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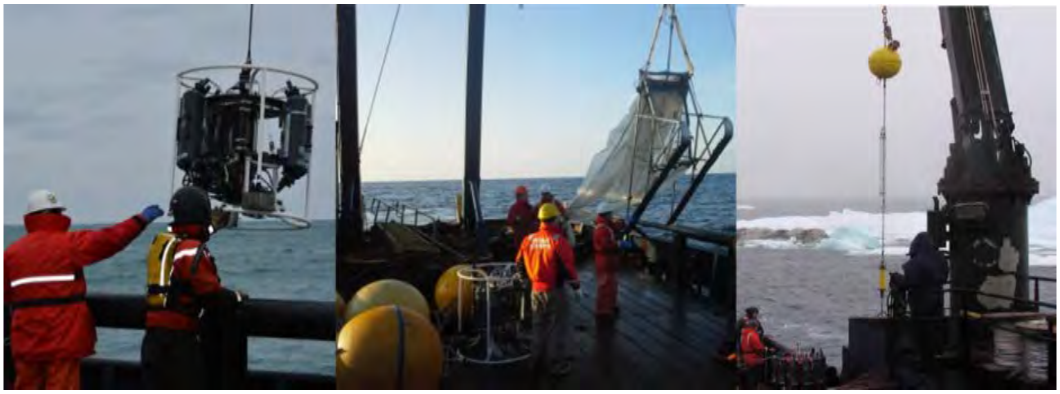
BOEM 2018-022

Arctic Whale Ecology Study (ARCWEST): Use of the Chukchi Sea by Endangered Baleen and Other Whales (Westward Extension of the BOWFEST)

Final Report of the Arctic Whale Ecology Study (ARCWEST)



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I. LIST OF ACRONYMS

ACC: Alaska Coastal Current

ADCP: Acoustic Doppler Current Profiler

AET: Acoustic Ecology Toolbox

AFSC: Alaska Fisheries Science Center

AIC: Akaike Information Criterion

ANOVA: Analysis of Variance

ARCWEST: Arctic Whale Ecology Study

ARGOS: Advanced Research and Global Observation Satellite

ARS: Area Restricted Search

ARTS: Air Rocket Transmitter System

ASAMM: Aerial Surveys of Arctic Marine Mammals

AtlW: Atlantic Water

AURAL: Autonomous Underwater Recorder for Acoustic Listening

AW: Anadyr Water

BIA: Biologically Important Area

BIC: Bayesian Information Criterion

BCB: Bering-Chukchi-Beaufort

BOEM: Bureau of Ocean Energy Management

BOWFEST: Bowhead Whale Feeding Ecology Study

BSW: Bering Sea Water

CHAOZ: Chukchi Sea Acoustics, Oceanography, and Zooplankton Study

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

CRC: Cascadia Research Collective

CSESP: Chukchi Sea Environmental Studies Program

CTD: Conductivity, Temperature, Depth sensor instrument package

CUA: Core Use Area

CI-CV: Copepodite Stages 1-5

DBO: Distributed Biological Observatory

DiFAR: Directional Frequency Analysis and Recording

DTAG: Suction Cup Acoustic Tag

DVM: Diel Vertical Migration

DWBA: Distorted Wave Born Approximation

FFT: Fast Fourier Transform

FM: Frequency Modulated

GAM: Generalized Additive Model

GCV: Generalized Cross-Validation

GLM: Generalized Linear Model

GMT: Greenwich Mean Time

GPS: Global Positioning System

IERP: Integrated Ecosystem Research Program

ITAE: Innovative Technology for Arctic Exploration

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

LFDCS: Low-frequency Detection and Classification System

LQ: Location Quality

MAG: Magnavox sonobuoy

MCMC: Markov Chain Monte Carlo

MML: Marine Mammal Laboratory

MW: Melt Water

NARR: North American Regional Reanalysis

NCEI: National Centers for Environmental Information

NCEP: National Centers for Environmental Prediction

NEPA: National Environmental Policy Act

NMDS: Non-metric Multi-Dimensional Scaling

NMFS: National Marine Fisheries Service

NOAA: National Oceanic and Atmospheric Administration

NPRW: North Pacific right whale

NSIDC: National Snow and Ice Data Center

PAM: Passive Acoustic Monitoring

PAR: Photosynthetically Active Radiation

PMEL: Pacific Marine Environmental Laboratory

PTT: Platform Terminal Transmitter

RHIB: Rigid-Hulled Inflatable Boat

SCM: Subsurface Chlorophyll Maximum

SLIP: St. Lawrence Island Polynya

SPL: Sound Pressure Level

SPOT 5: Smart POsition and Temperature tag ver5

SPW: Sparton sonobuoy

SSMI: Special Sensor Microwave Imager

SSSM: Switching State-Space Model

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

TEK: Traditional Ecological Knowledge

TFS: Truncated Fluid System

TIROS: Television Infrared Observation Satellite

USS: Undersea Sensor Systems sonobuoy

UTC: Coordinated Universal Time

VHF: Very High Frequency

WW: Winter Water

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V. EXECUTIVE SUMMARY

The Arctic Whale Ecology Study (ARCWEST) was initiated in 2012 through an Interagency Agreement between the Bureau of Ocean Energy Management (BOEM) and the Marine Mammal Laboratory (MML). The focus of the study was to determine relationships between dominant currents passing from the Bering Sea through the Chukchi Sea and prey resources delivered to the Barrow Arch area, and to provide information about the dynamic nature of those relationships relative to marine mammal distribution and habitat utilization in the eastern Chukchi and extreme western Beaufort Seas. It also provided important baseline data on the occurrence, distribution and habitat use of marine mammals in an area that is subject to rapid change and human industrial development.

The study had four principal objectives:

1. Estimate the spatial and temporal patterns of use of the Chukchi Sea by endangered bowhead, fin and humpback whales as well as gray, minke and beluga whales.
2. Assess population structure and stocks of origin of these animals via genetic analysis of tissue biopsy samples[1] and as appropriate, individual photo identification records.
3. Evaluate ecological relationships for the species, including physical and biological oceanography.
4. Conduct physical, chemical and biological oceanographic sampling to further understand the transport and advection of krill and nutrients from the northern Bering Sea through the Bering Strait and to the Barrow Canyon.

The objectives of ARCWEST were addressed using multiple research disciplines. Data were collected both over the short-term (roughly, one month), during ship surveys, and long-term, from year-round passive acoustic and biophysical moorings. Data were collected in three year-long mooring deployments (2012-13[2], 2013-14 and 2014-15), as well as during three field surveys in August and September of 2013, 2014, and 2015. Research efforts during the field season included visual surveys, photo-identification, tagging, zooplankton and oceanographic sampling (Conductivity, Temperature, and Depth (CTD) and Tucker sled zooplankton tows), passive acoustic monitoring (sonobuoys), and satellite-tracked drifter deployments. Research that occurred in the lab during the rest of the year, included long-term analysis from overwintering moorings (passive acoustic and biophysical). Figure 1 depicts the general study area and the main locations for data collection among the various research disciplines; also shown are the Burger, Klondike, and Statoil study areas for the industry-sponsored Chukchi Sea Environmental Studies Program (CSESP).

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[1] No biopsy samples were obtained so this topic is not discussed in the report.

[2] The biophysical moorings deployed in 2012 were a combination of funds from NOAA (FOCI) and those leftover from the BOEM-funded CHAOZ project. Analyses were funded by NOAA and are included in the synthesis section. Passive acoustic moorings from this year were deployed with CHAOZ funds but analyzed with ARCWEST funds, and so are included throughout the report.

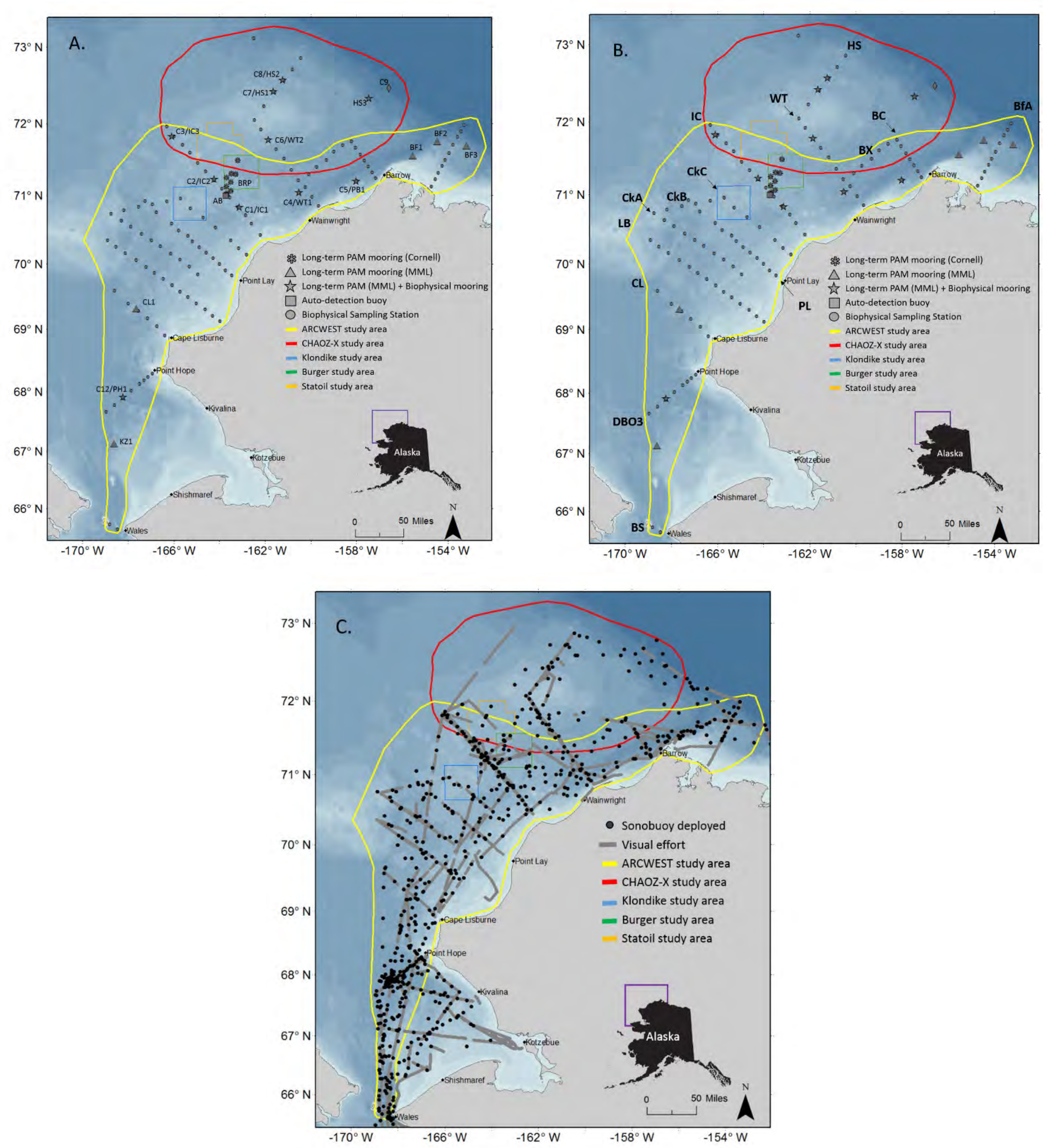

Figure 1. Maps showing the general study area for the ARCWEST project (yellow outline), the concurrent BOEM-funded CHAOZ-X project (red outline) and CSESP study areas (blue, orange, and green outlines). A) mooring locations; B) line transect sampling stations; and C) visual survey and passive acoustic monitoring effort, 2010-2016.

Results of this research help explain the distribution of marine mammals in the Bering and Chukchi Seas in relation to oceanographic conditions and potential prey availability. Important products of this work include the expansion of integrated biophysical (including oceanography, zooplankton indices, and marine mammal distribution) databases. Information from this study may be used by BOEM for pre- and post-lease analysis and documentation under the National Environmental Policy Act (NEPA) for any future Beaufort Sea or Chukchi Sea Lease Sales.

This report is organized into three areas of research (Sections VII –IX) which address the individual components, followed by a Synthesis section (Section X). Here, summaries for each section are presented, preceded by the key findings and recommendations from this research.

Key Findings

The Chukchi Sea ecosystem is complicated: landscape ecology, and regional and local forcing all combine to determine whether or not there will be favorable conditions for both the permanent and transitory residents. The residents of interest in this study, marine mammals, belong to several different feeding guilds, further complicating our goal of understanding how climate change and other anthropogenic forcing will affect them.

Marine Mammals

[Note for long-term moorings: Southern region = Cape Lisburne and south; northeastern region = east of Cape Lisburne]

- Spring migration was seen in both regions for bowhead and beluga whales, but was not confined to the nearshore leads in the northeastern region. The migration was multimodal for beluga whales, possibly due to a difference in timing for the two populations, or lead closures.
- Fall migration was seen in both regions for bowhead and beluga whales; and appears to be widely distributed across the northeastern region. Lower levels were seen for beluga than in the spring migration, although more even levels were seen inshore-offshore for bowhead whales). There may be evidence of a small fall pulse for bearded and ribbon seals. Multi-modal fall migrations were seen for bowhead and beluga whales, possibly due to a population timing difference (beluga) or sex/age segregation (both species). Gunshot calling was detected at the end of the migration for bowheads.
- For the ice season: low levels of calling activity were present for beluga, killer, and gray whales, ribbon seals, and walrus, and high levels were present for bearded seals overwinter in the northeastern region. No bowheads were detected overwinter. The southern region had low levels of beluga whales and high levels of bowhead whales, bearded seals, and walrus. Ribbon seal timing (April/May) coincided with their reproductive season in the Bering Sea. The high level of overwinter calling activity for walrus that was observed at the offshore Icy Cape site in the Chukchi Acoustics, Oceanography, and Zooplankton (CHAOZ) Study steadily declined from 2010 to 2015. The end of bearded seal calling was abrupt and consistent across locations/years.

- For the open water season: Calling activity was at low levels for bowhead whales (the highest levels were in the western Beaufort), and ribbon and bearded seals, and was at high levels for beluga, gray whales, and walrus in the northeastern region. No fins were detected, but analyses are incomplete. The southern region had very low levels of bowhead and minke whales, bearded and ribbon seals, and walrus, and high levels of gray, humpback, and fin whales. No belugas were detected in the open water season. Killer whale calling activity was highest for both regions in known gray whale hotspots.
- A double knock sound occurs simultaneously with beluga calling activity; current hypotheses are that this may be a fish sound.
- Seven cetacean species (bowhead, gray, humpback, fin, killer, and beluga whales, and harbor porpoise), two pinniped species (walrus and bearded seal), and polar bears were visually or acoustically detected in the ARCWEST study area in August - October. A combination of visual survey and passive acoustic monitoring is ideal.
- Satellite tagging provided novel information on habitat use and revealed heterogeneous movement patterns and important foraging areas for gray whales in the Chukchi and northern Bering Seas.

Oceanography

- On average, 40% of the transport through Bering Strait continues along the coast past Icy Cape. Monthly mean transport is greatest in summer and weakest during winter. On scale of days, the transport is highly correlated with local winds. Also, Atlantic water (AtlW) can be seen as far south as Icy Cape, more than 200 km from the slope.
- 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 increase in salinity. By late spring, the nitrate supply is usually replenished near the sea floor.
- Ice appears sometime in November and disappears in July. The largest ice keels appear in spring (often exceeding 20 m). The deepest keel (30 m) was observed at C4 in 2015.
- High concentrations of ammonium can be seen on the Pt. Hope line and in Barrow Canyon, indicating an active microbial loop of converting detritus into ammonium. Ammonium is the preferred nitrogen form for many phytoplankton.
- Mean chlorophyll-a concentrations were significantly ($p < 0.001$) different among the years with values from 2014 being the lowest.
- The offshore distribution of chlorophyll-a with depth was characterized by large subsurface patches – products of stable water column conditions and the settling of phytoplankton cells along the pycnocline.
- Values of chlorophyll increased as one approached the flanks for Hanna Shoal.

Zooplankton

- The zooplankton community composition showed great variability among years and within years the assemblages were often tied to specific water types. In one year, assemblages were strongly delineated between the eastern and western portions of the Chukchi shelf
- In one year, we observed strong evidence for physical transport of Arctic basin plankton species onto the Chukchi Sea shelf. The exact mechanism for this transport event was not clear.
- There was no clear evidence to support the conveyor belt hypothesis for euphausiid transport from the Bering Sea to the northern Chukchi. Adult and juvenile euphausiids were rare on the Chukchi shelf.
- Early life history stages of euphausiids were abundant in some years pointing to the possibility that euphausiids do reproduce in the Chukchi and that not all individuals are expatriates from the eastern or northern Bering Sea.
- Northward travel time of water from Bering Strait to Barrow Canyon takes, on average, ~100 days, although this varies as a function of the wind. That means that zooplankters spawning around in mid-July in the northern Bering Sea would not be able to transit the entire shelf before it became ice covered.
- We observed intermittent diel vertical migration (DVM) of sound scatterers on the shelf with stronger DVM behavior over the shelf break north of Hanna Shoal. The migration behavior at this location could have been from invertebrates or fishes.

Ambient noise

- Seismic airguns were detected during all open water seasons; the highest levels were in 2013 when multiple seismic surveys were underway. Vessel noise was also detected in every open water season; most ubiquitous levels were during 2012 and 2015, and corresponded to vessel activities associated with exploratory drilling operations.
- Ambient noise analyses conducted at two locations (one northeastern, one southern) indicate that three sources dominated the acoustic environment: bowhead whales, bearded seals, and walrus. Vessel noise was the exception during the open water season at both locations, along with ice formation at the northeastern site. The acoustic analyses conducted here provide useful tools for understanding the main contributors to the Arctic noise environment.

Synthesis

- Regression tree and Generalized Additive Model (GAM) analyses yielded few surprises among the Arctic marine mammal species. Month was a main factor determining calling activity for all but gray whales (who had very low calling activity levels overall), suggesting endogenous cycles. However, more consistent long-term lower-trophic-level data are needed to determine if external influences are also at play.

- Regression tree and GAM analyses also revealed ice factors as a secondary influence on calling activity levels for all Arctic marine mammal species except gray whales. Bowhead and beluga whales migrate in spring through areas with high ice concentrations. For bowhead whales, calling activity was linked with factors that were likely proxies for leads; ice thickness was important for beluga whales. Ice concentration appeared as a top factor for walrus and bearded seals, with variability in ice thickness additionally for walrus. Factors associated with possible benthic productivity were seen, instead, for gray whales.
- The Chukchi Sea polynya, which forms most years between Wainwright and Icy Cape, is believed to be an “export” system, resulting in an increase in primary productivity. However, for the five polynya events that occurred during the study, there were no observable effects on oceanographic conditions, the benthos, or upper trophic levels. Marine mammal detections were few and intermittent.
- The presence of a variety of different hotspots occur in the Chukchi and western Beaufort Seas (temporary vs. permanent, pelagic vs benthic) due to a combination of oceanographic (i.e., flow, winds, ice melt, and summer heating) and lower trophic (i.e., subsurface phytoplankton blooms, and export of ice algae) factors and their presence is reflected in the upper trophic level (i.e., marine mammal) data.
- This study provided short- and long-term data for Regions 2-5 of the Distributed Biological Observatory (DBO).
- Two alternative conceptual models were used to help predict how pelagic-benthic coupling may change with increased warming and decreased sea ice: early ice retreat with strong winds and less ice melt, and early ice retreated with weak winds and increased local ice melt.
- Recent fisheries surveys are beginning to show large numbers of fish in the two adjoining regions; we need to rethink our current ideas about potential immigration of species into the Chukchi and be able to better quantify how the impacts of loss of sea ice at lower trophic levels will cascade to impact marine mammals and other high level Arctic predators.

Section VII: Marine Mammal Distribution

Three year-long deployments of nine long-term passive acoustic recorders, totaling 10,374 days, were made within the ARCWEST study area from 2012-2015. Combined with the 1,218 days collected in this area during the 2010-2012 CHAOZ study and 466 days of data reanalyzed from the BOEM funded Bowhead Whale Feeding Ecology Study (BOWFEST) project, 12,058 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 ARCWEST 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 Traditional Ecological Knowledge (TEK).

Bowhead whales were detected April/June through December in the northeastern region and October through May in the southern region. The fall bowhead migration was seen as a pulse in calling activity; its level was consistent inshore-to-offshore, supporting a broad divergence of the migratory path over the northeastern Chukchi Sea. This fall pulse was multimodal in many locations and years, supporting TEK of age/sex segregation during migration. Associated with the end of the fall migratory pulse was the presence of a smaller pulse of bowhead gunshot calling. As expected, no calling activity was detected from January to March in the northeastern region in any year. However, calling activity was detected overwinter in the southern region, indicating that at least some portion of the population remains in the southern Chukchi (where the fall migratory pulse blended into the spring pulse) and does not migrate into the Bering Sea. The spring migration does not appear to be contained entirely in the nearshore lead. Calling activity was also present in the summer in the northeastern region (where the separation between the spring and fall pulses is indistinct). The highest levels of bowhead whale calling activity during the open water season were in the western Beaufort Sea near the Barrow hotspot, but lower levels of calling do exist during this time period in the northeastern Chukchi.

Two populations of beluga whales can pass through the ARCWEST study area: the eastern Chukchi Sea and eastern Beaufort Sea populations. Beluga whale 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 during the spring and fall migrations and during the ice season throughout the ARCWEST area, and during the summer open water season in the northeastern region. Spring calling was detected at all mooring locations, even those offshore, suggesting that beluga whales are not limited by high ice concentrations. For the open water season, the highest levels of calling were in the western Beaufort Sea, consistent with the summer range of the eastern Chukchi Sea population. Fall calling activity is generally low compared to the spring, suggesting that belugas are widely distributed across the Chukchi Sea shelf in the fall. Multimodal pulses were evident for both the spring and fall migrations, which could represent different populations, age/sex classes, and/or ice impeding migration. The presence of calling activity overwinter at most ARCWEST mooring locations and years suggests some belugas overwinter offshore. Finally, a double-knock sound was documented that may be produced by fish; this sound occurs simultaneously with beluga whale calling activity. A similar knocking sound, although higher in frequency, has been reported for sablefish (Riera et al., 2018), showing that fish are capable of producing this type of sound. Other possibilities are that this sound is not produced by the fish internally, but is generated by the fish eating organisms off the recorder; the sound could also be produced by the organisms growing (or living) on the instrument. Currently, the investigation is on hold until a larger sample size of results from multiple moorings and years is obtained from the Chukchi, Beaufort, and Bering Seas and more robust spatial and temporal trends can be determined.

For bearded seals, high and sustained levels of fall-through-spring calling activity were detected on every mooring in every year, providing evidence that they were 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. The abrupt end of calling in mid-late June was extremely consistent among mooring sites and years, and was not correlated with ice concentrations. There was a smaller, less sustained pulse of calling activity that occurred prior to the main ramp up of calling. The timing of this earlier pulse proceeded southwestward, occurred immediately prior to the ice arrival, and was much more defined in the southern Chukchi - possibly indicating a small fall migration. Lowest bearded seal calling levels were in July and August.

Combining all years and mooring sites, walrus calling activity was detected year-round in both ARCWEST regions. The summer pulse of calling activity ranged from May through October in the southern and June through September in the northeastern regions. The most saturated and sustained levels occurred at the Icy Cape sites which were the closest ARCWEST locations to Hanna Shoal; the lowest levels were at the 100 m deep Beaufort site. Overwinter calling was detected at most mooring sites, with the highest and most sustained winter levels at the southernmost mooring site. Overwinter calling was also seen in high levels at the offshore Icy Cape site, which steadily decreased from 2010 through 2015. The presence of walrus overwinter indicates the presence of leads or polynyas, so walrus calling may be used as a proxy for open water presence.

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, calling was detected in both the open water and ice seasons throughout the ARCWEST area. The highest and most sustained levels of summer calling activity were seen in the southern region off Point Hope, a known benthic hotspot. Additionally, some detections occurred at sites within the hotspot in the northeastern region between Barrow and Wainwright. As expected, very few calls were detected offshore, and no calls were detected in the western Beaufort Sea.

Several detections of subarctic species were made in the ARCWEST study area, predominantly in the southern Chukchi and during the open water season. Humpback whales were primarily detected in the southern region, although sporadic detections occurred in the northeastern portion; none were detected in the Beaufort Sea and none were detected outside of the open water season. Fin whales were only detected in the southern Chukchi, June through November, although analyses are incomplete for this species. Work on an in-house autodetector is scheduled for summer 2019 to be able to generate results for fin whale presence. Killer whales were detected at every site in the ARCWEST study area during open water season, although levels were highest in the southern region. The timing and distribution of killer whale calling activity aligned well with gray whale distribution; additionally, visual observations indicated these are the transient ecotype. Minke whales were primarily detected September through November in the southern region off Cape Lisburne; all detections were of the “boing” call type. Ribbon seal calling activity was present at low levels at all mooring sites in the ARCWEST study area. Main calling activity was centered in October/November at all sites, and ceased concurrently with ice formation; highest calling levels were in the western Beaufort close to their preferred feeding grounds on the continental slope. Ribbon seal calling was also detected April/May, concurrent with the reproductive season when all ribbon seals are thought to be in the Bering Sea.

In addition to moored recorders, sonobuoys were deployed every three hours throughout each cruise (dates ranging from August to October, depending on year) to obtain an evenly sampled cross-survey census of marine mammal presence. Concurrent with sonobuoy deployments, visual surveys, limited to daylight hours, were conducted to document the presence and distribution of all marine mammals encountered throughout the survey. 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 427 sonobuoys were deployed and 2,553 nm of trackline were visually surveyed in the study area. In total, six cetacean species (bowhead, gray, humpback, fin, killer, and beluga whales), and two pinniped species (walrus and bearded seals) were acoustically detected. Five cetacean species (bowhead, gray, humpback, and killer whales, and harbor porpoise), one pinniped species (walrus), and polar bears were visually sighted in the study area. The results of these four years of shipboard surveys have shown that the ARCWEST study area is an important one for both Arctic and subarctic species in the August-October time period. The combination of visual and acoustic surveys is essential to maximize the potential for detecting marine mammal presence. Either method alone runs the risk of missed detections and underestimation of the importance of an area to a particular species. We have found that fin, killer, and beluga whales, and walrus are more likely to be acoustically detected during the August-October time period of these cruises. Bowhead and humpback whales are equally likely to be sighted or acoustically detected. However, for gray whales, bearded seals, minke whales, and porpoises, 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.

Section VIII: Biophysical Patterns and Trends

Each year, year-long biophysical moorings were deployed at 6-7 sites, in conjunction with passive acoustic arrays to collect concurrent data. To avoid ice keels, instruments on each mooring were only ~10 m above the seafloor. These instruments 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 summer mooring recoveries and deployments to calibrate instruments on the moorings. Summer hydrographic surveys were also conducted yearly on 12 hydrographic transect lines. 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 were generally northeastward following bathymetry, and variability in currents was primarily wind-driven. Approximately 40% of the flow through Bering Strait passes the Icy Cape line. Bottom temperature ranged from approximately -1.8 to < 5.0 °C, with maximum temperatures occurring in late August or September when storms began mixing the water column. Salinity ranged from < 31 to ~34.5 psu and was highly variable, as a result of different water types, and the melting and freezing of sea ice. The highest turbidity occurred in fall when the winds began to increase and before the sea ice areal coverage became >80%.

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. While some of the changes in nitrate was associated with increasing salinity (i.e. advection), at other times increases nitrate did not appear related to other parameters. One possibility is nitrification. 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 increased to an average of ~4 m in March, with the thickest ice generally seen late in spring. The position of the ice influenced the water properties; the Alaska Coastal Current (ACC) and Winter Water (WW) appeared in both years, but Melt Water (MW) only appeared in 2012.

Ice algal blooms occurred below the ice and as the ice melted this production was exported to near bottom, where it continued to photosynthesize and produce oxygen into the summer. During summer, subsurface phytoplankton blooms were common, and fuel secondary productivity.

The zooplankton community composition greatly varied among years, although small copepods tended to dominate in all years. At least one year showed a predominance of benthic meroplankton larvae dominating the macroplankton. Water mass type (based on Temperature and Salinity) was strongly associated with areal differences in the zooplankton community structure. Intrusions of Arctic basin plankton species onto the shelf occurred; however, we observed their occurrence long after the intrusion event so the hydrography surrounding their new home did not always indicate basin water.

Plankton abundance generally appeared to be low during our summer expeditions. Missing from our net collections was evidence of a conveyor belt of euphausiids transported from the northern Bering Sea or evidence for persistent hot spots for baleen whale feeding (e.g., something similar to the Beaufort Sea - Barrow Canyon euphausiid trap). However in this season, there are few bowhead or other baleen whales feeding in this area. The main feeding grounds for bowheads are much farther to the east. Unresolved is whether or not high concentrations of euphausiids exist earlier in the year during the time when bowheads are migrating through the area. We did find evidence for euphausiid reproduction in the Chukchi, suggesting that not all of the euphausiids in the region are transported through the Bering Strait.

DVM was not a strong and constant factor in the distribution of zooplankton within the water column. Wavelet analysis of the Acoustic Doppler Current Profiler (ADCP) data did reveal locations and times when it was present. The strongest behavior was observed over deeper waters at the shelf break where migrators could have been composed of older euphausiids and fish. Both net and acoustic estimates indicated that zooplankton concentrations were often as high or higher near the bottom than they were in the rest of the water column on the Chukchi shelf in summer.

The shallow water column and difficulty predicting where the zooplankton spend most of their time in the water column may make it difficult to understand the exposure of plankton to oil, should there be an oil spill in the region. As acoustic instruments become more reliable, our knowledge of what happens during the winter and early spring will increase.

Section IX: Ambient noise contributors and acoustic environment analysis

The long-term distribution of vessel, airgun, and ice noise activity was also analyzed simultaneously with marine mammal calling activity. 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 were a few cases of airguns being detected that could not be attributed to a permitted activity on the U.S. OCS. Vessels were also detected during all open water seasons, with the highest and most ubiquitous levels occurring during 2012 and 2015 at the western and shoal locations, corresponding to the multi-vessel effort associated with the exploratory drilling operations at that time. And lastly, not surprisingly, ice noise was present overwinter at all locations and during all years.

The marine mammal, vessel, and airgun contributions to the acoustic environment are described for WT1 and PH1 for the 2012-2013 dataset. The PH1 mooring location (off Pt. Hope in the southern Chukchi) had a higher diversity of biological contributors than WT1 (off Wainwright in the northeastern Chukchi) for both seasons. As expected, bowhead whale signals dominated the environment during the migration period in spring and fall at 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 at 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 at 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 at PH1 did not differ as much between seasons. These differences could be due to higher ice related noise at PH1 than WT1. Vessels provided a lower contribution to the acoustic environment at PH1 than at WT1, although for both sites the vessel 50th spectral percentile often exceeded the one for marine mammal species. The PH1 mooring was closer to the Bering Strait and acoustic data from that site would normally be expected to show a stronger vessel traffic influence, however, WT1 was exposed to traffic related to oil and gas operations in the Chukchi Sea because Wainwright was 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 at these two locations.

Section X: Synthesis

A. Correlation of marine mammal distribution to biophysical parameters

For the statistical analyses (i.e., regression tree and GAM analyses) on marine mammals conducted for this study, analyses were limited to ARCWEST moorings C2, C4, and C5 and to biophysical variables which have 36% or fewer missing data points to minimize misleading results[3]. Sufficient acoustic data were available for the analysis of bowhead (including gunshot calls), gray, and beluga whales, bearded seals, and walrus.

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[3] The regression trees and GAMs can absorb small amounts of missing data, but if sections of missing data are on the order of weeks to months (which in our case is common because these data drop-outs tend to be a result of instrument failure), then there will not be sufficient data across all seasons to accurately model the temporal trends.

The combination of regression tree and GAM analyses presented here appears to be relevant to the known behaviors of the five Arctic marine mammal species. Month was a main factor determining calling activity for bowhead and beluga whales, bearded seals, and walrus, suggesting that the timing of their migrations is innate; however, more data on lower trophic level species are needed before external factors can be ruled out. Ice factors were found to be a secondary influence on calling activity levels for these four species. Bowhead whales migrate in spring through areas with high ice concentrations, and higher calling activity was linked with factors that were likely proxies for leads. Higher levels of calling activity were also seen with lower temperatures, which supports their ice-associative nature. Beluga whales also migrate through areas with high ice concentrations in the spring, but their calling activity levels are higher with lower ice thickness. Ice thickness was also an important factor for walrus; that the standard deviation metric was more important suggests the calling activity of walrus is higher during the ice breakup period than overwinter. For bearded seals, ice concentration was an important factor influencing their calling activity levels. Gray whales were the only Arctic species to not have month or ice as main factors influencing their calling activity, with factors possibly associated with benthic productivity being more important. However, since the data set contained very few days with gray whale calling, and with low calling levels on those days, it is unknown whether these results were due to low sample size.

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.

B. Polynyas

Large-scale polynyas in spring typically result in an increase in primary productivity, usually as a result of increased light availability. If phytoplankton production exceeds zooplankton grazing, then that excess production accumulates and falls to the seafloor, in what is known as an “export” system. The annual Chukchi Sea polynya is thought to be predominantly an export system, leading to carbon being exported to the seafloor, which in turn causes an increase in benthic productivity. However, this polynya has not been the focused study of benthic or plankton studies, and as such all hypotheses and results should be treated as preliminary.

Five major polynya events occurred during the ARCWEST and CHAOZ study period; warm, salty Atlantic water was evident at three of these. Despite the annual appearance of the Chukchi polynya each winter, which formed mainly nearshore between Wainwright and Icy Cape, marine mammals were detected only infrequently during these major polynya events. It is likely that these sporadic detections were overwintering individuals taking advantage of an opening in sea ice, and not a direct result of increased benthic productivity. We suggest three hypotheses for this lack of correlation between detections and increased benthic productivity: 1. The production pulse was too brief, or was not spatially constrained enough to create noticeable impacts within the polynya’s area; 2. The production pulse was not large enough (relative to the large amount of seasonal productivity) to be of great ecological importance; or 3. The lag between the phytoplankton bloom brought about by the polynya, its export to the benthos, and the subsequent increase in benthic biomass was too great a time span for any noticeable results to appear in the long-term moorings. While the results presented here were inconclusive, it highlights the needs for a dedicated study of the specific biophysical coupling surrounding the formation of polynyas and their general importance for the ecosystem.

C. Hotspots

The Chukchi and Beaufort Seas are home to productive areas of varying degrees for marine mammals. The Chukchi Sea is a flow-through shelf, and this flow brings heat, nutrients, and prey. Ice melt, summer heating, and variability in winds can all produce areas with stratification, especially along the coast where the ACC overlays Bering Sea Water (BSW). Subsurface phytoplankton blooms can form in these stratified waters and the export of this primary productivity along with irregular export of ice algae can fuel secondary productivity in the benthos. This tight benthic-pelagic coupling can sustain the higher trophic levels; the Ledyard Bay, Point Lay, and Icy Cape Lines are all examples of these ephemeral hotspots. More permanent hotpots are found along the Point Hope 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. Benthic feeders (i.e., gray whales, bearded seals, and walrus), are expected to aggregate around these prime benthic hotspots; the persistence of these hotspots is especially critical for walrus, who prefer a diet of sessile bivalves.

The remaining hotspot areas seen in this study are strongly influenced by bottom topography and currents. The Barrow Canyon and western Beaufort lines are situated in areas where these factors combine to bring nutrients (and pelagic prey) up from the deep basin, forming temporary hotspots by trapping prey for the upper trophic level species. This mechanism is important for energetically efficient feeding by pelagic species (e.g., bowhead whales). However, 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 inter-annually. 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 inter-annual interdisciplinary sampling.

D. Long range predictions

The timing of ice retreat and advance is critical to structuring arctic ecosystems - from 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, a bigger dump of carbon to the ocean bottom, a prolonged subsurface bloom, and perhaps a stronger fall bloom, all of which have implications on the ecosystem.

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. These data, including those collected for the BOEM-funded CHAOZ and Chukchi Acoustics

Oceanography and Zooplankton Study Extension (CHAOZ-X) studies, represent the only long-term integrated dataset of its kind for the Chukchi Sea and U.S. Arctic in general. 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. Addition of a benthic ecology component would help to address prey availability for those mammals that feed on benthic epifauna and infauna.

Because this area is predicted to undergo rapid change, it is important to know what is happening to currents and ice cover (and the distribution of marine mammals) during the crucial spring and fall months. Unfortunately, because of the ice cover, these seasons are currently inaccessible with present technologies, excepting moored long-term instrumentation. To help increase our understanding and knowledge of oceanographic conditions and how they impact the Arctic food chain, 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/underwater vehicles. 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.

VI. INTRODUCTION

A. Background

The western Arctic physical climate is rapidly changing. The lowest maximum extent for Arctic sea ice recorded to date in the 40-year satellite record was reached on March 7, 2017 (NSDIC, 2019). That maximum extent was 14.41 million square kilometers, which is 1.23 million square kilometers below the 1981 to 2010 average of 15.64 million square kilometers. The magnitude of this loss is substantial, especially considering earlier consensus of the climate research community was that this level of ice reduction would not be seen for another thirty years (Wang and Overland, 2009). As sea temperature, oceanographic currents, and trophodynamics are altered by climate change, parallel changes in baleen whale species composition, abundance, and distribution are expected (and already evidenced by local knowledge and opportunistic sightings). In addition, the observed northward retreat of the minimum extent of summer sea ice has the potential to create opportunities for the expansion of shipping, oil, and natural gas, related exploration and development into previously closed seasons and localities in the U.S. Arctic. The Department of the Interior is currently developing a new National Outer Continental Shelf Oil and Gas Leasing Program that could lead to expanded oil and gas activities in the Arctic. Regardless of industrial operations, the continuous reduction in sea ice will open maritime transportation lanes across the Arctic adding (to a potentially dramatic degree) to the ambient noise in the environment and increasing the possibility of ship strikes and environmental contamination from ship-based contaminants like oil and sewage. This combination of increasing anthropogenic impacts, coupled with the steadily increasing abundance and/or related seasonal range expansion by bowhead (*Balaena mysticetus*), gray (*Eschrichtius robustus*), humpback (*Megaptera novaeangliae*) and fin whales (*Balaenoptera physalus*) (e.g., see Clarke et al., 2013b; Delarue et al., 2013a; Crance et al., 2015; and Tsujii et al., 2016), requires that more complete information on the year-round presence of large whales is needed in the Chukchi Sea.

Marine spatial planning requires knowledge of the timing and location of marine mammal distribution, migrations, and movements to mitigate the impacts on protected species of oil exploration, extraction, and of shipping. Moreover, several species form an important part of the diet and cultural and spiritual traditions of most people in communities along the Russian and U.S. coasts of the Chukchi Sea and the Russian, U.S., and Canadian coasts of the Beaufort Sea. Detailed knowledge of marine mammal distribution, migration, and movement patterns is essential for effective population monitoring. Because all marine mammal species are subject to changes in environmental and biological variables such as oceanographic currents, sea temperature, sea ice cover, prey availability, and anthropogenic impacts, more complete information on the year-round presence of these species in the Chukchi Sea, how presence relates to these variables, and the transport of nutrient and prey through the Chukchi Sea is needed.

The ARCWEST study has five component projects which comprise two main themes: marine mammal occurrence, distribution, and movements (passive acoustics, visual observation, and satellite tagging) and biophysical patterns and trends (moored and shipboard oceanographic sampling and lower trophic level sampling). Visual surveys, along with sonobuoy deployments, provided distributional data on baleen whales and other marine mammals. Satellite tagging provided valuable information on both large- and fine-scale movements and habitat use of gray whales. Passive acoustic moorings provided year-round assessments of the seasonal occurrence of marine mammals, as well as anthropogenic (i.e., airguns, vessels) and environmental (i.e., ice) noise. Concurrently deployed bio-physical moorings enabled correlation of marine mammal distribution with biological and physical oceanographic conditions and indices of potential prey density. Satellite-tracked ocean current drifters examined potential pathways to the areas of high biological importance. As part of the BOEM-funded CHAOZ-X project, an analysis of ambient noise from each of the mooring locations was conducted to obtain a characterization of the regional soundscape including natural noise (e.g., rain, wind, waves, ice) contribution, marine mammal contribution, and anthropogenic noise (Mocklin and Friday, 2018). Our goal was to use these tools to understand the areas that support high biological productivity and the mechanisms responsible for the production so that we can predict, in a qualitative way, the effects of climate change on these preferred habitats.

B. Objectives of study

The overall goal of this multi-year interdisciplinary study was to use passive acoustic recorder deployments, visual and passive acoustic surveys, and satellite tagging to examine the distribution and movements of marine mammals in the Bering and Chukchi Seas. In addition, oceanographic and lower trophic level sampling and moorings were used to investigate the relationships between currents passing through the Bering Strait and resources delivered to the Barrow Arch area (an area of high bowhead whale and prey concentrations between Wainwright and Smith Bay), and the dynamic nature of those relationships relative to marine mammal distribution and habitat utilization in the eastern Chukchi and extreme western Beaufort Seas.

The specific objectives were:

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

2. Assess population structure and stocks of origin of these animals via genetic analysis of tissue biopsy samples[4] and as appropriate, individual photo identification records.

3. Evaluate ecological relationships for the species, including physical and biological oceanography.

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

C. Summary of research effort

The ARCWEST project shared ship time with the BOEM-funded CHAOZ-X project and, when possible, used National Oceanic and Atmospheric Administration (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

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[4] No biopsy samples were obtained during this research so it is not discussed in the report.

and collecting as much data as possible within a time frame that minimized potential conflicts with subsistence hunting. As a result, the cruise track and research operations frequently alternated between projects as well as the subcomponents of each project (visual observation, sonobuoy, tagging, mooring deployment and recovery, hydrography, and plankton sampling). In addition, the IC2/C2 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 IC3/C3 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[5] field seasons during the months of August, September and October. The 2013 survey occurred from 13 August through 18 September on board the F/V *Aquila.* The 2014 survey occurred from 7 September through 20 October on the F/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 F/V *Aquila.* The 2016 survey occurred from 3 to 29 September on board the F/V *Aquila*. For both projects, a total of 124[6] passive acoustic (118 year-long and 6 short-term) and 43 oceanographic moorings were successfully deployed (in addition, 8 moorings were re-deployed in 2015 at C1, C2, C4 and C9), a combined total of 287 hydrographic and 155 zooplankton sampling stations were conducted, resulting in 470 preserved samples, and 24 drifters were deployed. A total of 717 sonobuoys were deployed during the 24-hour passive acoustic monitoring, and 4,593 nm were surveyed for marine mammal and bird[7] observations. A total of 38 scientists from 16 organizations/institutions participated in the cruises.

Specifically within the main ARCWEST study area (the area encompassed by the yellow line in Figure 2, stretching from Bering Strait up to offshore Smith Bay in the Beaufort Sea), a total of 64[8] passive acoustic (58 year-long and 6 short-term) and 30 oceanographic moorings were deployed (in addition, 7 moorings were re-deployed in 2015), a total of 128 hydrographic and ~100 zooplankton sampling stations were conducted, and 21 drifters were deployed. A total of 358 sonobuoys were deployed during the 24-hour passive acoustic monitoring, and 2,553 nm were surveyed for marine mammal and bird observations.

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-VIII deal with marine mammal distribution and biophysical patterns and trends. Section IX presents the ARCWEST noise analysis. Section X synthesizes the research by

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[5] In 2016, funds from NOAA/OAR (with supplemental funds from the ARCWEST project) were available to conduct a fourth field season.

[6] This includes the moorings deployed in 2012 on the CHAOZ cruise, but paid for and analyzed with ARCWEST or CHAOZ-X funding (see Mocklin and Friday (2018) for more information). It also includes 5 moorings that failed, and additional moorings that were deployed by ARCWEST in the Bering Sea but analyzed with other funds (see Wright 2017a,b).

[7] 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.

[8] 10 of these passive acoustic moorings (2 Auto-detection buoys and 8 autonomous recorder moorings) were deployed by the CHAOZ-X project for the noise modeling and auto-detection buoy components of that project. At the time of deployment it was decided with input from BOEM that the most critical spot for this work was between the Burger and Klondike lease areas. Therefore, although these 10 recorders were located within the main ARCWEST study area they will not be included in this report.

focusing on 4 main topics: hotspots, polynyas, long-range predictions, and correlating marine mammal distribution to biophysical parameters using GAMs. The report culminates with Section XI which contains a summary of this study and recommendations for the future.

