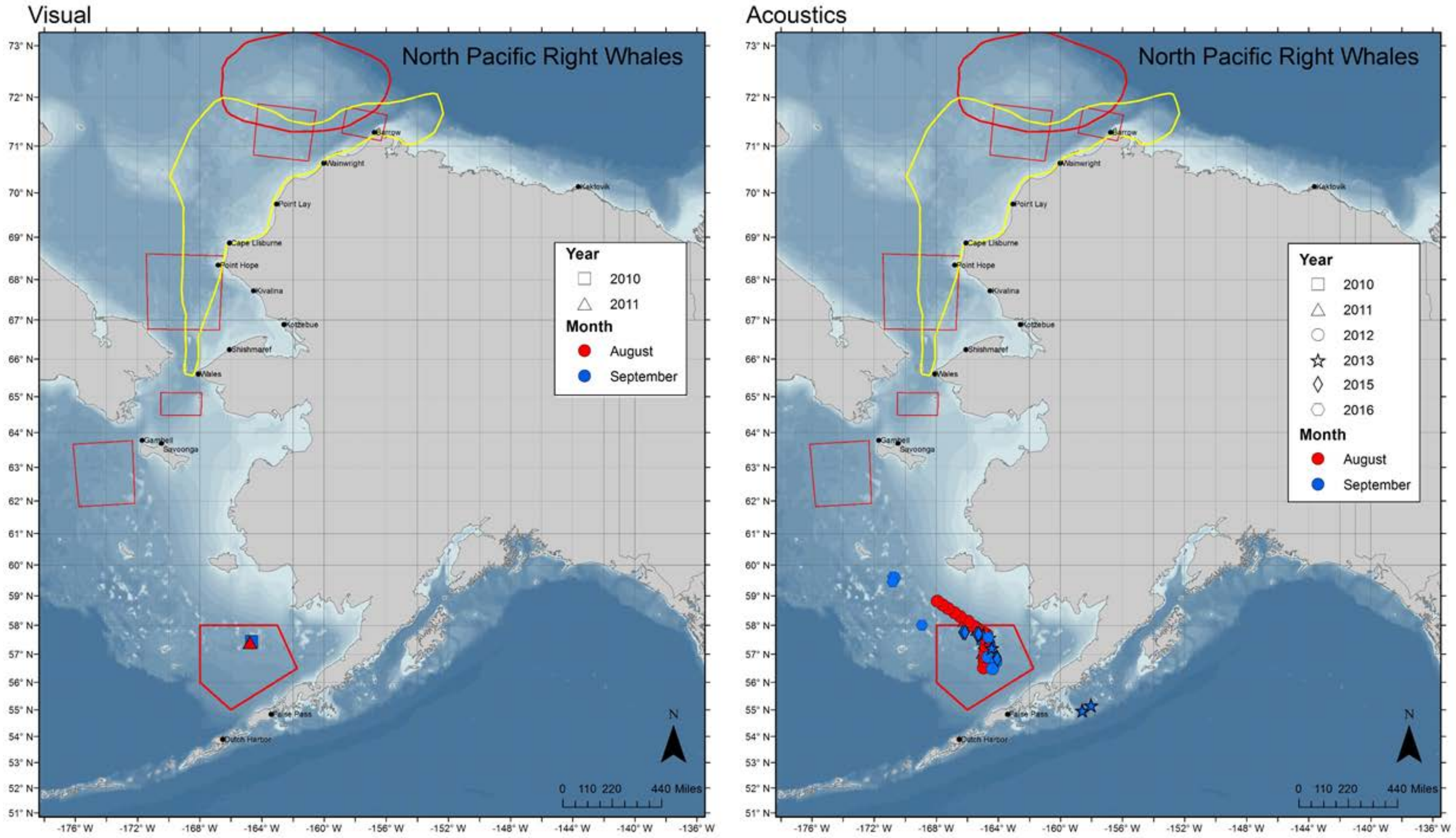
Appendix F. 3. Gray whale sightings and acoustic detections, 2010-2016.



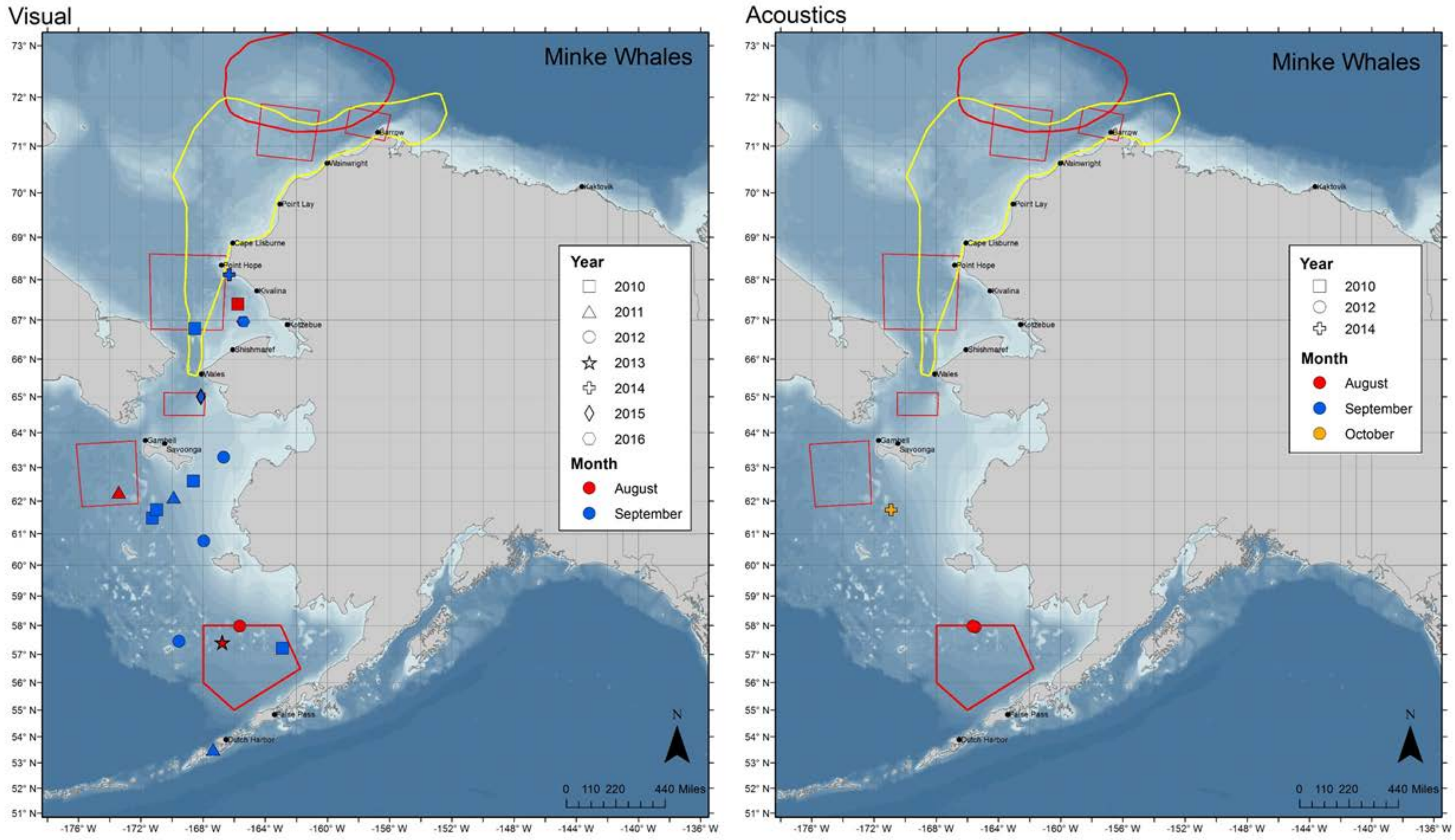
Appendix F. 4. Humpback whale sightings and acoustic detections, 2010-2016.