NOTE: Although the ARCWEST and CHAOZ-X studies (Mocklin and Friday, 2018) were separate research projects encompassing different study areas (waters feeding Barrow Canyon vs. Hanna Shoal), data from each add value to the other. To include these data without unnecessary duplication, the following guidelines are followed. Each report includes 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 is 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 are 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, focuses 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: KZ1, C12/PH1, CL1, C1/IC1, C2/IC2, C3/IC3, C4/WT1, C5/PB1, BF2)

1. Methods

Equipment

Three deployments of eleven long-term passive acoustic recorder moorings were made within the ARCWEST study area over the course of this project (Figure 2, Table 1). Five of the moorings (KZ1, CL1, BF1-3) were passive-acoustics only, but six of these moorings (PH1, IC1-3, WT1, and PB1) were located in close proximity to oceanographic moorings, and one (IC2) was deployed near an active zooplankton mooring. 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 2b, 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 can be detected on a recorder, 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.

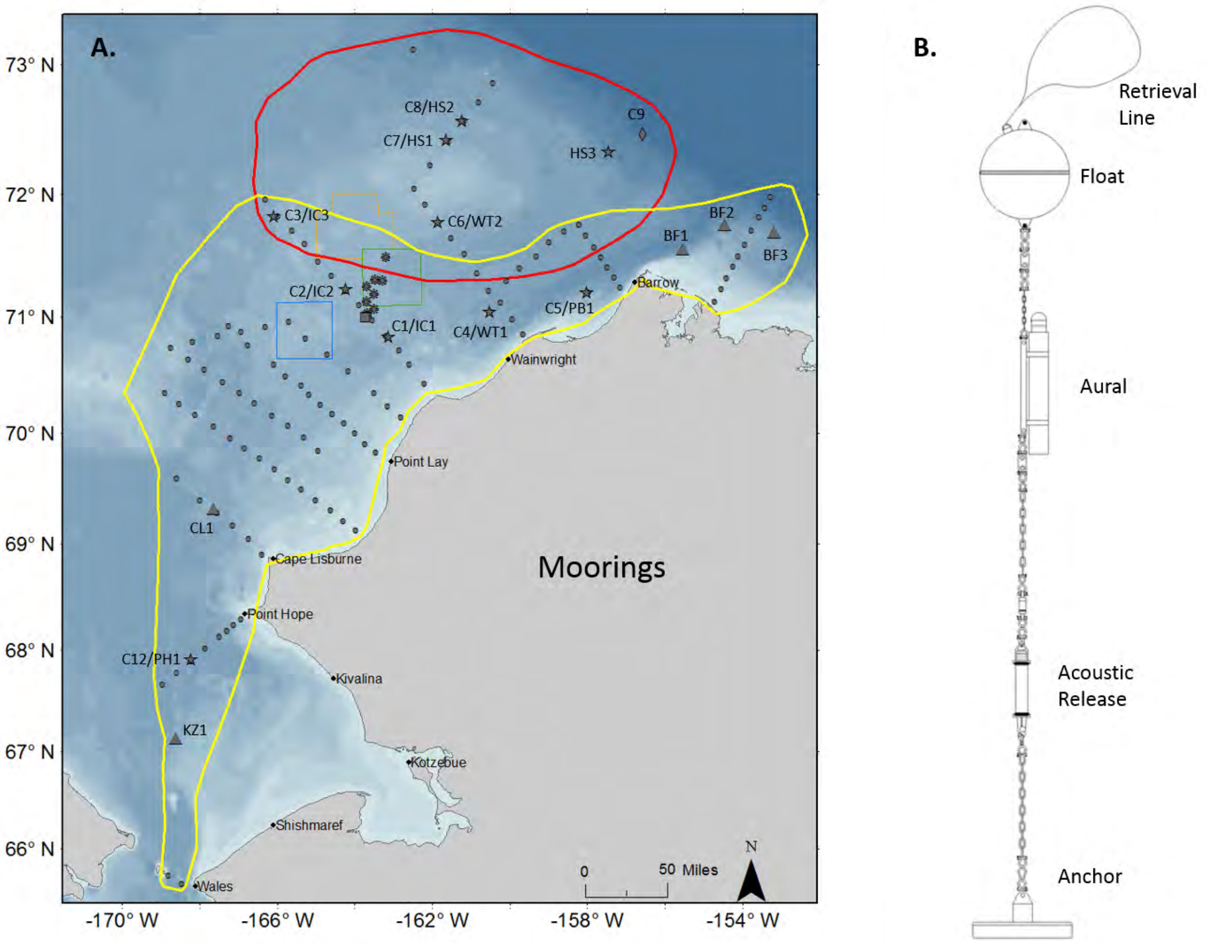

Figure 2. Location of long-term passive acoustic recorder moorings in the Chukchi Sea. A) Yellow = ARCWEST study area, Red = CHAOZ-X study area, blue box = KLONDIKE study area, orange box = STATOIL STUDY AREA, green box = BURGER STUDY AREA, triangles = passive acoustics mooring only, stars = passive acoustics and oceanographic mooring clusters. B) Passive acoustic recorder mooring diagram.

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

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
AW12_AU_BF2*	MC3	71.75147	154.47125	93	8/31/2012	8/31/2013	365	16384	85/300	8/27/2012	8/31/2013
AW12_AU_BF3	MC4	71.68858	153.17638	103	8/31/2012	8/31/2013	365	16384	85/300	8/27/2012	8/31/2013
AW12_AU_BF1	MC2	71.55130	155.54910	69	No	Data	-	16384	85/300	8/27/2012	8/31/2013
CX12_AU_IC2*	C2	71.20198	164.19890	43	8/27/2012	7/31/2013	338	16384	85/300	8/21/2012	8/27/2013
AW12_AU_WT1*	C4	71.04587	160.50890	49	8/30/2012	8/27/2013	362	16384	85/300	8/25/2012	8/27/2013
AW12_AU_IC1*	C1	70.81717	163.13643	43	8/25/2012	8/27/2013	367	16384	85/300	8/21/2012	8/27/2013
AW12_AU_CL1*	-	69.30680	167.64795	48	8/23/2012	8/25/2013	367	16384	85/300	8/19/2012	8/25/2013
AW12_AU_PH1*	C12	67.90895	168.19462	58	8/22/2012	8/22/2013	365	16384	85/300	8/18/2012	8/22/2013
AW12_AU_KZ1*	-	67.12480	168.60183	43	8/21/2012	8/22/2013	366	16384	85/300	8/17/2012	8/22/2013
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
AW13_AU_BF2*	MC3	71.75227	154.46588	100	9/3/2013	9/29/2014	391	16384	80/300	8/31/2013	9/29/2014
AW13_AU_BF3	MC4	71.68722	153.18062	101	9/3/2013	9/30/2014	392	16384	80/300	8/31/2013	9/30/2014
AW13_AU_BF1	MC2	71.55298	155.53217	74	9/3/2013	9/16/2014	378	16384	80/300	8/31/2013	9/29/2014
AW13_AU_PB1*	C5	71.20530	158.01907	49	9/2/2013	9/29/2014	392	16384	80/300	8/31/2013	9/29/2014
CX13_AU_IC2*	C2	71.20482	164.21065	45	8/28/2013	9/26/2014	394	16384	80/300	8/27/2013	9/26/2014
AW13_AU_WT1*	C4	71.04640	160.51130	42	8/29/2013	10/10/2014	407	16384	80/300	8/27/2013	10/10/2014
AW13_AU_IC1*	C1	70.82258	163.13848	45	8/28/2013	9/25/2014	393	16384	80/300	8/27/2013	9/25/2014
AW13_AU_CL1*	-	69.31592	167.63248	48	8/26/2013	9/24/2014	394	16384	80/300	8/25/2013	9/25/2014
AW13_AU_PH1*	C12	67.90745	168.20265	55	8/24/2013	9/29/2014	401	16384	80/300	8/22/2013	9/15/2014
AW13_AU_KZ1*	-	67.12323	168.60477	42	8/24/2013	9/24/2014	396	16384	80/300	8/22/2013	9/24/2014
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
AW14_AU_BF2*	MC3	71.75083	154.46520	109	10/1/2014	9/14/2015	348	16384	80/300	9/29/2014	9/14/2015
AW14_AU_BF3	MC4	71.68828	153.17793	123	10/1/2014	9/14/2015	348	16384	80/300	9/30/2014	9/14/2015
AW14_AU_BF1	MC2	71.55313	155.53155	82	10/1/2014	9/14/2015	348	16384	80/300	9/29/2014	9/14/2015
CX14_AU_IC2*	C2	71.21453	164.23825	50	9/27/2014	9/13/2015	351	16384	80/300	9/26/2014	9/13/2015
AW14_AU_PB1*	C5	71.20668	158.01407	52	10/1/2014	9/14/2015	348	16384	80/300	9/29/2014	9/14/2015
AW14_AU_WT1*	C4	71.03725	160.50607	50	10/11/2014	9/13/2015	337	16384	80/300	10/10/2014	9/13/2015
AW14_AU_IC1*	C1	70.82272	163.13928	50	9/26/2014	9/18/2015	357	16384	80/300	9/25/2014	9/18/2015
AW14_AU_CL1*	-	69.31735	167.62985	59	9/26/2014	9/19/2015	358	16384	80/300	9/24/2014	9/19/2015
AW14_AU_PH1*	C12	67.90793	168.20217	68	9/17/2014	9/20/2015	368	16384	80/300	9/15/2014	9/20/2015
AW14_AU_KZ1*	-	67.12355	168.60443	51	9/25/2014	9/21/2015	361	16384	80/300	9/24/2014	9/21/2015
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
AW15_AU_BF2	MC3	71.74977	154.46235	79	9/16/2015	9/8/2016	358	16384	80/300	9/14/2015	9/8/2016
AW15_AU_BF3	MC4	71.68642	153.17773	102	9/16/2015	9/8/2016	358	16384	80/300	9/14/2015	9/8/2016
AW15_AU_BF1	MC2	71.55230	155.53305	69	No	Data	-	16384	80/300	9/14/2015	9/8/2016
CX15_AU_IC2	C2	71.22937	164.22622	41	9/14/2015	9/14/2016	366	16384	80/300	9/13/2015	9/14/2016
AW15_AU_PB1	C5	71.20628	158.01543	46	9/15/2015	9/7/2016	358	16384	80/300	9/14/2015	9/7/2016
AW15_AU_WT1	C4	71.04697	160.50258	49	9/14/2015	9/7/2016	359	16384	80/300	9/13/2015	9/7/2016
AW15_AU_IC1	C1	70.83553	163.10920	42	9/19/2015	9/15/2016	362	16384	80/300	9/18/2015	9/15/2016
AW15_AU_CL1	-	69.31737	167.62287	49	MIA	MIA	-	16384	80/300	9/19/2015	-
AW15_AU_PH1	C12	67.91035	168.19830	57	9/22/2015	2/10/2016	141	16384	80/300	9/20/2015	9/21/2016
AW15_AU_KZ1	-	67.12360	168.60437	42	9/22/2015	9/21/2016	365	16384	80/300	9/21/2015	9/21/2016
AL16_AU_IC3	C3	71.82903	166.07923	43	9/15/2016	-	-	16384	80/300	9/14/2016	-
AL16_AU_BF2	MC3	71.75407	154.45635	98	9/9/2016	-	-	16384	80/300	9/8/2016	-
AL16_AU_BF1	MC2	71.54967	155.53850	67	9/9/2016	-	-	16384	80/300	9/8/2016	-
AL16_AU_IC2	C2	71.22930	164.21422	41	9/15/2016	-	-	16384	80/300	9/14/2016	-
AL16_AU_PB1	C5	71.20558	158.00163	46	9/8/2016	-	-	16384	80/300	9/7/2016	-
AL16_AU_WT1	C4	71.04170	161.51555	48	9/8/2016	-	-	16384	80/300	9/7/2016	-
AL16_AU_IC1	C1	70.83477	163.11362	43	9/17/2016	-	-	16384	80/300	9/15/2016	-
AL16_AU_CC2	C11	70.01563	166.85975	47	9/20/2016	-	-	16384	80/300	9/19/2016	-
AL16_AU_CL1	-	69.31898	167.60778	49	9/21/2016	-	-	16384	80/300	9/20/2016	-
AL16_AU_PH1	C12	67.90683	167.19998	57	9/22/2016	-	-	16384	80/300	9/21/2016	-

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 Greenwich Mean Time (GMT)) information (i.e., AU-AWWT01-130908-051000.wav is an AURAL recorder deployed for the ARCWEST project at the inshore Wainwright mooring site (WT1) on 8 September 2013 at 05:10 am GMT). These data were also backed up to external hard drives and sent to the Northeast Fisheries Science Center (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[9] in the low frequency band; bowhead, North Pacific right (NPRW), humpback, gray, and minke whales, walrus, unidentified pinnipeds, as well as vessel noise and seismic airguns in the mid-frequency

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[9] The CL1 and PH1 moorings in 2012-13 and 2013-14 were analyzed for fin whales. We have been working with Cornell to revisit the efficacy of using autodectors for fin whales. The ARCWEST 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.

band; and beluga, killer whale, minke whale (boing call), bearded and ribbon seals, and environmental noise (ice) in the high frequency band.

Substantial overlap of call repertoires among baleen whales in the Arctic and sub-Arctic, 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 a lot of signals cannot be distinguished visually on a spectrogram, they sound different aurally to a human analyst. 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 3 – 5.

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 3; Watkins et al., 1987; Edds 1988).

Bowhead, NPRW, gray, and humpback whales all make similar sounds that can sometimes be easily confused. Bowhead whales were identified by their song, characterized by repetitive, high frequency (up to several kHz), exaggerated, curving calls, and multiple singers (Figure 4a; 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 monitoring (PAM) efforts.

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 4c; 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 4b); (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 4d; Crance et al., 2017). The impulsive gunshot call has also been recorded from bowhead whales in spring and summer months off Barrow, AK, 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 4e; 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 4f; 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 (118-80 Hz; Edds-Walton, 2000) and pulse trains (Risch et al., 2013) in the low frequency band, and truly bizarre boing noises, 2-3 s pulsed calls, in the higher frequencies (0.3 - 4 kHz, Figure 5e; Rankin and Barlow, 2005; Delarue et al., 2013b).

Bearded seals were identified by their characteristic long-duration trills (Figure 5c; 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 5d). Pinnipeds as a whole also produce a set of very non-descript sounds including barks, grunts, growls, and snorts (Figure 4g). 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 5b; 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 5a; 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 5f). Vessel noise was easily recognized by the presence of multiple narrowband tonal sounds which 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 4h). Typically larger vessels created louder, lower frequency sounds than smaller ships (Richardson et al., 1995). Seismic airguns produce loud, impulsive, broadband signals that may look and sound spectrographically similar to gunshots (Figure 4i). However, airgun pulses are produced at very patterned and regular intervals for very long periods of time (Guerra et al., 2011).

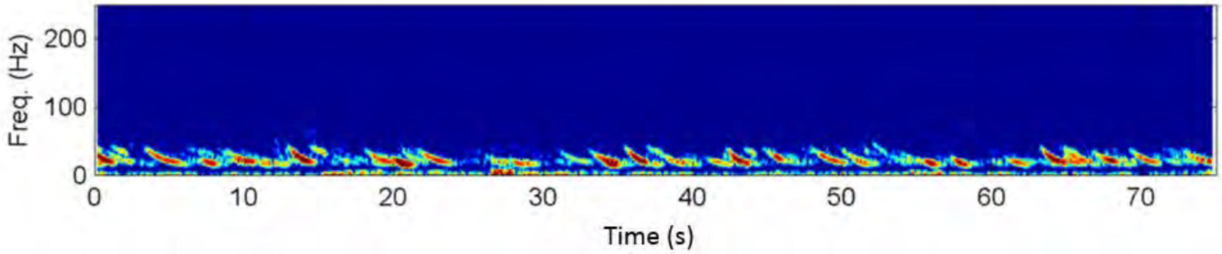

Figure 3. Spectrogram of exemplar calls used to identify fin whales, a low-frequency species.

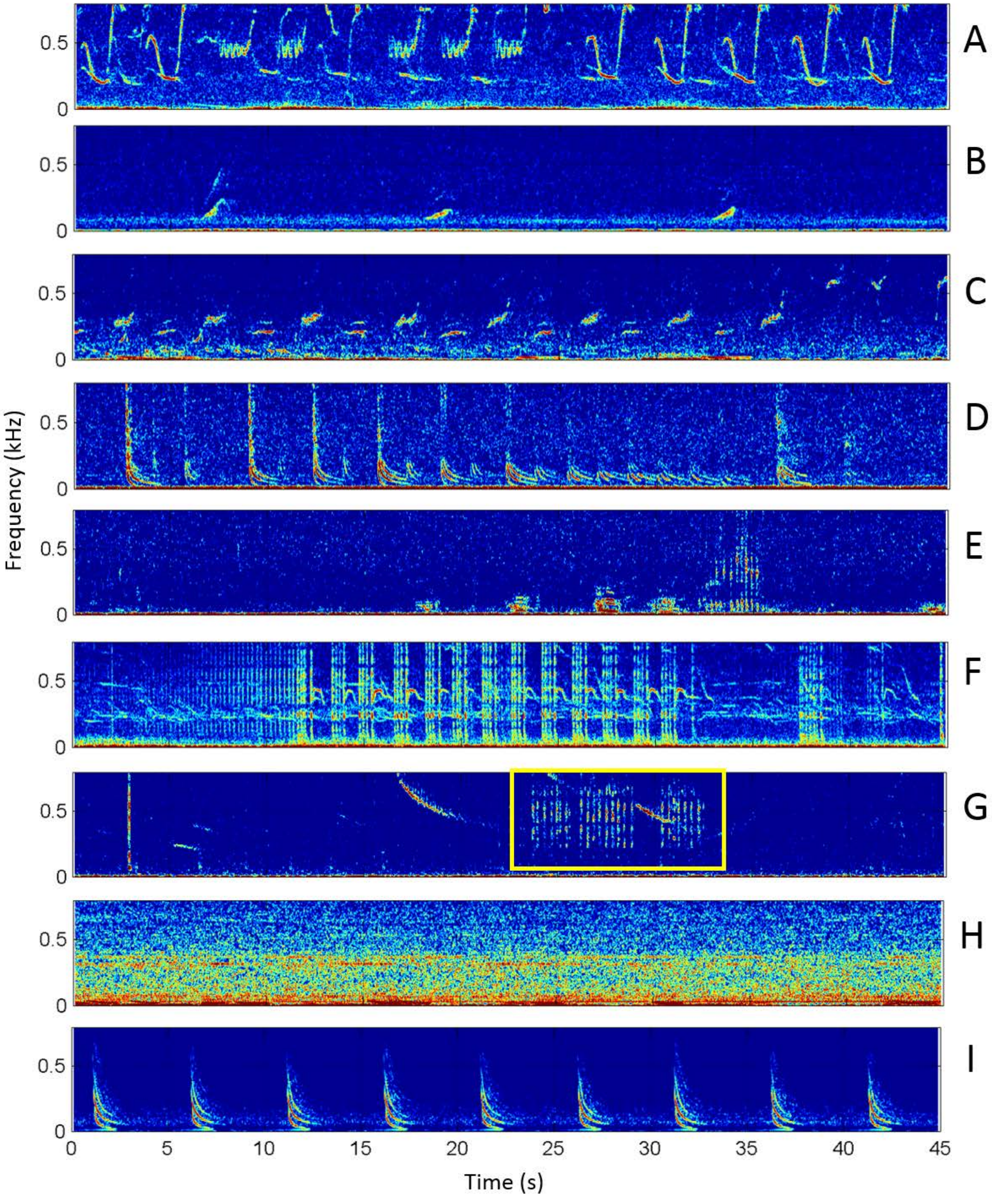

Figure 4. Spectrograms of examples of calls used to identify mid-frequency species. From top to bottom: A) bowhead whale moans, B) NPRW upcalls, C) humpback whale calls, D) gunshot calls, E) gray whale moans and bongo calls, F) walrus knocks and bell calls, G) unidentified pinniped grunts and barks, outlined in yellow box, H) vessel noise, and I) seismic airguns.

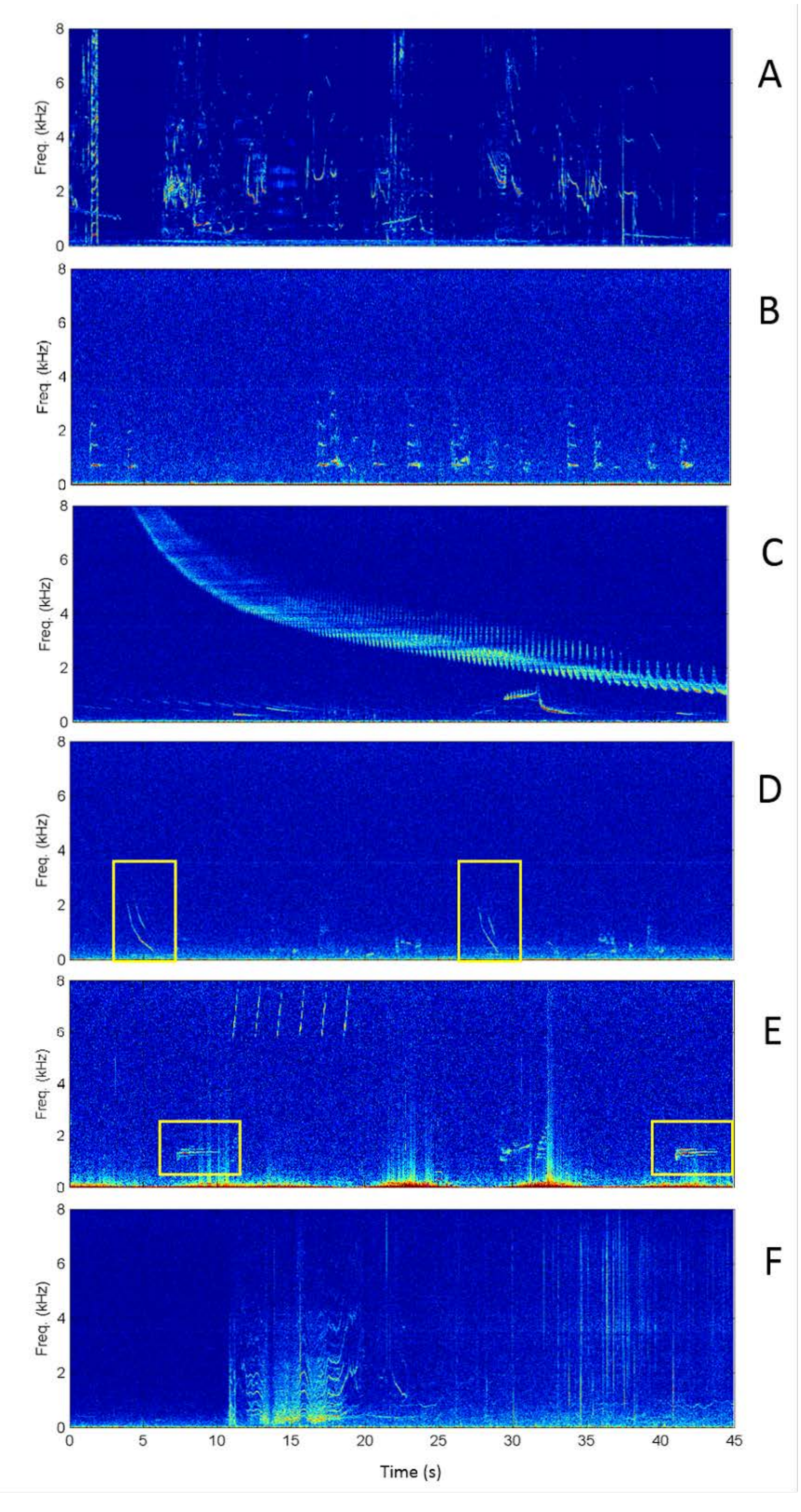

Figure 5. Spectrograms of examples of calls used to identify high-frequency species. From top to bottom: A) beluga whale calls, B) killer whale calls, C) bearded seal trills, D) ribbon seal calls, outlined in yellow boxes, E) minke whale boing, outlined in yellow boxes, and F) ice noise, visible as long duration, variable signals as well as impulsive signals.

Data Quality Control and auto-detection algorithms

Thorough reviews of analyst results were conducted by in-house senior analysts during the training process, and mooring results were occasionally spot-checked by those senior analysts for data quality control purposes. Throughout the ARCWEST study we have attempted to implement an auto-detection software program for fin whale calls. The low-frequency detection and classification system (LFDCS; Mark Baumgartner, Woods Hole Oceanographic Institution) was used to automatically detect fin whale vocalizations. The LFDCS is an Interactive Data Language-based program that uses manually created call libraries to apply discriminant function analysis across seven measurements, called call attributes, taken from each auto-detected call. The analyst selects exemplary calls, in this case fin whale calls, to create a call library. The LFDCS is then run on novel data sets and uses this comprehensive call library for comparison in discriminant function analysis to classify all of its auto-detections. Over two-hundred exemplars were carefully selected for the fin whale call library. The call 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.

Although Cornell attempted to run a fin whale call detector on these data, the results were too poor to replace manual analysis. Existing autodetectors have historically not applied well to our data due to the high self-noise of our recorders. However, an in-house autodetection process (Woodrich, *in prep*) has demonstrated good results in identifying a variety of call types in our data and discriminating calls from mooring self-noise. This detector will be applied to fin pulses to determine fin presence per 3 minute bin of recording effort. Manuscripts are planned for 2020 to incorporate the results from this effort, if successful.

2. *Results*

A total of 12,058 days of acoustic data were included in this report. 10,374 days were analyzed from the nine ARCWEST long-term passive acoustic recorders deployed from 2012 through 2015. An additional 1218 days of CHAOZ data results (i.e., from the 2010 and 2011 IC1-3 mooring deployments) are reproduced here, for consistency as well as ease of accessibility. Furthermore, 466 days of data from the BOWFEST BF2 mooring site (2010-2012) were reanalyzed[10] for all species to provide data from the eastern portion of the ARCWEST study area. 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 analyzed at only the CL1 and PH1 (both 2012-2014) moorings for this report[11].

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

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[10] These were analyzed for only bowhead whales during the BOWFEST project. For more information, see Shelden and Mocklin, 2013.

[11] Only ten mooring-years of ARCWEST data 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 ARCWEST 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.

calls[12] 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 6), they 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 map panel figures (e.g., Figure 7), they 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 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, including humpback, minke, fin, and killer whales, and ribbon seals, were most often detected in the southeastern Chukchi Sea and had varying degrees of calling activity; their results will be presented following those for the Arctic species. Lastly, because the analysis was consistent with that for the marine mammals, the season trends in vessel, seismic airgun, and ice noise will be presented. 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)). In addition, summary tables for the percent of days with calling/noise activity for each mooring site by year and by month can be found in the Appendix (Appendix C. 1. and Appendix C. 2.). Details on methods for obtaining ice data can be found in Section VIII.C.

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

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

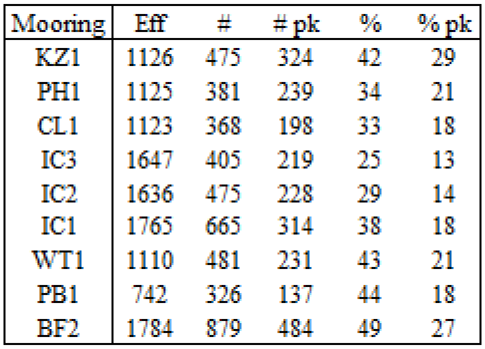
Species	Year	KZ1			PH1			CL1			IC3			IC2			IC1			WT1			PB1			BF2		
		#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%
Bowhead	2010	0	0	-	0	0	-	0	0	-	60	113	**53**	70	113	**62**	64	113	**57**	0	0	-	0	0	-	45	103	**44**
Bowhead	2011	0	0	-	0	0	-	0	0	-	40	284	**14**	75	297	**25**	120	298	**40**	0	0	-	0	0	-	158	363	**44**
Bowhead	2012	64	133	**48**	57	132	**43**	47	131	**36**	82	261	**31**	72	267	**27**	115	363	**32**	75	124	**60**	0	0	-	181	334	**54**
Bowhead	2013	134	364	**37**	117	365	**32**	122	365	**33**	97	364	**27**	128	338	**38**	156	365	**43**	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**	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**	96	256	**38**	103	257	**40**	130	257	**51**
Beluga	2010	0	0	-	0	0	-	0	0	-	8	113	**7**	23	113	**20**	26	113	**23**	0	0	-	0	0	-	35	103	**34**
Beluga	2011	0	0	-	0	0	-	0	0	-	19	284	**7**	32	297	**11**	71	298	**24**	0	0	-	0	0	-	100	363	**28**
Beluga	2012	25	133	**19**	48	132	**36**	20	131	**15**	30	261	**11**	36	267	**13**	71	363	**20**	27	124	**22**	0	0	-	166	334	**50**
Beluga	2013	63	364	**17**	135	365	**37**	42	365	**12**	57	364	**16**	67	338	**20**	86	365	**24**	74	365	**20**	32	121	**26**	174	363	**48**
Beluga	2014	85	365	**23**	118	364	**32**	51	364	**14**	92	365	**25**	68	365	**19**	100	365	**27**	100	364	**27**	93	364	**26**	163	364	**45**
Beluga	2015	60	264	**23**	53	263	**20**	31	254	**12**	21	260	**8**	30	256	**12**	73	261	**28**	56	250	**22**	55	257	**21**	125	257	**49**
Bearded	2010	0	0	-	0	0	-	0	0	-	26	113	**23**	52	113	**46**	64	113	**57**	0	0	-	0	0	-	68	103	**66**
Bearded	2011	0	0	-	0	0	-	0	0	-	224	284	**79**	252	297	**85**	258	298	**87**	0	0	-	0	0	-	225	363	**62**
Bearded	2012	45	133	**34**	74	132	**56**	67	131	**51**	226	261	**87**	226	267	**85**	234	363	**64**	74	124	**60**	0	0	-	287	334	**86**
Bearded	2013	221	364	**61**	265	365	**73**	223	365	**61**	223	364	**61**	261	338	**77**	188	365	**52**	253	365	**69**	96	121	**79**	277	363	**76**
Bearded	2014	227	365	**62**	250	364	**69**	226	364	**62**	203	365	**56**	275	365	**75**	228	365	**62**	258	364	**71**	296	364	**81**	247	364	**68**
Bearded	2015	163	264	**62**	163	263	**62**	151	254	**59**	177	260	**68**	180	256	**70**	176	261	**67**	177	250	**71**	213	257	**83**	215	257	**84**
Walrus	2010	0	0	-	0	0	-	0	0	-	38	113	**34**	20	113	**18**	35	113	**31**	0	0	-	0	0	-	2	103	**2**
Walrus	2011	0	0	-	0	0	-	0	0	-	106	284	**37**	76	297	**26**	110	298	**37**	0	0	-	0	0	-	0	363	**0**
Walrus	2012	18	133	**14**	13	132	**10**	18	131	**14**	76	261	**29**	21	267	**8**	79	363	**22**	1	124	**1**	0	0	-	7	334	**2**
Walrus	2013	109	364	**30**	52	365	**14**	59	365	**16**	81	364	**22**	68	338	**20**	97	365	**27**	50	365	**14**	4	121	**3**	31	363	**9**
Walrus	2014	133	365	**36**	37	364	**10**	55	364	**15**	88	365	**24**	69	365	**19**	85	365	**23**	70	365	**19**	59	364	**16**	7	364	**2**
Walrus	2015	131	264	**50**	21	264	**8**	50	263	**19**	45	260	**17**	32	256	**13**	33	261	**13**	43	256	**17**	29	257	**11**	10	257	**4**
Gray	2010	0	0	-	0	0	-	0	0	-	0	113	**0**	1	113	**1**	6	113	**5**	0	0	-	0	0	-	0	103	**0**
Gray	2011	0	0	-	0	0	-	0	0	-	0	284	**0**	0	297	**0**	5	298	**2**	0	0	-	0	0	-	0	363	**0**
Gray	2012	2	133	**2**	56	132	**42**	5	131	**4**	0	261	**0**	0	267	**0**	13	363	**4**	0	124	**0**	0	0	-	0	334	**0**
Gray	2013	17	364	**5**	127	365	**35**	1	365	**<1**	0	364	**0**	0	338	**0**	1	365	**<1**	0	365	**0**	2	121	**2**	0	363	**0**
Gray	2014	57	365	**16**	128	364	**35**	0	364	**0**	1	365	**<1**	0	365	**0**	0	365	**0**	1	365	**<1**	5	364	**1**	0	364	**0**
Gray	2015	31	264	**12**	57	264	**22**	45	263	**17**	1	260	**<1**	0	256	**0**	0	261	**0**	1	256	**<1**	49	257	**19**	0	257	**0**

Bowhead whales

Bowhead whale calling activity was detected on all ARCWEST study area moorings for all years where data were available (Figure 6, Table 2). Among the mooring sites, the recorder with the highest proportion of bowhead calling activity was the one closest to Barrow Canyon (BF2) followed by the two nearest to BF2 along the shore from Wainwright to Barrow (WT1 and PB1), while the lowest were the two offshore Icy Cape (IC2 and IC3; Table 3). Peak calling for all sites occurred on approximately half the days with calling activity present; the southern Chukchi sites, PH1 and KZ1, saw a higher level of 60-70% peak vs. regular calling activity (Table 3).

The months where calls were detected varied among the sites (Figures 7-12; Table 4), with calling detected from approximately April/June through December for those moorings east of Cape Lisburne (i.e., northeastern sites: IC1-3, WT1, PB1, BF2) and from approximately October through May for those moorings from Cape Lisburne and south (i.e., southern Chukchi sites: KZ1, PH1, CL1). The highest monthly averages were more consistent among mooring sites, with maximum monthly averages in April/May and October/December.

Table 3. Total bowhead whale calling activity, 2010-2015, for all ARCWEST 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
KZ1	1126	475	324	42	29
PH1	1125	381	239	34	21
CL1	1123	368	198	33	18
IC3	1647	405	219	25	13
IC2	1636	475	228	29	14
IC1	1765	665	314	38	18
WT1	1110	481	231	43	21
PB1	742	326	137	44	18
BF2	1784	879	484	49	27

Both the bowhead spring and fall migrations were seen as pulses in calling activity in every year and on every mooring where data are available (Figure 6, Table 5). The spring migration started roughly March-April at the southern Chukchi sites and April-May at the northeastern sites; end dates were also staggered with a May-June end in the southern Chukchi and June-July end in the northeast. Detection of the bowhead spring migration was greatest at the inshore and least at the offshore locations (Figure 6; Table 4, 5). Dates for the fall pulse in calling activity were generally earlier in the northeastern sites compared to the southern Chukchi sites, but this varied among moorings and years (Table 5). The spring and fall pulses in calling activity were temporally close during the open water season for the northeastern moorings, and during the ice period for the southern Chukchi moorings. In fact, it is very difficult to determine when the spring pulse ends and the fall pulse starts for the northeastern moorings (or vice versa for the southern ones). The date ranges for those pulses listed in Table 5, therefore, should be considered rough estimates.

The trend in spring versus fall calling activity varied among mooring sites. At the southern Chukchi and offshore northeastern sites, saturated calling levels (100% calling activity) were sustained longer in the fall than in the spring; at the northeastern sites saturated calling was sustained slightly longer in the spring than in the fall, although this varied among years (Figure 6). In some years and location, the fall and spring pulses of calling were actually multimodal (Figure 6). The clearest example of this can be found in the fall 2010 pulse at the three Icy Cape sites (IC1-3), as well as the fall 2014 pulse for most sites. (Figure 6).

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

Month	KZ1			PH1			CL1			IC3			IC2			IC1			WT1			PB1			BF2		
	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%
Jan	68	93	**73**	46	93	**49**	30	93	**32**	0	155	**0**	4	155	**3**	7	155	**5**	4	93	**4**	0	62	**0**	1	155	**1**
Feb	34	84	**40**	12	84	**14**	1	84	**1**	0	141	**0**	0	141	**0**	0	141	**0**	1	84	**1**	1	56	**2**	0	141	**0**
Mar	40	93	**43**	20	93	**22**	5	93	**5**	0	155	**0**	2	155	**1**	5	155	**3**	0	93	**0**	10	62	**16**	2	155	**1**
Apr	86	90	**96**	78	90	**87**	59	90	**66**	0	150	**0**	7	150	**5**	70	150	**47**	67	90	**74**	49	60	**82**	96	150	**64**
May	63	93	**68**	71	93	**76**	91	93	**98**	2	138	**1**	34	143	**24**	138	155	**89**	90	93	**97**	58	62	**94**	152	155	**98**
Jun	7	90	**8**	5	90	**6**	22	90	**24**	2	98	**2**	31	111	**28**	70	147	**48**	47	90	**52**	37	60	**62**	135	150	**90**
Jul	0	93	**0**	1	93	**1**	3	93	**3**	19	93	**20**	21	93	**23**	53	124	**43**	37	93	**40**	38	62	**61**	114	153	**75**
Aug	0	103	**0**	0	103	**0**	0	102	**0**	35	99	**35**	7	74	**9**	9	121	**7**	11	95	**12**	17	62	**27**	65	123	**53**
Sep	0	111	**0**	9	110	**8**	0	109	**0**	54	158	**34**	48	154	**31**	31	157	**20**	66	103	**64**	40	72	**56**	107	142	**75**
Oct	6	93	**6**	15	93	**16**	17	93	**18**	120	155	**77**	137	155	**88**	108	155	**70**	67	93	**72**	44	62	**71**	133	155	**86**
Nov	79	90	**88**	47	90	**52**	76	90	**84**	125	150	**83**	132	150	**88**	125	150	**83**	70	90	**78**	22	60	**37**	71	150	**47**
Dec	92	93	**99**	77	93	**83**	64	93	**69**	48	155	**31**	52	155	**34**	49	155	**32**	21	93	**23**	10	62	**16**	3	155	**2**

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. The degree to which gunshot call activity (Figure 13, green) coincided with general bowhead calling activity varied among mooring locations. There was a strong correlation seen at the more central mooring sites (CL1, IC1-3, WT1) during the fall migratory pulse, more than half of the spring pulses of bowhead calling activity also have gunshot calls detected. In contrast, very low levels of gunshot calling activity were present at the BF2 and KZ1 mooring site. Although the PH1 mooring site showed some correlation between fall calling pulses and gunshot calling activity, there were also many days during the open water season, and without any other bowhead calls present, where there were many days with gunshots detected.

The peaks in gunshot call activity occurred near the end of each pulse in bowhead calling activity during the start of the ice period. This was not as noticeable during the spring thaw period, perhaps because the pulse of bowhead calling was not as pronounced (Figure 9).

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 6.

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
	IC2	14-Sep	15-Dec	7-Oct	12-Dec	-	-	14-Sep	15-Dec	4-Jun	31-Oct
	IC1	14-Sep	12-Dec	27-Sep	12-Dec	-	-	26-Sep	12-Dec	2-Jun	23-Oct
	BF2	20-Sep	22-Nov	20-Sep	16-Oct	-	-	20-Sep	12-Nov	26-Jul	18-Oct
2011	IC3	20-Sep	3-Dec	10-Oct	30-Nov	-	-	29-Sep	3-Dec	5-Jul	22-Nov
	IC2	29-Mar	1-Dec	9-Oct	30-Nov	9-Jun	18-Jun	24-Sep	1-Dec	9-Jun	14-Nov
	IC1	4-Mar	1-Dec	15-Apr	27-Nov	25-Mar	27-Jun	30-Sep	1-Dec	4-Jun	12-Nov
	BF2	28-Mar	29-Nov	28-Mar	11-Nov	28-Mar	24-Jun	18-Aug	13-Nov	14-Jul	15-Oct
2012	KZ1	28-Oct	31-Dec	1-Nov	31-Dec	-	-	28-Oct	17-Jan	9-Jun	16-Nov
	PH1	1-Sep	28-Dec	15-Oct	27-Dec	-	-	14-Oct	2-Jan	17-Jun	16-Nov
	CL1	16-Oct	3-Dec	19-Oct	30-Nov	-	-	16-Oct	3-Dec	27-Jun	14-Nov
	IC3	28-Aug	29-Nov	21-Sep	25-Nov	-	-	28-Aug	29-Nov	27-Jul	3-Nov
	IC2	23-Apr	4-Dec	19-Sep	25-Nov	23-Apr	19-May	16-Sep	4-Dec	24-Jul	1-Nov
	IC1	11-Apr	5-Dec	16-Apr	29-Nov	11-Apr	3-Jun	15-Oct	5-Dec	24-Jul	1-Nov
	WT1	3-Sep	11-Dec	10-Sep	25-Nov	-	-	30-Oct	4-Dec	9-Aug	1-Nov
	BF2	21-Jan	11-Dec	22-Apr	21-Nov	16-Apr	26-Jul	31-Aug	26-Nov	6-Aug	3-Nov
2013	KZ1	1-Jan	31-Dec	1-Jan	31-Dec	18-Mar	27-May	30-Oct	11-Feb	8-Jun	26-Nov
	PH1	1-Jan	31-Dec	3-Apr	31-Dec	30-Mar	5-Jun	31-Oct	10-Feb	11-Jun	25-Nov
	CL1	3-Apr	31-Dec	10-Apr	31-Dec	3-Apr	16-Jun	31-Oct	12-Jan	21-Jun	24-Nov
	IC3	9-Jul	23-Dec	28-Aug	23-Dec	-	-	14-Aug	23-Dec	21-Jul	26-Oct
	IC2	16-May	23-Dec	23-Sep	21-Dec	16-May	17-Jul	19-Sep	23-Dec	25-Jul	26-Oct
	IC1	13-Apr	23-Dec	14-Apr	21-Dec	13-Apr	16-Jun	21-Sep	23-Dec	27-Jul	30-Oct
	WT1	19-Jan	15-Dec	12-Apr	14-Dec	12-Apr	26-Jun	5-Sep	15-Dec	31-Jul	30-Oct
	PB1	4-Sep	27-Dec	5-Sep	13-Dec	-	-	4-Sep	14-Dec	1-Aug	31-Oct
	BF2	11-Apr	22-Nov	18-Apr	20-Nov	11-Apr	15-Jul	11-Aug	22-Nov	1-Aug	24-Oct
2014	KZ1	1-Jan	31-Dec	1-Jan	31-Dec	4-Apr	13-Jun	6-Nov	11-Feb	30-May	11-Dec
	PH1	1-Jan	31-Dec	1-Jan	31-Dec	27-Mar	29-May	29-Nov	25-Jan	30-May	7-Dec
	CL1	1-Jan	31-Dec	1-Jan	31-Dec	7-Apr	7-Jun	30-Oct	23-Jan	7-Jun	29-Nov
	IC3	19-May	11-Dec	30-Jul	10-Dec	-	-	22-Sep	11-Dec	30-Jul	3-Nov
	IC2	29-Mar	12-Dec	10-May	9-Dec	9-May	13-Jun	20-Sep	12-Dec	17-Jul	2-Nov
	IC1	2-Apr	8-Dec	29-Apr	7-Dec	28-Apr	10-Jun	18-Sep	8-Dec	21-Jul	3-Nov
	WT1	5-Apr	7-Dec	5-Apr	18-Oct	5-Apr	15-Jun	16-Sep	5-Nov	24-Jul	31-Oct
	PB1	5-Feb	1-Dec	12-Apr	15-Oct	9-Apr	15-Jun	14-Sep	18-Oct	3-Aug	24-Oct
	BF2	6-Apr	26-Oct	14-Apr	13-Oct	6-Apr	20-Jul	26-Sep	26-Oct	30-Jul	20-Oct
2015	KZ1	1-Jan	24-May	1-Jan	7-May	20-Mar	12-May	-	-	24-May	27-Nov
	PH1	1-Jan	21-May	1-Jan	10-May	24-Mar	21-May	-	-	1-Jun	28-Nov
	CL1	1-Jan	3-Jul	1-Jan	27-May	27-Mar	30-May	-	-	13-Jun	20-Nov
	IC3	29-May	16-Sep	4-Jul	11-Sep	3-Jul	22-Jul	5-Aug	16-Sep	30-Jun	12-Nov
	IC2	2-Jan	7-Sep	2-Jan	5-Jul	20-May	12-Jul	-	-	15-Jun	18-Nov
	IC1	1-Jan	13-Jul	2-Jan	5-Jul	1-Apr	13-Jul	-	-	15-Jun	2-Nov
	WT1	2-Jan	13-Sep	3-Jan	21-Jul	1-Apr	13-Jun	-	-	30-Jun	5-Oct
	PB1	9-Mar	13-Sep	2-Apr	11-Jul	2-Apr	19-Jun	-	-	7-Jul	30-Oct
	BF2	2-Apr	8-Sep	11-Apr	30-Jul	2-Apr	2-Aug	-	-	5-Aug	20-Oct

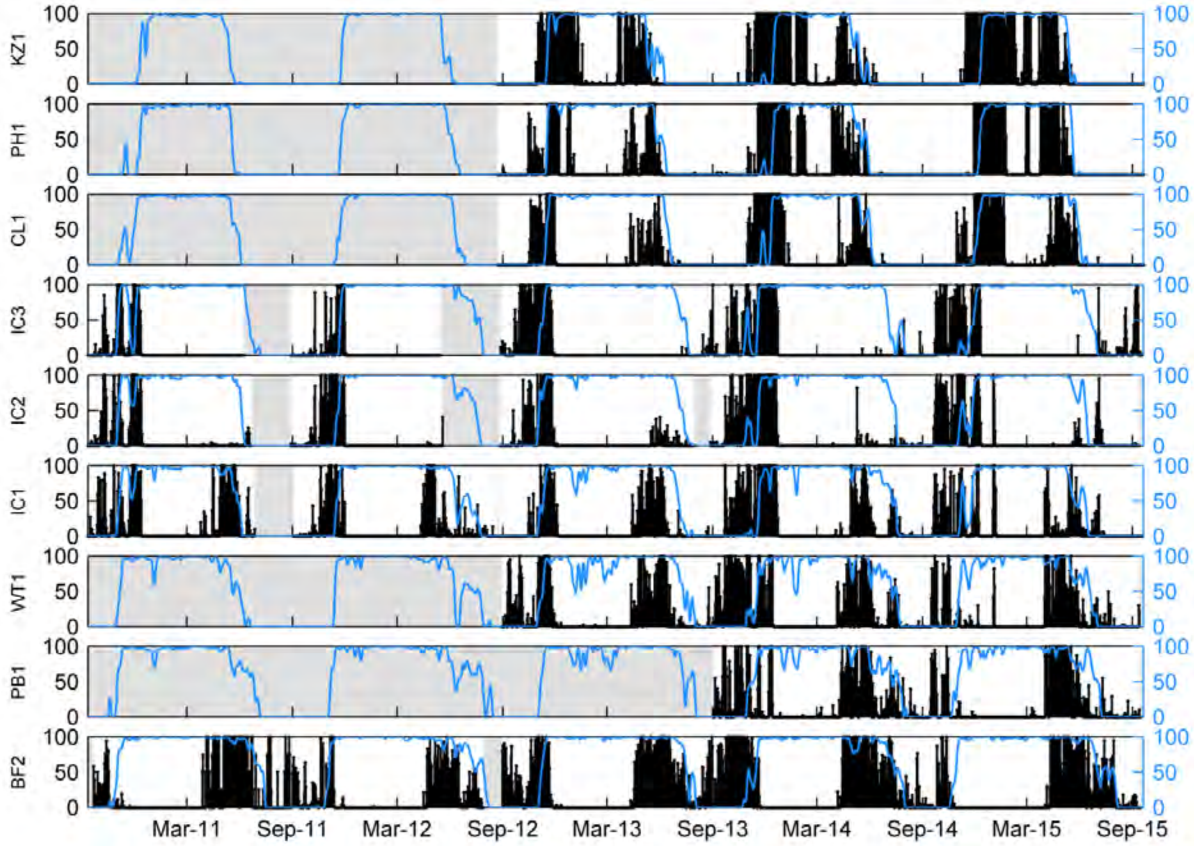


Figure 6. Bowhead whale calling activity (presented as the percentage of ten-minute time intervals with calls) for the nine ARCWEST locations (Figure 2A), 2010-2015. Blue line indicates percent ice cover (zero-phase, three-day moving average). Gray shading indicates no data.

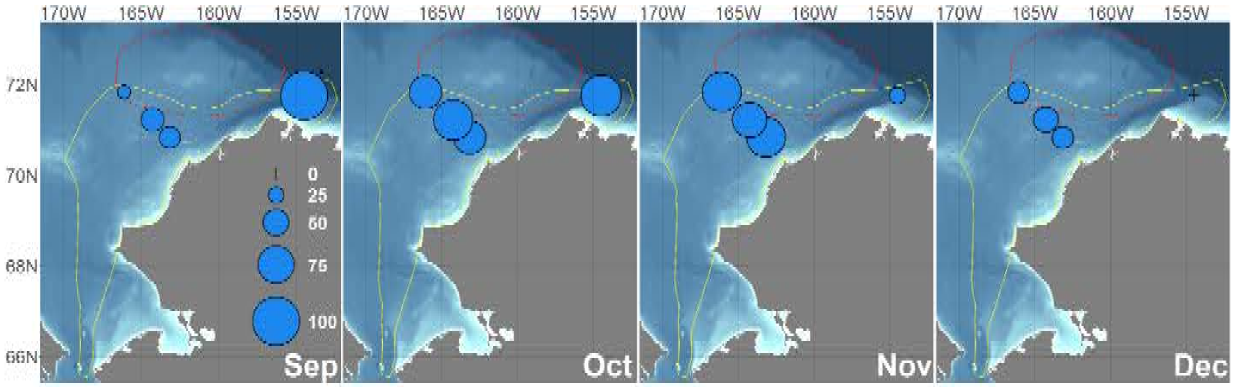


Figure 7. Monthly bowhead whale calling distribution, 2010. Graduated scale in the September panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 3. for numbers used to generate figure.

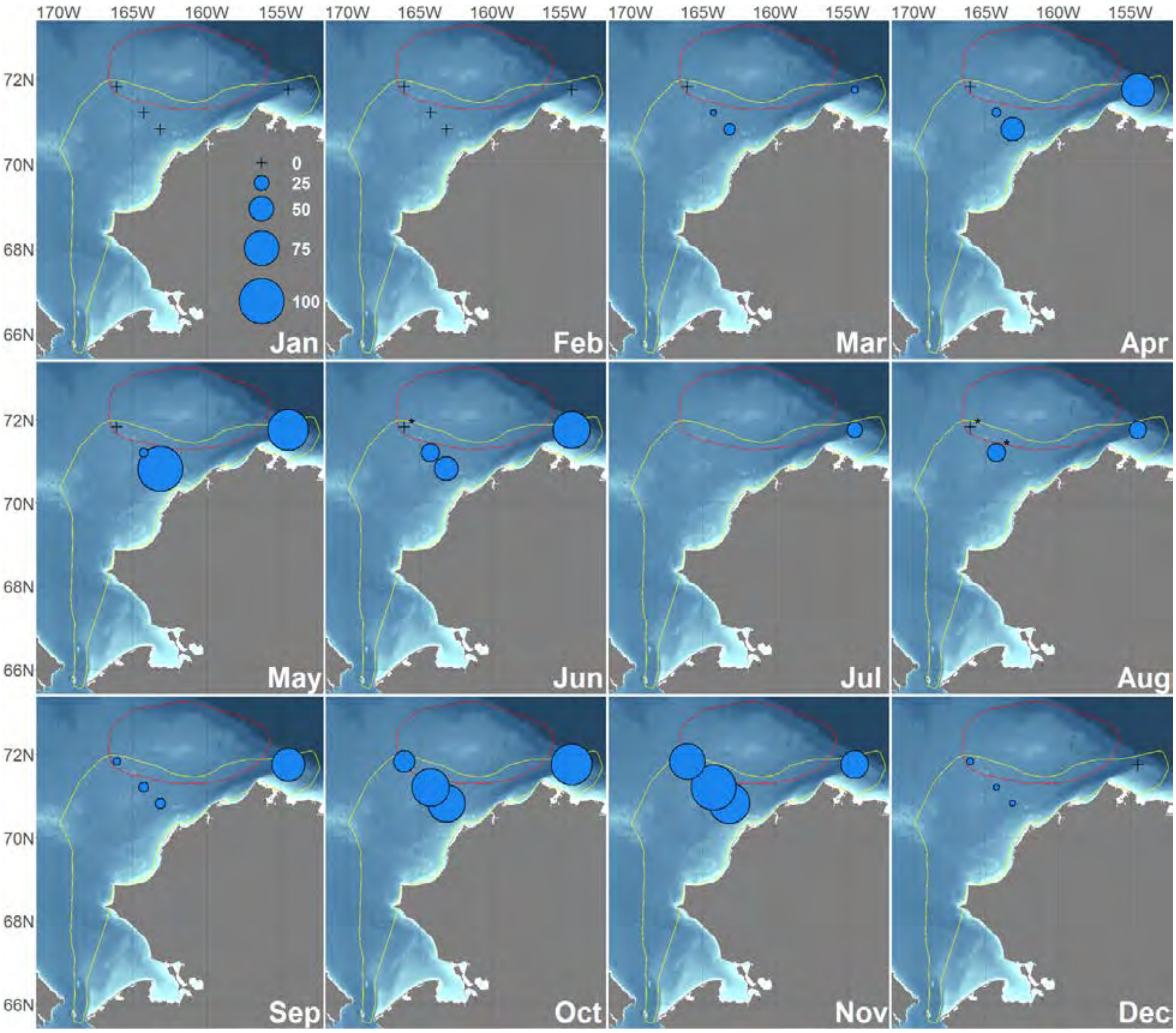


Figure 8. Monthly bowhead whale calling distribution, 2011. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 3. for numbers used to generate figure.

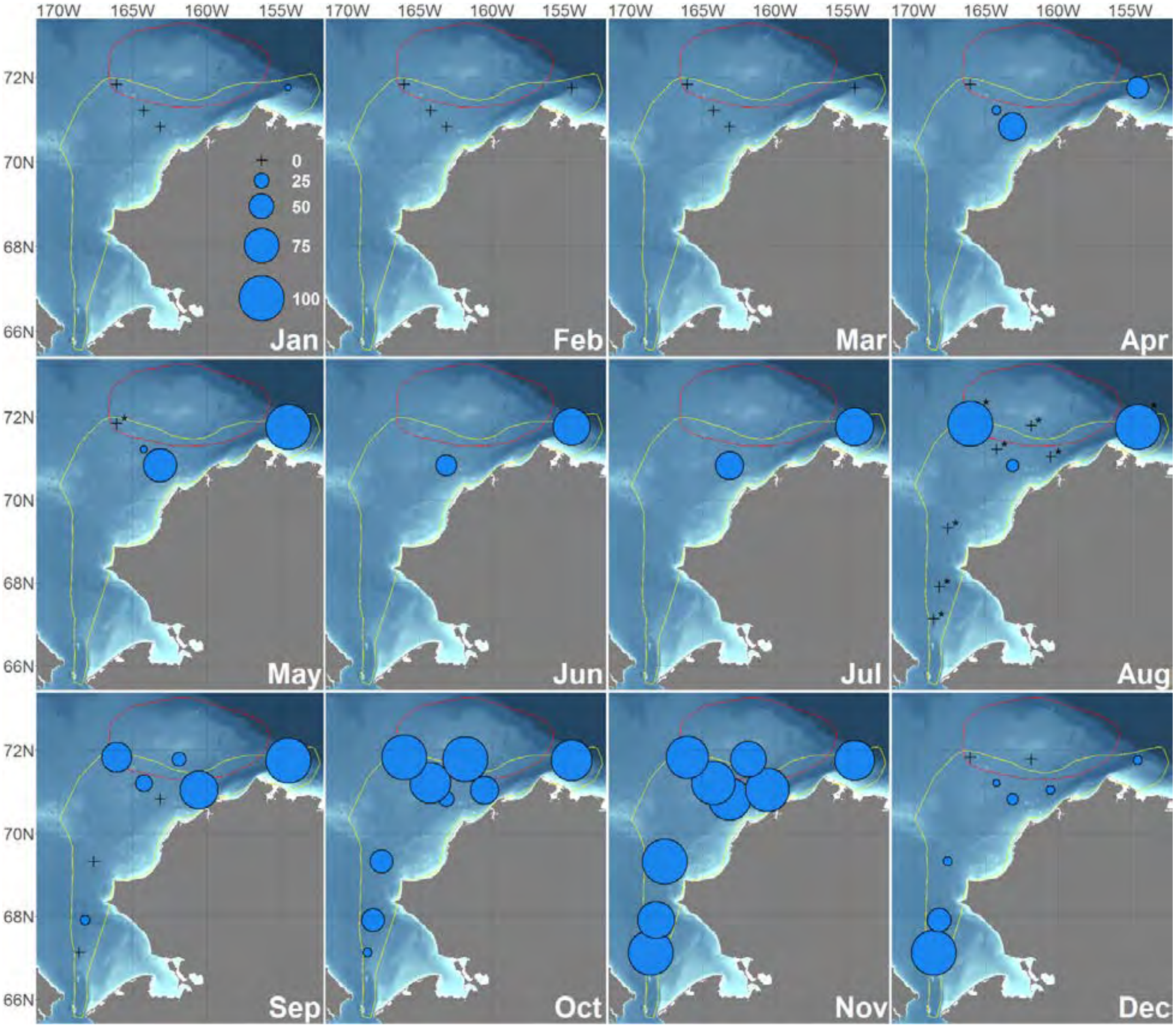


Figure 9. Monthly bowhead whale calling distribution, 2012. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 3. for numbers used to generate figure.

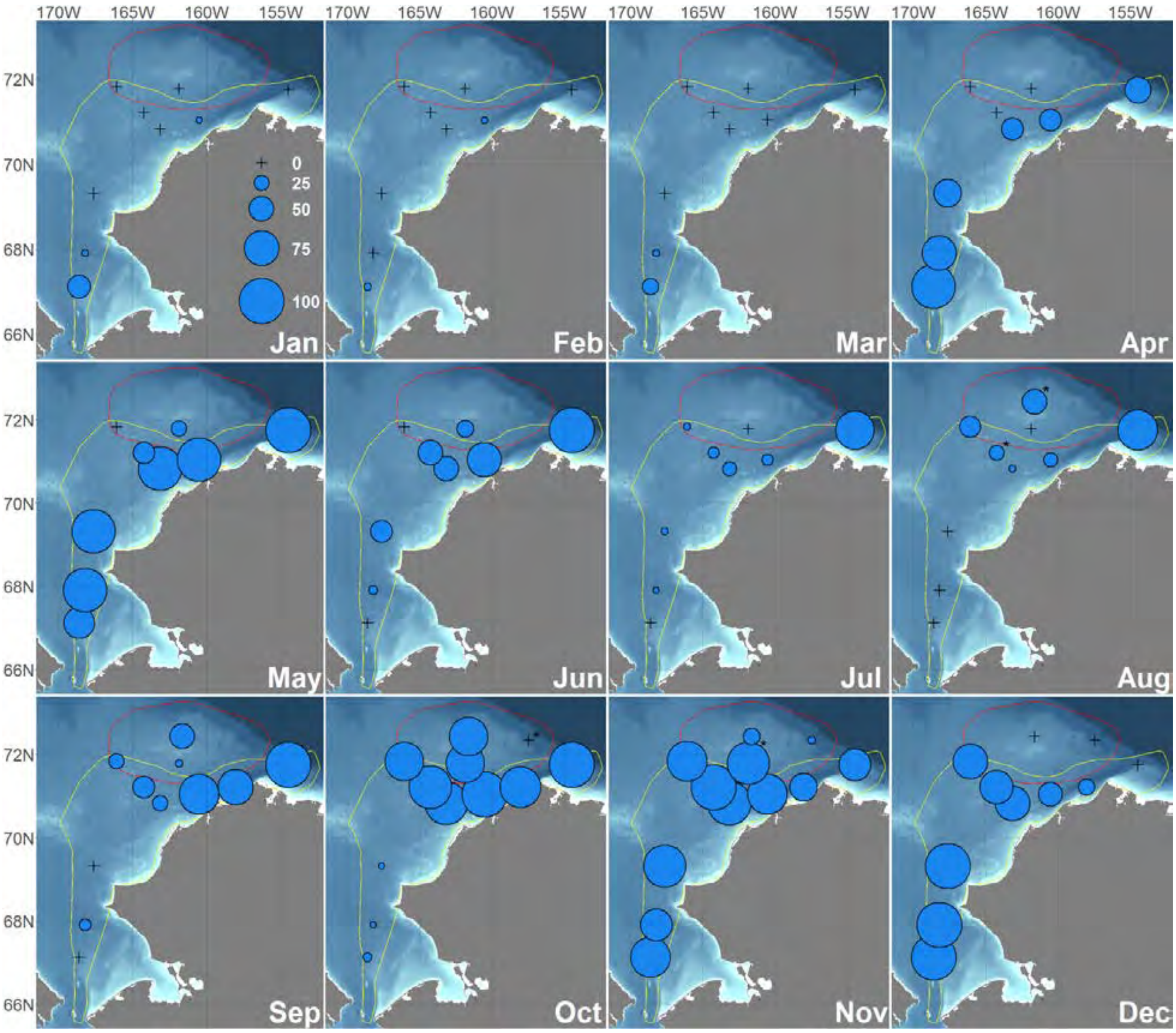


Figure 10. Monthly bowhead whale calling distribution, 2013. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 3. for numbers used to generate figure.

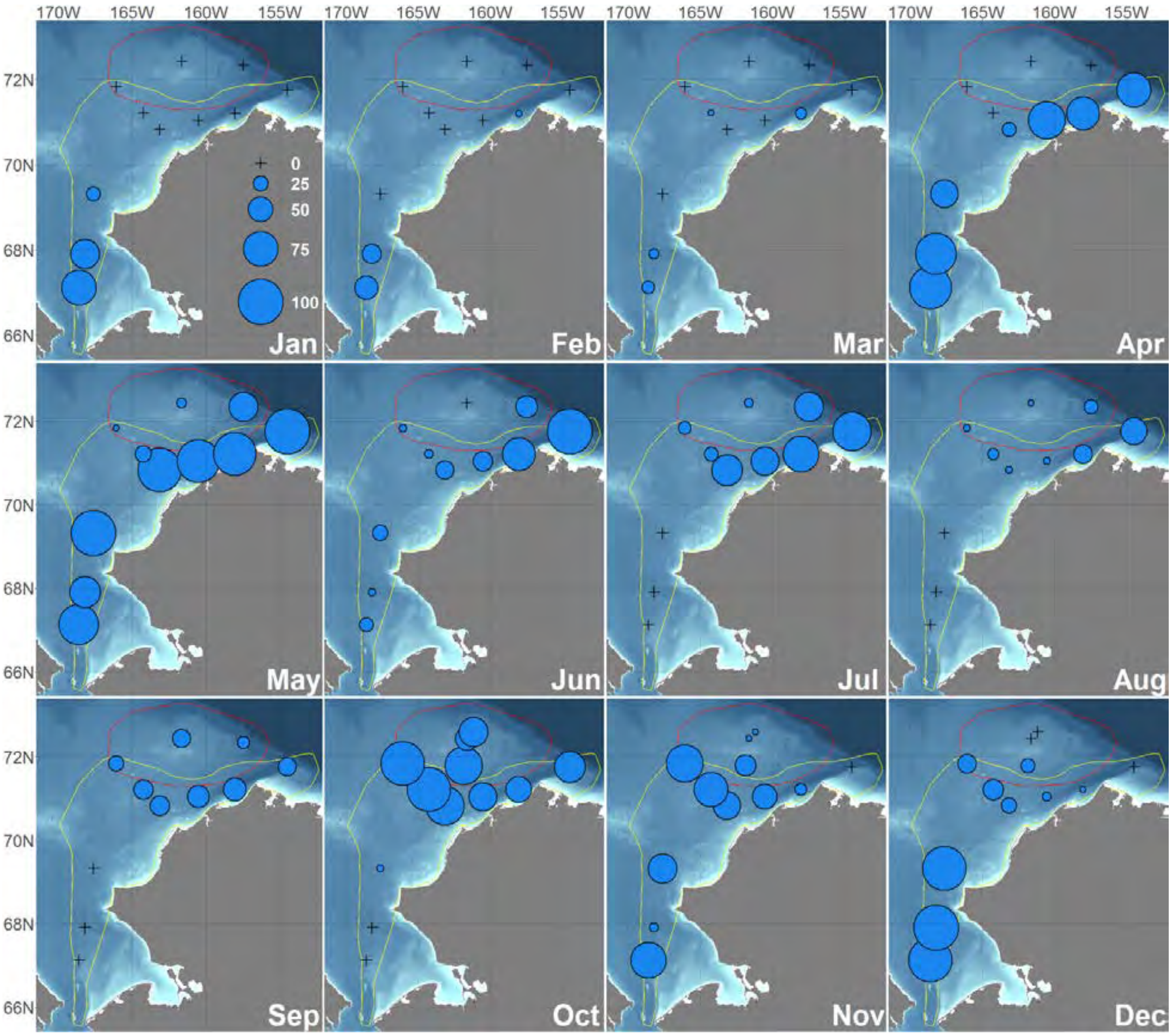


Figure 11. Monthly bowhead whale calling distribution, 2014. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 3. for numbers used to generate figure.

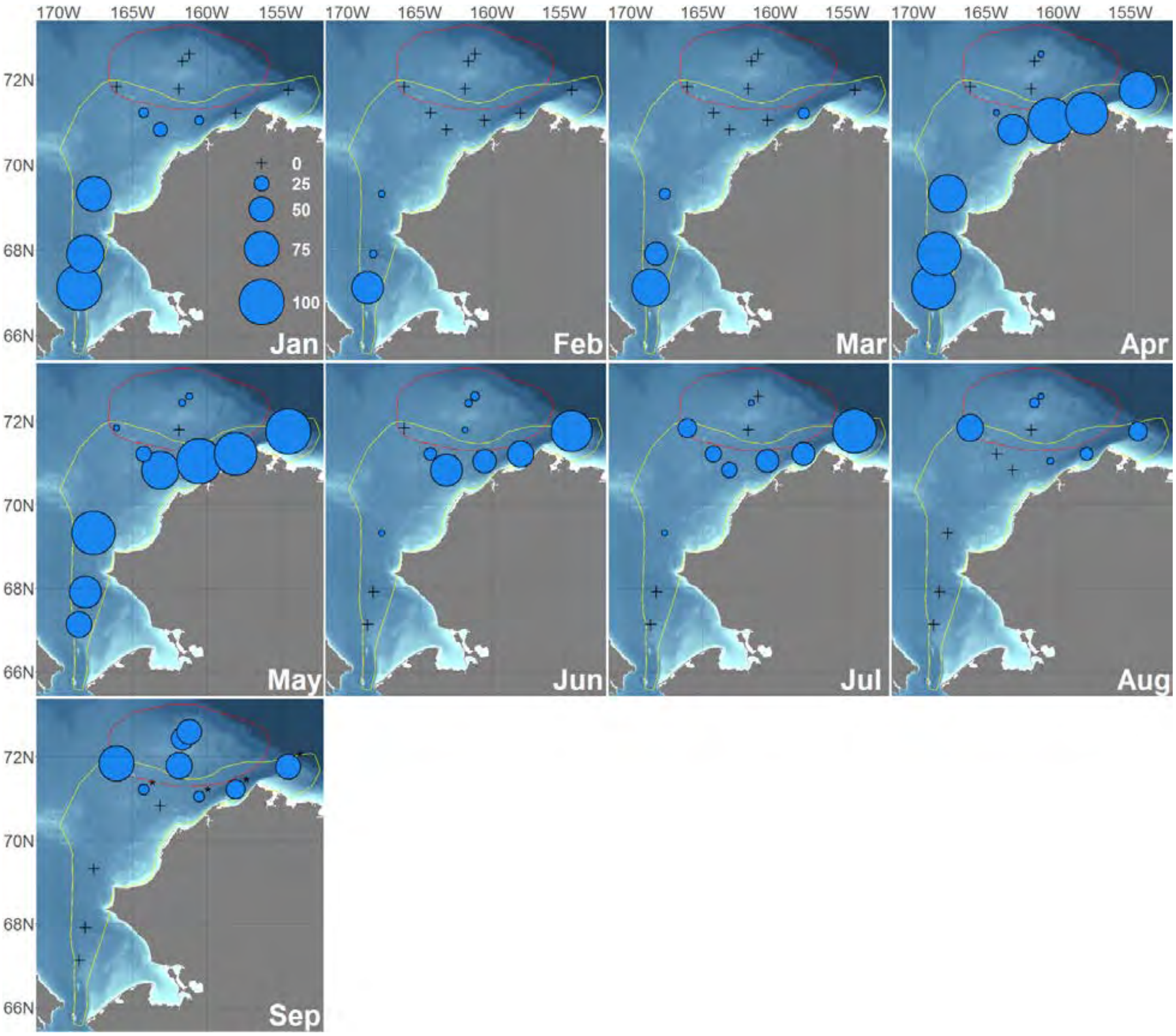


Figure 12. Monthly bowhead whale calling distribution, 2015. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 3. for numbers used to generate figure.

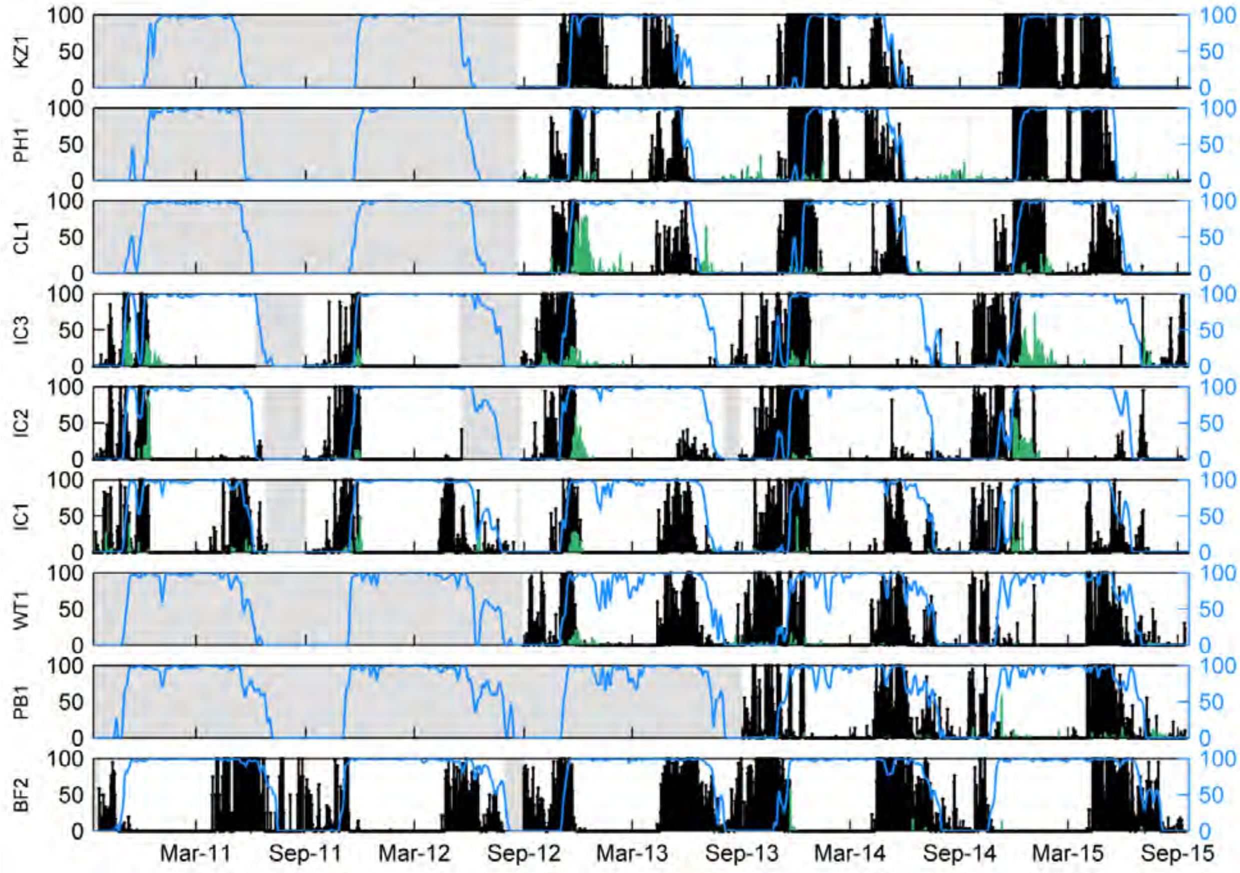


Figure 13. Gunshot call activity (green) overlaid on bowhead whale calling activity (presented as the percentage of ten-minute time intervals with calls) for the nine ARCWEST locations (Figure 2A), 2010-2015. Blue line indicates percent ice cover (zero-phase, three day moving average). Gray shading indicates no data.

Beluga whales

Like bowhead whales, beluga whale calling activity was detected on all the ARCWEST study area moorings for all years where data were available (Figure 14; Table 2). Among the mooring sites, the recorder with the highest proportion of bowhead calling activity was the one closest to Barrow Canyon (BF2) followed by PH1 in the southern Chukchi Sea, while the lowest were the two offshore Icy Cape (IC2-3) and CL1 in the Southern Chukchi (Table 6). Peak calling for all sites was low (Table 6). The months where calls were detected varied among the sites (Figures 15 - 20; Table 7), with calling detected from approximately April through November for those moorings east of Cape Lisburne (i.e., northeastern sites: IC1-3, WT1, PB1, BF2) and from approximately October through May for those moorings from Cape Lisburne and west (i.e., southern Chukchi sites: KZ1, PH1, CL1). The highest monthly averages were more consistent among mooring sites, with maximum monthly averages typically in April/May. No clear patterns in timing (Table 8) were seen either longitudinally (northeast vs. southern), or with distance from shore (IC1 vs. IC3).

Both the beluga spring and fall migrations were seen as pulses in calling activity in every year and on every mooring where data are available (Figure 14; Table 8). In general, both the spring and fall pulses decreased from inshore to offshore along the Icy Cape line (Figure 14; Table 7). In general, the timing of the spring and fall pulses of calling activity showed a west-to-east pattern between the southern and northeastern sites, with approximately a month delay between the start of the spring pulse at KZ1 and its start at BF2 (Table 8). However, unlike those for bowhead whales, these spring and fall pulses maintained their temporal spacing relative to each other across moorings and years. The exception is the BF2 site, where there appears to be a consistent presence of beluga calling activity throughout the open water season; the date ranges for pulses at that site (Table 5), therefore, should be considered rough estimates.

The trend in spring versus fall calling activity varied among mooring sites. For the majority of the sites (CL1, IC1-3, WT1, PB1, BF2), the spring pulse in calling activity was more sustained and at a higher level than that from the fall. The two southernmost sites (KZ1, PH1), however, showed no clear pattern in fall calling versus spring calling across years (Figure 14). As was seen for bowhead whales, the fall and spring pulses of beluga whale calling were sometimes multimodal (e.g., spring 2011 IC1, fall 2012 PH1; Figure 14).

Table 6. Total beluga whale calling activity, 2010-2015, for all ARCWEST 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
KZ1	1126	233	16	21	1
PH1	1124	354	67	31	6
CL1	1114	144	25	13	2
IC3	1647	227	7	14	<1
IC2	1636	256	7	16	<1
IC1	1765	427	72	24	4
WT1	1103	257	30	23	3
PB1	742	180	9	24	1
BF2	1784	763	150	43	8

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

Month	KZ1			PH1			CL1			IC3			IC2			IC1			WT1			PB1			BF2		
	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%
Jan	14	93	**15**	20	93	**22**	0	93	**0**	11	155	**7**	5	155	**3**	5	155	**3**	2	93	**2**	6	62	**10**	17	155	**11**
Feb	13	84	**15**	4	84	**5**	0	84	**0**	5	141	4	6	141	4	3	141	**2**	0	84	**0**	4	56	**7**	1	141	**1**
Mar	38	93	**41**	41	93	44	6	93	**6**	4	155	**3**	9	155	**6**	13	155	**8**	1	93	**1**	5	62	**8**	5	155	**3**
Apr	67	90	**74**	71	90	**79**	66	90	**73**	42	150	**28**	60	150	40	94	150	**63**	52	90	**58**	31	60	**52**	74	150	49
May	24	93	**26**	62	93	**67**	37	93	**40**	40	138	**29**	59	143	**41**	114	155	**74**	66	93	**71**	39	62	**63**	132	155	**85**
Jun	1	90	**1**	9	90	**10**	3	90	**3**	22	98	**22**	24	111	**22**	38	147	**26**	29	90	**32**	9	60	**15**	62	150	**41**
Jul	1	93	**1**	0	93	**0**	0	93	**0**	6	93	**6**	5	93	**5**	9	124	**7**	13	89	**15**	21	62	**34**	122	153	**80**
Aug	0	103	**0**	0	103	**0**	0	102	**0**	3	99	**3**	2	74	**3**	3	121	**2**	4	94	4	8	62	**13**	91	123	74
Sep	0	111	**0**	2	109	**2**	0	100	**0**	2	158	**1**	3	154	**2**	8	157	**5**	7	102	**7**	4	72	6	78	142	**55**
Oct	3	93	**3**	14	93	**15**	0	93	**0**	24	155	**15**	22	155	**14**	53	155	**34**	37	93	40	26	62	**42**	103	155	**66**
Nov	44	90	**49**	85	90	**94**	30	90	**33**	59	150	**39**	51	150	**34**	77	150	**51**	42	90	**47**	24	60	40	66	150	44
Dec	28	93	**30**	46	93	49	2	93	**2**	9	155	**6**	10	155	**6**	10	155	**6**	4	92	4	3	62	**5**	12	155	**8**

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 14.

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
	IC2	20-Oct	31-Dec	-	-	-	-	2-Nov	15-Dec	4-Jun	31-Oct
	IC1	15-Sep	2-Dec	24-Nov	26-Nov	-	-	18-Oct	2-Dec	2-Jun	23-Oct
	BF2	29-Sep	30-Nov	11-Nov	11-Nov	-	-	29-Sep	15-Nov	26-Jul	18-Oct
2011	IC3	3-Apr	23-Nov	-	-	3-Apr	21-Apr	3-Nov	23-Nov	5-Jul	22-Nov
	IC2	18-Jan	12-Dec	-	-	15-Mar	20-Apr	5-Nov	24-Nov	9-Jun	14-Nov
	IC1	12-Jan	18-Dec	30-Apr	19-Nov	27-Mar	19-Jun	5-Oct	23-Nov	4-Jun	12-Nov
	BF2	25-Apr	8-Dec	25-Apr	4-Nov	25-Apr	4-Jun	29-Oct	13-Nov	14-Jul	15-Oct
2012	KZ1	27-Oct	1-Dec	1-Nov	7-Nov	-	-	27-Oct	1-Dec	9-Jun	16-Nov
	PH1	13-Sep	25-Dec	27-Oct	25-Nov	-	-	27-Oct	3-Dec	17-Jun	16-Nov
	CL1	2-Nov	27-Dec	-	-	-	-	2-Nov	28-Nov	27-Jun	14-Nov
	IC3	18-Jan	15-Nov	14-Nov	14-Nov	12-Apr	7-May	3-Nov	15-Nov	27-Jul	3-Nov
	IC2	31-Jan	15-Dec	8-May	19-May	2-Apr	19-May	1-Nov	18-Nov	24-Jul	1-Nov
	IC1	19-Jan	5-Dec	24-Apr	10-Nov	11-Apr	27-May	19-Oct	5-Dec	24-Jul	1-Nov
	WT1	2-Oct	2-Dec	9-Nov	10-Nov	-	-	31-Oct	2-Dec	9-Aug	1-Nov
	BF2	9-Jan	30-Dec	21-Apr	6-Nov	17-Apr	28-Jul	1-Sep	6-Dec	6-Aug	3-Nov
2013	KZ1	1-Jan	25-Dec	19-Mar	2-May	12-Mar	8-May	14-Nov	25-Dec	8-Jun	26-Nov
	PH1	4-Jan	24-Dec	16-Mar	14-Dec	15-Mar	10-Jun	28-Oct	19-Dec	11-Jun	25-Nov
	CL1	20-Mar	2-Dec	14-Apr	2-May	4-Apr	7-May	19-Nov	2-Dec	21-Jun	24-Nov
	IC3	1-Jan	29-Dec	4-Nov	4-Nov	9-Apr	12-Jun	30-Sep	27-Nov	21-Jul	26-Oct
	IC2	30-Jan	23-Nov	20-Apr	20-Apr	3-Apr	14-Jun	3-Oct	23-Nov	25-Jul	26-Oct
	IC1	27-Feb	28-Dec	8-Apr	23-Oct	22-Mar	27-May	9-Oct	10-Dec	27-Jul	30-Oct
	WT1	11-Jan	4-Dec	25-Apr	7-May	16-Apr	28-Jun	4-Oct	22-Nov	31-Jul	30-Oct
	PB1	5-Oct	23-Dec	-	-	-	-	5-Oct	30-Nov	1-Aug	31-Oct
	BF2	1-Jan	20-Nov	9-May	11-Oct	10-Apr	2-Jun	12-Sep	4-Nov	1-Aug	24-Oct
2014	KZ1	14-Jan	31-Dec	6-Apr	5-Dec	14-Mar	29-Apr	2-Nov	13-Jan	30-May	11-Dec
	PH1	2-Jan	30-Dec	20-Mar	5-Dec	20-Mar	25-May	29-Oct	6-Dec	30-May	7-Dec
	CL1	23-Mar	18-Nov	2-Apr	1-May	23-Mar	2-Jun	2-Nov	18-Nov	7-Jun	29-Nov
	IC3	3-Jan	3-Dec	26-Nov	27-Nov	18-Apr	29-Jun	6-Oct	3-Dec	30-Jul	3-Nov
	IC2	13-Apr	25-Nov	8-May	9-May	13-Apr	20-May	24-Sep	25-Nov	17-Jul	2-Nov
	IC1	3-Jan	28-Nov	22-Apr	16-Nov	31-Mar	25-Jun	13-Sep	28-Nov	21-Jul	3-Nov
	WT1	31-Mar	9-Dec	6-Apr	22-Nov	31-Mar	3-Jun	27-Oct	26-Nov	24-Jul	31-Oct
	PB1	16-Jan	2-Dec	27-Apr	31-Jul	10-Apr	28-May	21-Sep	2-Dec	3-Aug	24-Oct
	BF2	7-Apr	25-Dec	25-Apr	5-Oct	7-Apr	1-Jun	21-Jun	25-Nov	30-Jul	20-Oct
2015	KZ1	1-Jan	6-Jul	30-Mar	27-Apr	24-Mar	5-May	-	-	24-May	27-Nov
	PH1	7-Jan	27-May	26-Mar	3-May	24-Mar	27-May	-	-	1-Jun	28-Nov
	CL1	31-Mar	8-Jun	12-Apr	5-May	6-Apr	25-May	-	-	13-Jun	20-Nov
	IC3	4-Jan	20-Jul	25-Apr	27-Apr	24-Apr	19-Jun	-	-	30-Jun	12-Nov
	IC2	12-Apr	26-Jul	16-Apr	28-Apr	12-Apr	1-Jun	-	-	15-Jun	18-Nov
	IC1	15-Jan	29-Jul	11-Apr	3-Jun	9-Apr	4-Jul	-	-	15-Jun	2-Nov
	BF2	6-Apr	13-Sep	23-Apr	20-Aug	6-Apr	1-Jun	17-Jun	13-Sep	5-Aug	20-Oct
	WT1	2-Apr	19-Jul	26-Apr	11-May	2-Apr	19-Jun	-	-	7-Jul	30-Oct
	PB1	3-Jan	12-Sep	21-Apr	17-May	-	-	-	-	30-Jun	5-Oct

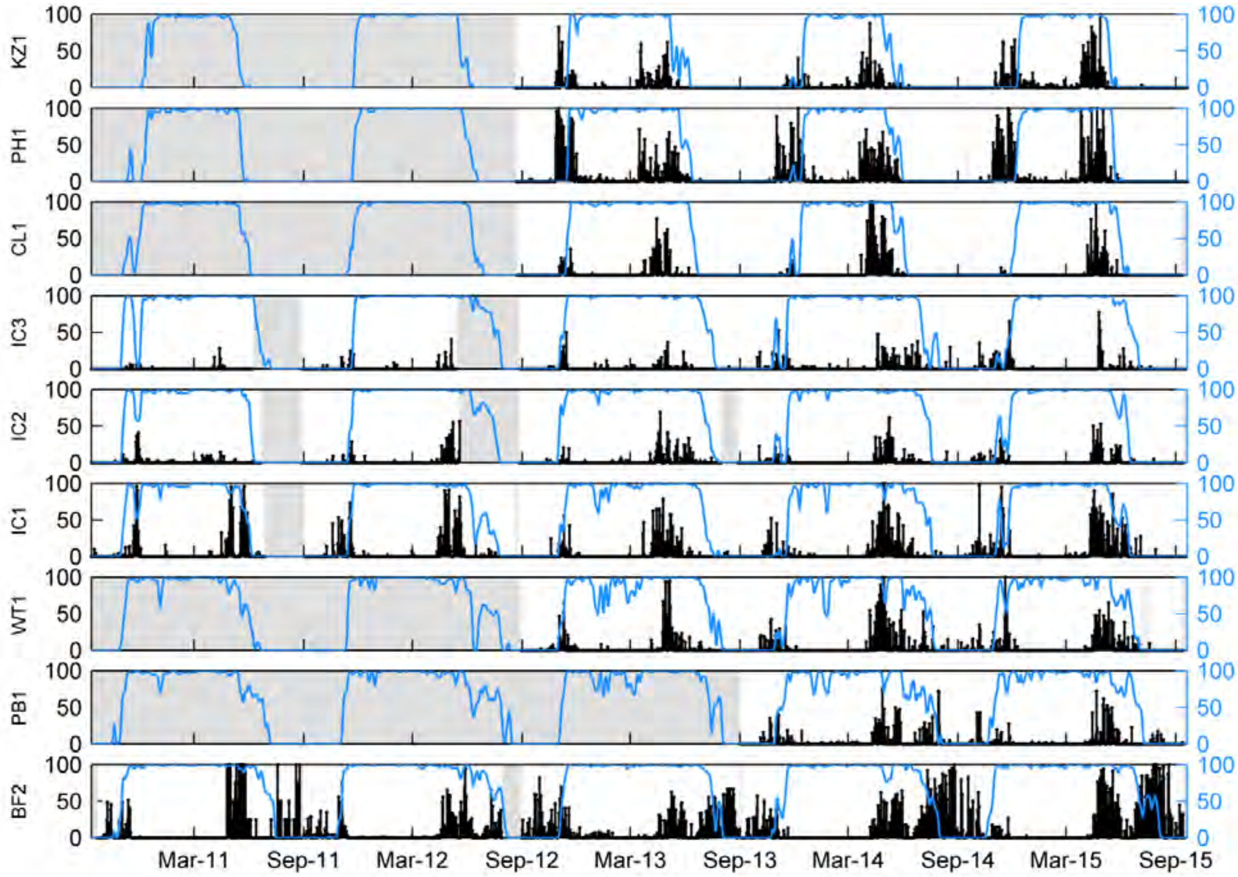


Figure 14. Beluga whale calling activity (presented as the percentage of ten-minute time intervals with calls) for the nine ARCWEST locations (see Figure 2A), 2010-2015. Blue line indicates percent ice cover (zero-phase, three-day moving average). Gray shading indicates no data.

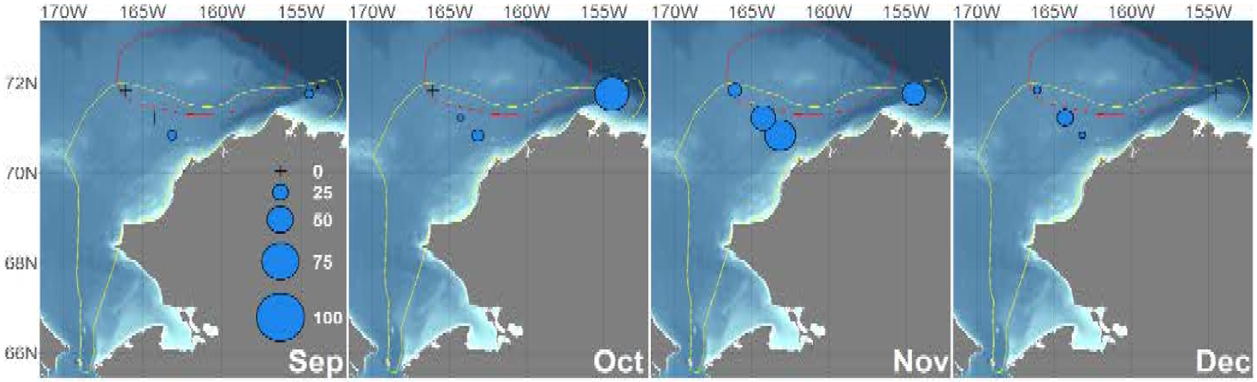


Figure 15. Monthly beluga whale calling distribution, 2010. Graduated scale in the September panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of e effort are indicated with a *; see Appendix C. 4. for numbers used to generate figure.