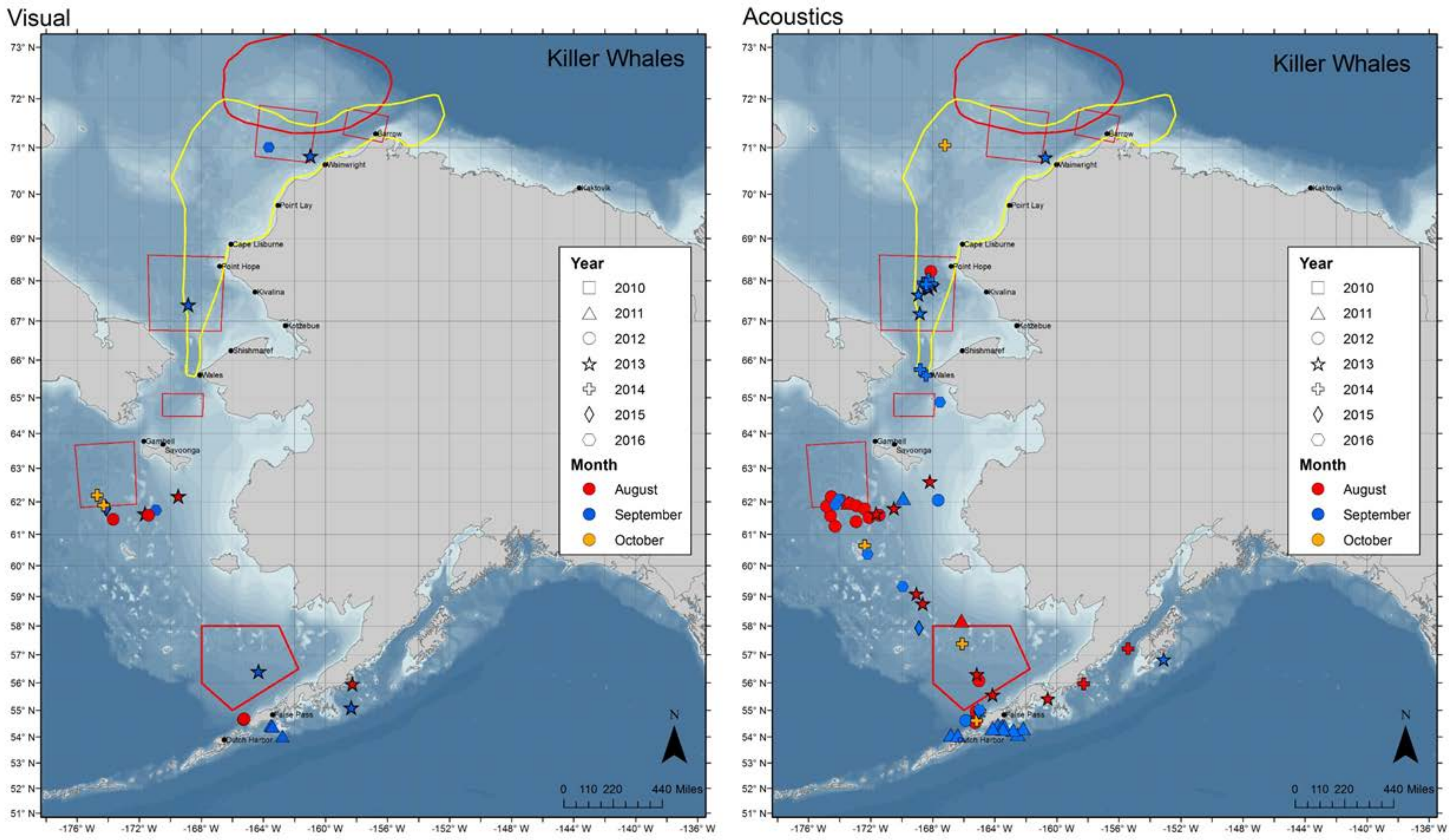
Appendix F. 5. Fin whale sightings and acoustic detections, 2010-2016.



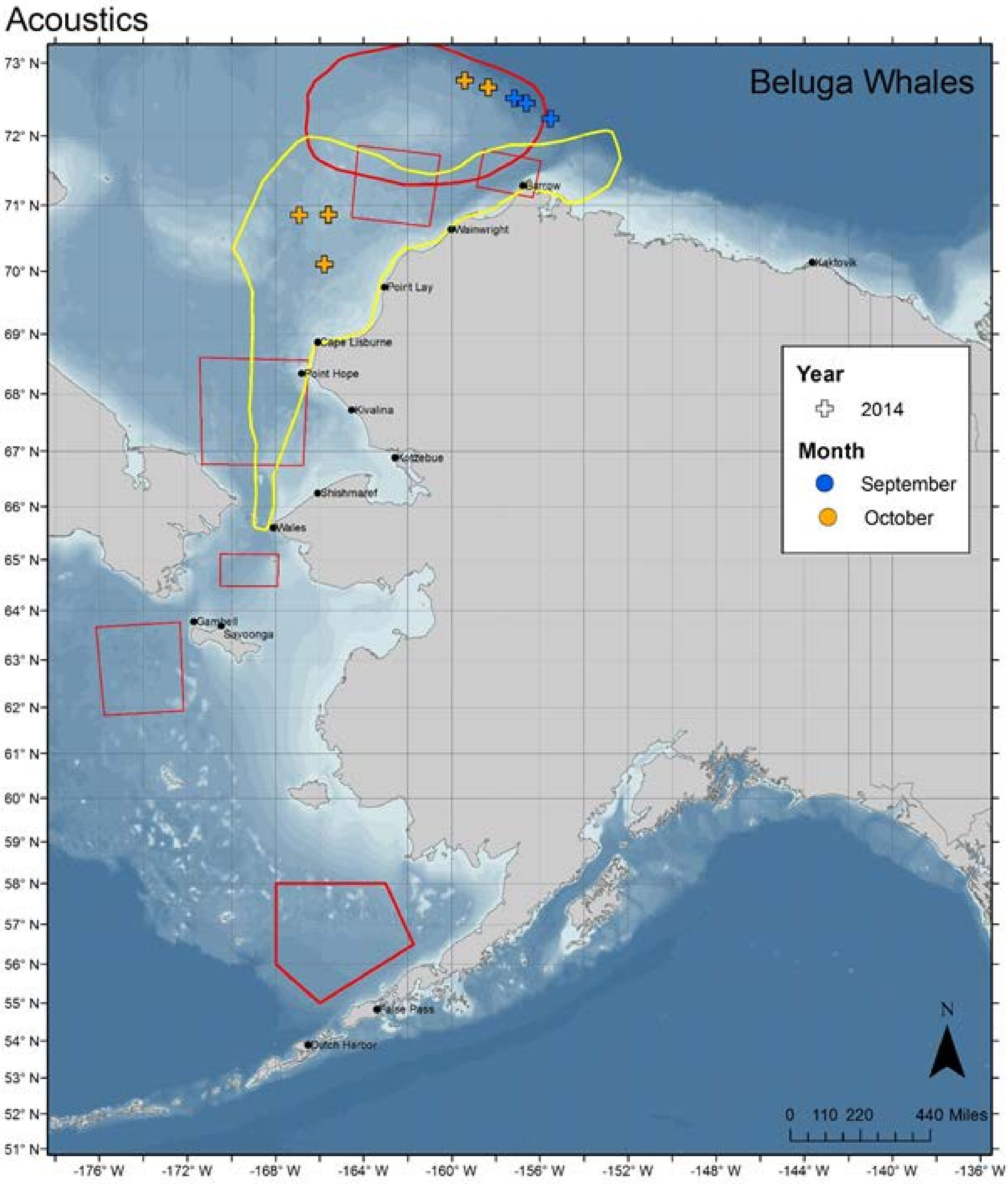
Appendix F. 6. North Pacific right whale sightings and acoustic detections, 2010-2016.



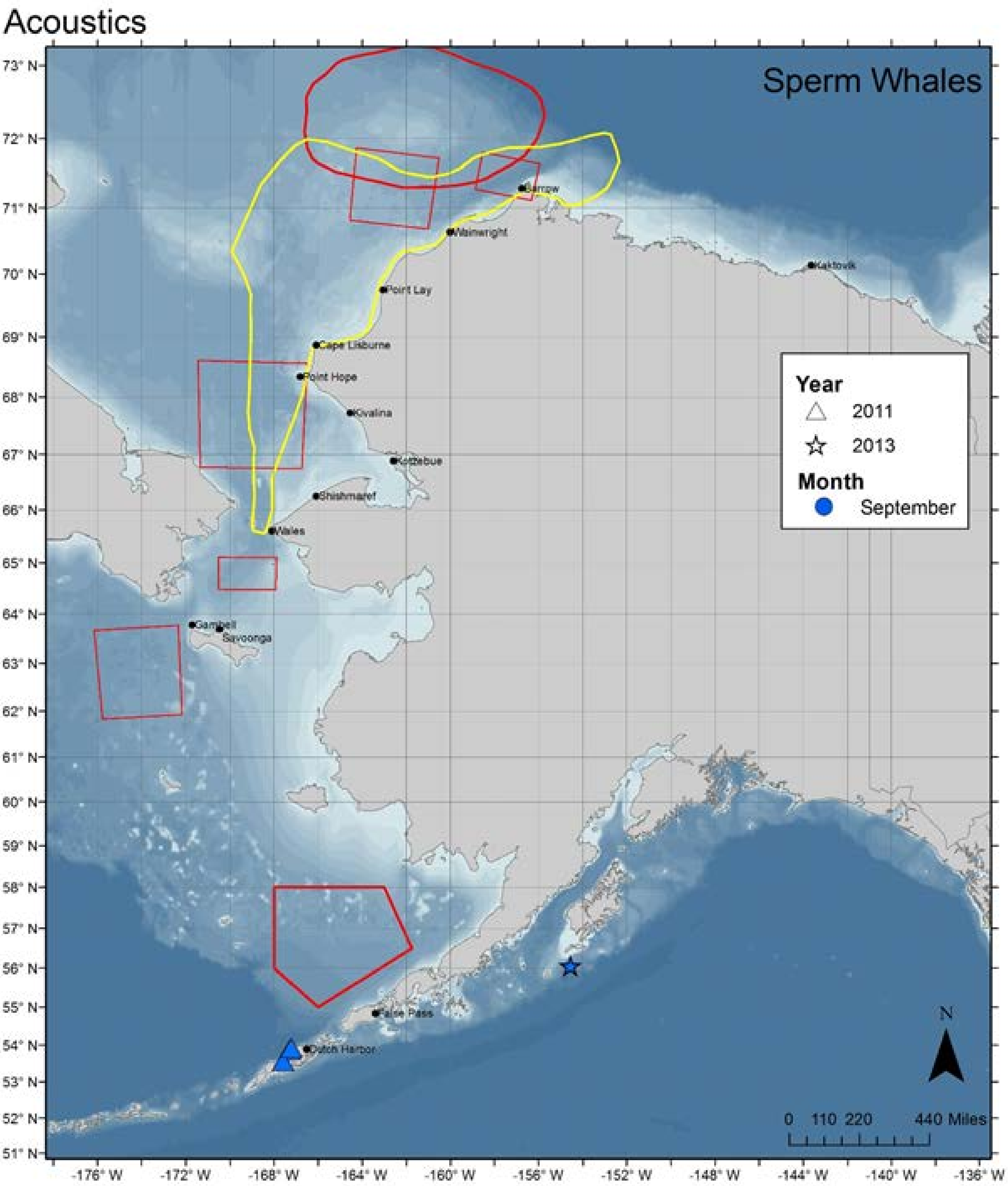
Appendix F.7. Minke whale sightings and acoustic detections, 2010-2016.