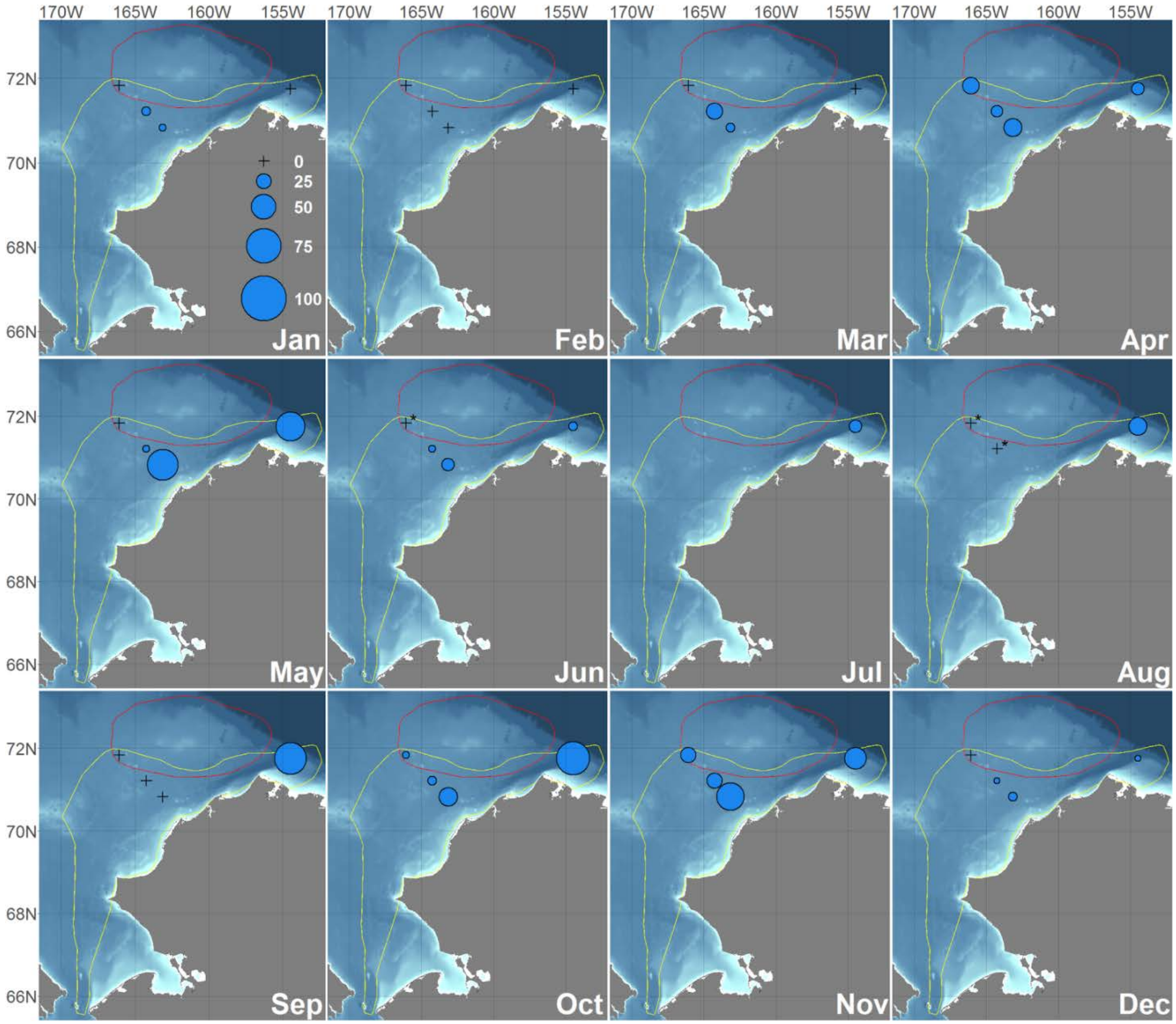


Figure 16. Monthly beluga whale calling distribution, 2011. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month effort are indicated with a *; see Appendix C. 4. for numbers used to generate figure.

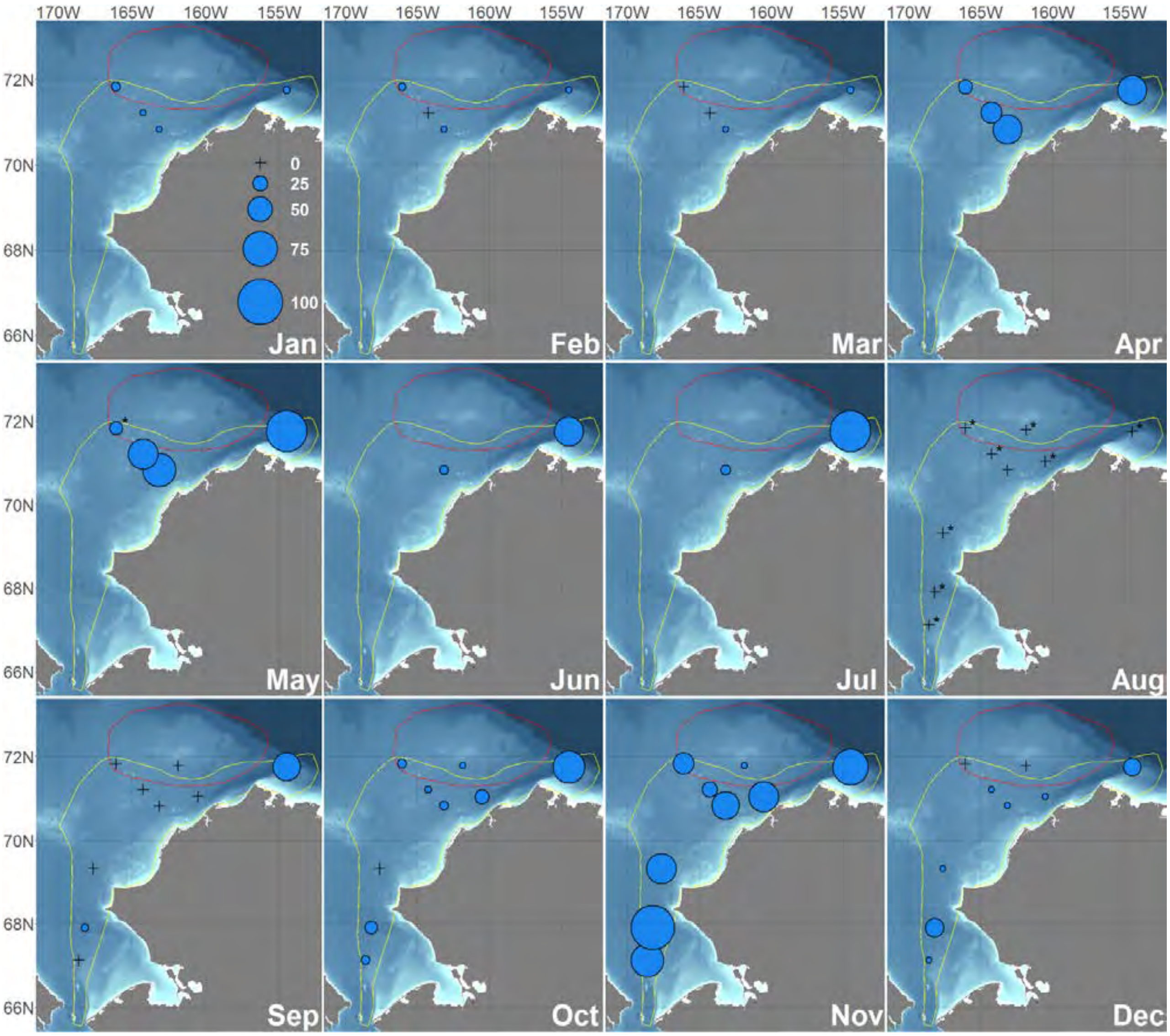


Figure 17. Monthly beluga whale calling distribution, 2012. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 4. for numbers used to generate figure.

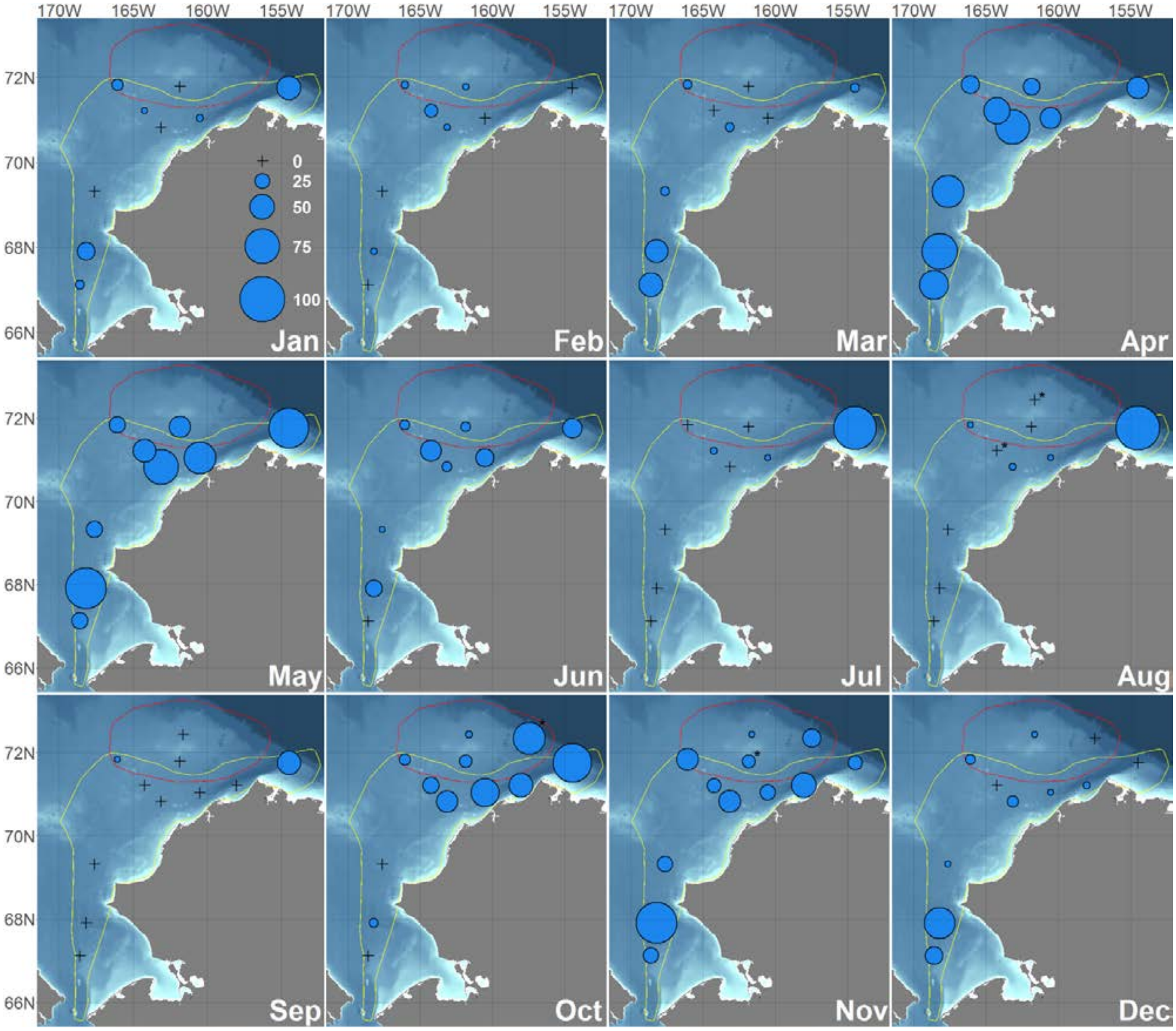


Figure 18. Monthly beluga whale calling distribution, 2013. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of eff effort are indicated with a *; see Appendix C. 4. for numbers used to generate figure.

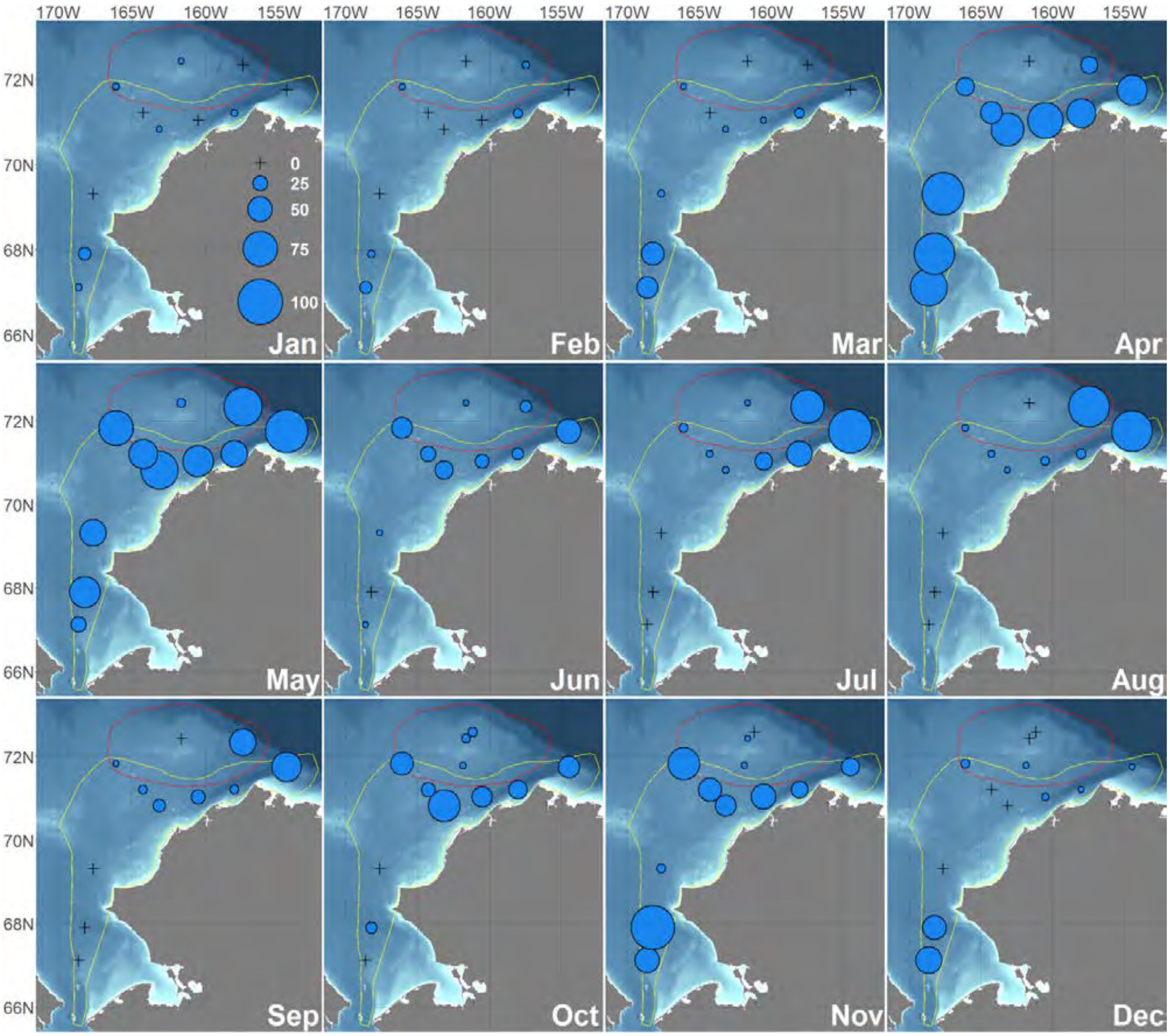


Figure 19. Monthly beluga whale calling distribution, 2014. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 4. for numbers used to generate figure.

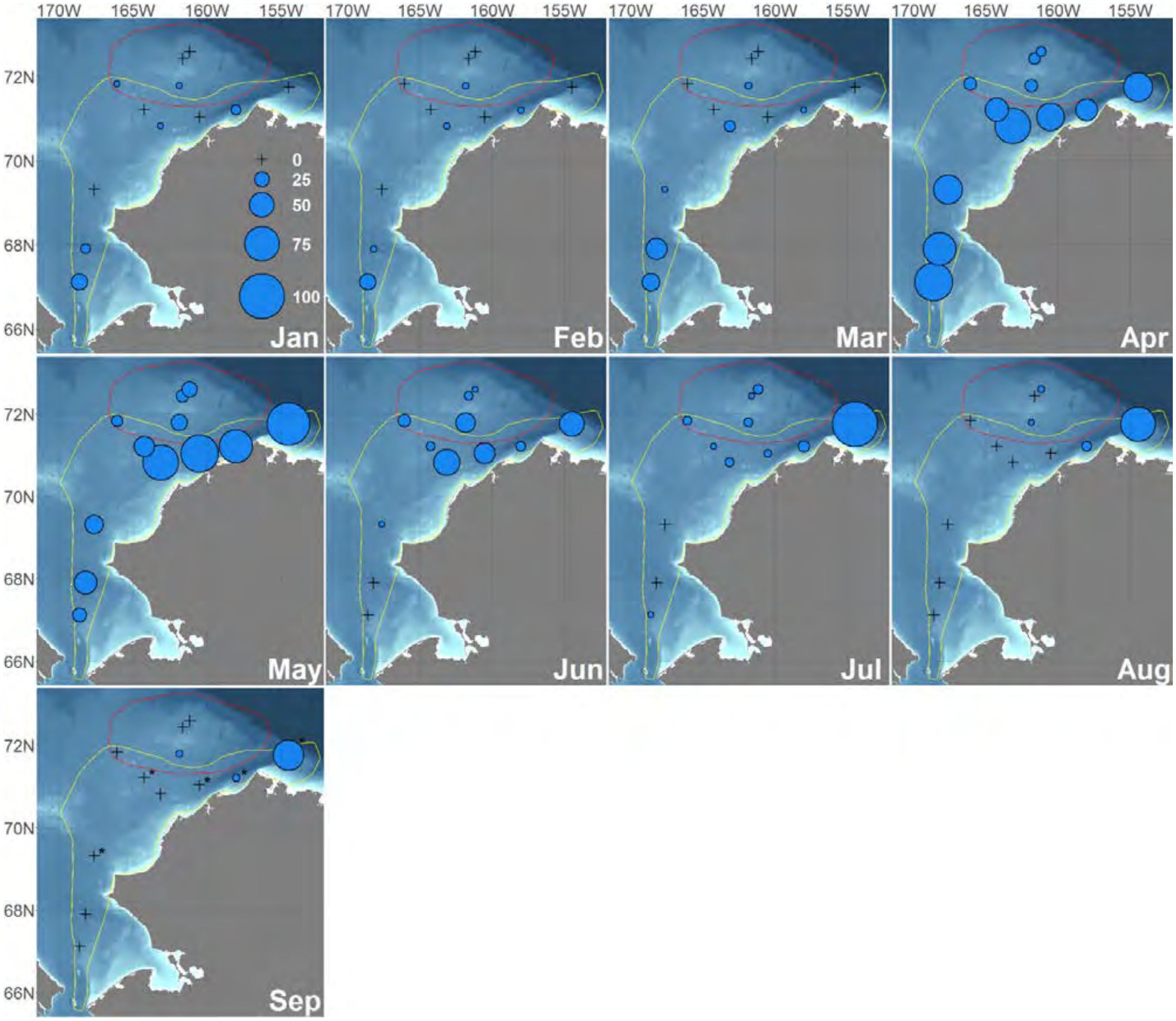
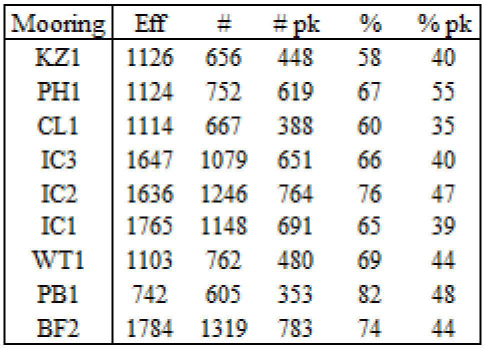


Figure 20. Monthly beluga whale calling distribution, 2015. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 4. for numbers used to generate figure.

Bearded seals

Bearded seal calling activity was near ubiquitous at all ARCWEST moorings sites for all years where data were available (Figure 17; 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 PB1 site had the greatest proportion of days with calls, while the PH1 site had the highest percentage of days with peak calling (Table 9). Peak calling for all sites occurred on 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 three southern Chukchi sites, which had no calling (or extremely low calling) between July and September (Figures 22-27; Table 10). 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 November-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 most cases a smaller pulse of calling activity was seen before the main pulse; the timing of this precursor pulse appears to track southwestward, possible indicating a fall migration. 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. For all sites, the general trend in calling was that it was lowest in July-August, increased from September through February, and was present on all days of the month for all years from approximately March through May (Table 10).

Table 9. Total bearded seal calling activity, 2010-2015, for all ARCWEST 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
KZ1	1126	656	448	58	40
PH1	1124	752	619	67	55
CL1	1114	667	388	60	35
IC3	1647	1079	651	66	40
IC2	1636	1246	764	76	47
IC1	1765	1148	691	65	39
WT1	1103	762	480	69	44
PB1	742	605	353	82	48
BF2	1784	1319	783	74	44

The most striking feature of the seasonal timing of bearded seal calling activity is its abrupt cessation in the spring (Figure 21). For the three overwinter calling periods with full recording effort, the average ending date for all mooring sites ranged within a few days (i.e., 27 June 2013, 28 June 2014, and 23 June 2015; Figure 21). The standard deviation for all mooring sites within each overwinter period varied between 8 and 9 days. Comparing timing among geographically similar sites for all full-effort years yielded tighter correspondence, with the northeastern Chukchi sites averaging 1 July with a standard deviation of 4 days, and the southern sites a half-month earlier at 16 June and a standard deviation of 5 days. In general, there was no evident inter-annual or inter-site trend among years for the start of the main pulse. Likewise, there were no clear trends among years or mooring locations for the start date of peak calling (days with >50% calling activity).

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

Month	KZ1			PH1			CL1			IC3			IC2			IC1			WT1			PB1			BF2		
	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%
Jan	89	93	**96**	90	93	**97**	71	93	**76**	136	155	**88**	153	155	**99**	143	155	**92**	84	93	**90**	58	62	**94**	130	155	**84**
Feb	73	84	**87**	81	84	**96**	84	84	**100**	126	141	**89**	139	141	**99**	135	141	**96**	84	84	**100**	56	56	**100**	141	141	**100**
Mar	93	93	**100**	93	93	**100**	92	93	**99**	149	155	**96**	155	155	**100**	155	155	**100**	93	93	**100**	62	62	**100**	154	155	**99**
Apr	90	90	**100**	90	90	**100**	90	90	**100**	150	150	**100**	150	150	**100**	150	150	**100**	90	90	**100**	60	60	**100**	149	150	**99**
May	93	93	**100**	93	93	**100**	93	93	**100**	138	138	**100**	143	143	**100**	155	155	**100**	93	93	**100**	62	62	**100**	155	155	**100**
Jun	45	90	**50**	46	90	**51**	60	90	**67**	95	98	**97**	111	111	**100**	132	147	**90**	88	90	**98**	57	60	**95**	150	150	**100**
Jul	0	93	**0**	2	93	**2**	1	93	**1**	4	93	4	13	93	**14**	18	124	**15**	16	89	**18**	18	62	**29**	58	153	**38**
Aug	1	103	**1**	1	103	**1**	0	102	**0**	8	99	**8**	12	74	**16**	11	121	**9**	13	94	**14**	33	62	**53**	39	123	**32**
Sep	1	111	**1**	6	109	**6**	9	100	**9**	55	158	**35**	57	154	**37**	21	157	**13**	43	102	**42**	56	72	**78**	87	142	**61**
Oct	69	93	**74**	81	93	**87**	55	93	**59**	60	155	**39**	78	155	**50**	52	155	**34**	44	93	**47**	49	62	**79**	77	155	**50**
Nov	63	90	**70**	90	90	**100**	71	90	**79**	45	150	**30**	104	150	**69**	64	150	**43**	41	90	**46**	42	60	**70**	63	150	**42**
Dec	39	93	**42**	79	93	**85**	41	93	**44**	113	155	**73**	131	155	**85**	112	155	**72**	73	92	**79**	52	62	**84**	116	155	**75**

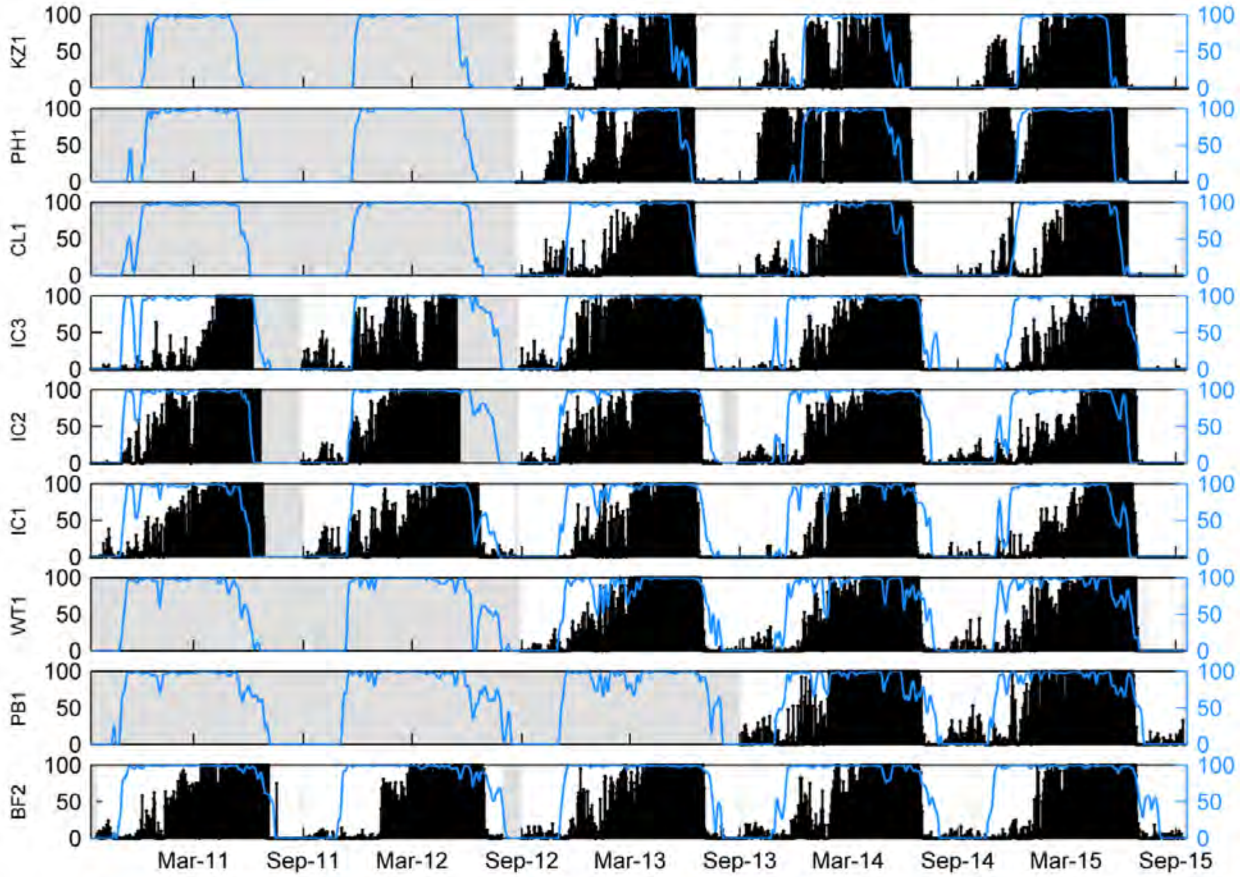


Figure 21. Bearded seal calling activity (presented as the percentage of ten-minute time intervals with calls) for the nine ARCWEST locations (see Figure 2A), 2010-2015. Blue line indicates percent ice cover (zero-phase, three-day moving average). Gray shading indicates no data.

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 21. 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
	IC2	10/7/2010	6/21/2011	11/24/2010	6/21/2011	11/29/2010	6/21/2011	10/31/2010	6/9/2011
	IC1	9/25/2010	6/27/2011	11/10/2010	6/27/2011	12/15/2010	6/26/2011	10/23/2010	6/4/2011
	BF2	9/20/2010	7/18/2011	1/11/2011	7/5/2011	1/13/2011	7/5/2011	10/18/2010	7/14/2011
2011-12	IC3	8/30/2011	12/31/2011	11/22/2011	5/14/2012	11/25/2011	5/14/2012	11/22/2011	7/27/2012
	IC2	8/29/2011	5/19/2012	11/14/2011	5/19/2012	11/22/2011	5/19/2012	11/14/2011	7/24/2012
	IC1	9/8/2011	8/20/2012	11/14/2011	6/23/2012	11/22/2011	6/23/2012	11/12/2011	7/24/2012
	BF2	9/4/2011	7/29/2012	1/1/2012	7/6/2012	1/10/2012	6/30/2012	10/15/2011	8/6/2012
2012-13	KZ1	10/9/2012	6/19/2013	1/1/2013	6/19/2013	1/5/2013	6/18/2013	11/16/2012	6/8/2013
	PH1	10/8/2012	7/2/2013	12/20/2012	6/18/2013	10/26/2012	6/16/2013	11/16/2012	6/11/2013
	CL1	9/16/2012	6/23/2013	1/3/2013	6/23/2013	1/17/2013	6/17/2013	11/14/2012	6/21/2013
	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
	IC2	9/2/2012	7/23/2013	10/6/2012	6/30/2013	11/13/2012	6/29/2013	11/1/2012	7/25/2013
	IC1	11/11/2012	6/25/2013	11/24/2012	6/25/2013	12/4/2012	6/24/2013	11/1/2012	7/27/2013
	WT1	9/1/2012	7/9/2013	11/25/2012	7/5/2013	12/13/2012	7/1/2013	11/1/2012	7/31/2013
	BF2	9/3/2012	8/5/2013	11/11/2012	7/11/2013	12/4/2012	7/3/2013	11/3/2012	8/1/2013
2013-14	KZ1	10/1/2013	6/13/2014	12/19/2013	6/13/2014	12/22/2013	6/12/2013	11/26/2013	5/30/2014
	PH1	9/27/2013	6/15/2014	10/1/2013	6/15/2014	10/2/2013	6/15/2014	11/25/2013	5/30/2014
	CL1	9/29/2013	6/30/2014	12/26/2013	6/26/2014	12/29/2013	6/17/2014	11/24/2013	6/7/2014
	IC3	9/24/2013	7/5/2014	12/11/2013	7/5/2014	12/19/2013	7/1/2014	10/26/2013	7/30/2014
	IC2	8/31/2013	7/16/2014	12/14/2013	7/7/2014	12/23/2013	7/1/2014	10/26/2013	7/17/2014
	IC1	10/17/2013	7/16/2014	12/17/2013	6/26/2014	1/6/2014	6/22/2014	10/30/2013	7/21/2014
	WT1	7/28/2013	7/31/2014	12/13/2013	7/4/2014	12/18/2013	7/1/2014	10/30/2013	7/24/2014
	PB1	9/5/2013	7/14/2014	11/13/2013	7/7/2014	11/29/2013	7/2/2014	10/31/2013	8/3/2014
	BF2	8/30/2013	7/18/2014	1/27/2014	7/3/2014	2/2/2014	7/1/2014	10/24/2013	7/30/2014
2014-15	KZ1	9/25/2014	6/19/2015	12/9/2014	6/12/2015	12/14/2014	6/8/2015	12/11/2014	5/24/2015
	PH1	9/21/2014	6/12/2015	12/13/2014	6/11/2015	10/5/2014	6/11/2015	12/7/2014	6/1/2015
	CL1	9/6/2014	7/3/2015	1/20/2015	6/14/2015	11/12/2014	6/14/2015	11/29/2014	6/13/2015
	IC3	11/22/2014	6/28/2015	12/9/2014	6/28/2015	12/23/2014	6/24/2015	11/3/2014	6/30/2015
	IC2	8/2/2014	7/6/2015	12/8/2014	6/30/2015	12/15/2014	6/27/2015	11/2/2014	6/15/2015
	IC1	8/18/2014	6/28/2015	12/14/2014	6/28/2015	1/18/2015	6/25/2015	11/3/2014	6/15/2015
	WT1	8/20/2014	7/1/2015	12/18/2014	7/1/2015	12/20/2014	6/27/2015	10/31/2014	6/30/2015
	PB1	8/9/2014	9/13/2015	10/26/2014	6/28/2015	9/26/2014	6/24/2015	10/24/2014	7/7/2015
	BF2	8/6/2014	7/14/2015	11/25/2014	7/2/2015	1/7/2015	6/27/2015	10/20/2014	8/5/2015
2015-16	KZ1	-	-	-	-	-	-	11/27/2015	-
	PH1	-	-	-	-	-	-	11/28/2015	-
	CL1	-	-	-	-	-	-	11/20/2015	-
	IC3	8/2/2015	9/6/2015	-	-	-	-	11/12/2015	-
	IC2	-	-	-	-	-	-	11/18/2015	-
	IC1	-	-	-	-	-	-	11/2/2015	-
	BF2	7/25/2015	9/10/2015	-	-	-	-	10/20/2015	-
	PB1	-	-	-	-	-	-	10/30/2015	-
	WT1	-	-	-	-	-	-	10/5/2015	-

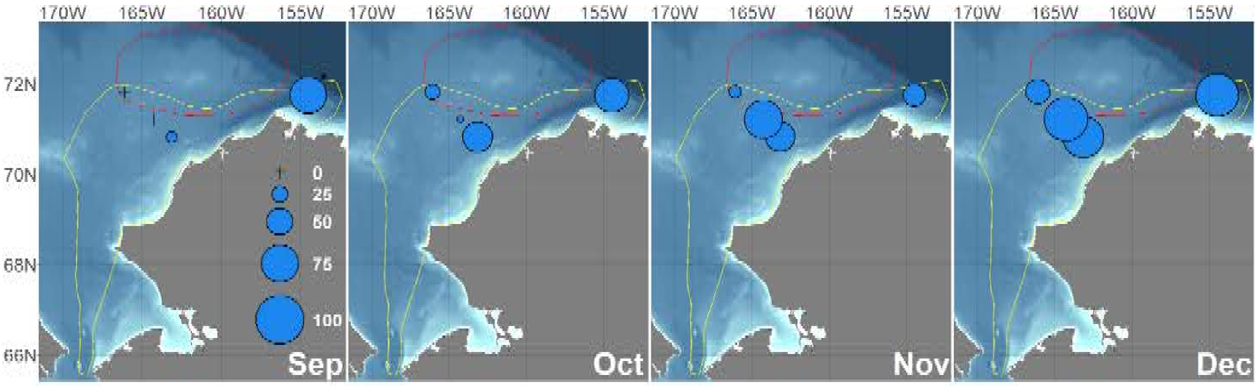


Figure 22. Monthly bearded seal calling distribution, 2010. Graduated scale in the September panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. for numbers used to generate figure.

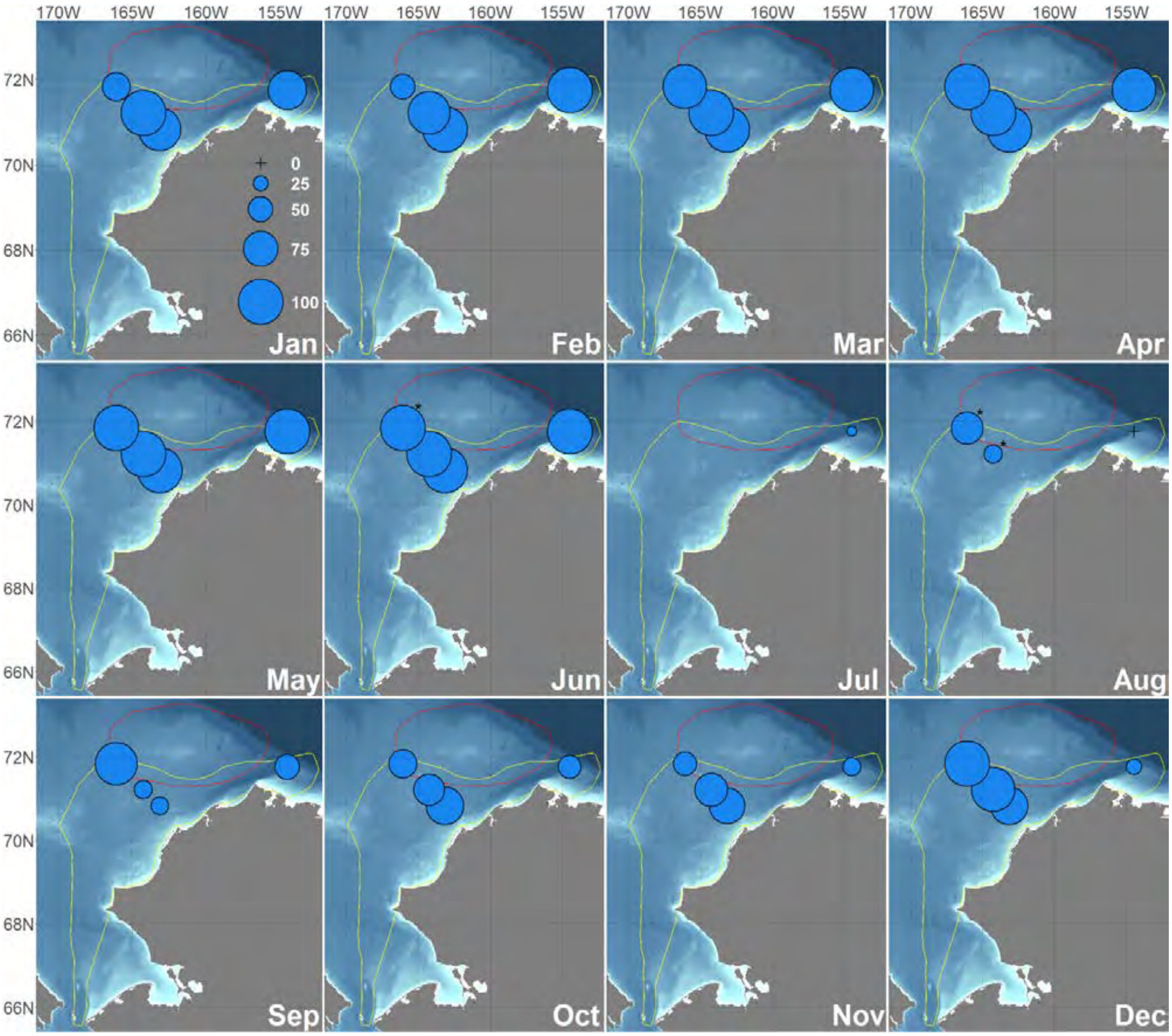


Figure 23. Monthly bearded seal calling distribution, 2011. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. for numbers used to generate figure.

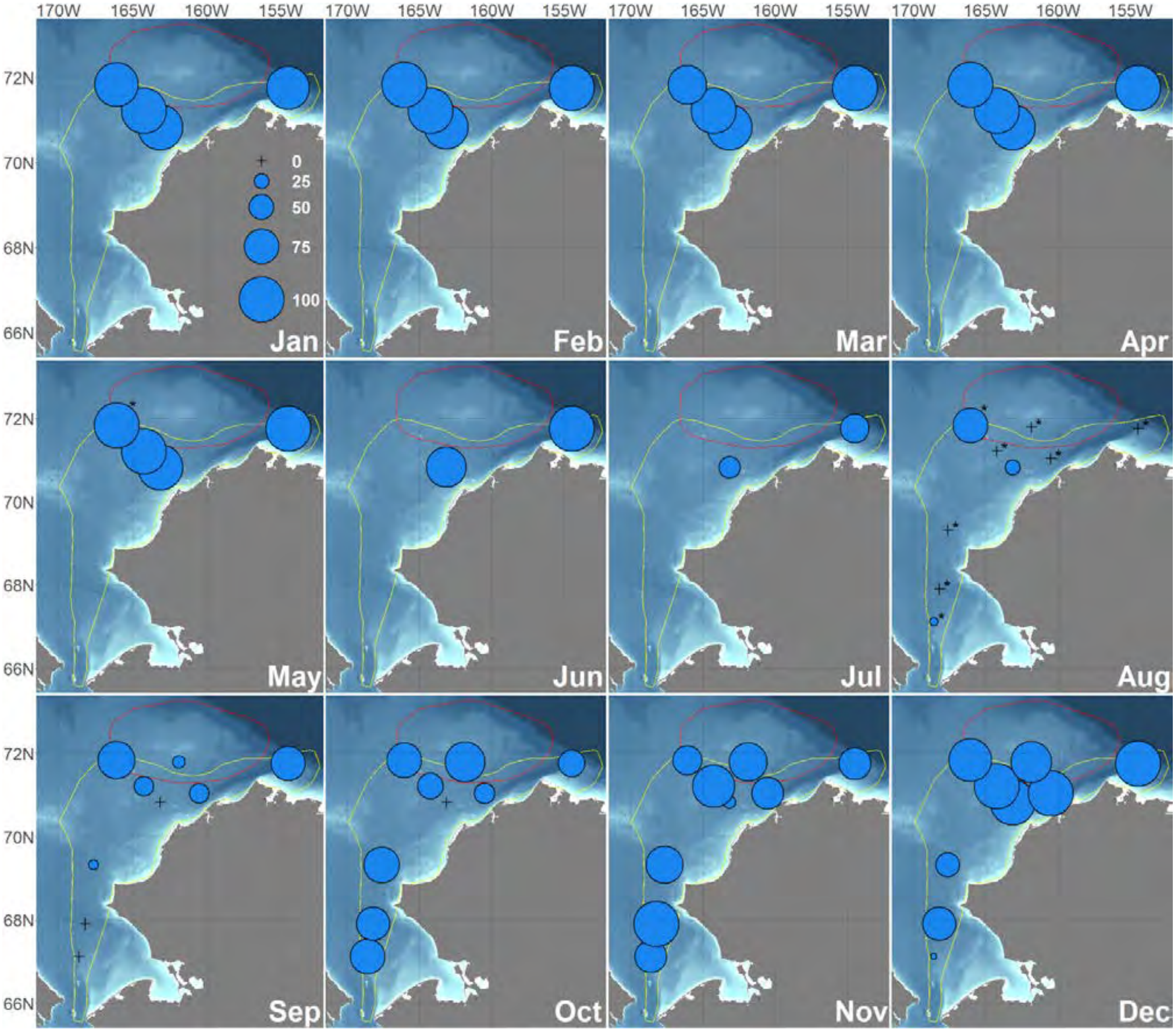


Figure 24. Monthly bearded seal calling distribution, 2012. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 5 for numbers used to generate figure.

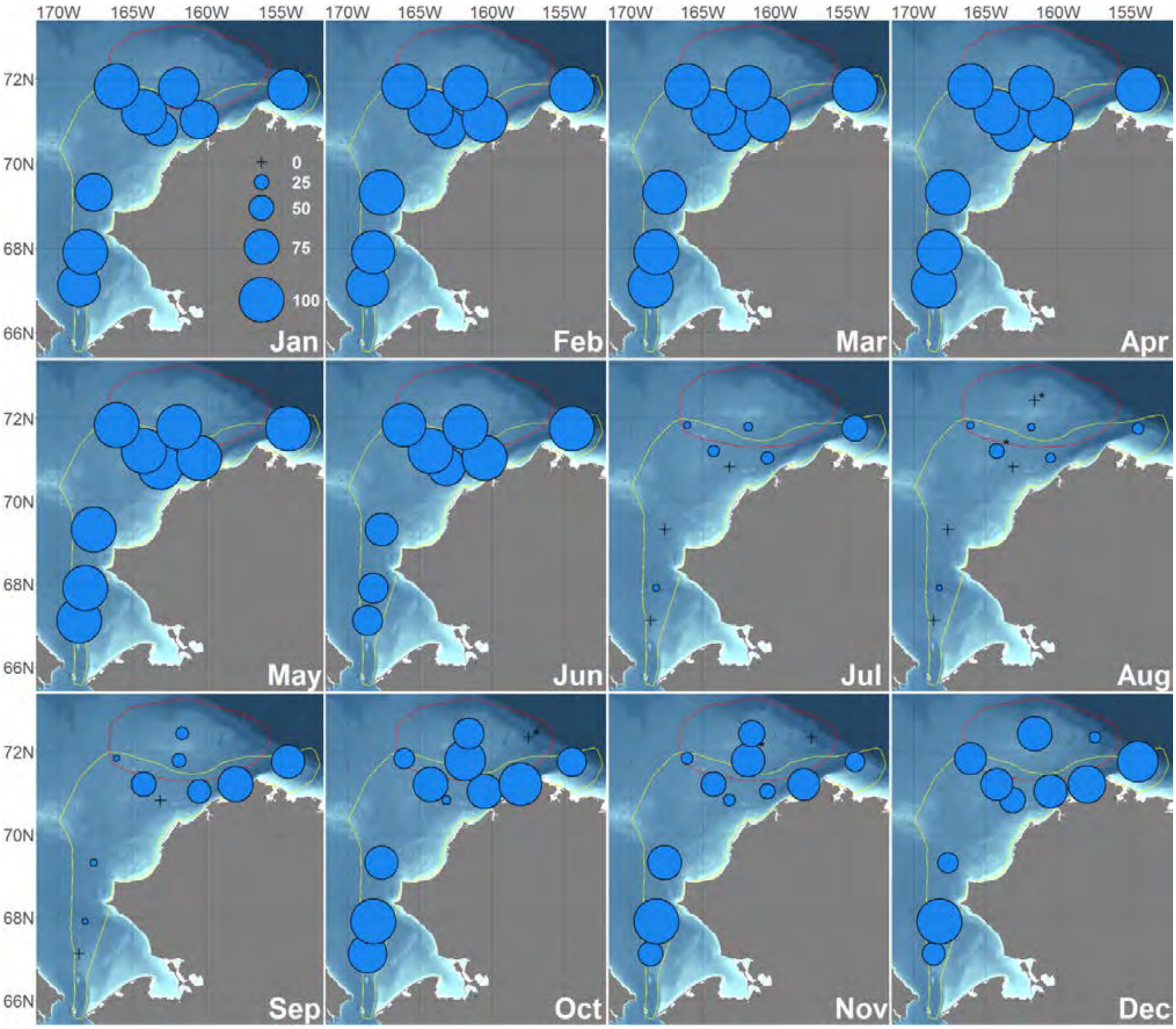


Figure 25. Monthly bearded seal calling distribution, 2013. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 5 for numbers used to generate figure.