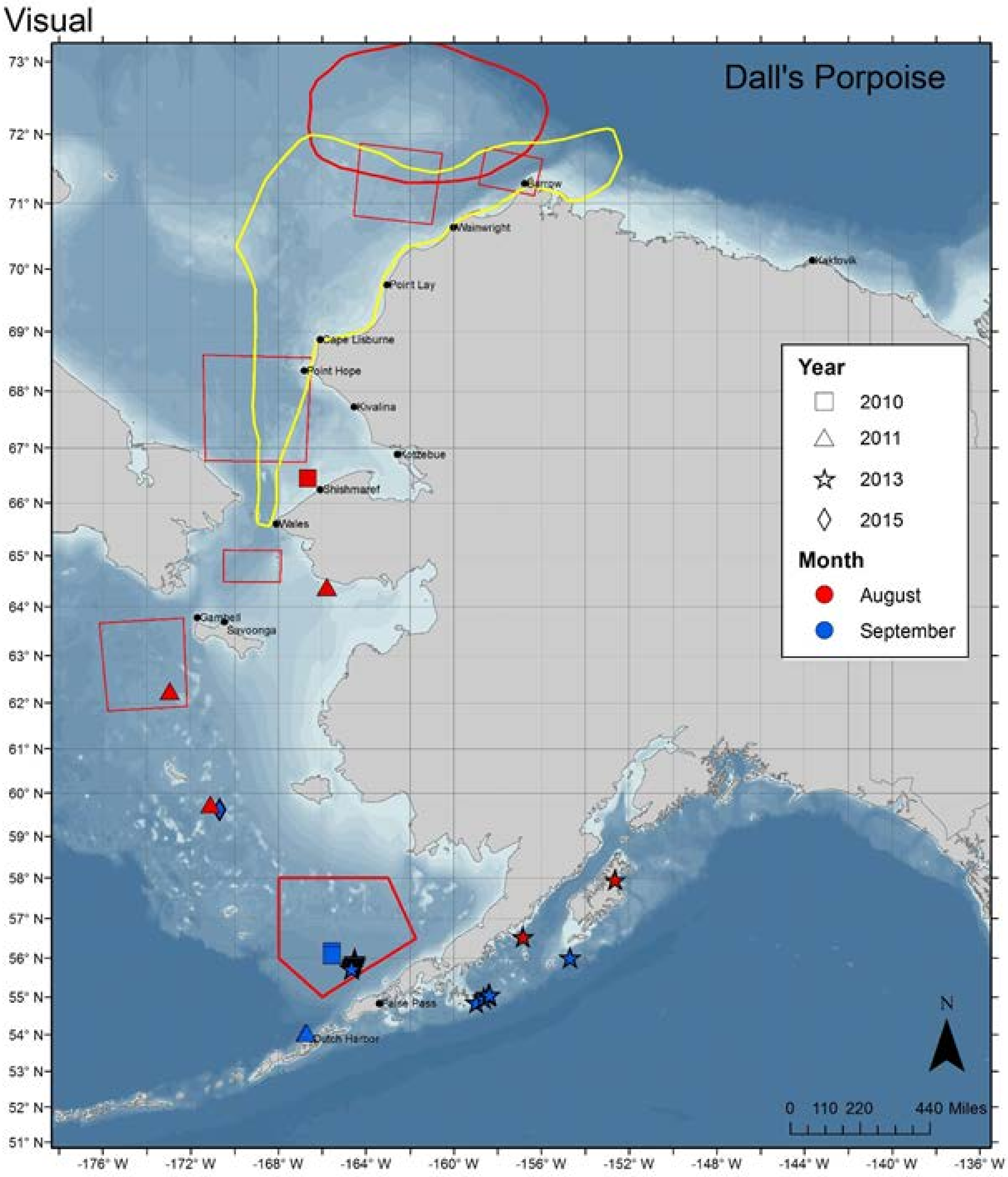
Appendix F. 8. Killer whale sightings and acoustic detections, 2010-2016.



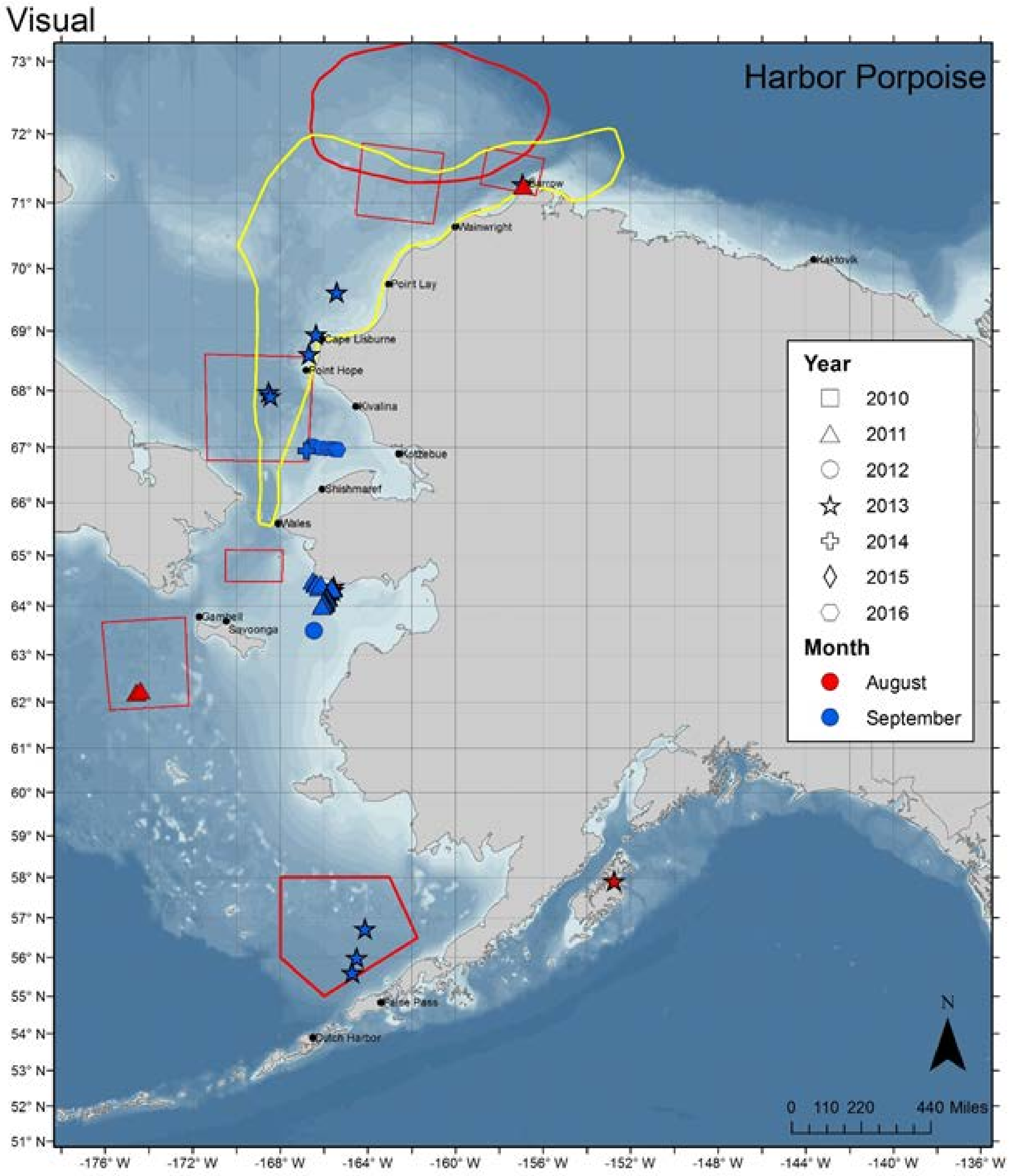
Appendix F. 9. Beluga whale acoustic detections, 2010-2016.