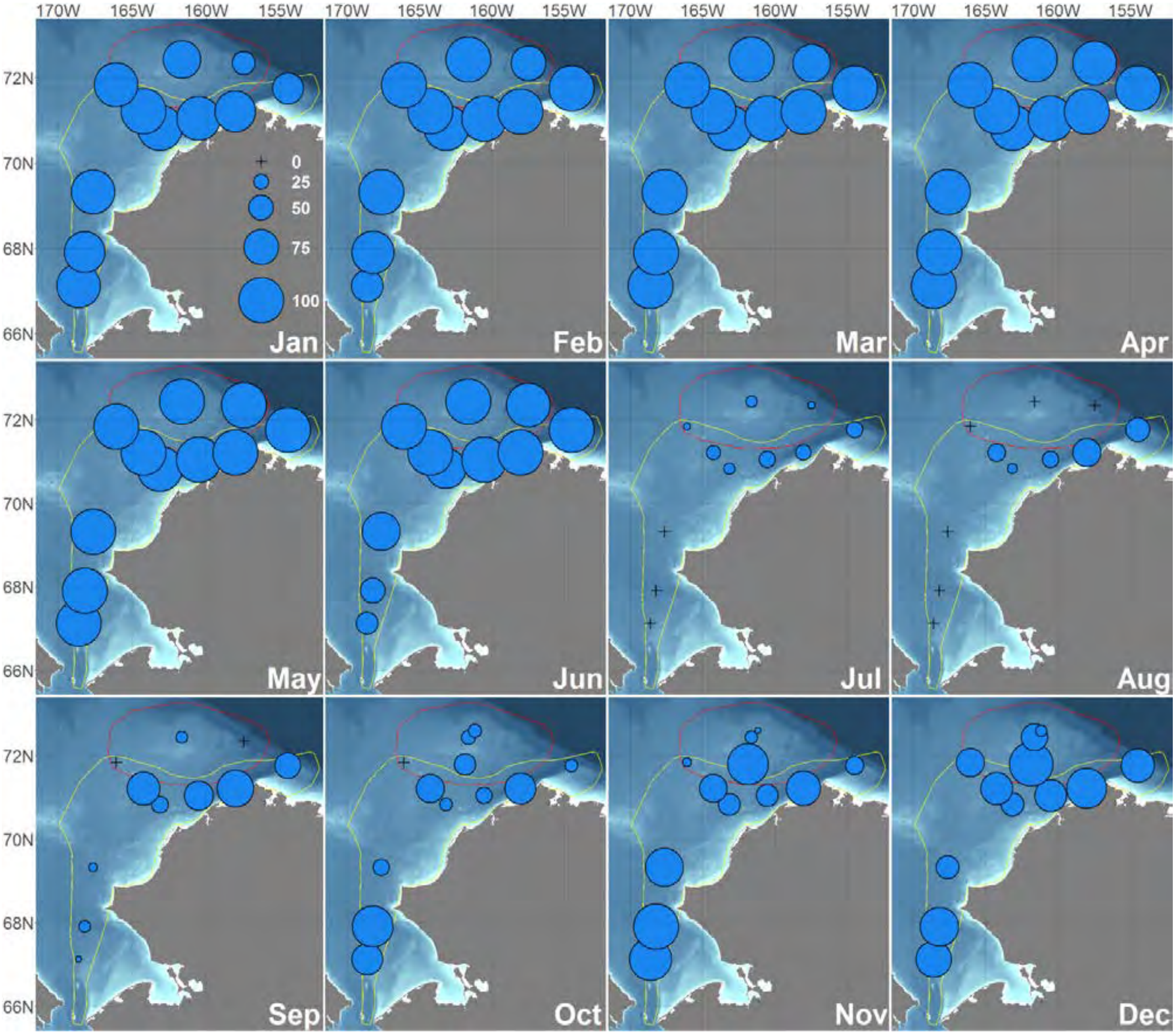


Figure 26. Monthly bearded seal calling distribution, 2014. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 5 for numbers used to generate figure.

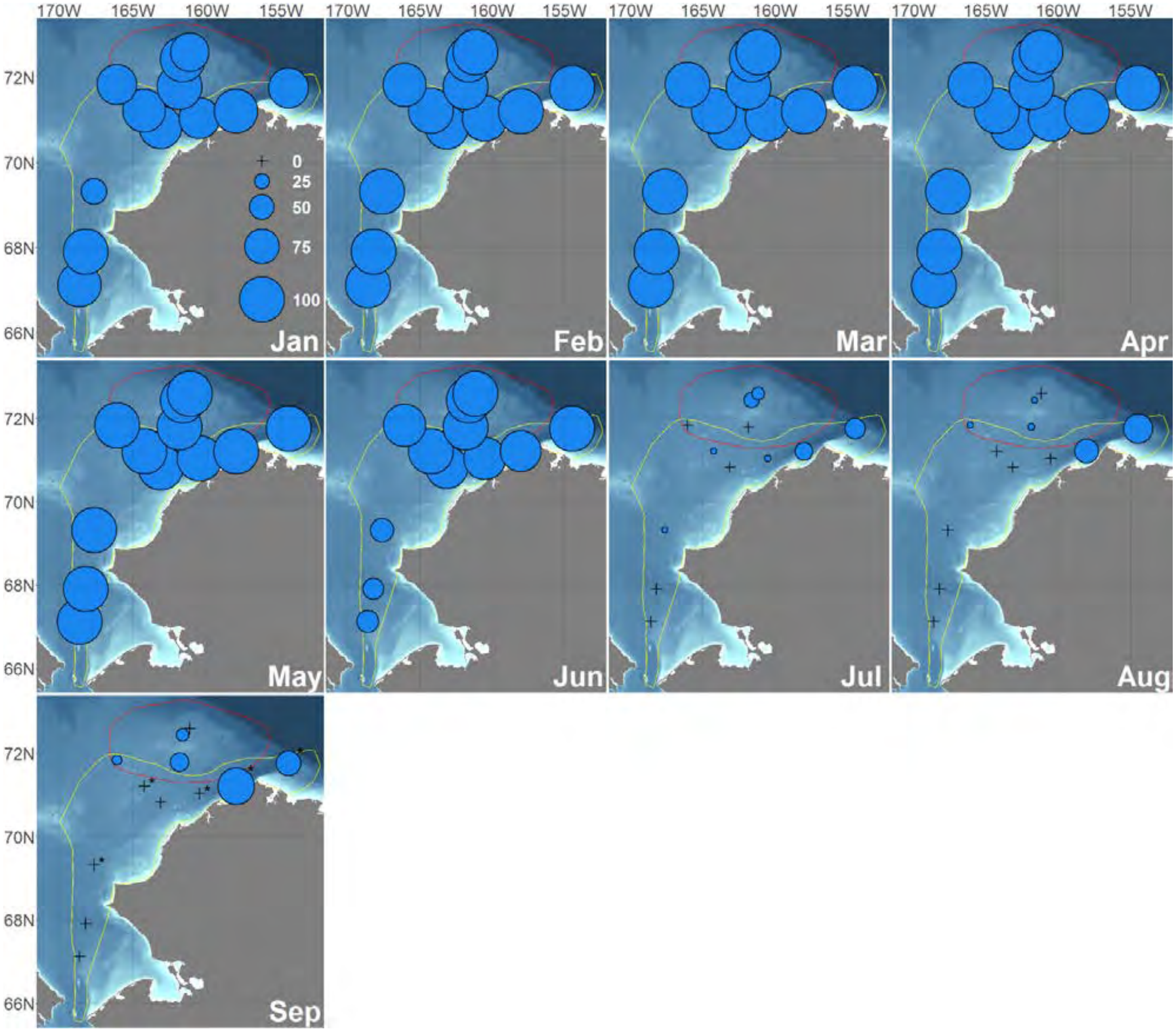


Figure 27. Monthly bearded seal calling distribution, 2015. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 5 for numbers used to generate figure.

Walrus

Walrus calling activity was detected on all ARCWEST study area moorings for all years where data were available (Figure 28; Table 2), with the exception of the site furthest northeast (BF1) in 2011. Among all mooring sites, the most southern site (KZ1) had the highest percentage of days with calling activity detected, while BF1 had the lowest (Figure 29; Table 12). Peak calling activity followed this same trend, with nearly half of all days with calls at KZ1 being peak calling days while only 14% at BF2 were peak calling days (Table 12). The months with calling activity varied among mooring sites. The moorings along the Icy Cape line had walrus calling activity detected in all months (Table 13), while the PB1 site at the head of Barrow Canyon had the least number of months with calling present. The majority of the calling activity was detected June through September at the sites east of the Icy Cape Line, and March through December along the Icy Cape line (with the exception of the offshore site, IC3, which maintained a steady level of days with calling activity year-round). The PH1 and CL1 moorings in the southern Chukchi saw a slightly longer range of months (May through October) with calling activity than those to the east of Icy Cape. The southernmost site, KZ1, had calling detected from November through June (Figures 29-34; Table 13).

Walrus had two periods with calling activity - summer and winter (Figure 28; 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 most sites could not be described as a pulse - it was either a steady trickle of days with low detections or practically non-existent. However, there are two notable exceptions. Winter calling at the offshore Icy Cape site (IC3), in contrast, had high levels of sustained calling activity overwinter, which steadily decreased throughout the five years of recordings. In addition, most calling detected at the southernmost site (KZ1) occurred primarily overwinter (Figure 29-34).

The summer pulse of calling began between May and June for most years at the northern Chukchi sites (i.e., CL1, IC1-3, WT1, and PB1). This pulse started earlier at the southern Chukchi mooring sites (i.e., KZ1 and PH1), and later at the northeastern most site (BF2). The majority of moorings/years saw an end to the summer pulse of calling in October, with an earlier end at the northeastern most site (BF2) in August, and a wide range of months (June - December) at the southernmost sites (KZ1 and PH1). Bouts of low level calling activity distributed throughout the year blurs the lines between the summer and winter pulses, and so the date ranges presented in Table 14 should be considered approximate. Winter pulse dates varied among years and mooring sites with no apparent trends evident (Figures 29-34; Table 14).

Table 12. Total walrus calling activity, 2010-2015, for all ARCWEST 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
KZ1	1126	391	173	35	15
PH1	1125	123	34	11	3
CL1	1123	182	32	16	3
IC3	1647	434	93	26	6
IC2	1636	286	67	17	4
IC1	1765	439	143	25	8
WT1	1110	164	42	15	4
PB1	742	92	29	12	4
BF2	1784	57	8	3	<1

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

Month	KZ1			PH1			CL1			IC3			IC2			IC1			WT1			PB1			BF2		
	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%
Jan	40	93	**43**	0	93	**0**	0	93	**0**	26	155	**17**	1	155	**1**	5	155	**3**	0	93	**0**	0	62	**0**	1	155	**1**
Feb	36	84	**43**	2	84	**2**	1	84	**1**	50	141	**35**	1	141	**1**	6	141	4	0	84	**0**	0	56	**0**	1	141	**1**
Mar	71	93	**76**	7	93	**8**	3	93	**3**	40	155	**26**	2	155	**1**	18	155	**12**	1	93	**1**	0	62	**0**	7	155	**5**
Apr	57	90	**63**	0	90	**0**	2	90	**2**	23	150	**15**	9	150	**6**	16	150	**11**	2	90	**2**	0	60	**0**	3	150	**2**
May	81	93	**87**	37	93	40	11	93	**12**	11	138	**8**	5	143	**3**	13	155	**8**	0	93	**0**	0	62	**0**	2	155	**1**
Jun	46	90	**51**	45	90	**50**	74	90	**82**	42	98	**43**	75	111	**68**	99	147	**67**	33	90	**37**	25	60	**42**	2	150	**1**
Jul	0	93	**0**	3	93	**3**	16	93	**17**	71	93	**76**	54	93	**58**	89	124	**72**	55	93	**59**	36	62	**58**	20	153	**13**
Aug	3	103	**3**	6	103	**6**	4	102	4	34	99	**34**	8	74	**11**	25	121	**21**	42	95	**44**	14	62	**23**	12	123	**10**
Sep	3	111	**3**	10	110	**9**	31	109	**28**	58	158	**37**	62	154	40	80	157	**51**	23	103	**22**	7	72	**10**	2	142	**1**
Oct	0	93	**0**	7	93	**8**	39	93	**42**	35	155	**23**	43	155	**28**	45	155	**29**	5	93	**5**	1	62	**2**	0	155	**0**
Nov	9	90	**10**	2	90	**2**	1	90	**1**	12	150	**8**	21	150	**14**	26	150	**17**	2	90	**2**	7	60	**12**	2	150	**1**
Dec	45	93	**48**	4	93	**4**	0	93	**0**	32	155	**21**	5	155	**3**	17	155	**11**	1	93	**1**	2	62	**3**	5	155	**3**

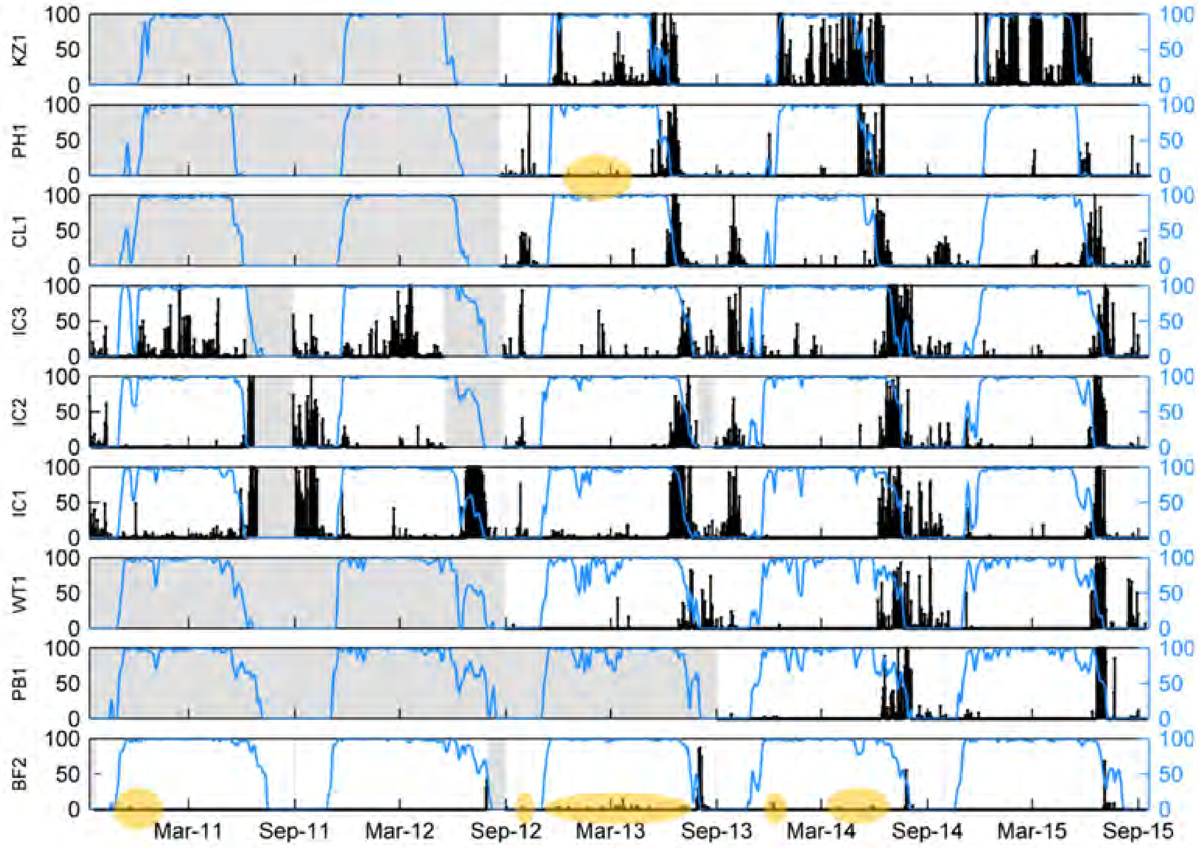


Figure 28. Walrus calling activity (presented as the percentage of ten-minute time intervals with calls) for the nine ARCWEST locations (see Figure 2A), 2010-2015. Blue line indicates percent ice cover (zero-phase, three-day moving average). Yellow shading highlights low level detections. Gray shading indicates no data.

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 28.

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
	IC2	10-Sep	12-Nov	10-Sep	9-Oct	10-Sep	10-Oct	12-Nov-10	18-Apr-11	4-Jun	31-Oct
	IC1	10-Sep	30-Dec	10-Sep	10-Sep	10-Sep	17-Oct	8-Nov-10	20-May-11	2-Jun	23-Oct
	BF2	20-Nov	20-Dec	-	-	-	-	20-Nov-10	20-Dec-10	26-Jul	18-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
	IC2	25-Jan	18-Dec	13-Jun	9-Oct	31-May	4-Nov	20-Nov-11	11-May-12	9-Jun	14-Nov
	IC1	15-Jan	4-Dec	30-May	22-Nov	29-May	3-Nov	16-Nov-11	31-May-12	4-Jun	12-Nov
	BF2	-	-	-	-	-	-	-	-	14-Jul	15-Oct
2012	KZ1	22-Nov	30-Dec	29-Nov	5-Dec	-	-	22-Nov-12	5-May-13	9-Jun	16-Nov
	PH1	25-Aug	19-Dec	10-Oct	11-Oct	25-Aug	20-Oct	19-Dec-12	13-Mar-13	17-Jun	16-Nov
	CL1	22-Sep	24-Oct	-	-	22-Sep	24-Oct	9-Apr-13	9-Apr-13	27-Jun	14-Nov
	IC3	9-Jan	2-Oct	16-Feb	29-Sep	28-Aug	2-Oct	9-Jan-13	21-May-13	27-Jul	3-Nov
	IC2	4-Mar	2-Oct	-	-	19-Sep	2-Oct	14-May-13	17-May-13	24-Jul	1-Nov
	IC1	18-Feb	27-Dec	23-Jun	26-Sep	14-Jun	7-Oct	20-Nov-12	14-Apr-13	24-Jul	1-Nov
	WT1	13-Sep	13-Sep	-	-	13-Sep	13-Sep	13-Mar-13	2-Apr-13	9-Aug	1-Nov
	BF2	28-Jul	18-Dec	-	-	28-Jul	30-Sep	27-Nov-12	10-Jul-13	6-Aug	3-Nov
2013	KZ1	30-Jan	31-Dec	14-Mar	25-Dec	7-May	26-Jun	29-Nov-13	17-May-14	8-Jun	26-Nov
	PH1	6-Feb	2-Dec	26-May	1-Dec	11-May	25-Oct	28-Nov-13	6-Mar-14	11-Jun	25-Nov
	CL1	9-Apr	22-Oct	7-Jun	3-Oct	6-Jun	22-Oct	1-Feb-14	24-May-14	21-Jun	24-Nov
	IC3	9-Jan	16-Dec	8-Feb	11-Oct	26-Jun	22-Oct	30-Oct-13	20-Feb-14	21-Jul	26-Oct
	IC2	14-May	21-Nov	21-Jun	30-Sep	1-Jun	17-Oct	10-Nov-13	7-May-14	25-Jul	26-Oct
	IC1	8-Feb	26-Nov	12-Jun	10-Oct	7-Jun	20-Oct	26-Nov-13	26-Nov-13	27-Jul	30-Oct
	WT1	13-Mar	18-Dec	17-Jul	21-Aug	26-Jun	4-Oct	18-Dec-13	18-Dec-13	31-Jul	30-Oct
	PB1	26-Sep	13-Dec	-	-	26-Sep	26-Sep	22-Nov-13	13-Dec-13	1-Aug	31-Oct
	BF2	21-Jan	8-Dec	1-Aug	5-Aug	28-Jul	18-Aug	6-Dec-13	1-Jun-14	1-Aug	24-Oct
2014	KZ1	1-Jan	31-Dec	4-Jan	14-Dec	21-May	4-Dec	9-Dec-14	19-Apr-15	30-May	11-Dec
	PH1	1-Mar	8-Dec	4-May	17-Jun	4-May	5-Sep	8-Dec-14	5-Mar-15	30-May	7-Dec
	CL1	1-Feb	9-Nov	4-Jun	17-Jun	2-Jun	9-Nov	6-Mar-15	7-May-14	7-Jun	29-Nov
	IC3	14-Jan	24-Dec	23-Jun	5-Aug	2-Jun	9-Oct	8-Dec-14	17-Mar-15	30-Jul	3-Nov
	IC2	7-May	20-Dec	21-Jun	29-Jul	10-Jun	9-Oct	7-Nov-14	26-Feb-15	17-Jul	2-Nov
	IC1	8-Jun	18-Dec	9-Jun	6-Sep	8-Jun	7-Oct	7-Nov-14	20-Mar-15	21-Jul	3-Nov
	WT1	7-Jun	16-Nov	13-Jun	7-Nov	7-Jun	7-Oct	7-Nov-14	16-Nov-14	24-Jul	31-Oct
	PB1	13-Jun	28-Nov	18-Jun	4-Aug	13-Jun	3-Oct	5-Nov-14	28-Nov-14	3-Aug	24-Oct
	BF2	29-Mar	6-Aug	26-Jul	26-Jul	24-Jul	6-Aug	-	-	30-Jul	20-Oct
2015	KZ1	2-Jan	5-Sep	6-Jan	11-Jun	22-Apr	5-Sep	-	-	24-May	27-Nov
	PH1	4-Mar	1-Sep	21-Aug	21-Aug	22-May	1-Sep	-	-	1-Jun	28-Nov
	CL1	6-Mar	19-Sep	7-Jun	28-Jun	24-May	19-Sep	-	-	13-Jun	20-Nov
	IC3	12-Mar	1-Sep	24-Jun	24-Aug	9-Jun	1-Sep	-	-	30-Jun	12-Nov
	IC2	26-Feb	22-Aug	17-Jun	7-Jul	6-Jun	22-Aug	-	-	15-Jun	18-Nov
	IC1	20-Mar	23-Aug	19-Jun	4-Jul	2-Jun	23-Aug	-	-	15-Jun	2-Nov
	WT1	11-Jun	13-Sep	13-Jun	30-Aug	11-Jun	13-Sep	-	-	30-Jun	5-Oct
	PB1	13-Jun	1-Sep	21-Jun	22-Jul	13-Jun	1-Sep	-	-	7-Jul	30-Oct
	BF2	3-Jul	6-Aug	4-Jul	5-Jul	3-Jul	6-Aug	-	-	5-Aug	20-Oct

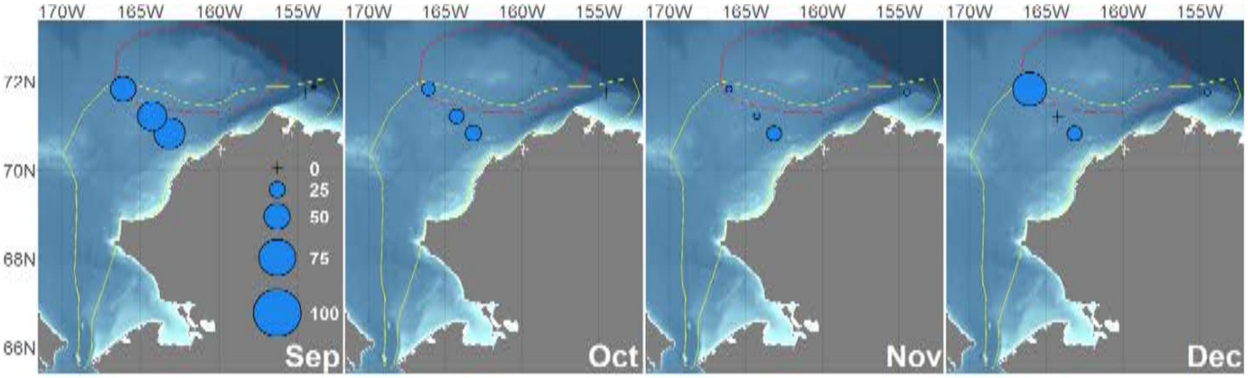


Figure 29. Monthly walrus calling distribution, 2010. Graduated scale in the September panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 6. for numbers used to generate figure.

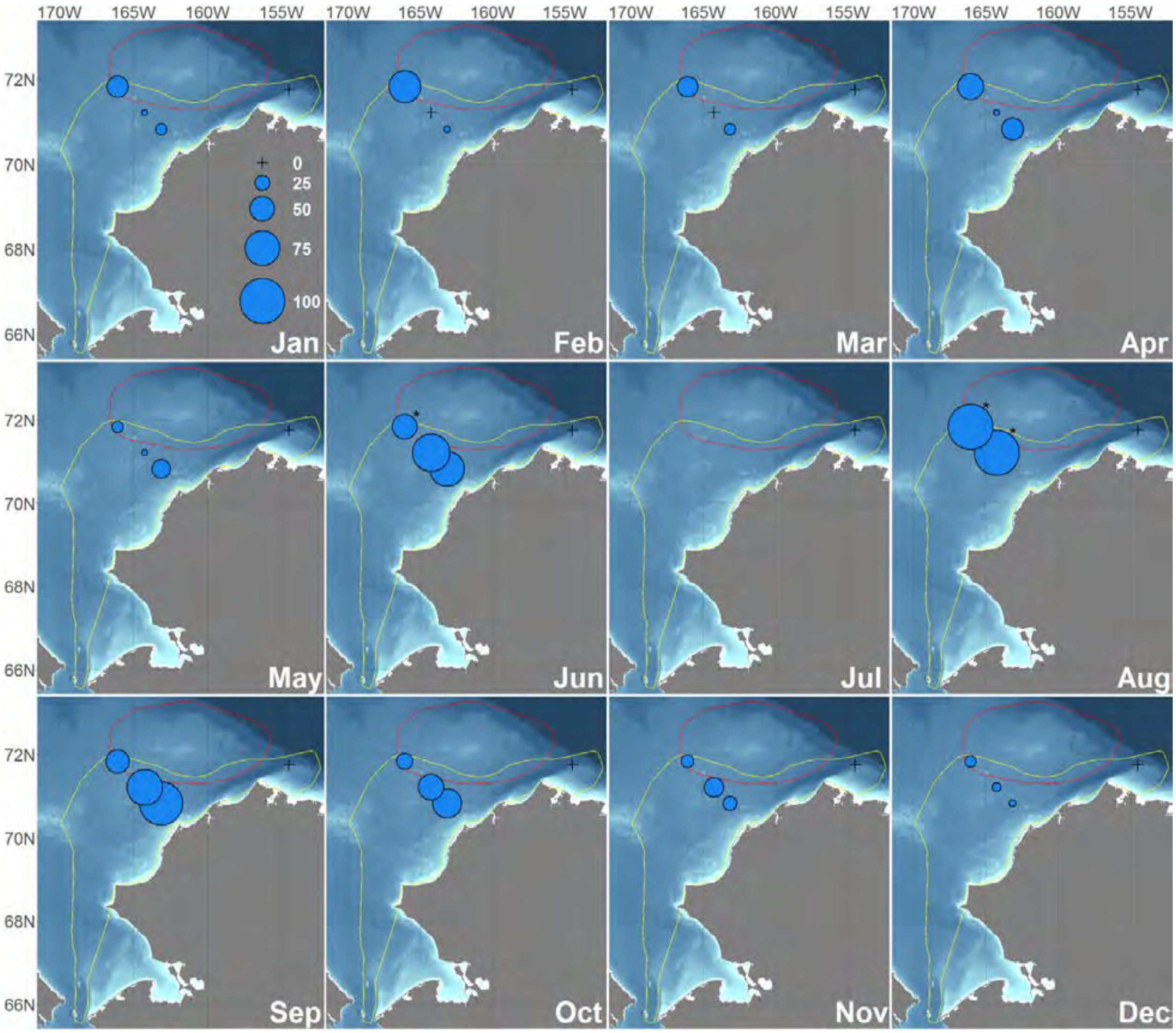


Figure 30. Monthly walrus calling distribution, 2011. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 6. for numbers used to generate figure.

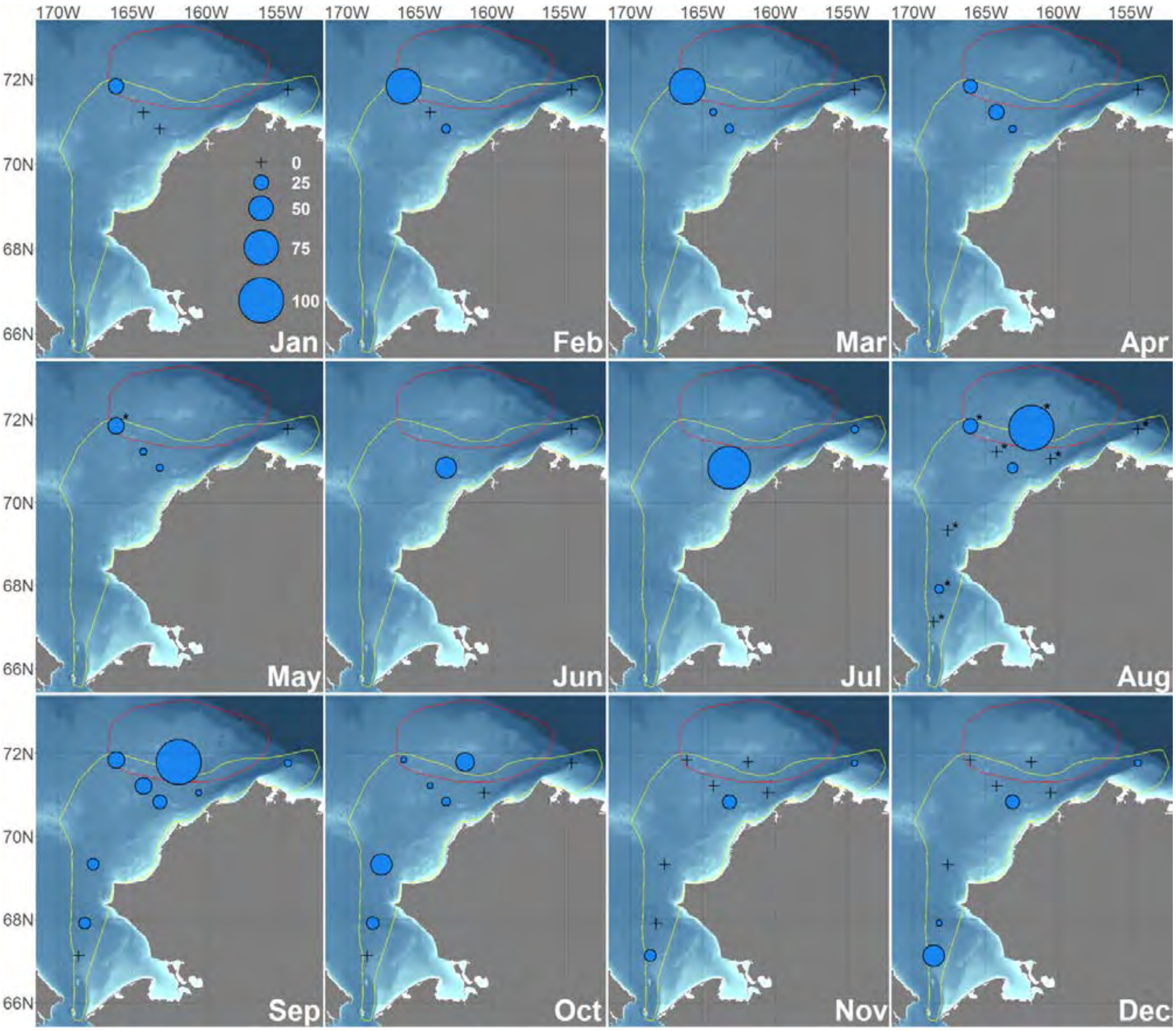


Figure 31. Monthly walrus calling distribution, 2012. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 6. for numbers used to generate figure.

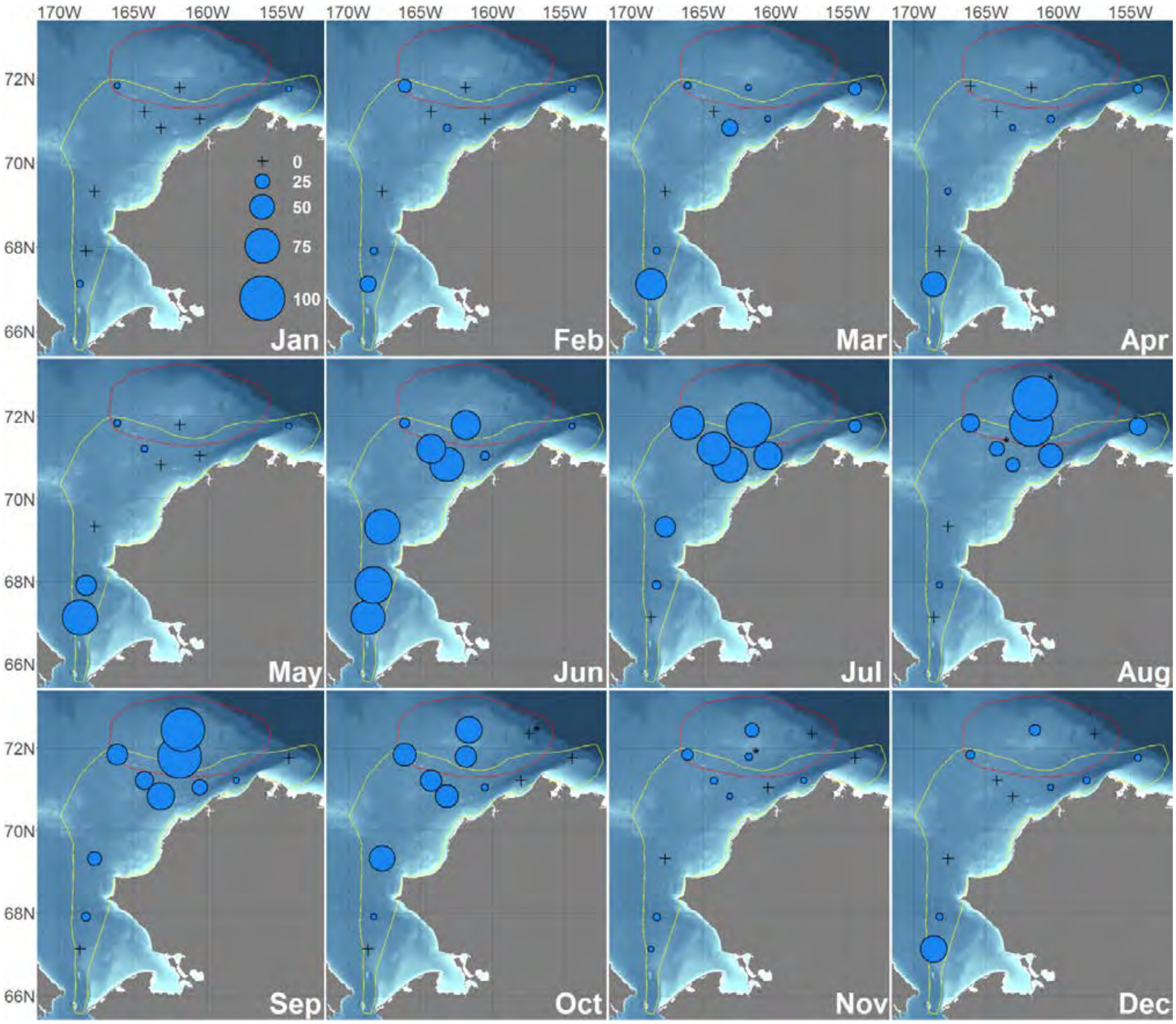


Figure 32. Monthly walrus calling distribution, 2013. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 6. for numbers used to generate figure.

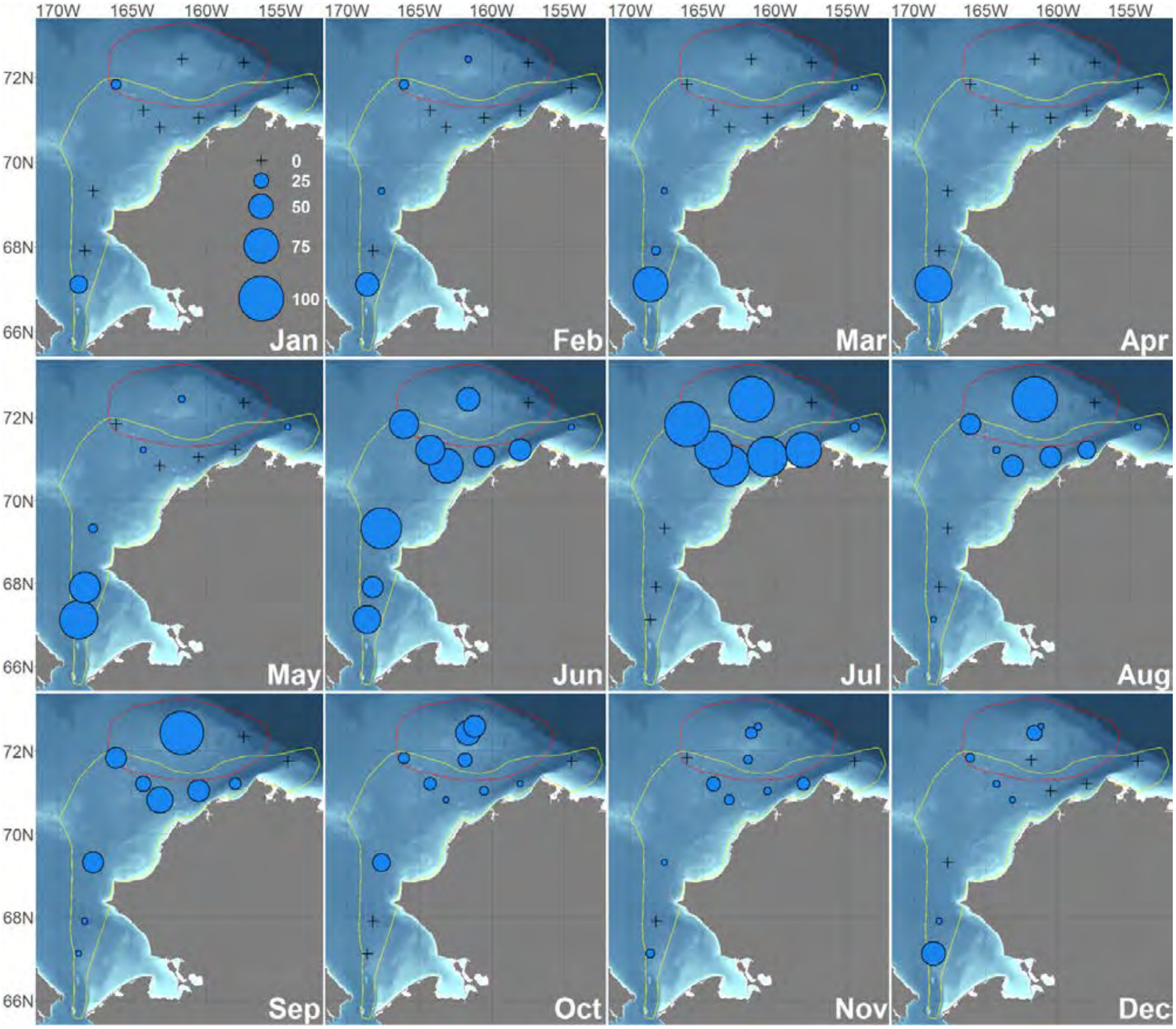


Figure 33. Monthly walrus calling distribution, 2014. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 6. for numbers used to generate figure.

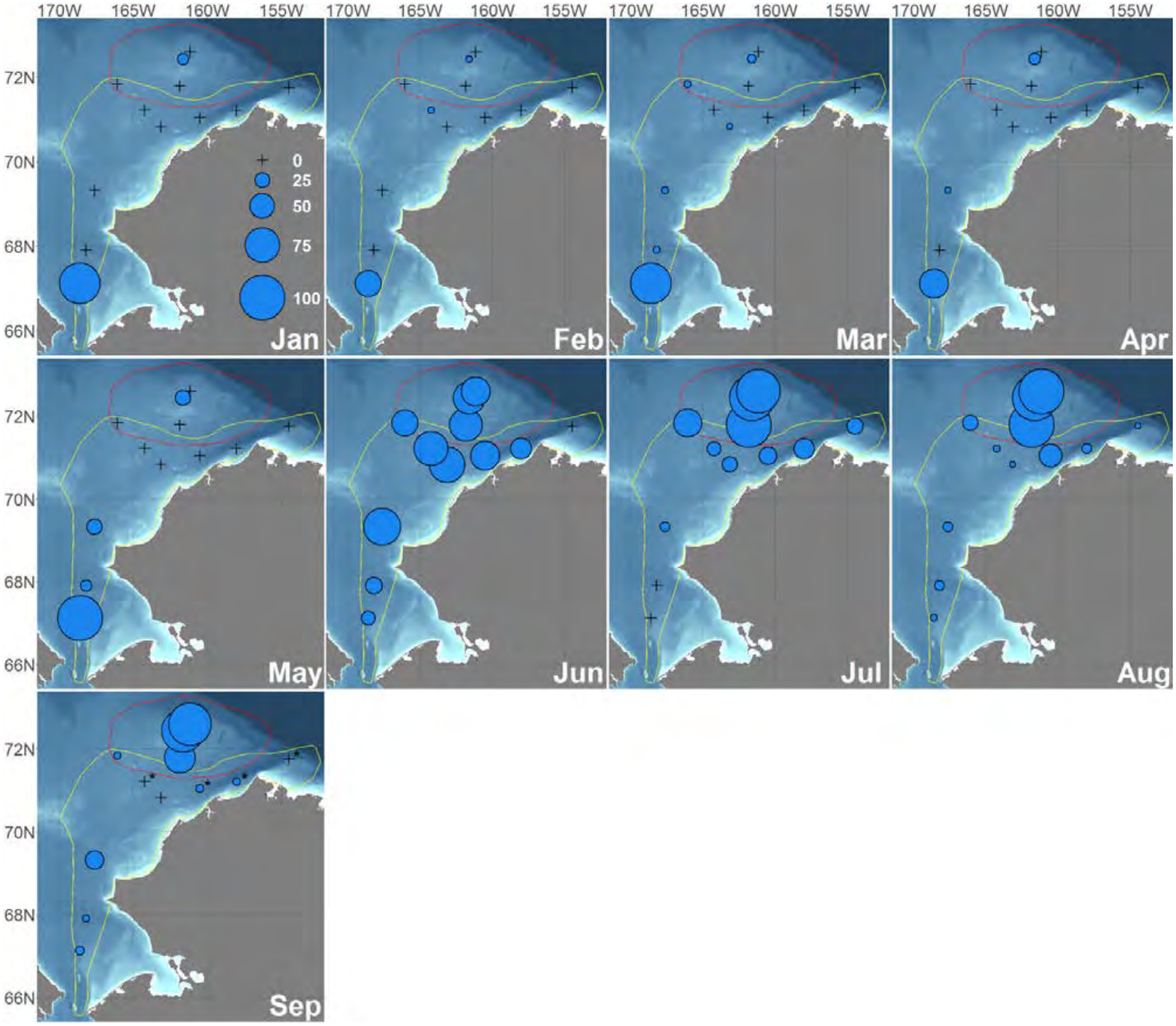


Figure 34. Monthly walrus calling distribution, 2015. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 6. for numbers used to generate figure.

Gray whales

Gray whale calling activity, contrary to that seen for the other Arctic species, was detected on only a few of the ARCWEST mooring sites (Figure 35; Table 2). The sites with the highest percentage of days with calling activity were those in the southern Chukchi Sea (KZ1, PH1, CL1) and at the inshore site between Barrow and Wainwright, AK (Figure 35; Table 15). Peak calling activity also followed this same trend, with almost half of all days with calls at PH1 being peak calling days while only 20% at PB1 were peak calling days (Table 15).

The months with calling activity were similar among mooring sites (Figures 36-41; Table 16). In the southern Chukchi (KZ1, PH1, CL1), calling activity that occurred on more than one day ranged from April through November, while that at the northeastern sites (namely IC1 and PB1) spanned from May through November. Calling activity at the offshore Icy Cape sites (IC2 & IC3) was minimal with a total of 1 and 2 days with calling, respectively, over the entire five years of data collection (Table 16). The same was true for the WT1 and BF2 sites, which had 2 and 0 days with calls detected, respectively.