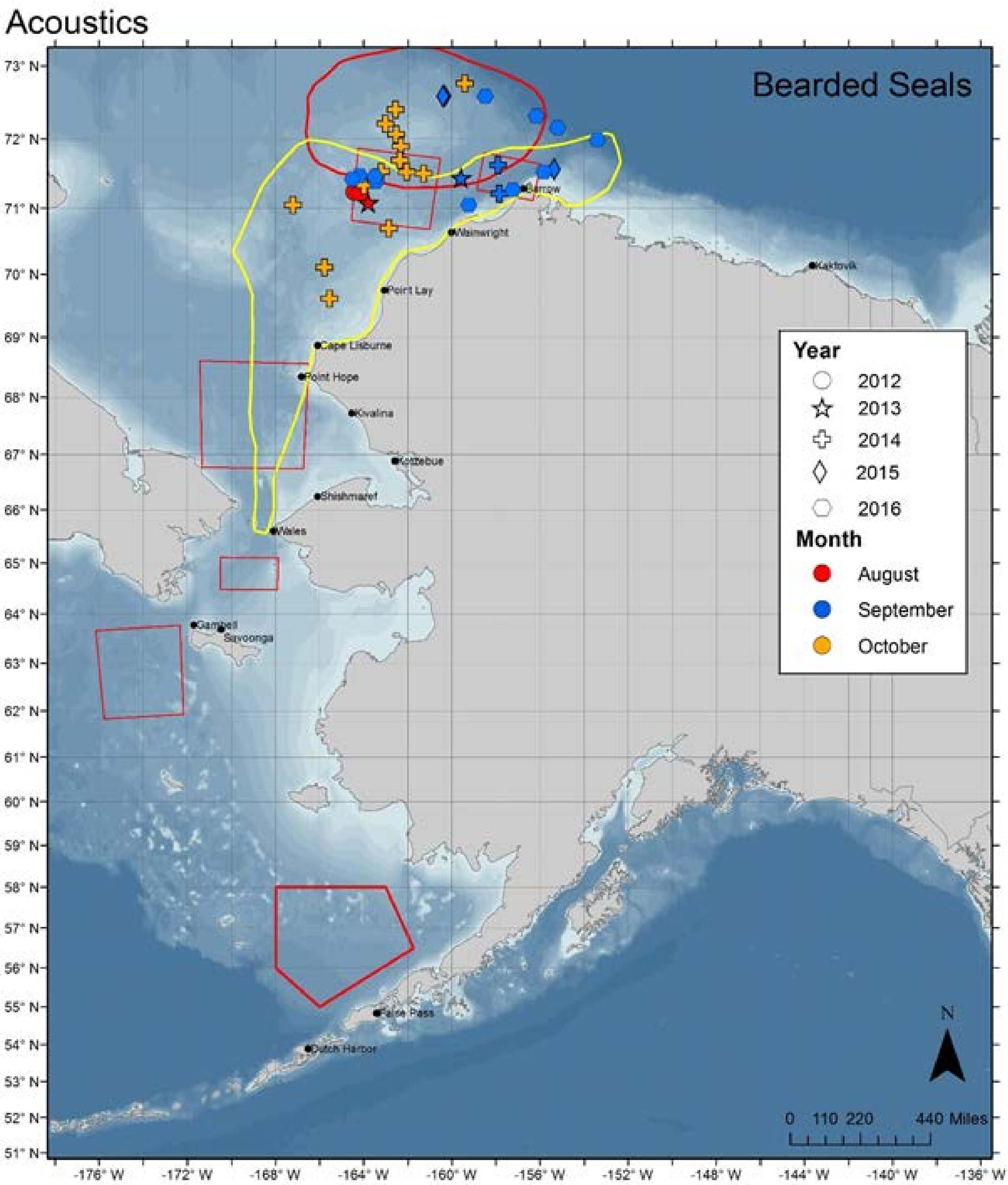
Appendix F. 10. Sperm whale acoustic detections, 2010-2016.



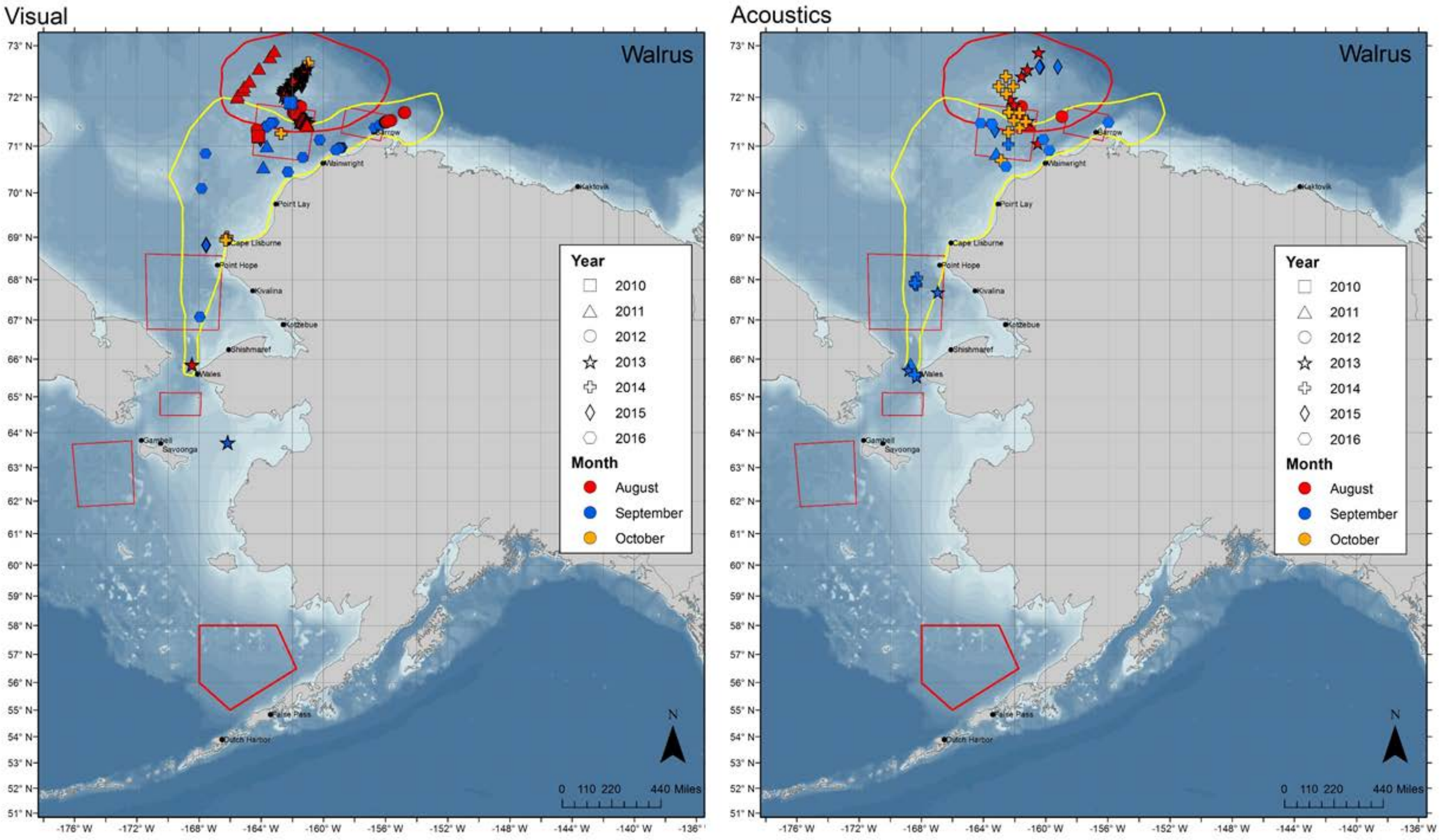
Appendix F. 11. Dall's porpoise sightings, 2010-2016.



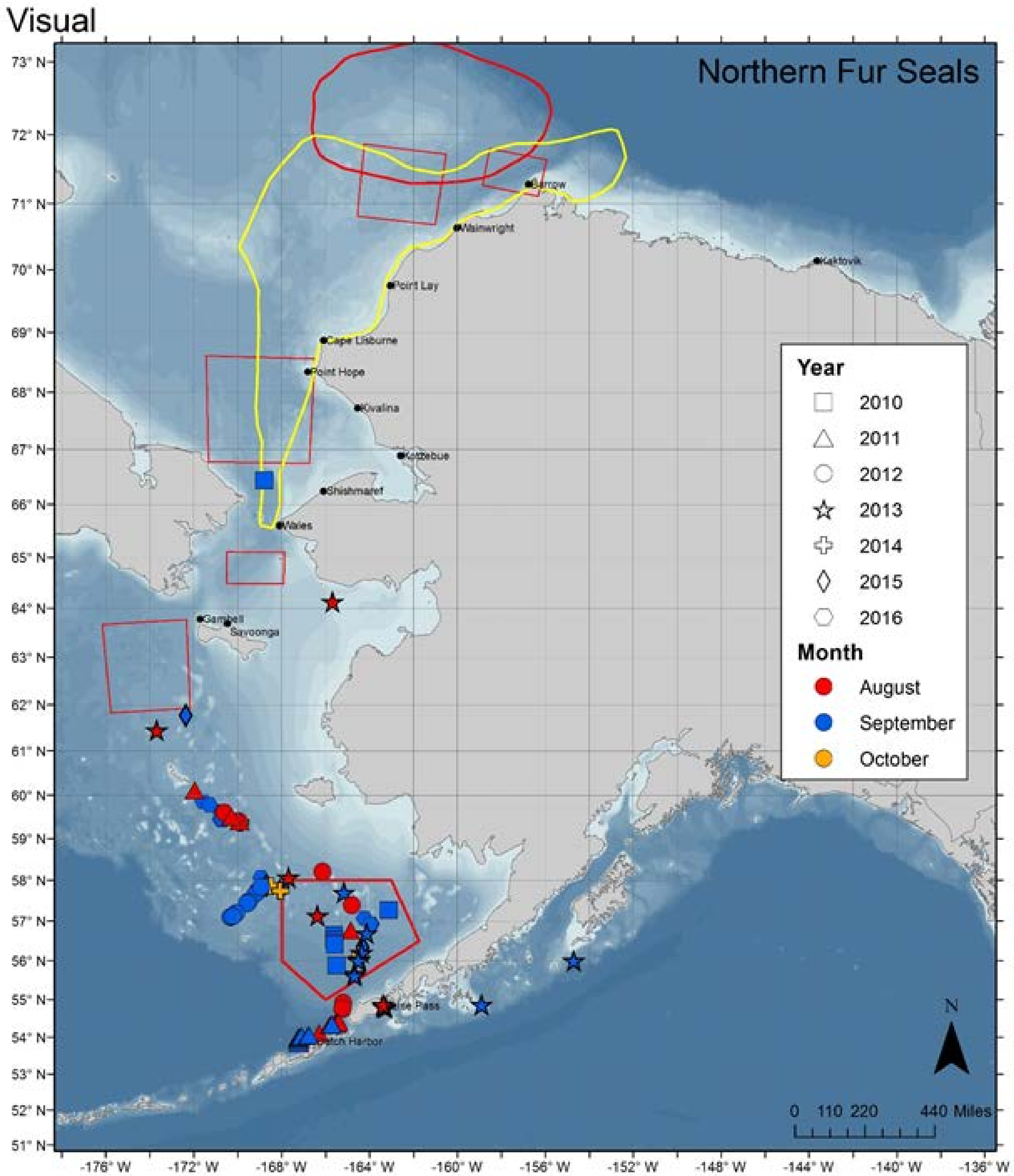
Appendix F. 1. Harbor porpoise sightings, 2010-2016.



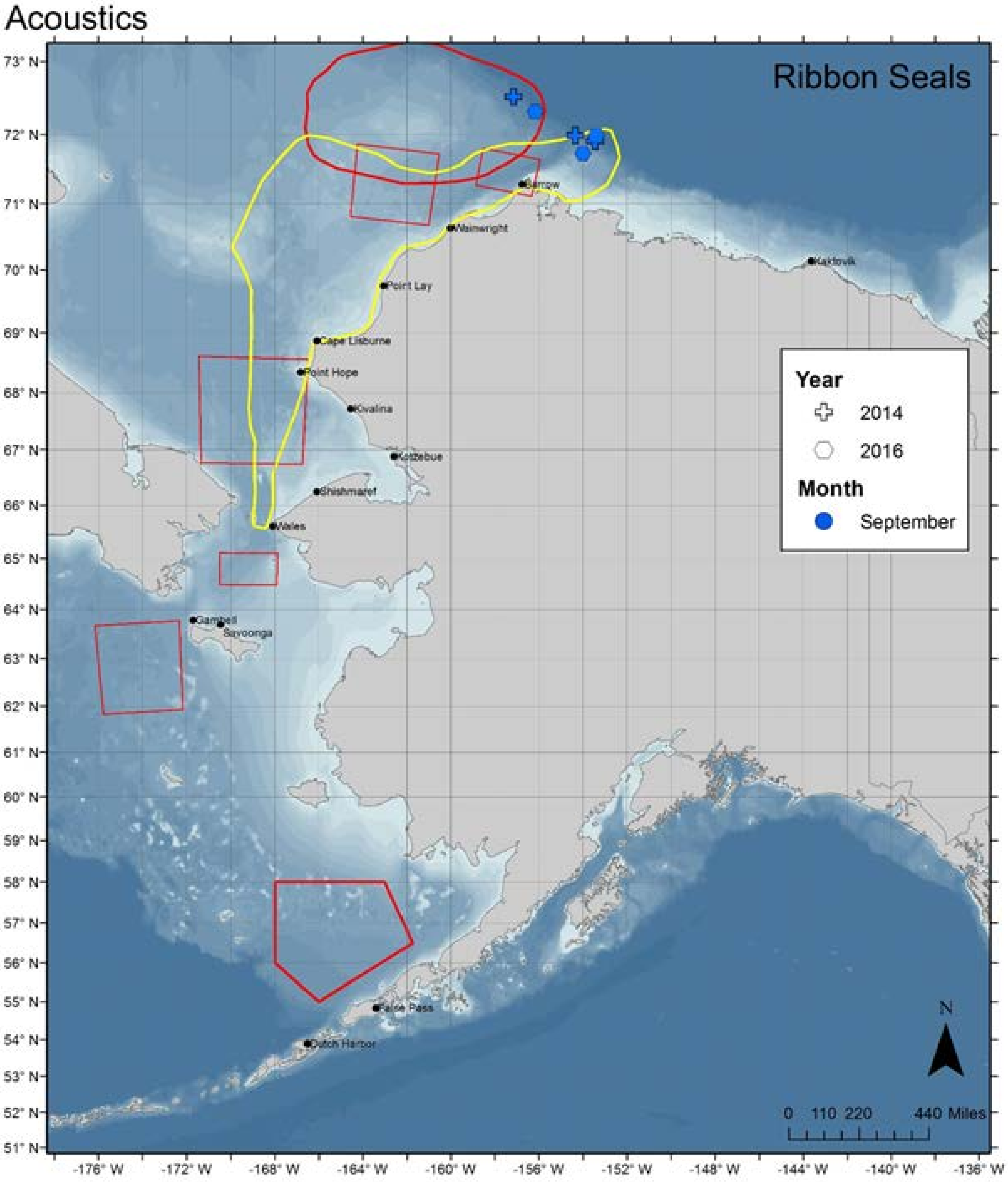
Appendix F. 2. Bearded seal acoustic detections, 2010-2016.