Similar to the walrus results, gray whales had two periods with calling activity - summer and winter (Figure 35; Table 17). The vast majority of the calling occurred during the summer pulse, between June and November at the southern sites and between August and October at the northeastern sites. Winter calling activity varied among years and locations, but occurred between November and July. The highest number of days with winter calling was at the IC1 site during the 2011 to 2012 overwinter period (10 days), followed by seven days at the KZ1 site during the 2013-2014 period. Two or less days of calling activity was seen on each of the remaining mooring with overwinter calling (IC1, CL1, KZ1, PB1).

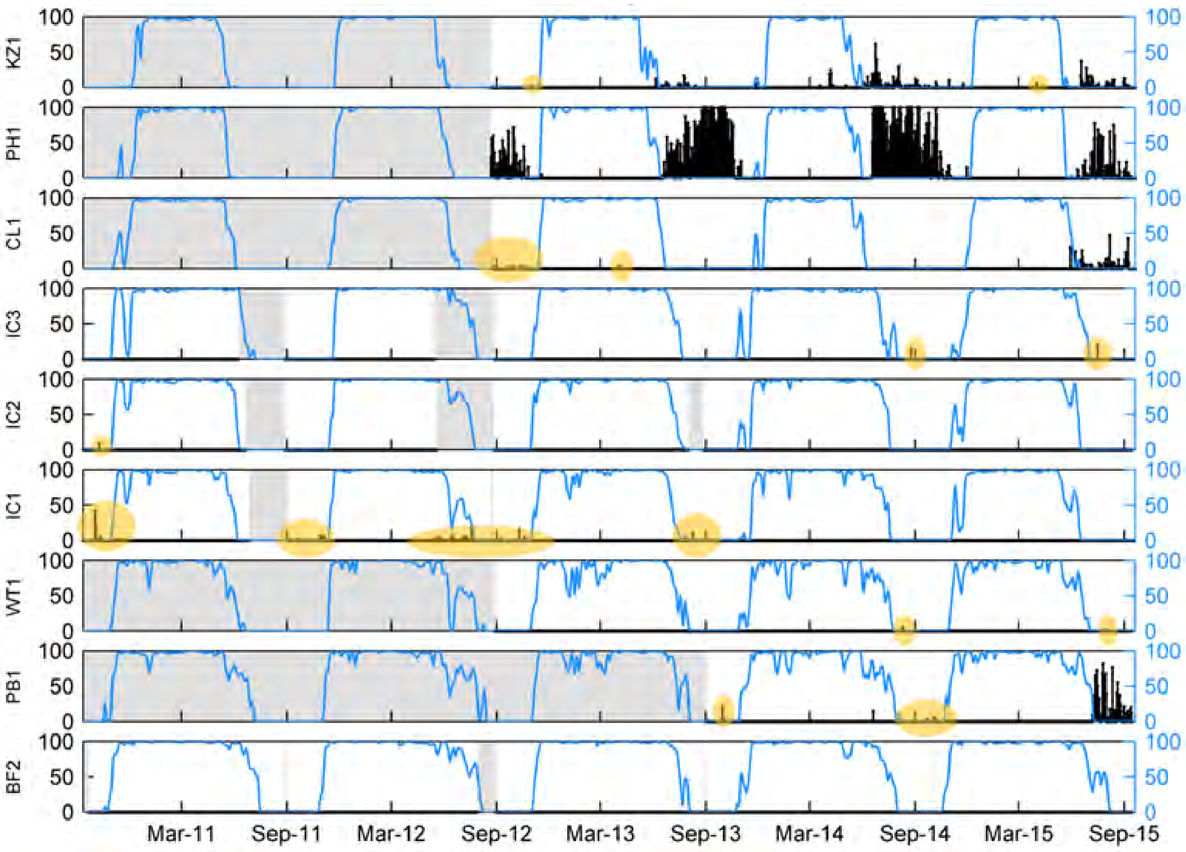


Figure 35. Gray whale calling activity (presented as the percentage of ten-minute time intervals with calls) for the nine ARCWEST locations (see Figure 2A), 2010-2015. Blue line indicates percent ice cover (zero-phase, three-day moving average). Yellow shading highlights low level detections. Gray shading indicates no data.

Table 15. Total gray whale calling activity, 2010-2015, for all ARCWEST 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
KZ1	1126	107	1	10	<1
PH1	1125	368	152	33	14
CL1	1123	51	0	5	0
IC3	1647	2	0	<1	0
IC2	1636	1	0	<1	0
IC1	1765	25	0	1	0
WT1	1110	2	0	<1	0
PB1	742	56	11	8	1
BF2	1784	0	0	0	0

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

Month	KZ1			PH1			CL1			IC3			IC2			IC1			WT1			PB1			BF2		
	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%
Jan	0	93	**0**	0	93	**0**	0	93	**0**	0	155	**0**	0	155	**0**	0	155	**0**	0	93	**0**	0	62	**0**	0	155	**0**
Feb	0	84	**0**	0	84	**0**	0	84	**0**	0	141	**0**	0	141	**0**	0	141	**0**	0	84	**0**	0	56	**0**	0	141	**0**
Mar	1	93	**1**	0	93	**0**	0	93	**0**	0	155	**0**	0	155	**0**	0	155	**0**	0	93	**0**	0	62	**0**	0	155	**0**
Apr	5	90	**6**	0	90	**0**	1	90	**1**	0	150	**0**	0	150	**0**	0	150	**0**	0	90	**0**	0	60	**0**	0	150	**0**
May	2	93	**2**	0	93	**0**	1	93	**1**	0	138	**0**	0	143	**0**	2	155	**1**	0	93	**0**	0	62	**0**	0	155	**0**
Jun	34	90	**38**	35	90	**39**	10	90	**11**	0	98	**0**	0	111	**0**	3	147	**2**	0	90	**0**	1	60	**2**	0	150	**0**
Jul	28	93	**30**	85	93	**91**	9	93	**10**	1	93	**1**	0	93	**0**	5	124	**4**	1	93	**1**	22	62	**35**	0	153	**0**
Aug	20	103	**19**	88	103	**85**	18	102	**18**	1	99	**1**	0	74	**0**	1	121	**1**	1	95	**1**	19	62	**31**	0	123	**0**
Sep	10	111	**9**	90	110	**82**	10	109	**9**	0	158	**0**	0	154	**0**	2	157	**1**	0	103	**0**	11	72	**15**	0	142	**0**
Oct	3	93	**3**	66	93	**71**	2	93	**2**	0	155	**0**	1	155	**1**	8	155	**5**	0	93	**0**	3	62	**5**	0	155	**0**
Nov	4	90	**4**	4	90	**4**	0	90	**0**	0	150	**0**	0	150	**0**	4	150	**3**	0	90	**0**	0	60	**0**	0	150	**0**
Dec	0	93	**0**	0	93	**0**	0	93	**0**	0	155	**0**	0	155	**0**	0	155	**0**	0	93	**0**	0	62	**0**	0	155	**0**

Table 17. Key timing events for gray 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 35.

Year	Mooring	Calling		Peak Calling		Summer Pulse*		Winter Pulse*		Ice End Date	Ice Start Date
		Start	End	Start	End	Start	End	Start	End		
2010	IC2	8-Oct	8-Oct	-	-	8-Oct	8-Oct	-	-	4-Jun	31-Oct
	IC1	1-Oct	9-Nov	-	-	1-Oct	11-Oct	11/9/2010	11/9/2010	2-Jun	23-Oct
2011	IC1	20-Sep	5-Nov	-	-	20-Sep	5-Nov	5/16/2012	7/21/2012	4-Jun	12-Nov
2012	KZ1	1-Nov	13-Nov	-	-	1-Nov	13-Nov	-	-	9-Jun	16-Nov
	PH1	22-Aug	18-Nov	23-Aug	1-Oct	22-Aug	18-Nov	-	-	17-Jun	16-Nov
	CL1	29-Aug	18-Oct	-	-	29-Aug	18-Oct	4/4/2013	4/4/2013	27-Jun	14-Nov
	IC1	16-May	19-Oct	-	-	8-Sep	19-Oct	-	-	24-Jul	1-Nov
2013	KZ1	5-Jun	27-Nov	-	-	5-Jun	13-Aug	11/27/2013	5/3/2014	8-Jun	26-Nov
	PH1	16-Jun	1-Nov	25-Jun	18-Oct	16-Jun	1-Nov	-	-	11-Jun	25-Nov
	CL1	4-Apr	4-Apr	-	-	-	-	-	-	21-Jun	24-Nov
	IC1	9-Aug	9-Aug	-	-	9-Aug	9-Aug	-	-	27-Jul	30-Oct
	PB1	30-Sep	1-Oct	-	-	30-Sep	1-Oct	6/20/2014	6/20/2014	1-Aug	31-Oct
2014	KZ1	19-Mar	24-Nov	24-Jun	24-Jun	4-Jun	24-Nov	4/1/2015	5/25/2015	30-May	11-Dec
	PH1	17-Jun	30-Nov	18-Jun	9-Oct	17-Jun	30-Nov	-	-	30-May	7-Dec
	IC3	25-Aug	25-Aug	-	-	25-Aug	25-Aug	-	-	30-Jul	3-Nov
	WT1	10-Aug	10-Aug	-	-	10-Aug	10-Aug	-	-	24-Jul	31-Oct
	PB1	20-Jun	5-Oct	-	-	6-Aug	5-Oct	-	-	3-Aug	24-Oct
2015	KZ1	1-Apr	8-Sep	-	-	17-Jun	8-Sep	-	-	24-May	27-Nov
	PH1	11-Jun	12-Sep	10-Jul	15-Aug	11-Jun	12-Sep	-	-	1-Jun	28-Nov
	CL1	30-May	8-Sep	-	-	30-May	8-Sep	-	-	13-Jun	20-Nov
	IC3	16-Jul	16-Jul	-	-	16-Jul	16-Jul	-	-	30-Jun	12-Nov
	WT1	30-Jul	30-Jul	-	-	30-Jul	30-Jul	-	-	30-Jun	5-Oct
	PB1	7-Jul	13-Sep	12-Jul	20-Aug	7-Jul	13-Sep	-	-	7-Jul	30-Oct

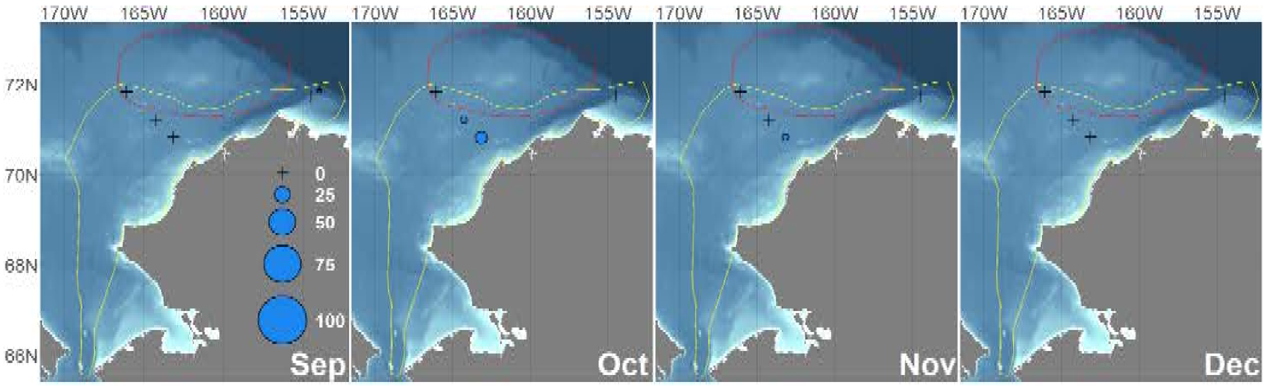


Figure 36. Monthly gray whale calling distribution, 2010. Graduated scale in the September panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 7. for numbers used to generate figure.

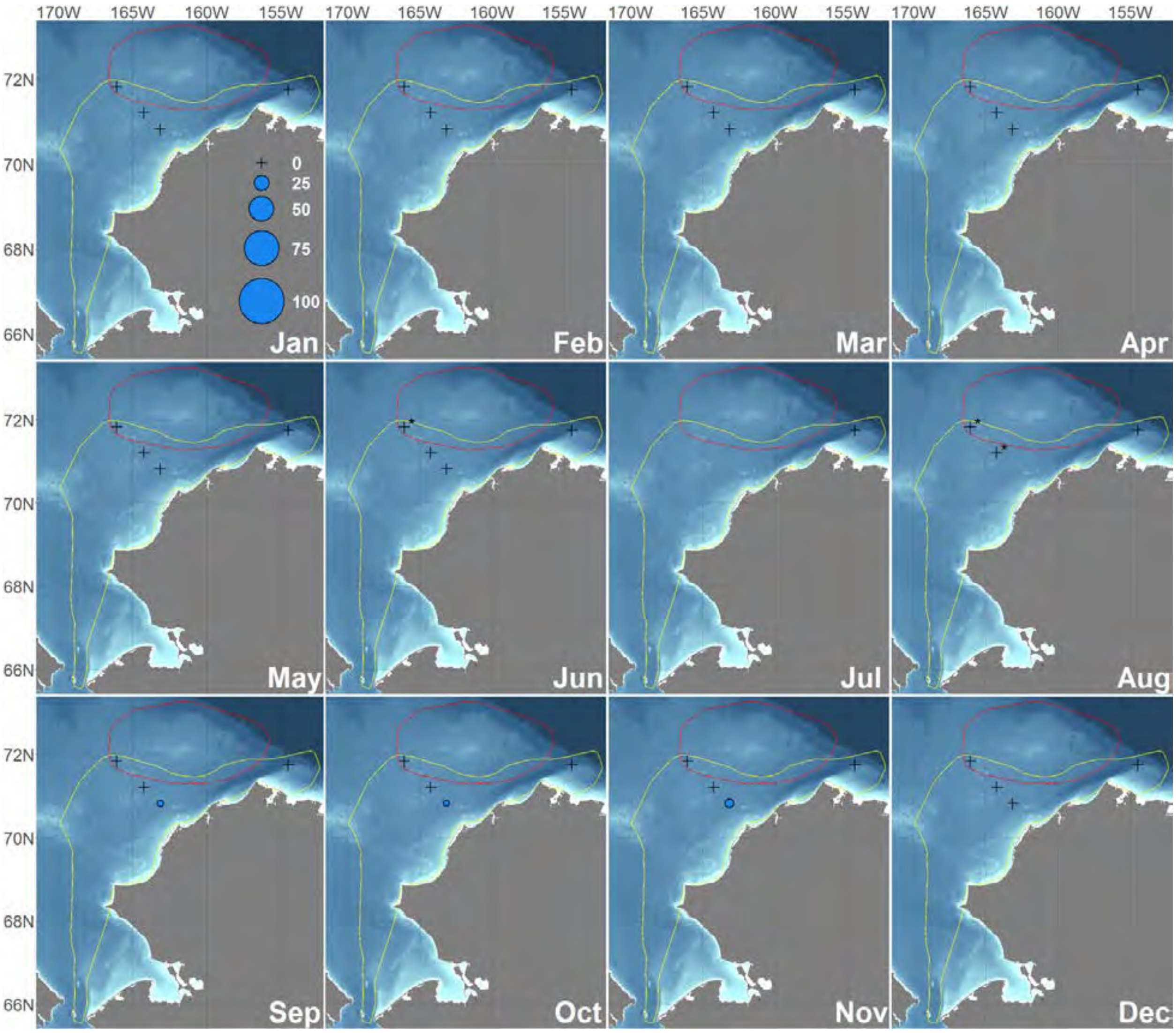


Figure 37. Monthly gray whale calling distribution, 2011. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 7. for numbers used to generate figure.

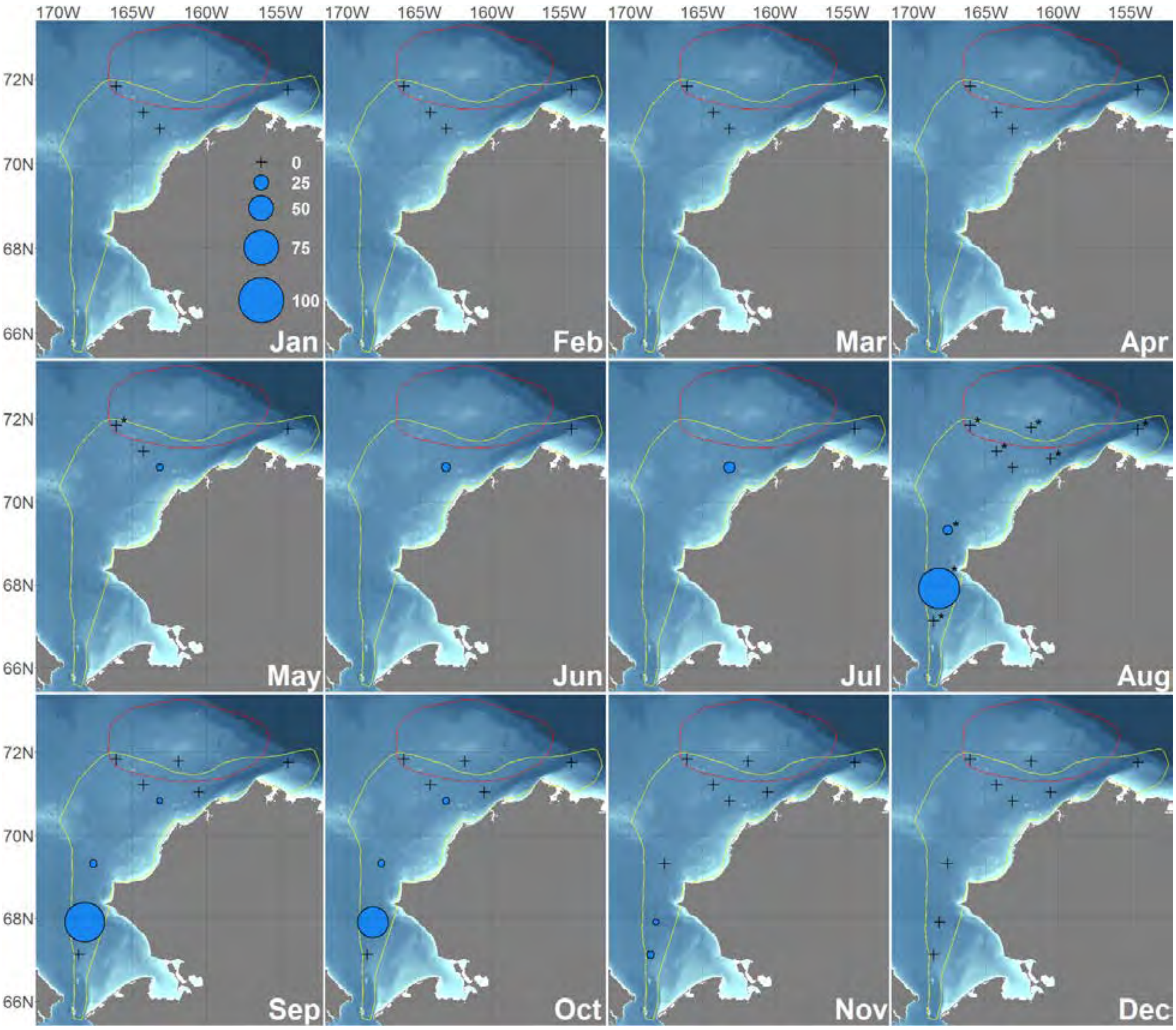


Figure 38. Monthly gray whale calling distribution, 2012. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 7. for numbers used to generate figure.

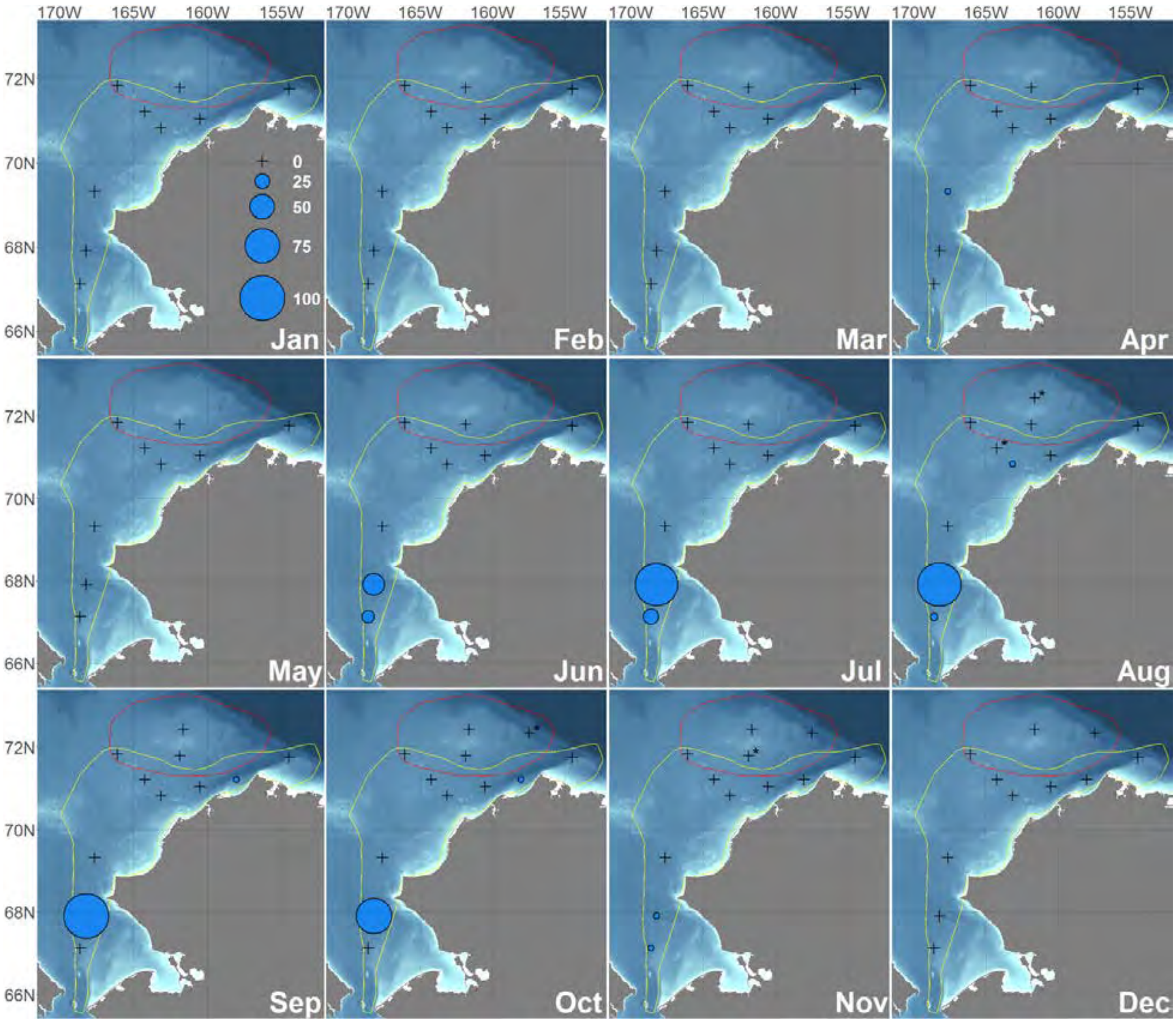


Figure 39. Monthly gray whale calling distribution, 2013. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 7. for numbers used to generate figure.

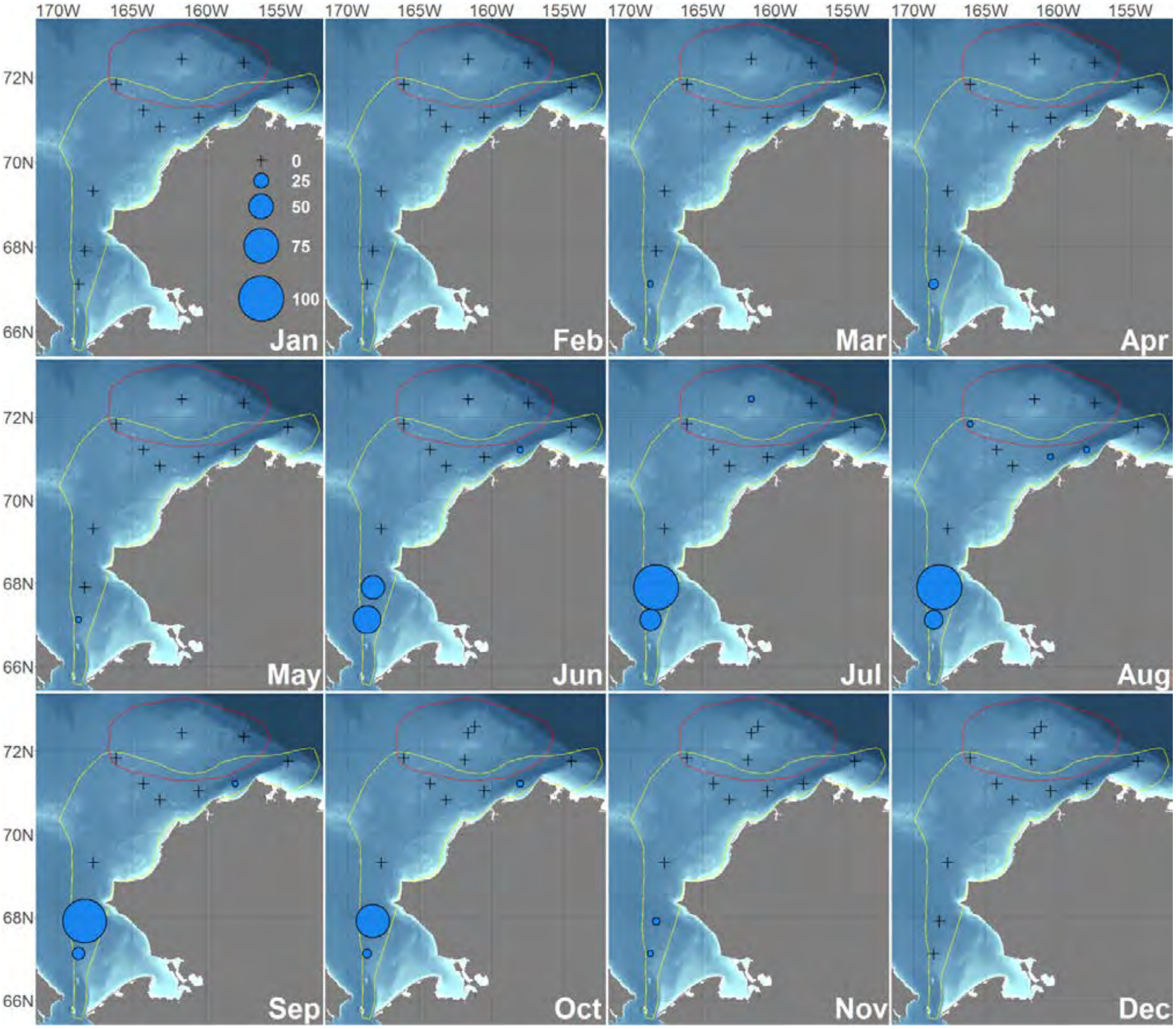


Figure 40. Monthly gray whale calling distribution, 2014. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 7. for numbers used to generate figure.

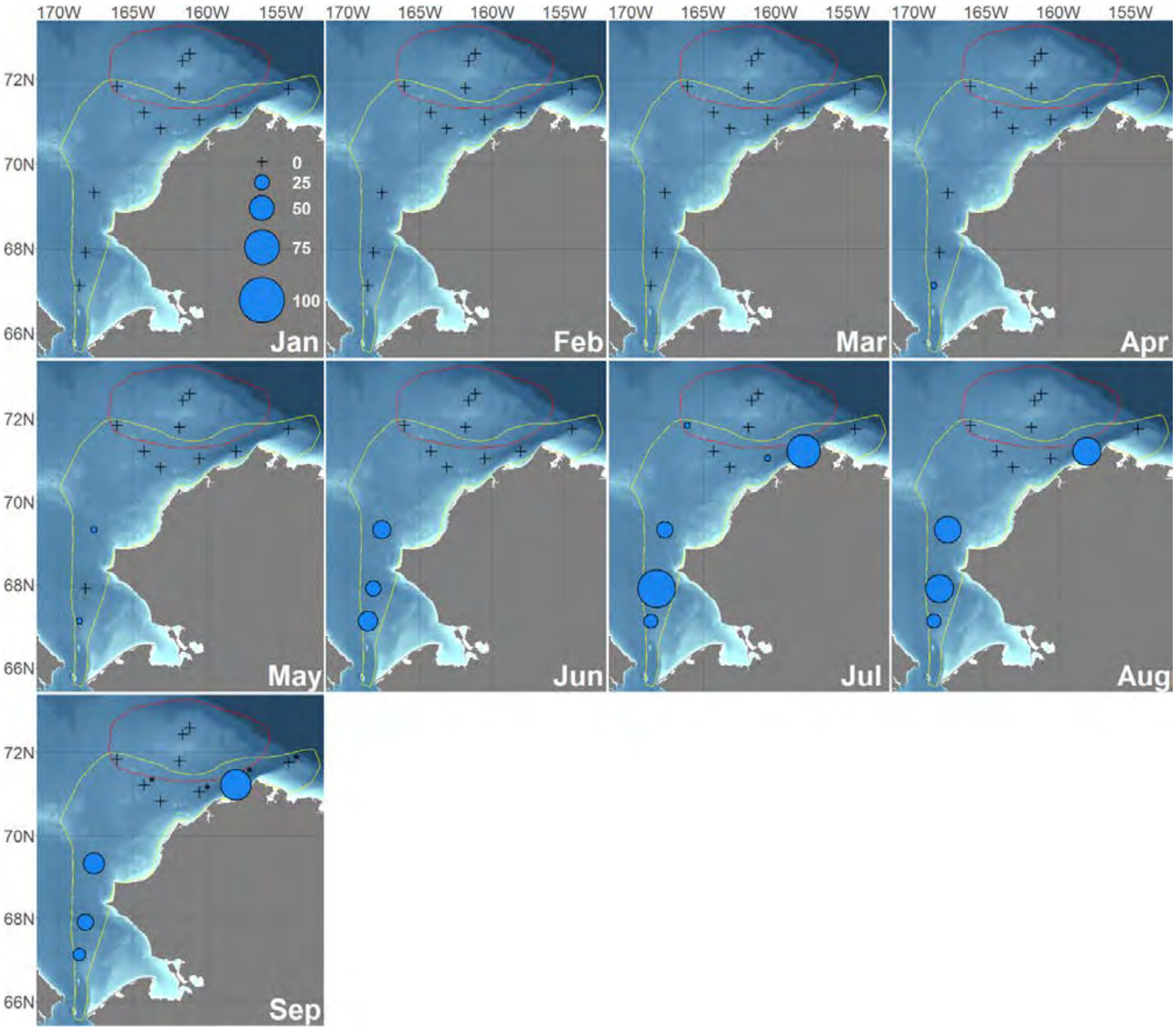


Figure 41. Monthly gray whale calling distribution, 2015. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 7. for numbers used to generate figure.

Subarctic species

Because the ARCWEST study area encompassed the southern Chukchi Sea, several subarctic species (humpback, fin, killer, and minke whales, and ribbon seals) were detected in varying levels over primarily the open water (summer) season. A variety of pinniped grunts, yelps, and barks were detected but not identified to species. 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 and tables are not included in this report. The rest of the species analyzed (sperm and right whales) did not have any calling activity detected.

Humpback whales

Humpback whales were detected at all three moorings in the southern Chukchi Sea (KZ1, PH1, CL1) and off Wainwright (WT1) and Icy Cape (IC3) in the northeastern Chukchi. The number of days with humpback calling activity decreased northward (Figure 42; Table 18). The percentage of days with calling that were at peak calling levels was low - with the KZ1 mooring having the maximum at 4% (Table 18). Humpback calling was detected from June through November; no overwintering calls were detected at any site in any year (Figures 43-48; Table 19). In addition, no consistent trends were seen in the start and end dates for the calling activity pulses among mooring sites or years (Table 20).

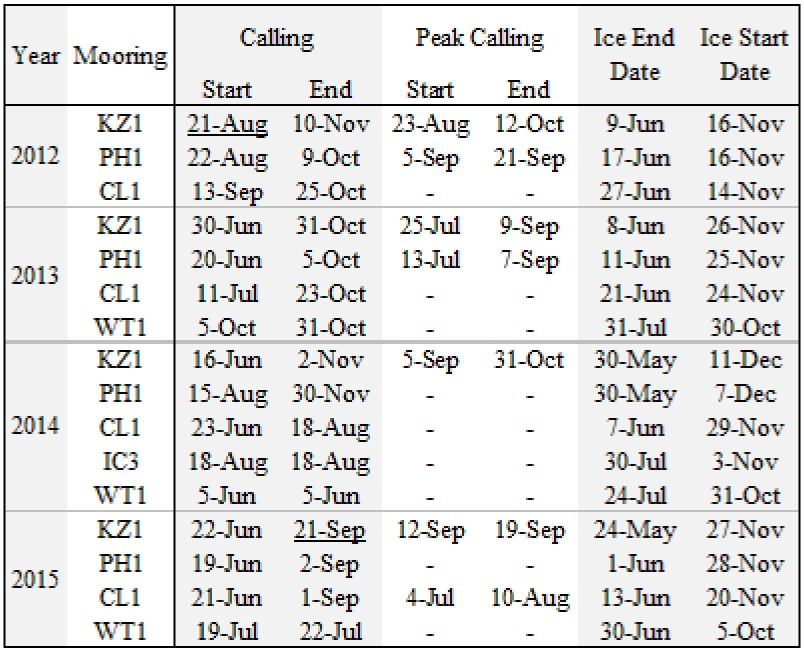
Table 18. Total humpback whale calling activity, 2010-2015, for all ARCWEST mooring locations. Number of days with recordings (Eff), number of days with calling activity (#), number of days with calling activity > 50% (#pk), percent of days with calling activity.

Mooring	Eff	#	# pk	%	% pk
KZ1	1126	206	45	18	4
PH1	1125	133	15	12	1
CL1	1123	44	3	4	<1
IC3	1647	1	0	<1	0
IC2	1636	0	0	0	0
IC1	1765	0	0	0	0
WT1	1110	6	0	1	0
PB1	742	0	0	0	0
BF2	1784	0	0	0	0

Table 19. Average monthly humpback whale calling activity, 2010-2015, for all ARCWEST mooring locations. Number of days with calling activity (#), number of days with recordings (Eff), percent of days with calling activity per month (%).

Month	KZ1			PH1			CL1			IC3			IC2			IC1			WT1			PB1			BF2		
	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%
Jan	0	93	**0**	0	93	**0**	0	93	**0**	0	155	**0**	0	155	**0**	0	155	**0**	0	93	**0**	0	62	**0**	0	155	**0**
Feb	0	84	**0**	0	84	**0**	0	84	**0**	0	141	**0**	0	141	**0**	0	141	**0**	0	84	**0**	0	56	**0**	0	141	**0**
Mar	0	93	**0**	0	93	**0**	0	93	**0**	0	155	**0**	0	155	**0**	0	155	**0**	0	93	**0**	0	62	**0**	0	155	**0**
Apr	0	90	**0**	0	90	**0**	0	90	**0**	0	150	**0**	0	150	**0**	0	150	**0**	0	90	**0**	0	60	**0**	0	150	**0**
May	0	93	**0**	0	93	**0**	0	93	**0**	0	138	**0**	0	143	**0**	0	155	**0**	0	93	**0**	0	62	**0**	0	155	**0**
Jun	9	90	**10**	3	90	**3**	3	90	**3**	0	98	**0**	0	111	**0**	0	147	**0**	1	90	**1**	0	60	**0**	0	150	**0**
Jul	30	93	**32**	23	93	**25**	15	93	**16**	0	93	**0**	0	93	**0**	0	124	**0**	2	93	**2**	0	62	**0**	0	153	**0**
Aug	49	103	**48**	40	103	**39**	17	102	**17**	1	99	**1**	0	74	**0**	0	121	**0**	0	95	**0**	0	62	**0**	0	123	**0**
Sep	66	111	**59**	56	110	**51**	5	109	**5**	0	158	**0**	0	154	**0**	0	157	**0**	0	103	**0**	0	72	**0**	0	142	**0**
Oct	50	93	**54**	10	93	**11**	4	93	**4**	0	155	**0**	0	155	**0**	0	155	**0**	3	93	**3**	0	62	**0**	0	155	**0**
Nov	2	90	**2**	1	90	**1**	0	90	**0**	0	150	**0**	0	150	**0**	0	150	**0**	0	90	**0**	0	60	**0**	0	150	**0**
Dec	0	93	**0**	0	93	**0**	0	93	**0**	0	155	**0**	0	155	**0**	0	155	**0**	0	93	**0**	0	62	**0**	0	155	**0**

Table 20. Key timing events for humpback 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 42.



Year	Mooring	Calling		Peak Calling		Ice End Date	Ice Start Date
		Start	End	Start	End		
2012	KZ1	21-Aug	10-Nov	23-Aug	12-Oct	9-Jun	16-Nov
	PH1	22-Aug	9-Oct	5-Sep	21-Sep	17-Jun	16-Nov
	CL1	13-Sep	25-Oct	-	-	27-Jun	14-Nov
2013	KZ1	30-Jun	31-Oct	25-Jul	9-Sep	8-Jun	26-Nov
	PH1	20-Jun	5-Oct	13-Jul	7-Sep	11-Jun	25-Nov
	CL1	11-Jul	23-Oct	-	-	21-Jun	24-Nov
	WT1	5-Oct	31-Oct	-	-	31-Jul	30-Oct
2014	KZ1	16-Jun	2-Nov	5-Sep	31-Oct	30-May	11-Dec
	PH1	15-Aug	30-Nov	-	-	30-May	7-Dec
	CL1	23-Jun	18-Aug	-	-	7-Jun	29-Nov
	IC3	18-Aug	18-Aug	-	-	30-Jul	3-Nov
	WT1	5-Jun	5-Jun	-	-	24-Jul	31-Oct
2015	KZ1	22-Jun	21-Sep	12-Sep	19-Sep	24-May	27-Nov
	PH1	19-Jun	2-Sep	-	-	1-Jun	28-Nov
	CL1	21-Jun	1-Sep	4-Jul	10-Aug	13-Jun	20-Nov
	WT1	19-Jul	22-Jul	-	-	30-Jun	5-Oct

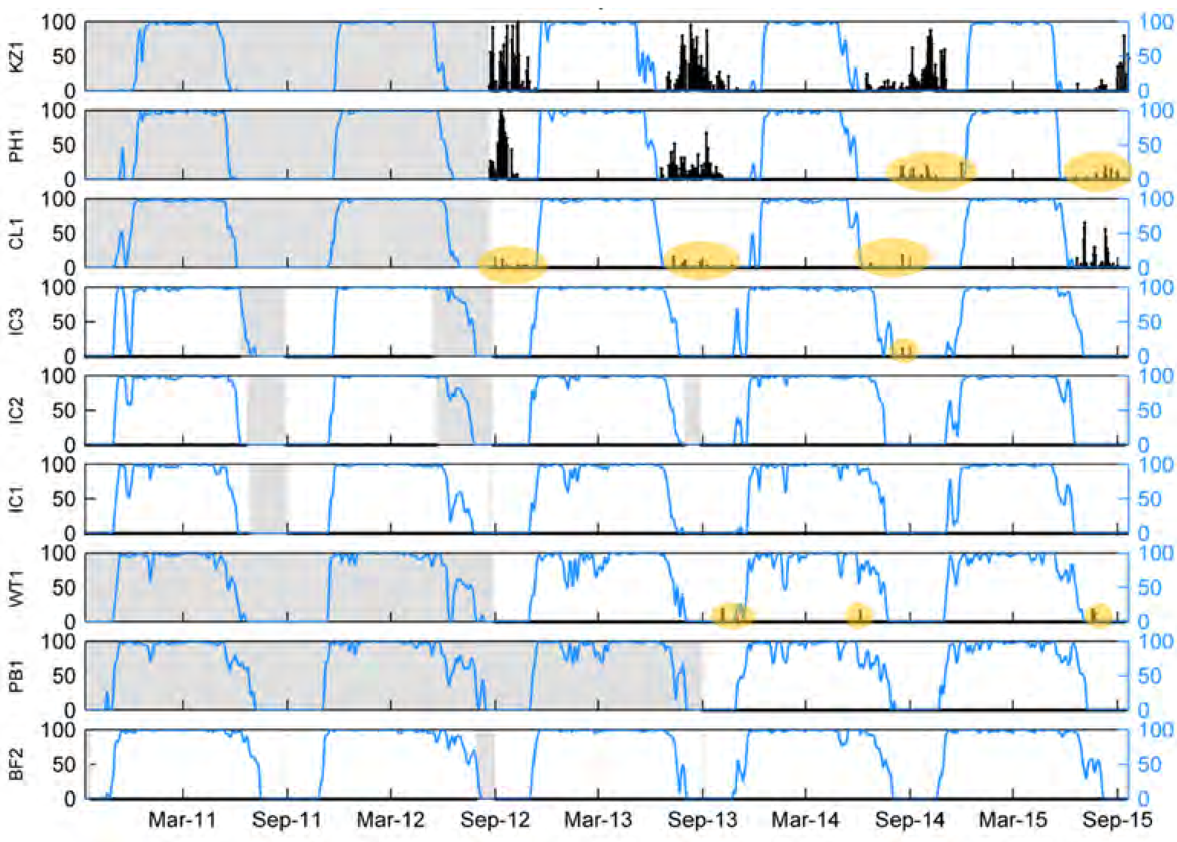


Figure 42. Humpback whale calling activity (presented as the percentage of ten-minute time intervals with calls) for the nine ARCWEST locations (see Figure 2), 2010-2015. Blue line indicates percent ice cover (zero-phase, three-day moving average). Yellow shading highlights low level detections. Gray shading indicates no data.

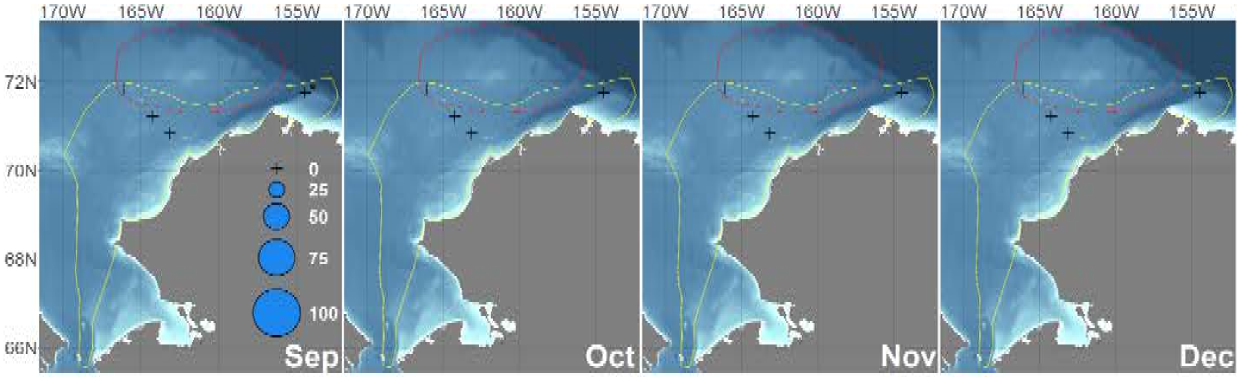


Figure 43. Monthly humpback whale calling distribution, 2010. Graduated scale in the September panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 8. for numbers used to generate figure.