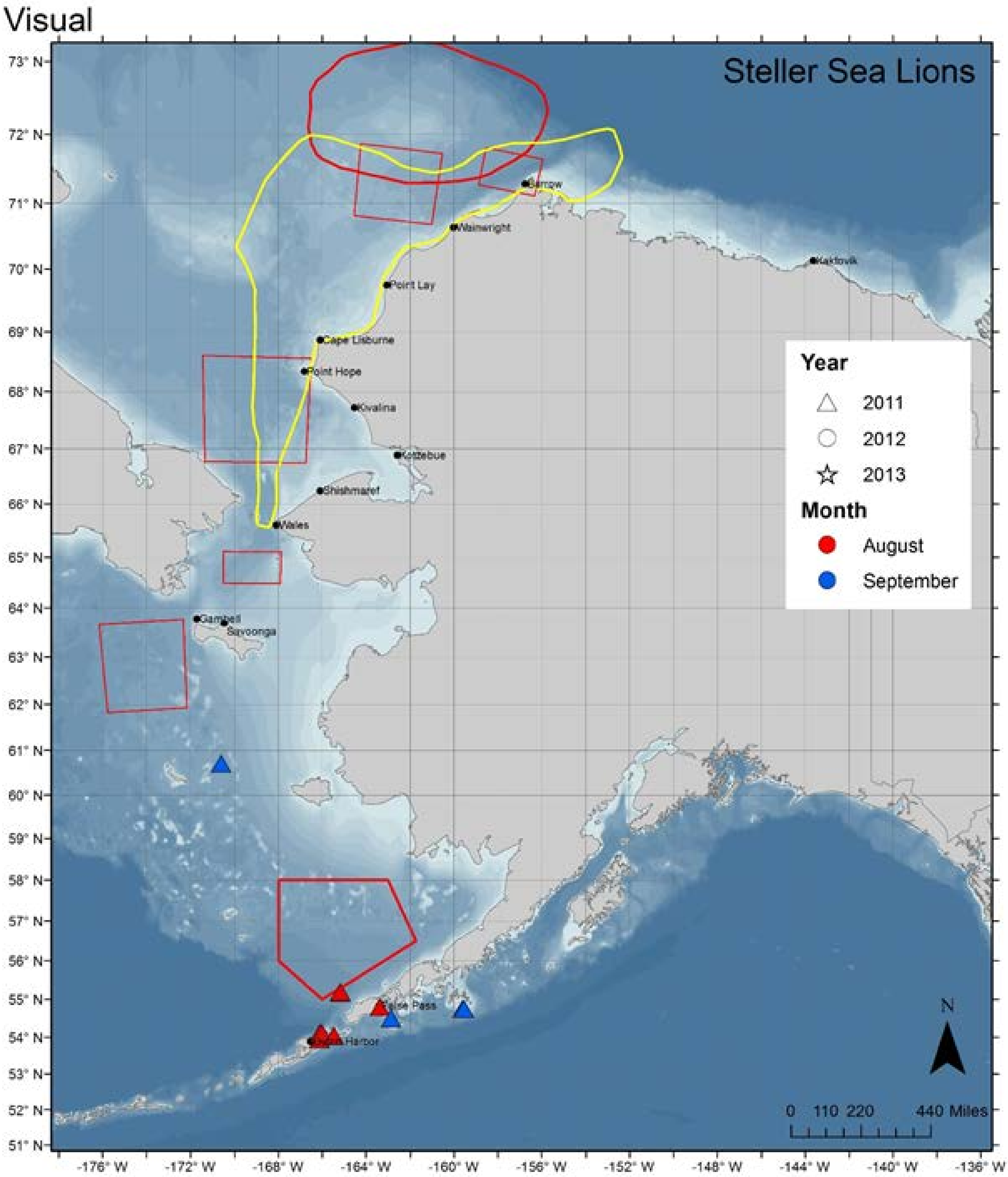
Appendix F. 14. Walrus sightings and acoustic detections, 2010-2016.



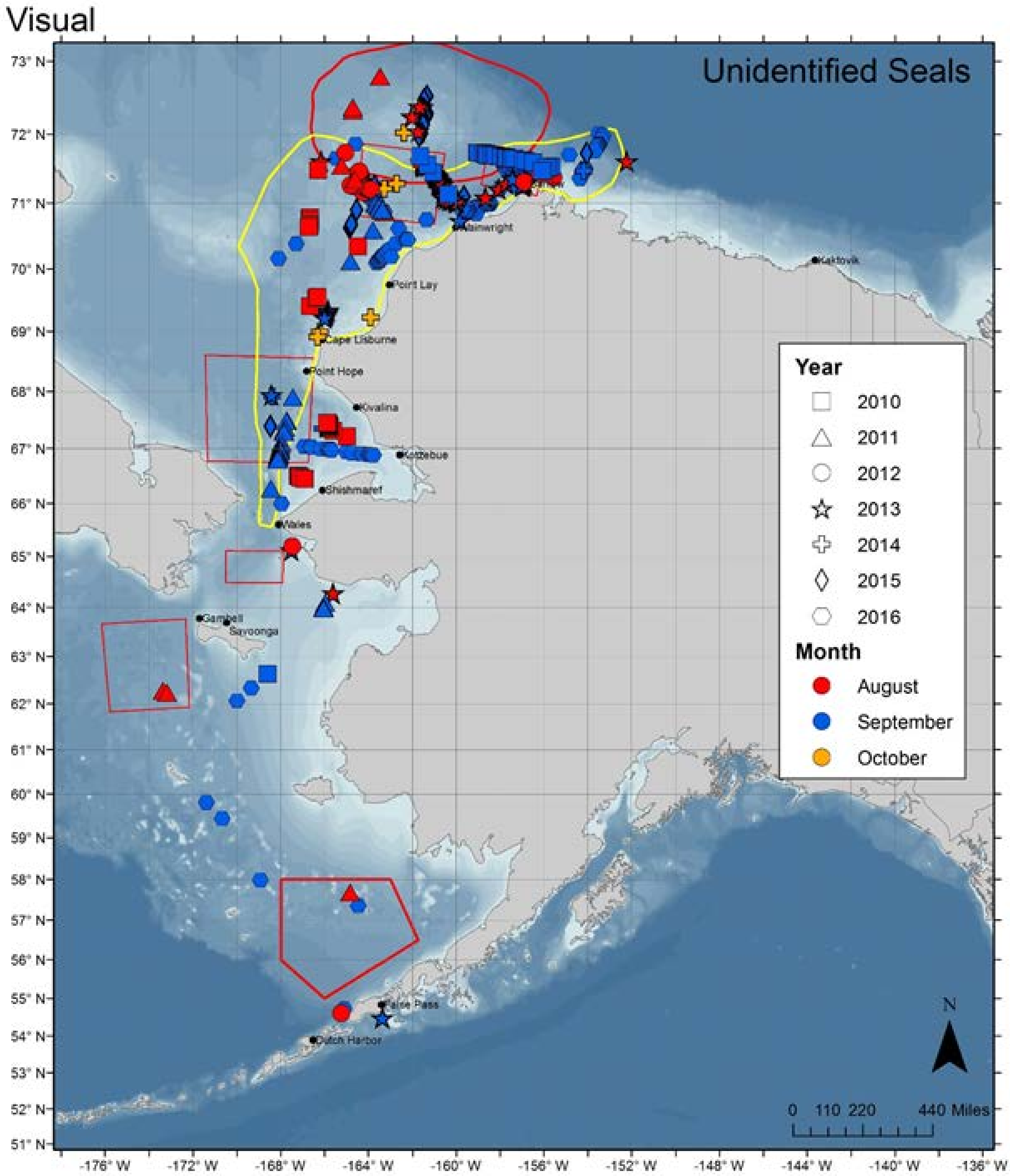
Appendix F. 15. Northern fur seal sightings, 2010-20162.



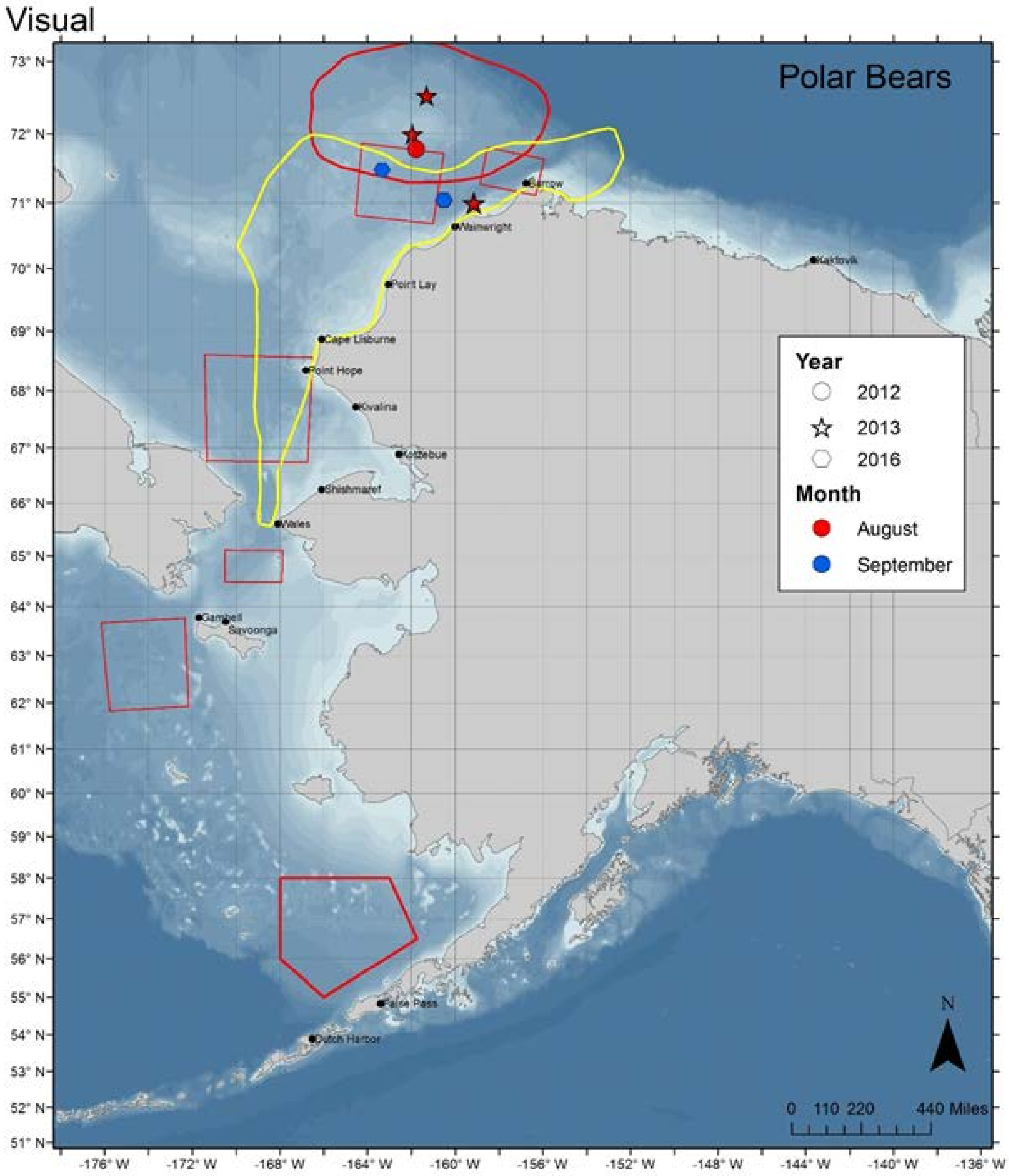
Appendix F. 16. Ribbon seal acoustic detections, 2010-2016.



Appendix F. 17. Stellar sea lion sightings, 2010-2016.



Appendix F. 18. Unidentified seal sightings, 2010-2016.



Appendix F. 19. Polar bear sightings, 2010-2016.

G. List of electronic files

1. Sonobuoy deployment tables. These are tables showing every sonobuoy deployed during the CHAOZ-X cruises, as well as species detected, for 2013-2016. File name:
    a. 2013: "CHAOZ-X 2013 sonobuoy deployments.pdf"
    b. 2014: "CHAOZ-X 2014 sonobuoy deployments.pdf"
    c. 2015: "CHAOZ-X 2015 sonobuoy deployments.pdf"
    d. 2016: "CHAOZ-X 2016 sonobuoy deployments.pdf"
2. Summary table of daily averaged variables across disciplines. This table contains daily average values for each variable that was collected. This spreadsheet also contains one tab per mooring location. File name: "ARCWESTandCHAOZ-X_SummaryTable_DailyAverageValues.xls"
3. Passive acoustic results for all species at all moorings: "PNGrsltsforGAM_10mincallRslts.xlsx"
4. CTD and plankton reports, detailing samples and measurements collected at each transect sampling station for the 2010-2012 field surveys.
    a. 2013: "CHAOZ-X_2013_CTD&planktonReport.pdf"
    b. 2014: "CHAOZ-X_2014_CTD&planktonReport.pdf"
    c. 2015: "CHAOZ-X_2015_CTD&planktonReport.pdf"
5. Modeled noise animations (n=24 .avi files) showing aggregate sound fields as a result of noise from wind, vessels, a drilling operation including support vessels out of Wainwright, AK.
6. Long-term passive acoustic animations of monthly averages of species/sound sources from 2010-2015 (n=15 .gif files from: airgun, bearded, beluga, bowhead, dblknck, fin, genpin, gray, gunshot, humpback, ice, orca, ribbon, vessel, walrus)
7. Archived Samples list. This document contains a list of all data samples, their approximate file size, and their location, for all data collected during the CHAOZ-X study. File name: "CHAOZ-X Archived Samples List.pdf"
8. Technical Summary. This is a brief (3-4 page) summary report of the CHAOZ-X project. File name: "CHAOZ-X M13PG00026 Technical Summary.pdf"

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The Department of the Interior Mission

Protecting America's Great Outdoors and Powering Our Future