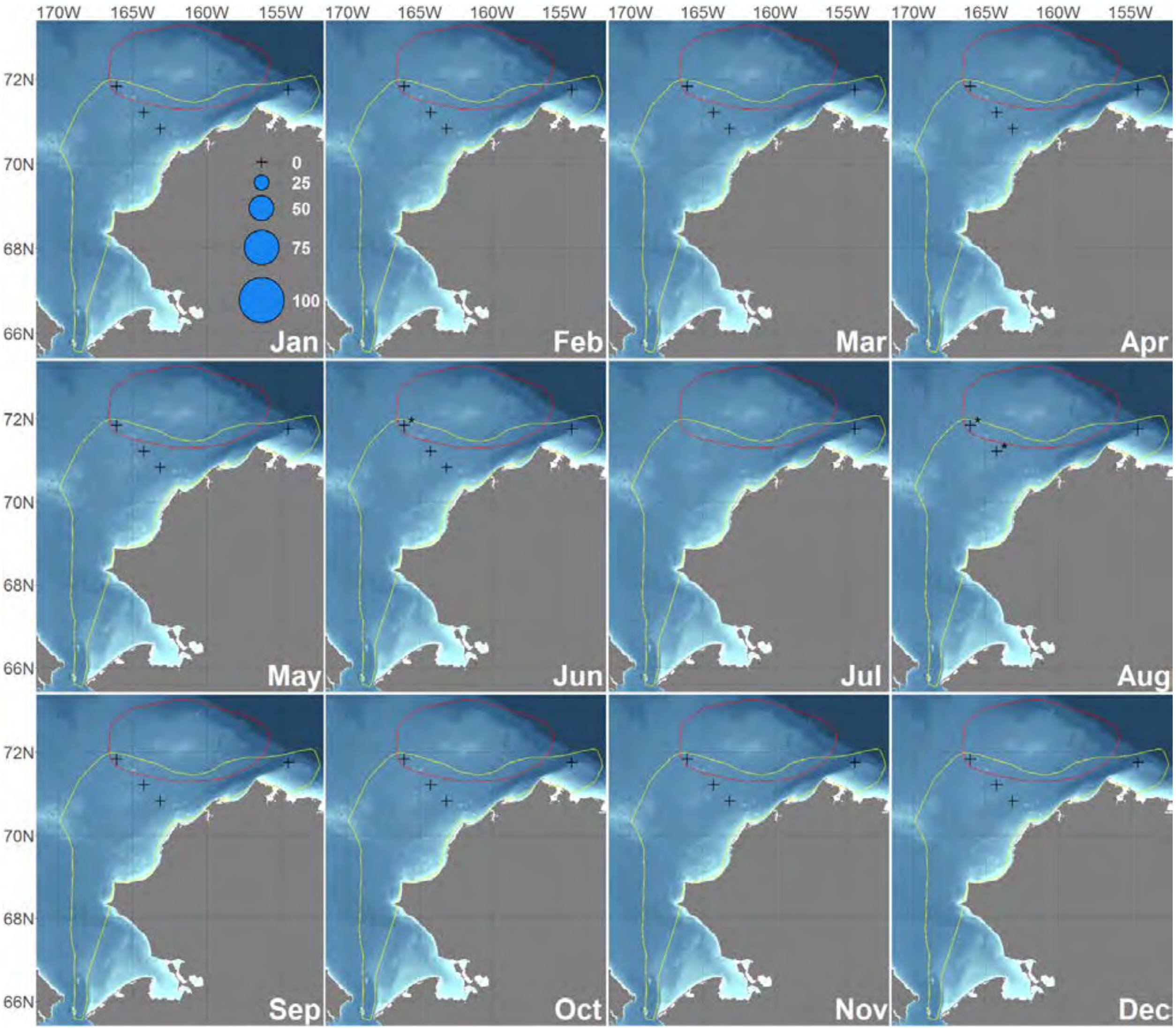


Figure 44. Monthly humpback whale calling distribution, 2011. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 8. for numbers used to generate figure.

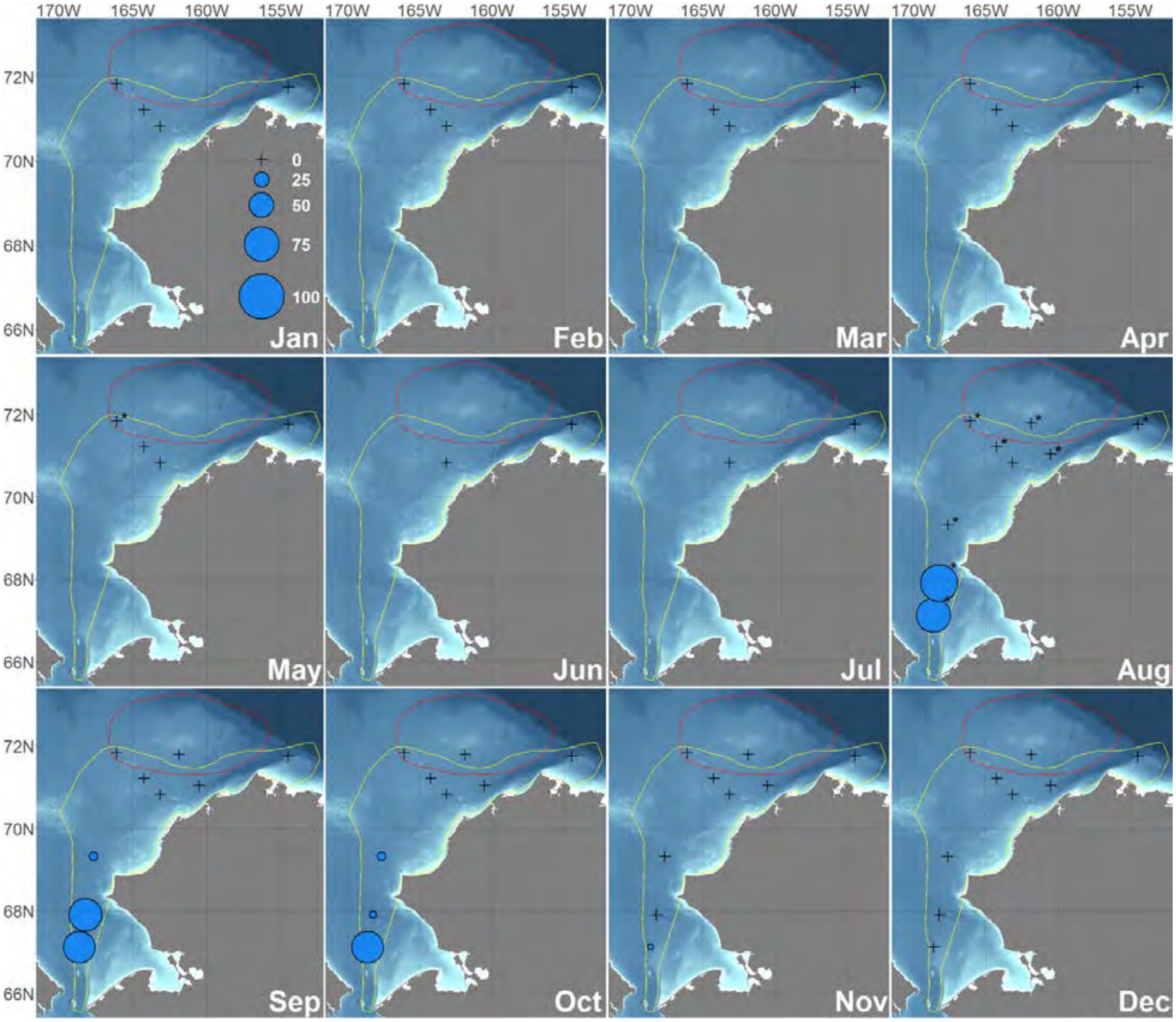


Figure 45. Monthly humpback whale calling distribution, 2012. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 8. for numbers used to generate figure.

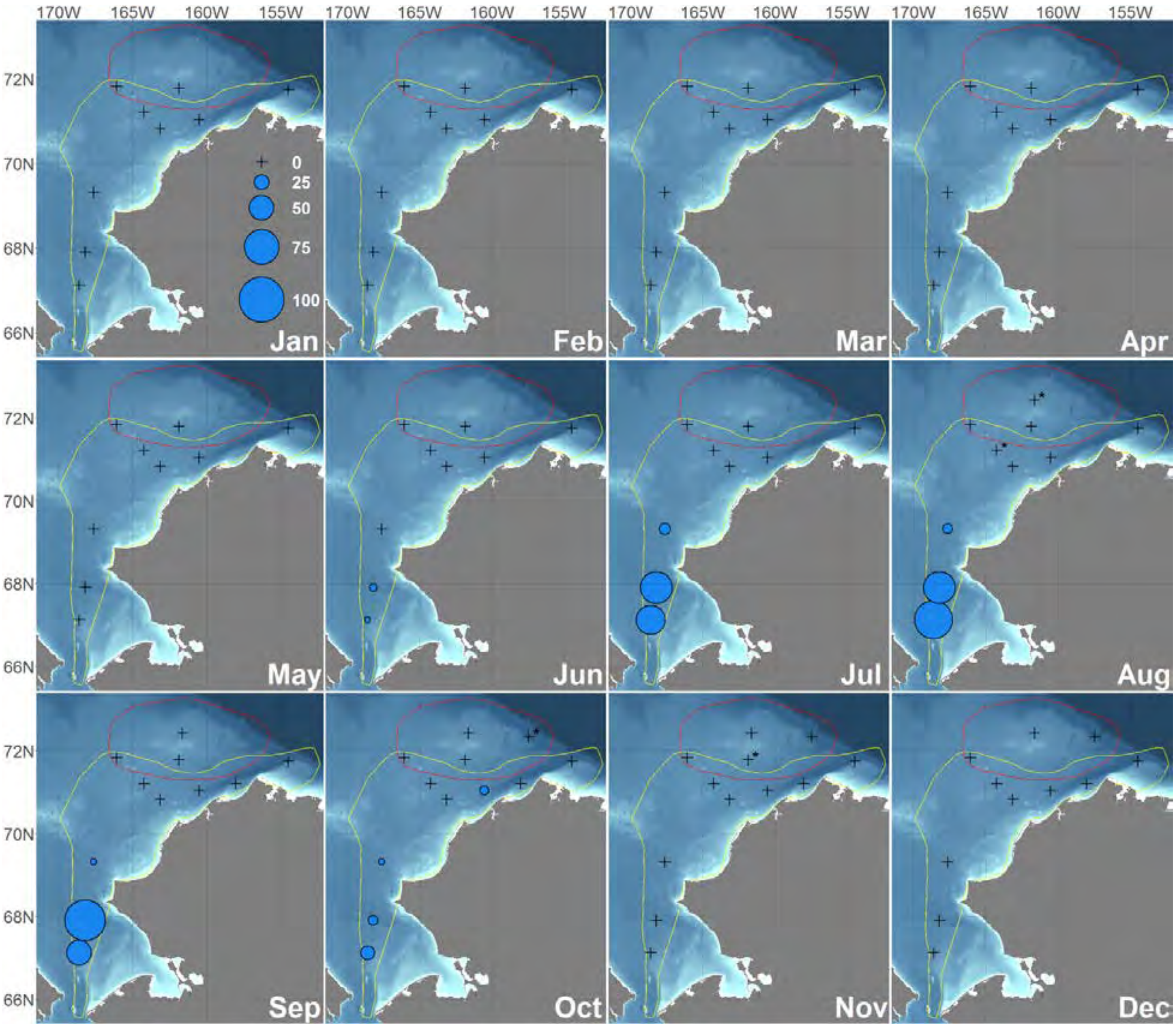


Figure 46. Monthly humpback whale calling distribution, 2013. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 8. for numbers used to generate figure.

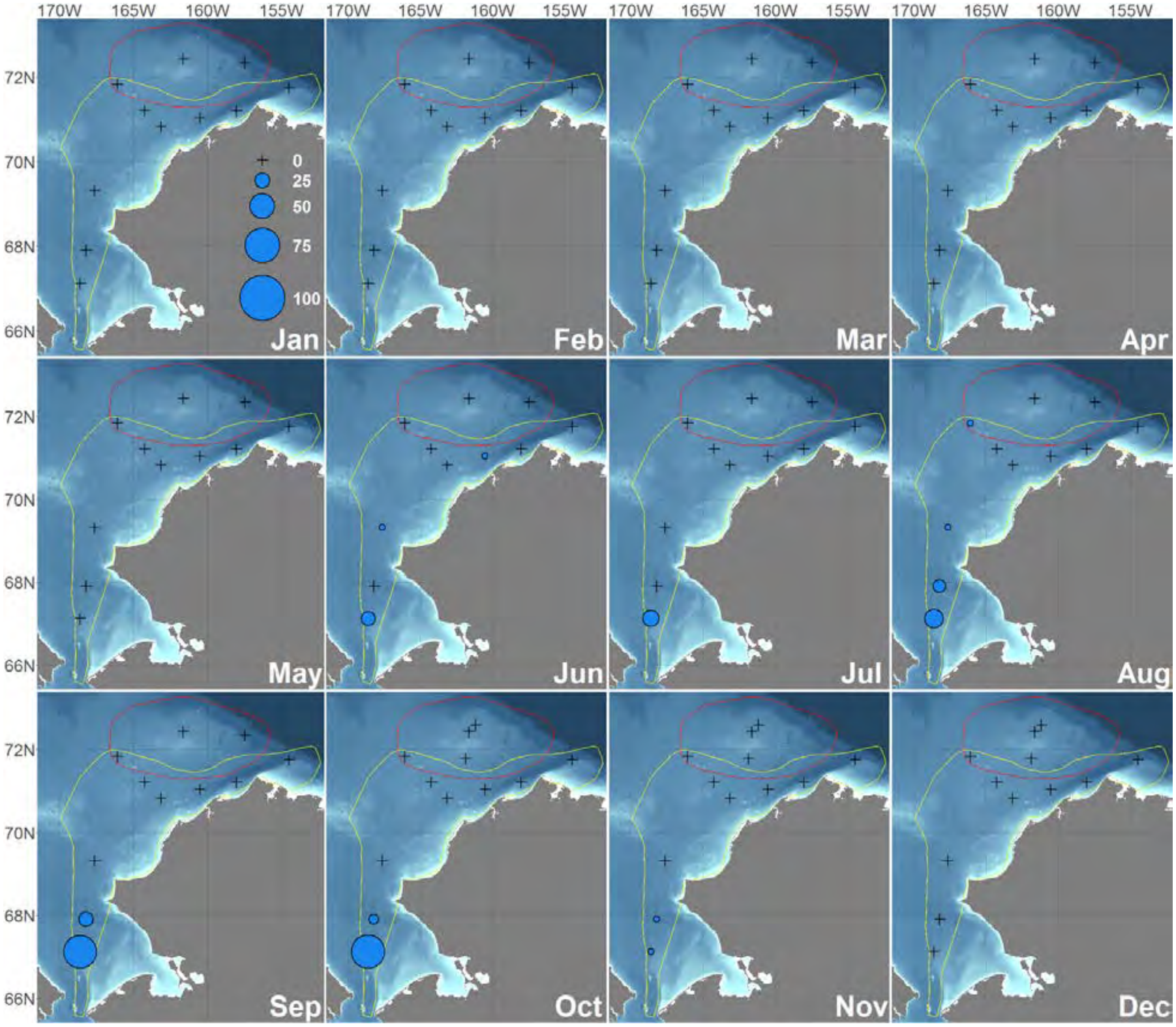


Figure 47. Monthly humpback whale calling distribution, 2014. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 8. for numbers used to generate figure.

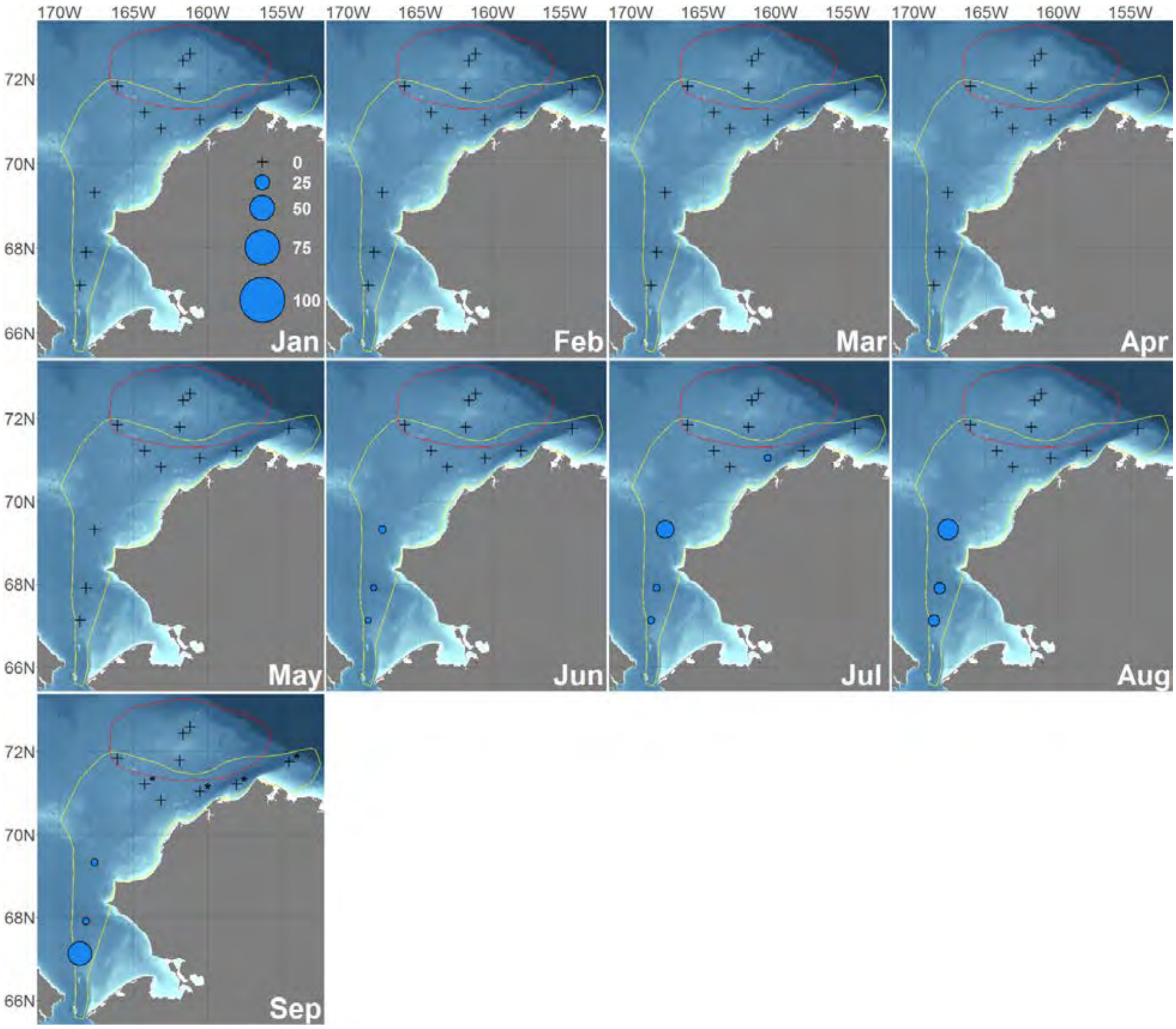


Figure 48. Monthly humpback whale calling distribution, 2015. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 8. for numbers used to generate figure.

Fin whales

As mentioned above, analysis for fin whales was completed on just two years each of two mooring sites (CL1, and PH1), plus two years each of three sites (IC1-3) were analyzed for the CHAOZ project. For these five mooring sites, only two (PH1 and CL1) contained fin whale detections (Figure 49; Table 21). The percentage of days with calling was moderate, however, with calls occurring on approximately 10-20% of all days analyzed (Table 21). Of these days with calling activity, approximately 5% were at peak calling levels (Table 21). Calling was detected between June and November at the more southern site (PH1) and between July and October for CL1 which was further to the northeast (Figures 50-52; Table 22); no calling was detected overwinter at any site during any year. The data currently suggest that start dates are fairly consistent among years for a particular mooring site, with the ending dates also close among mooring sites (Table 23).

Table 21. Total fin whale calling activity, 2010-2014, for completed ARCWEST 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
KZ1	0	0	0	NaN	NaN
PH1	755	163	49	22	6
CL1	763	107	27	14	4
IC3	532	0	0	0	0
IC2	550	0	0	0	0
IC1	646	0	0	0	0
WT1	0	0	0	NaN	NaN
PB1	0	0	0	NaN	NaN
BF2	0	0	0	NaN	NaN

Table 22. Average monthly fin whale calling activity, 2010-2014, for completed ARCWEST mooring locations. Number of days with calling activity (#), number of days with recordings (Eff), percent of days with calling activity per month (%)

Month	KZ1			PH1			CL1			IC3			IC2			IC1			WT1			PB1			BF2		
	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%
Jan	0	0	-	0	62	**0**	0	62	**0**	0	62	**0**	0	62	**0**	0	62	**0**	0	0	-	0	0	-	0	0	-
Feb	0	0	-	0	56	**0**	0	56	**0**	0	57	**0**	0	57	**0**	0	57	**0**	0	0	-	0	0	-	0	0	-
Mar	0	0	-	0	62	**0**	0	62	**0**	0	62	**0**	0	62	**0**	0	62	**0**	0	0	-	0	0	-	0	0	-
Apr	0	0	-	0	60	**0**	0	60	**0**	0	60	**0**	0	60	**0**	0	60	**0**	0	0	-	0	0	-	0	0	-
May	0	0	-	0	62	**0**	0	62	**0**	0	45	**0**	0	50	**0**	0	62	**0**	0	0	-	0	0	-	0	0	-
Jun	0	0	-	11	60	**18**	0	60	**0**	0	8	**0**	0	21	**0**	0	57	**0**	0	0	-	0	0	-	0	0	-
Jul	0	0	-	13	62	**21**	14	62	**23**	0	0	-	0	0	-	0	31	**0**	0	0	-	0	0	-	0	0	-
Aug	0	0	-	43	72	**60**	25	71	**35**	0	3	**0**	0	3	**0**	0	22	**0**	0	0	-	0	0	-	0	0	-
Sep	0	0	-	61	75	**81**	45	84	**54**	0	51	**0**	0	51	**0**	0	49	**0**	0	0	-	0	0	-	0	0	-
Oct	0	0	-	33	62	**53**	23	62	**37**	0	62	**0**	0	62	**0**	0	62	**0**	0	0	-	0	0	-	0	0	-
Nov	0	0	-	2	60	**3**	0	60	**0**	0	60	**0**	0	60	**0**	0	60	**0**	0	0	-	0	0	-	0	0	-
Dec	0	0	-	0	62	**0**	0	62	**0**	0	62	**0**	0	62	**0**	0	62	**0**	0	0	-	0	0	-	0	0	-

Table 23. Key timing events for fin 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 49.

Year	Mooring	Calling		Peak Calling		Ice End Date	Ice Start Date
		Start	End	Start	End		
2012	PH1	22-Aug	31-Oct	26-Aug	10-Oct	17-Jun	16-Nov
	CL1	28-Aug	31-Oct	13-Sep	24-Oct	27-Jun	14-Nov
2013	PH1	13-Jun	2-Nov	25-Jul	2-Nov	11-Jun	25-Nov
	CL1	18-Jul	27-Oct	25-Jul	27-Oct	21-Jun	24-Nov
2014	PH1	6-Jun	15-Sep	23-Aug	15-Sep	30-May	7-Dec
	CL1	18-Jul	21-Sep	16-Sep	21-Sep	7-Jun	29-Nov

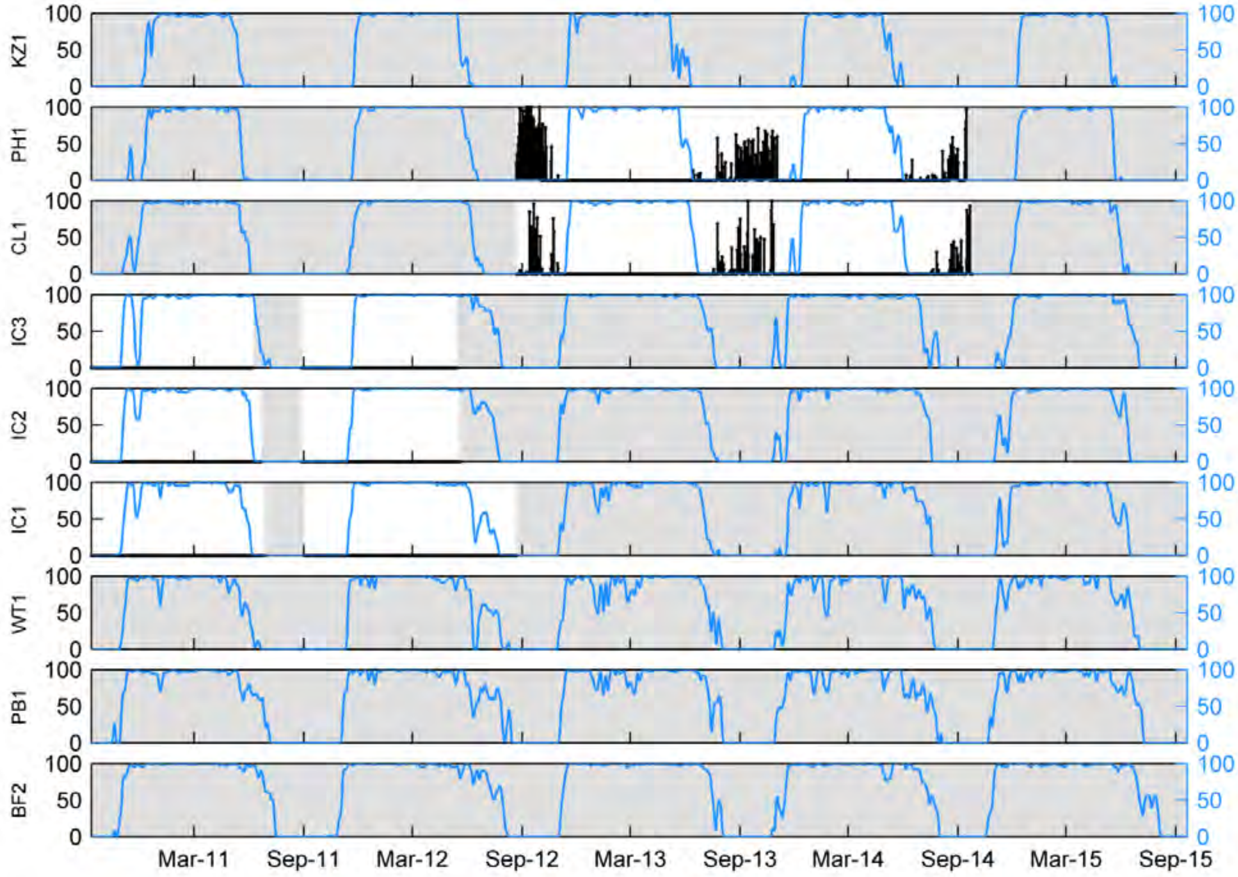


Figure 49. Fin whale calling activity (presented as the percentage of ten-minute time intervals with calls) for the nine ARCWEST locations (see Figure 2A), 2010-2015. Blue line indicates percent ice cover (zero-phase, three-day moving average). Gray shading indicates no data or data not yet analyzed.

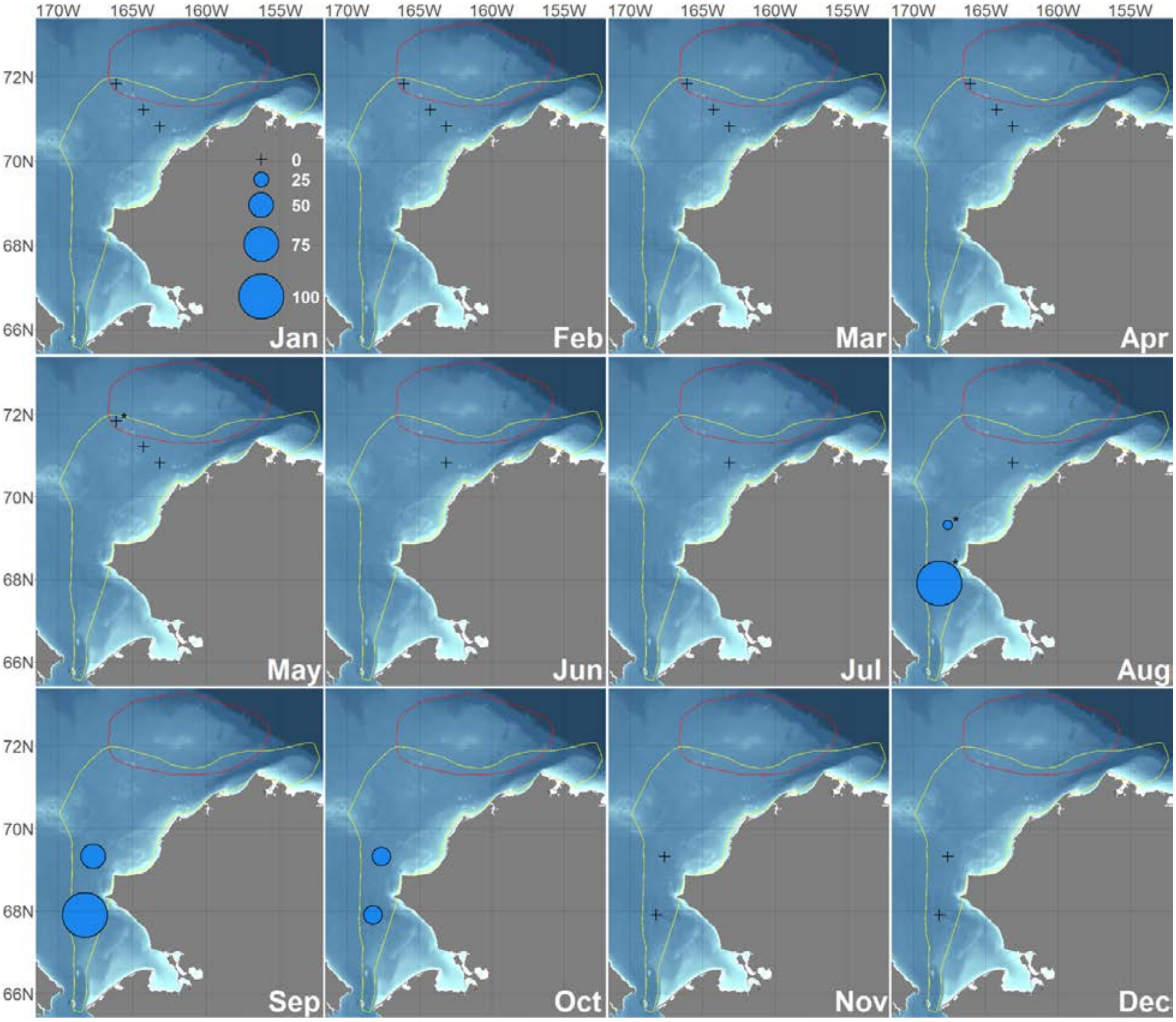


Figure 50. Monthly fin whale calling distribution, 2012. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 9. for numbers used to generate figure.

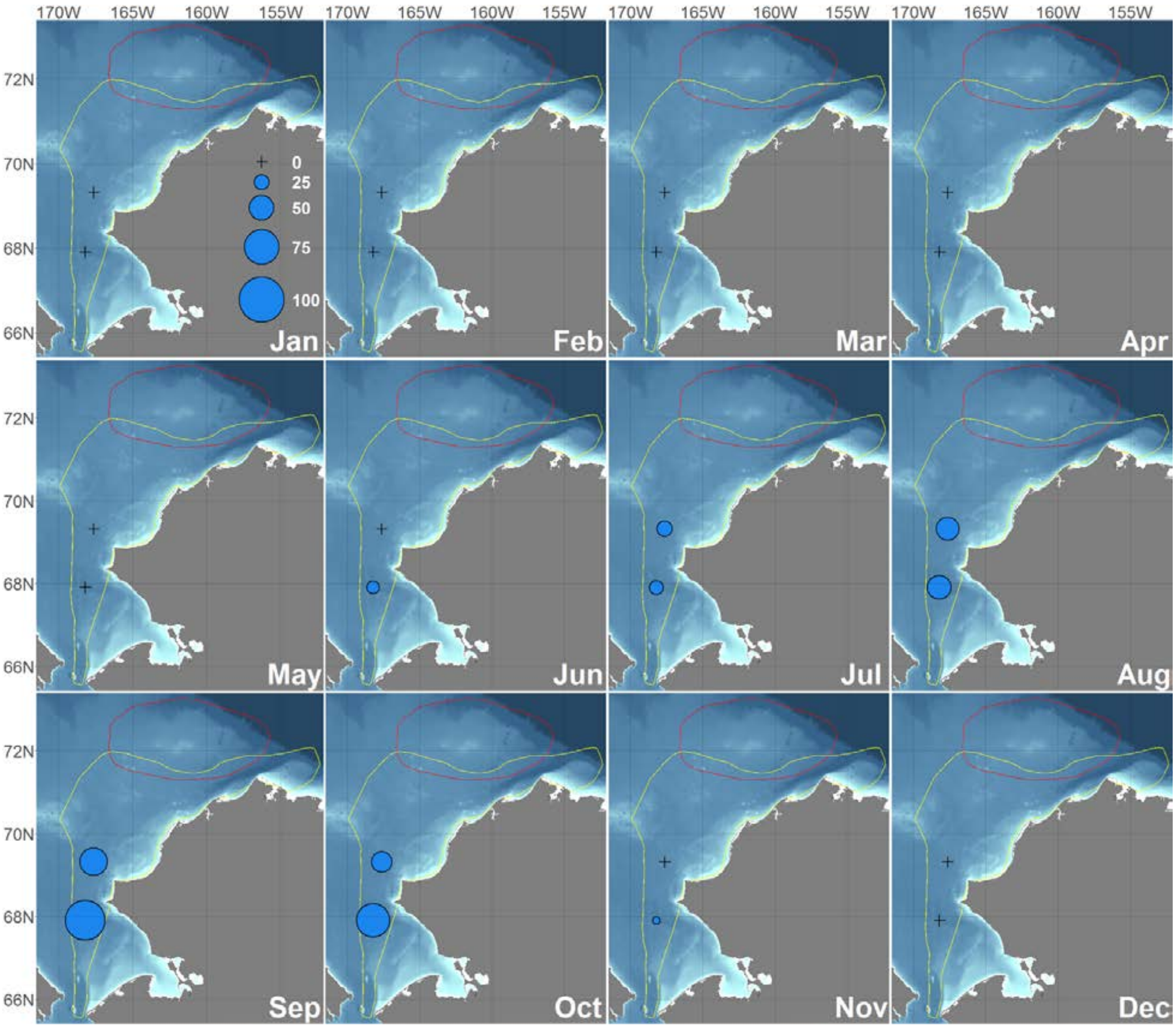


Figure 51. Monthly fin whale calling distribution, 2013. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 9. for numbers used to generate figure.

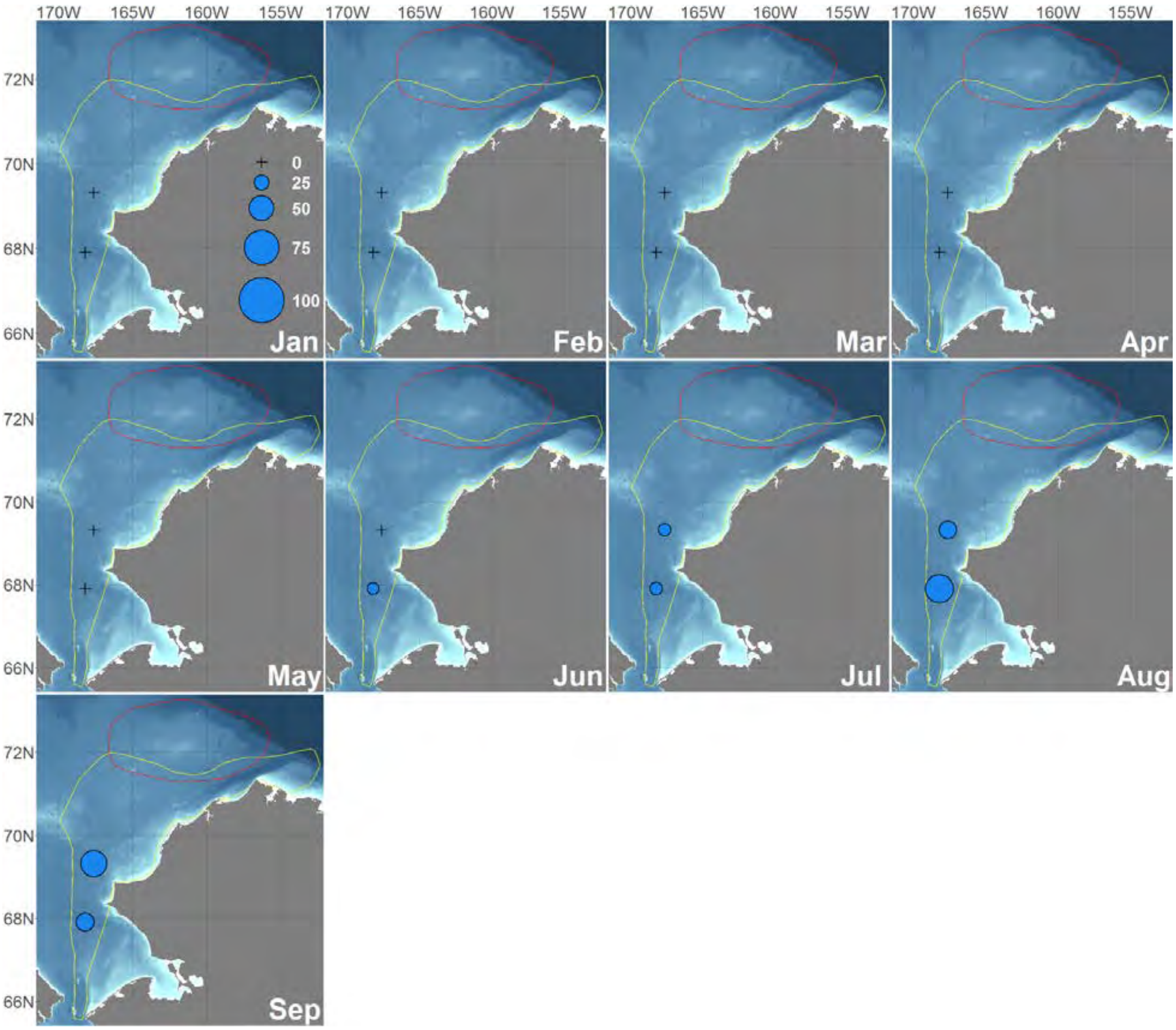


Figure 52. Monthly fin whale calling distribution, 2014. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 9. for numbers used to generate figure.

Killer whales

Killer whales were detected at every mooring site in the ARCWEST study area (Table 24), but not consistently across years (Figure 53). The mooring sites with the highest proportion of days with calls detected were the southernmost two (KZ1 and PH1), with the PB1 site in the northeastern Chukchi a distant third (Table 24). Peak calling was minimal (i.e., levels ≤ 1%). Calling was detected from June through November, although a few days from March to May had detections (Figures 54-59; Table 25). No calling was detected from December through February at any site or during any year. Furthermore, no consistent start or end dates were seen among mooring sites or years (Table 26).

Table 24. Total killer whale calling activity, 2010-2015, for all ARCWEST 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
KZ1	1126	97	3	9	<1
PH1	1124	110	7	10	1
CL1	1114	6	0	1	0
IC3	1647	1	0	<1	0
IC2	1636	1	0	<1	0
IC1	1765	8	0	<1	0
WT1	1103	1	0	<1	0
PB1	742	16	0	2	0
BF2	1784	7	0	<1	0

Table 25. Average monthly killer whale calling activity, 2010-2015, for all ARCWEST mooring locations. Number of days with calling activity (#), number of days with recordings (Eff), percent of days with calling activity per month (%).

Month	KZ1			PH1			CL1			IC3			IC2			IC1			WT1			PB1			BF2		
	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%
Jan	0	93	**0**	0	93	**0**	0	93	**0**	0	155	**0**	0	155	**0**	0	155	**0**	0	93	**0**	0	62	**0**	0	155	**0**
Feb	0	84	**0**	0	84	**0**	0	84	**0**	0	141	**0**	0	141	**0**	0	141	**0**	0	84	**0**	0	56	**0**	0	141	**0**
Mar	0	93	**0**	0	93	**0**	1	93	**1**	0	155	**0**	0	155	**0**	0	155	**0**	0	93	**0**	0	62	**0**	0	155	**0**
Apr	0	90	**0**	0	90	**0**	0	90	**0**	0	150	**0**	1	150	**1**	0	150	**0**	0	90	**0**	0	60	**0**	2	150	**1**
May	0	93	**0**	0	93	**0**	0	93	**0**	0	138	**0**	0	143	**0**	1	155	**1**	0	93	**0**	1	62	**2**	0	155	**0**
Jun	21	90	**23**	23	90	**26**	1	90	**1**	0	98	**0**	0	111	**0**	1	147	**1**	0	90	**0**	0	60	**0**	1	150	**1**
Jul	17	93	**18**	33	93	**35**	1	93	**1**	0	93	**0**	0	93	**0**	0	124	**0**	0	89	**0**	3	62	**5**	1	153	**1**
Aug	23	103	**22**	25	103	**24**	1	102	**1**	0	99	**0**	0	74	**0**	0	121	**0**	0	94	**0**	0	62	**0**	0	123	**0**
Sep	18	111	**16**	24	109	**22**	2	100	**2**	1	158	**1**	0	154	**0**	1	157	**1**	1	102	**1**	1	72	**1**	1	142	**1**
Oct	11	93	**12**	3	93	**3**	0	93	**0**	0	155	**0**	0	155	**0**	3	155	**2**	0	93	**0**	4	62	**6**	2	155	**1**
Nov	7	90	**8**	2	90	**2**	0	90	**0**	0	150	**0**	0	150	**0**	2	150	**1**	0	90	**0**	7	60	**12**	0	150	**0**
Dec	0	93	**0**	0	93	**0**	0	93	**0**	0	155	**0**	0	155	**0**	0	155	**0**	0	92	**0**	0	62	**0**	0	155	**0**

Table 26. Key timing events for killer 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 53.

Year	Mooring	Calling		Peak Calling		Ice End	Ice Start
		Start	End	Start	End	Date	Date
2011	IC1	3-Sep	10-Oct	-	-	4-Jun	12-Nov
2012	KZ1	11-Oct	11-Oct	-	-	9-Jun	16-Nov
	PH1	27-Aug	27-Oct	-	-	17-Jun	16-Nov
	IC3	10-Sep	10-Sep	-	-	27-Jul	3-Nov
	IC2	20-Apr	20-Apr	-	-	24-Jul	1-Nov
	IC1	11-May	24-Jun	-	-	24-Jul	1-Nov
	WT1	15-Sep	15-Sep	-	-	9-Aug	1-Nov
	BF2	28-Apr	22-Oct	-	-	6-Aug	3-Nov
2013	KZ1	27-Jun	15-Nov	8-Sep	8-Sep	8-Jun	26-Nov
	PH1	14-Jun	30-Sep	4-Jul	12-Jul	11-Jun	25-Nov
	CL1	15-Sep	23-Sep	-	-	21-Jun	24-Nov
	IC1	1-Nov	12-Nov	-	-	27-Jul	30-Oct
	PB1	22-Oct	21-Nov	-	-	1-Aug	31-Oct
	BF2	28-Jun	2-Jul	-	-	1-Aug	24-Oct
2014	KZ1	11-Jun	26-Nov	11-Jun	11-Jun	30-May	11-Dec
	PH1	12-Jun	24-Nov	7-Jul	14-Jul	30-May	7-Dec
	CL1	4-Mar	17-Aug	-	-	7-Jun	29-Nov
	PB1	1-May	5-Nov	-	-	3-Aug	24-Oct
2015	KZ1	2-Jun	21-Aug	20-Jun	20-Jun	24-May	27-Nov
	PH1	15-Jun	24-Aug	-	-	1-Jun	28-Nov
	CL1	24-Jun	24-Jun	-	-	13-Jun	20-Nov
	BF2	28-Apr	28-Apr	-	-	5-Aug	20-Oct

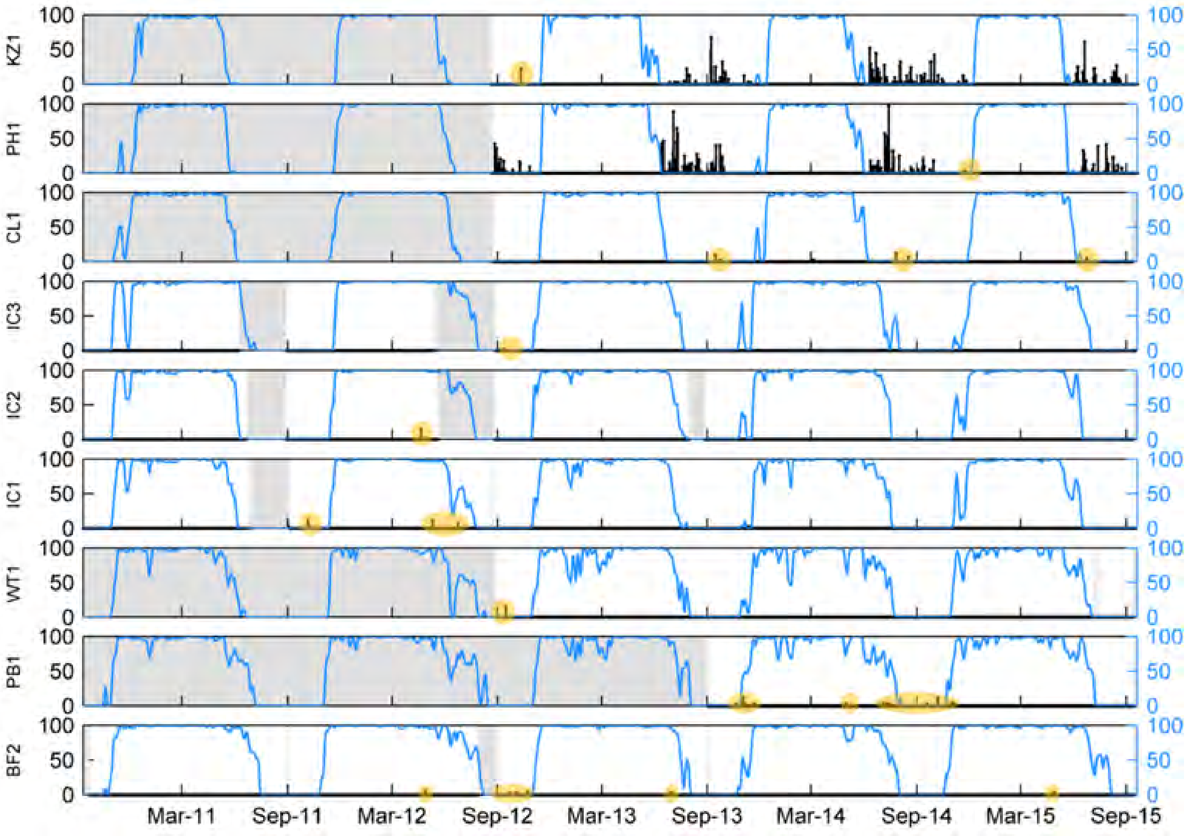


Figure 53. Killer whale calling activity (presented as the percentage of ten-minute time intervals with calls) for the nine ARCWEST locations (see Figure 2A), 2010-2015. Blue line indicates percent ice cover (zero-phase, three-day moving average). Yellow shading highlights low level detections. Gray shading indicates no data.

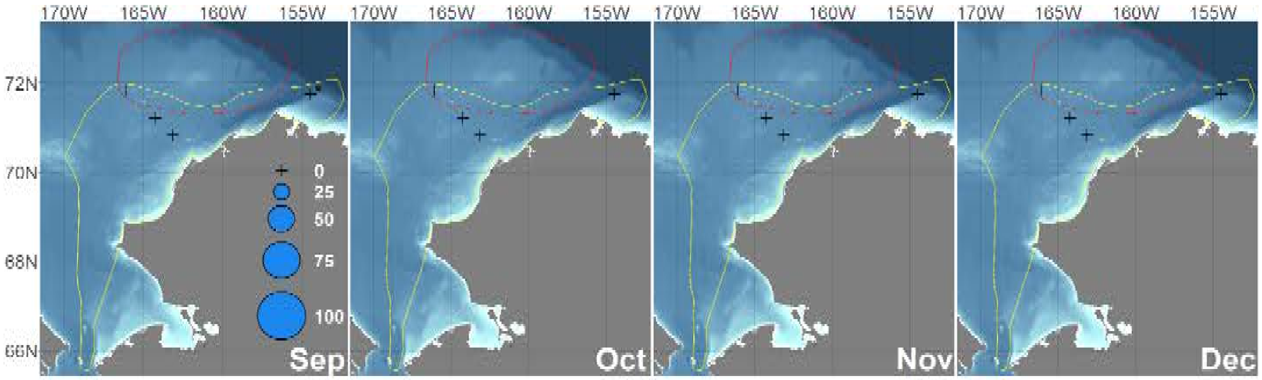


Figure 54. Monthly killer whale calling distribution, 2010. Graduated scale in the September panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 10. for numbers used to generate figure.

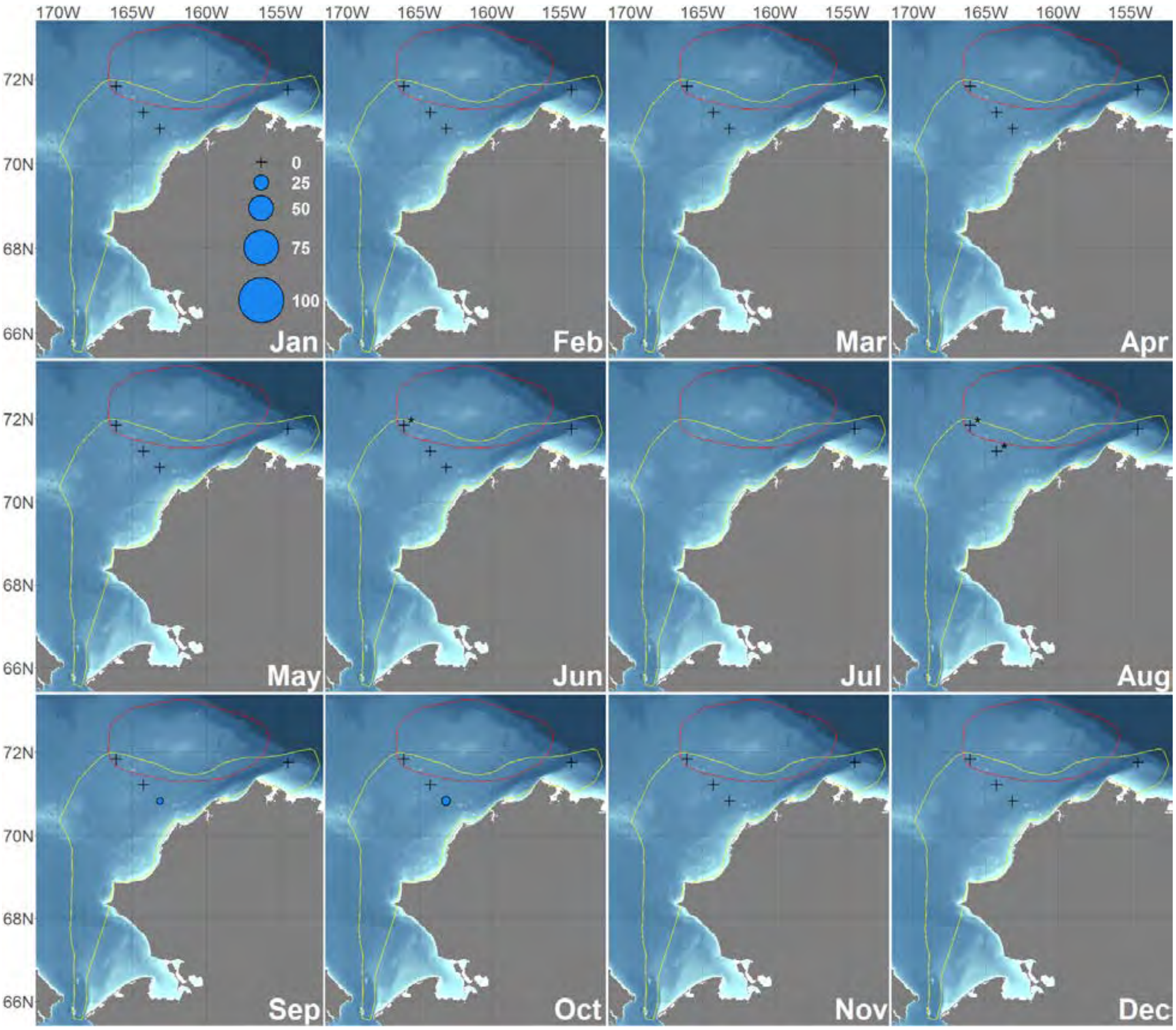


Figure 55. Monthly killer whale calling distribution, 2011. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 10. for numbers used to generate figure.

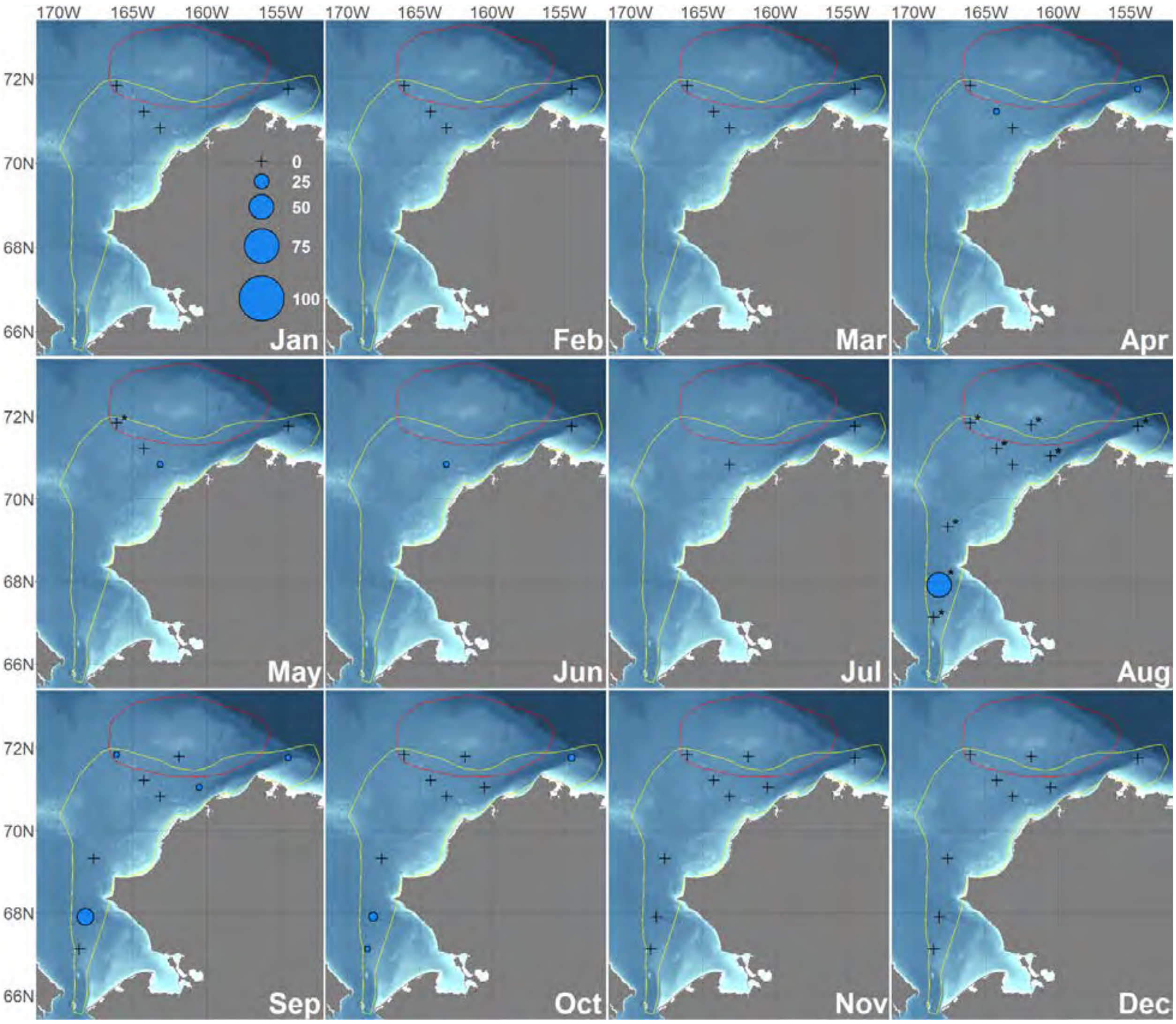


Figure 56. Monthly killer whale calling distribution, 2012. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 10. for numbers used to generate figure.

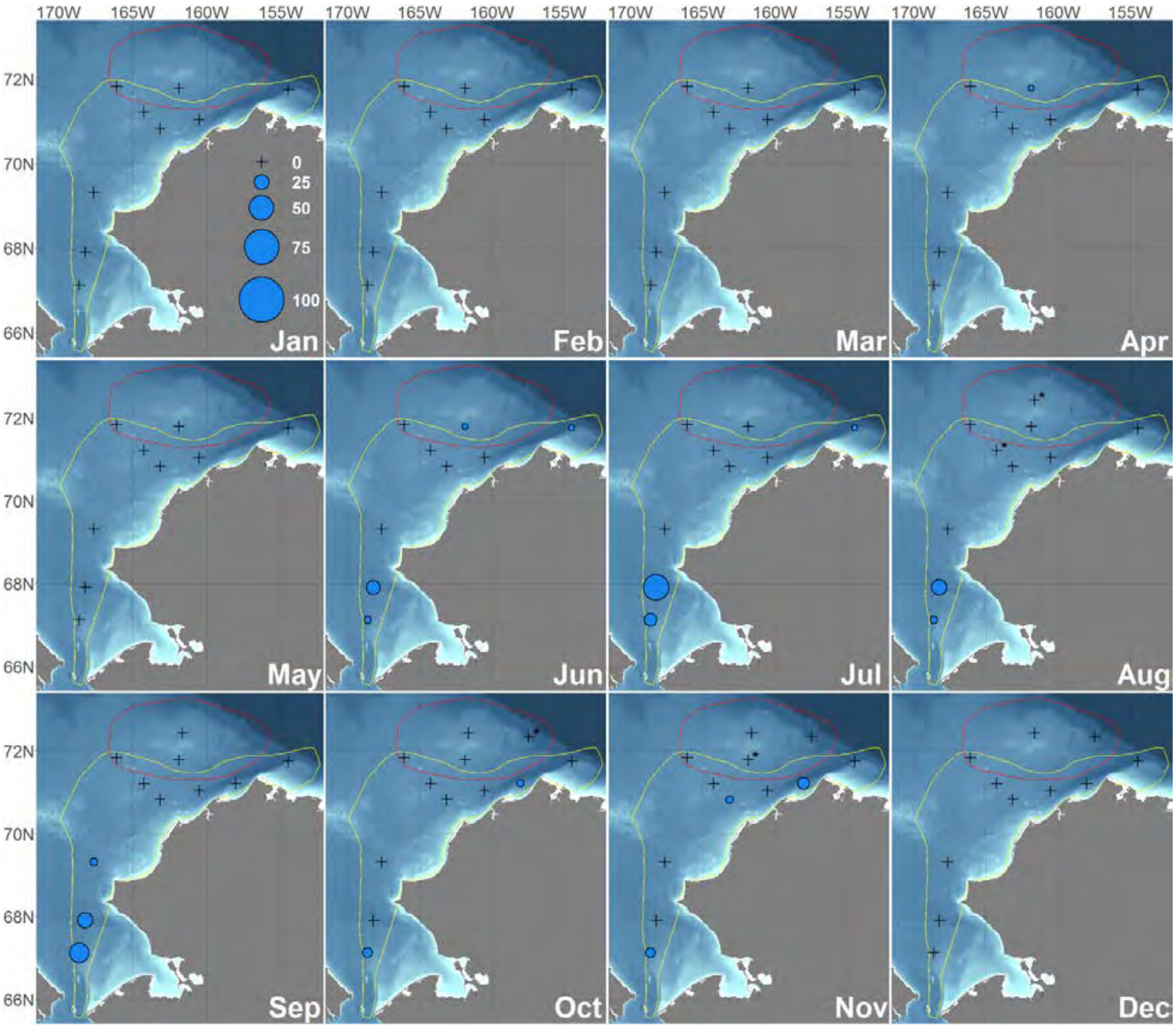


Figure 57. Monthly killer whale calling distribution, 2013. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 10. for numbers used to generate figure.

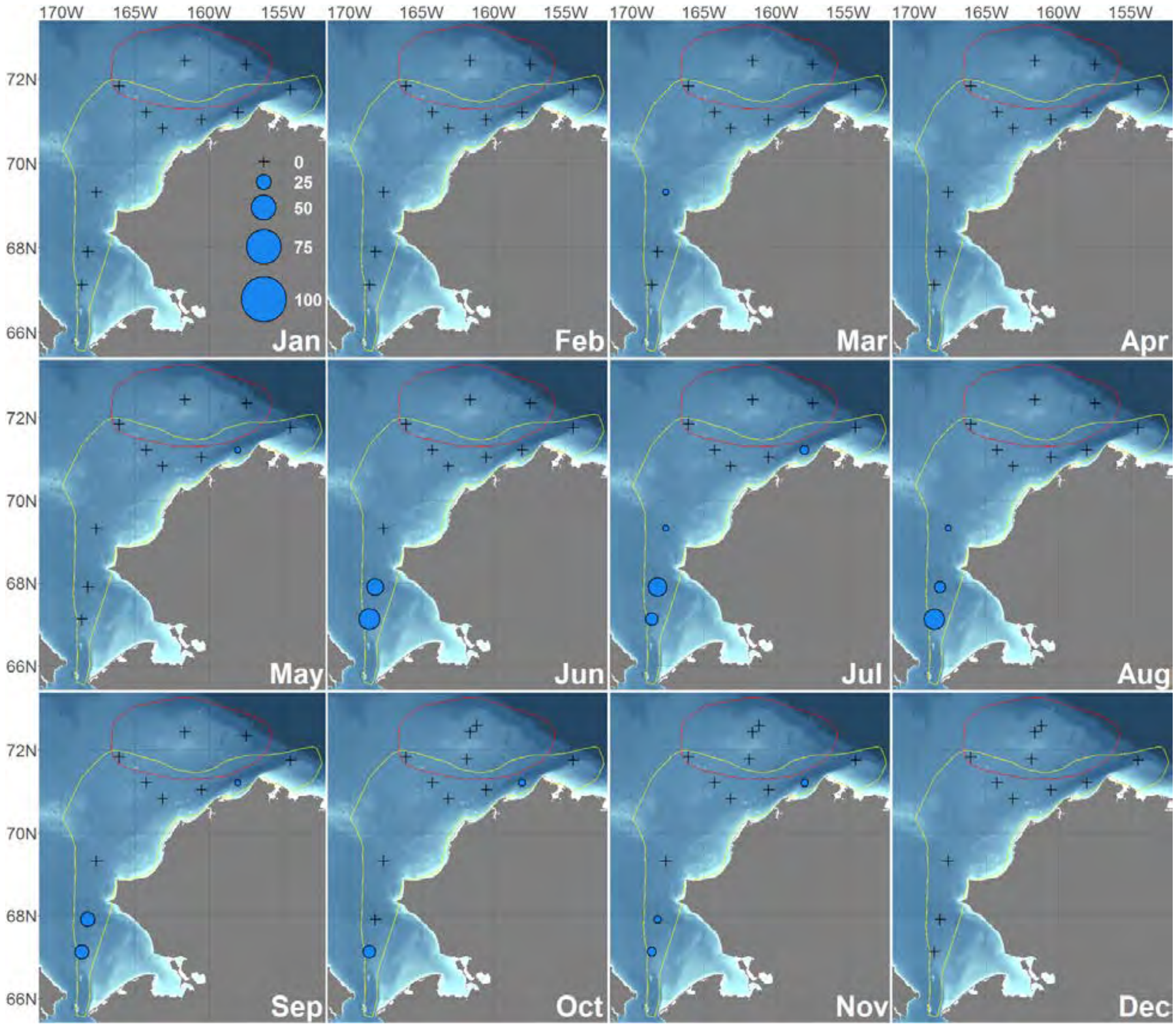


Figure 58. Monthly killer whale calling distribution, 2014. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 10. for numbers used to generate figure.

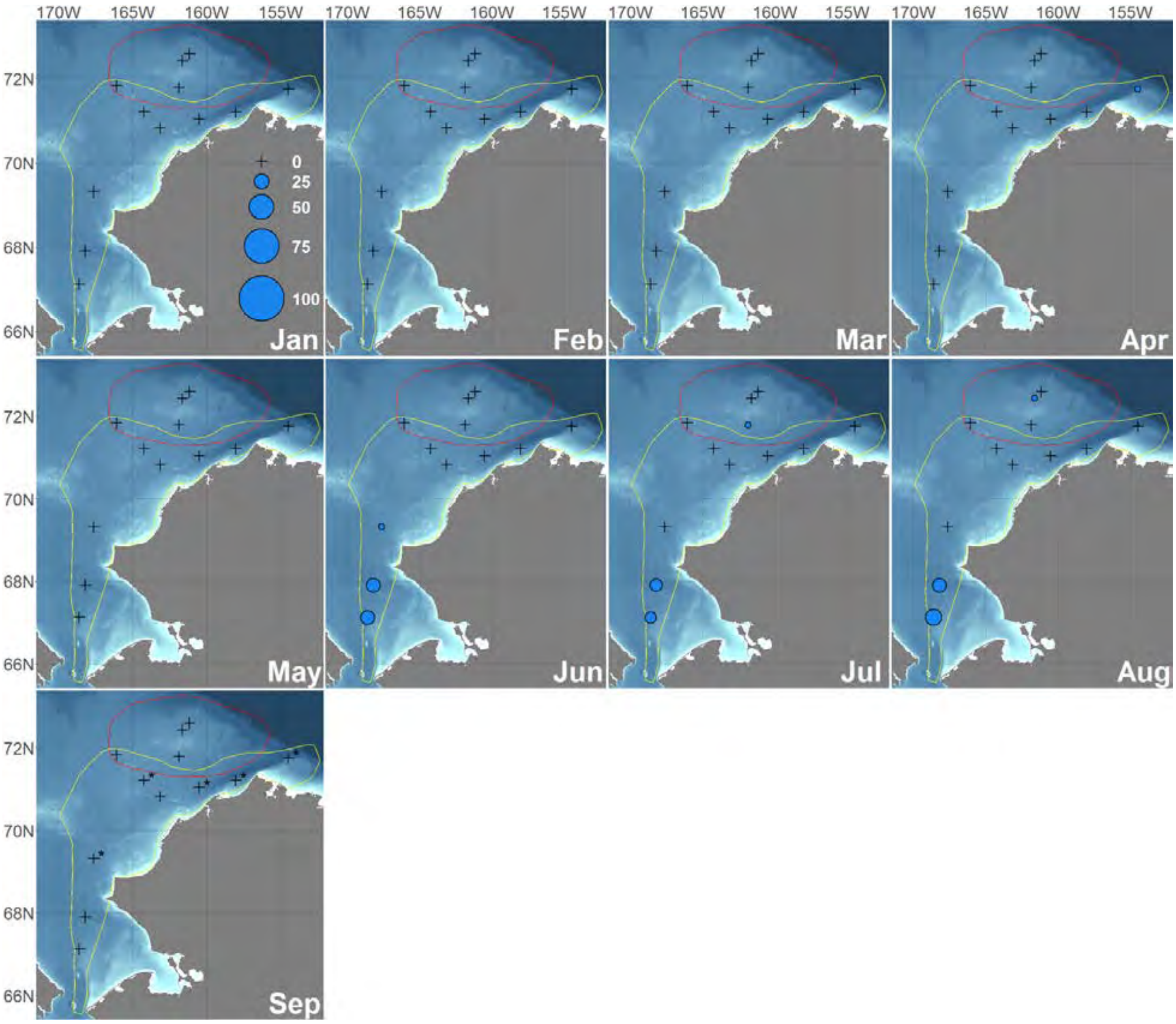
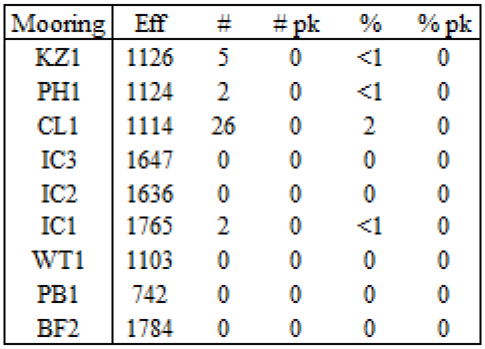


Figure 59. Monthly killer whale calling distribution, 2015. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 10. for numbers used to generate figure.

Minke whales

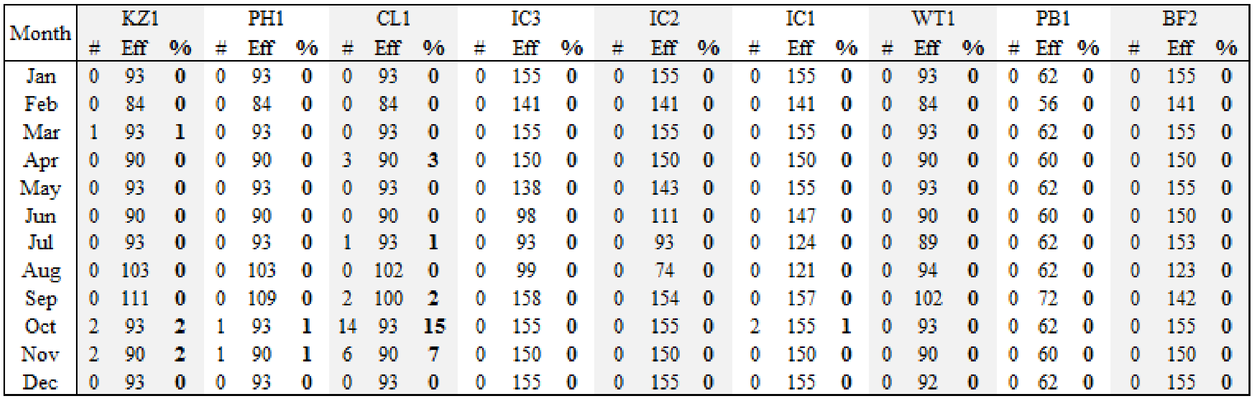
No minke whale pulsed calls (Winn and Perkins, 1976) were detected at any location on any year. However, minke whale boing calls (Rankin and Barlow, 2005) were detected at all three southern mooring sites and at the inshore Icy Cape site (IC1) in the northeastern Chukchi Sea (Figure 60; Table 27). The CL1 site had the greatest proportion of days with calls detected, but this amounted to just 2% (Table 27). Calling activity did not reach peak levels for any mooring during any year (Table 27). The majority of days with boing calls present were between September and November, although a few days were seen in March, April, and July (Figures 61-66; Table 28). As with the other subarctic species, minke whale detections occurred primarily during the open water period, however a handful of days in the ice period had detections (Figure 60; Table 28). No consistent timing of start or end dates of the calling were seen (Table 29).

Table 27. Total minke whale ('boing' call) calling activity, 2010-2015, for all ARCWEST 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
KZ1	1126	5	0	<1	0
PH1	1124	2	0	<1	0
CL1	1114	26	0	2	0
IC3	1647	0	0	0	0
IC2	1636	0	0	0	0
IC1	1765	2	0	<1	0
WT1	1103	0	0	0	0
PB1	742	0	0	0	0
BF2	1784	0	0	0	0

Table 28. Average minke whale ('boing' call) calling activity, 2010-2015, for all ARCWEST mooring locations. Number of days with calling activity (#), number of days with recordings (Eff), percent of days with calling activity per month (%).



Month	KZ1			PH1			CL1			IC3			IC2			IC1			WT1			PB1			BF2		
	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%
Jan	0	93	0	0	93	0	0	93	0	0	155	0	0	155	0	0	155	0	0	93	0	0	62	0	0	155	0
Feb	0	84	0	0	84	0	0	84	0	0	141	0	0	141	0	0	141	0	0	84	0	0	56	0	0	141	0
Mar	1	93	1	0	93	0	0	93	0	0	155	0	0	155	0	0	155	0	0	93	0	0	62	0	0	155	0
Apr	0	90	0	0	90	0	3	90	3	0	150	0	0	150	0	0	150	0	0	90	0	0	60	0	0	150	0
May	0	93	0	0	93	0	0	93	0	0	138	0	0	143	0	0	155	0	0	93	0	0	62	0	0	155	0
Jun	0	90	0	0	90	0	0	90	0	0	98	0	0	111	0	0	147	0	0	90	0	0	60	0	0	150	0
Jul	0	93	0	0	93	0	1	93	1	0	93	0	0	93	0	0	124	0	0	89	0	0	62	0	0	153	0
Aug	0	103	0	0	103	0	0	102	0	0	99	0	0	74	0	0	121	0	0	94	0	0	62	0	0	123	0
Sep	0	111	0	0	109	0	2	100	2	0	158	0	0	154	0	0	157	0	0	102	0	0	72	0	0	142	0
Oct	2	93	2	1	93	1	14	93	15	0	155	0	0	155	0	2	155	1	0	93	0	0	62	0	0	155	0
Nov	2	90	2	1	90	1	6	90	7	0	150	0	0	150	0	0	150	0	0	90	0	0	60	0	0	150	0
Dec	0	93	0	0	93	0	0	93	0	0	155	0	0	155	0	0	155	0	0	92	0	0	62	0	0	155	0

Table 29. Key timing events for minke whale 'boing call' 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 60.

Year	Mooring	Calling		Peak Calling		Ice End Date	Ice Start Date
		Start	End	Start	End		
2011	IC1	18-Oct	19-Oct	-	-	4-Jun	12-Nov
2012	KZ1	19-Oct	7-Nov	-	-	9-Jun	16-Nov
	CL1	18-Oct	5-Nov	-	-	27-Jun	14-Nov
2013	KZ1	20-Mar	27-Oct	-	-	8-Jun	26-Nov
	PH1	1-Nov	1-Nov	-	-	11-Jun	25-Nov
	CL1	30-Sep	6-Nov	-	-	21-Jun	24-Nov
2014	KZ1	3-Nov	3-Nov	-	-	30-May	11-Dec
	PH1	7-Oct	7-Oct	-	-	30-May	7-Dec
	CL1	5-Apr	13-Sep	-	-	7-Jun	29-Nov

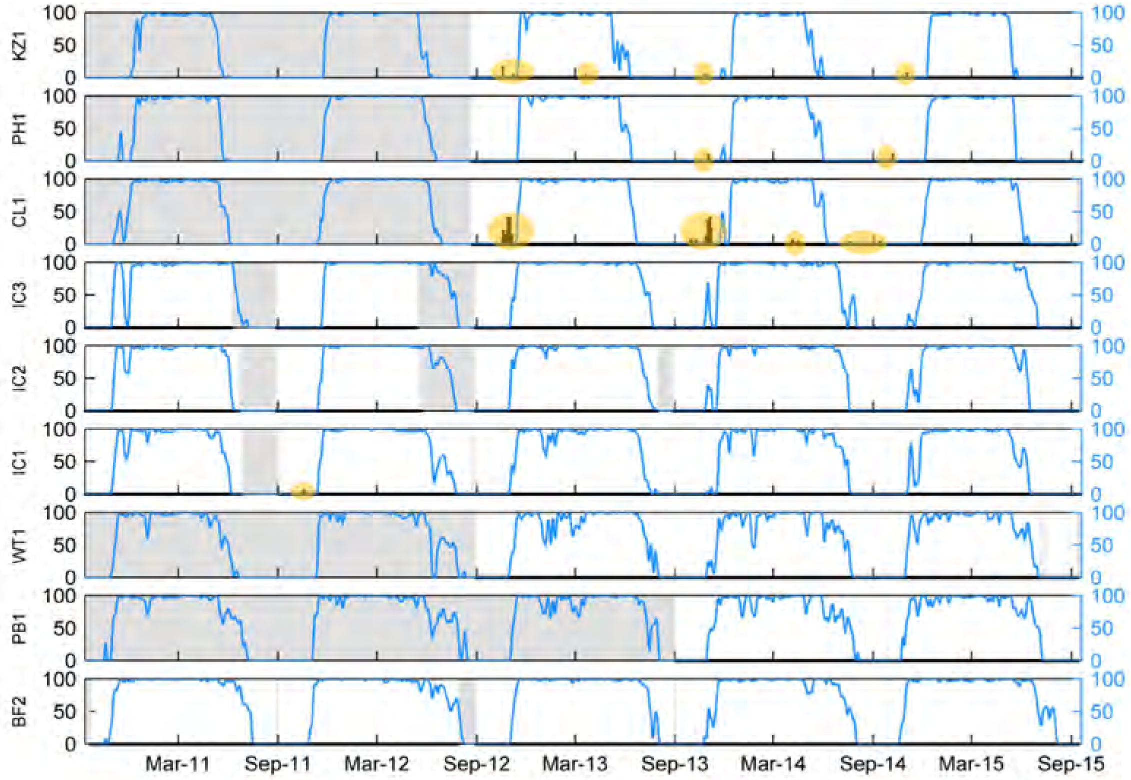


Figure 60. Minke whale 'boing call' activity (presented as the percentage of ten-minute time intervals with calls) for the nine ARCWEST locations (see Figure 2A), 2010-2015. Blue line indicates percent ice cover (zero-phase, three-day moving average). Yellow shading highlights low level detections. Gray shading indicates no data.

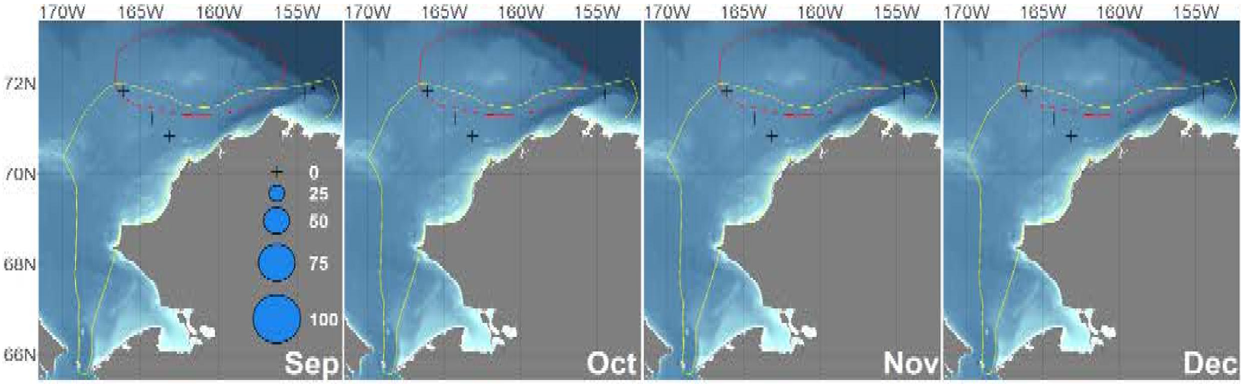


Figure 61. Monthly minke whale ('boing' call) distribution, 2010. Graduated scale in the September panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 11 for numbers used to generate figure.

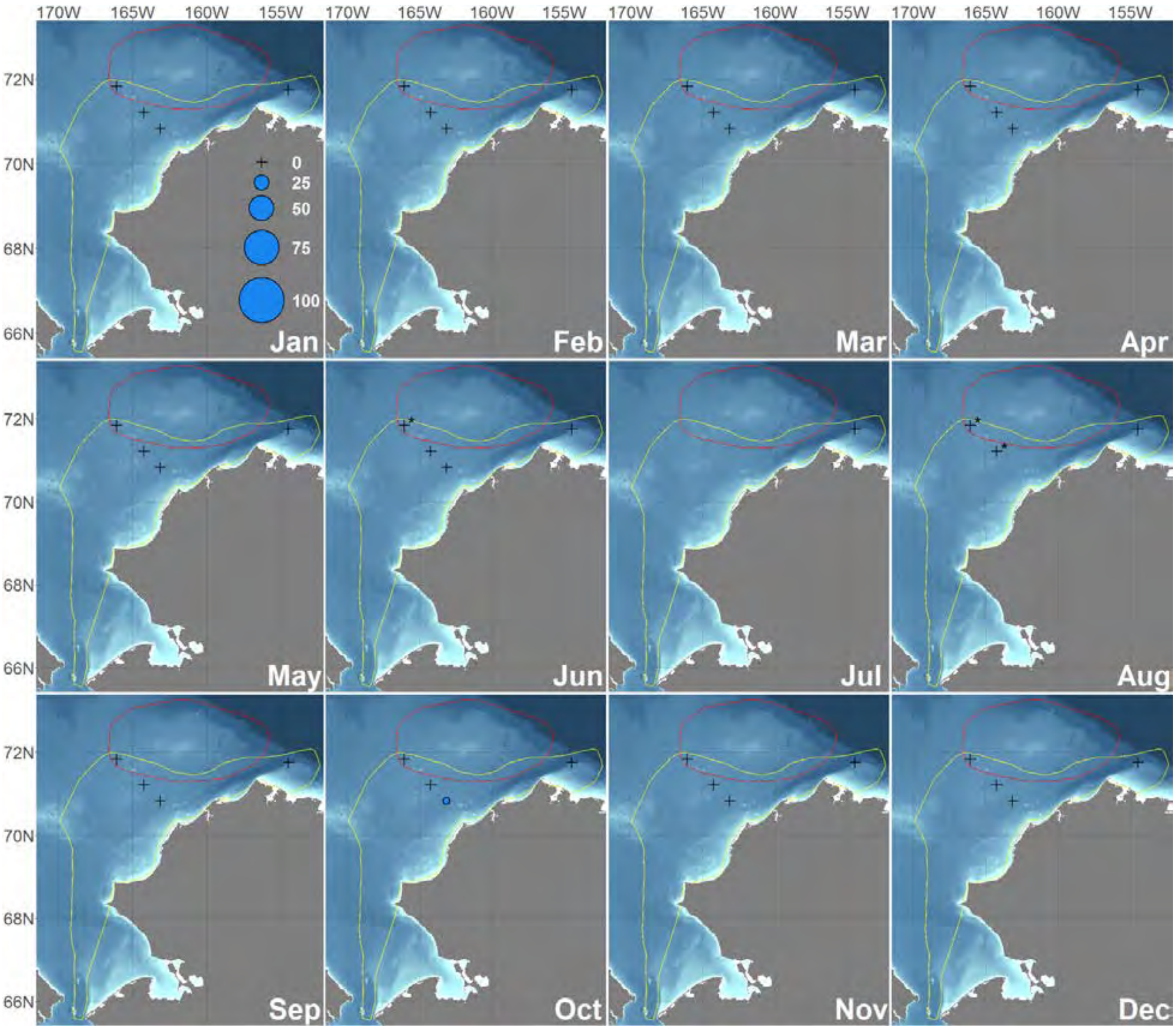


Figure 62. Monthly minke whale ('boing' call) distribution, 2011. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 11 for numbers used to generate figure.

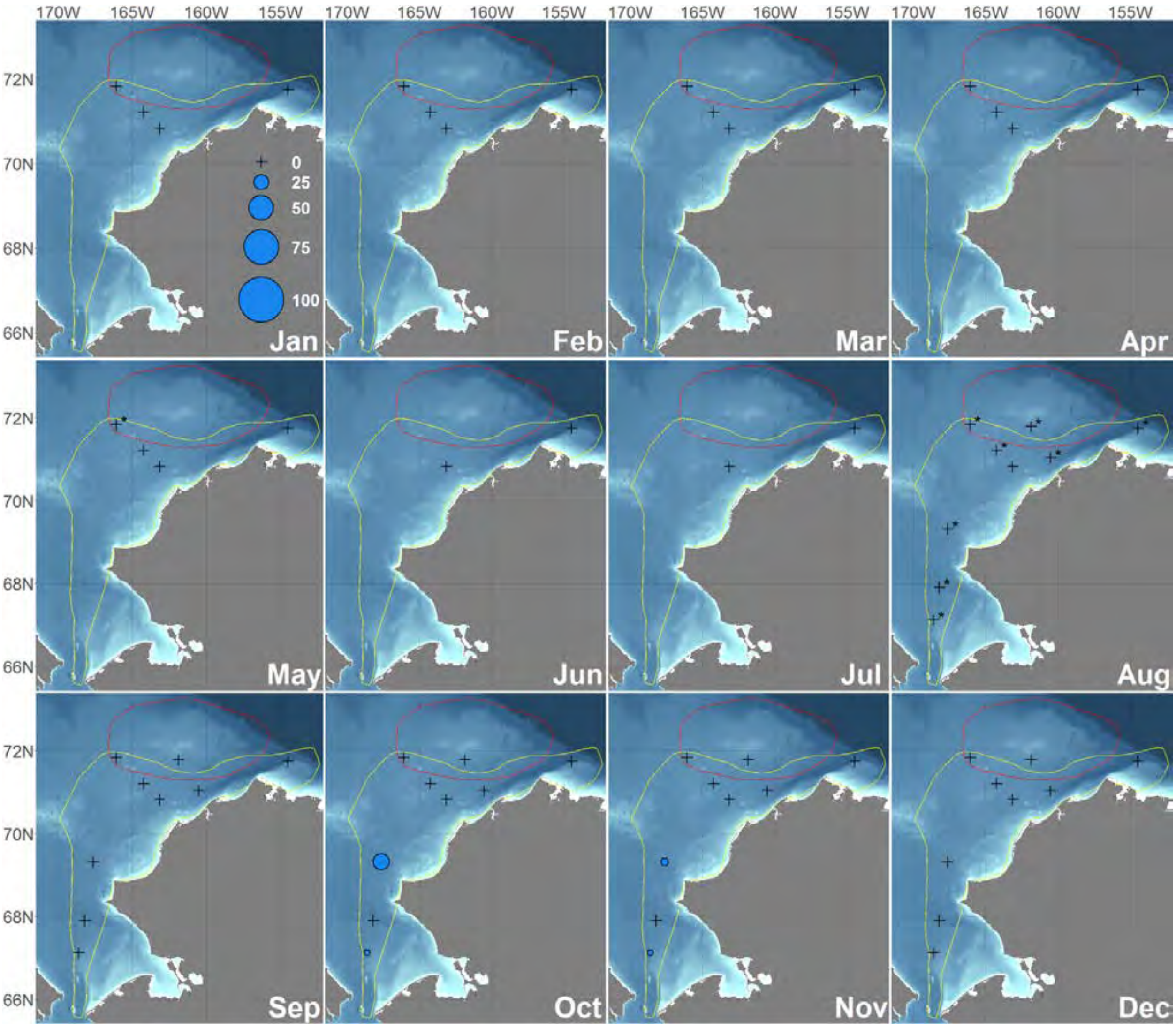


Figure 63. Monthly minke whale ('boing' call) distribution, 2012. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 11 for numbers used to generate figure.

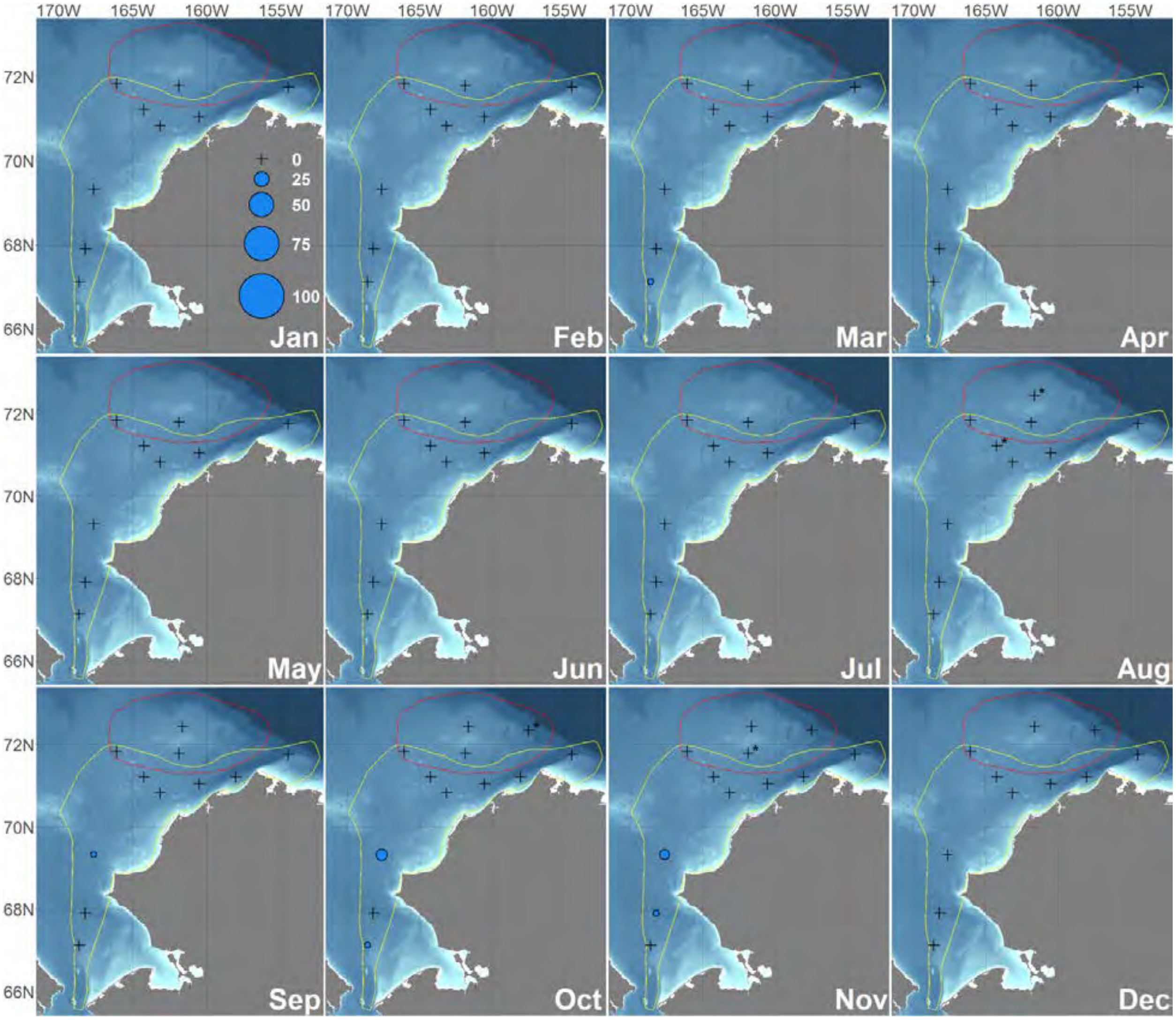


Figure 64. Monthly minke whale ('boing' call) distribution, 2013. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 11 for numbers used to generate figure.

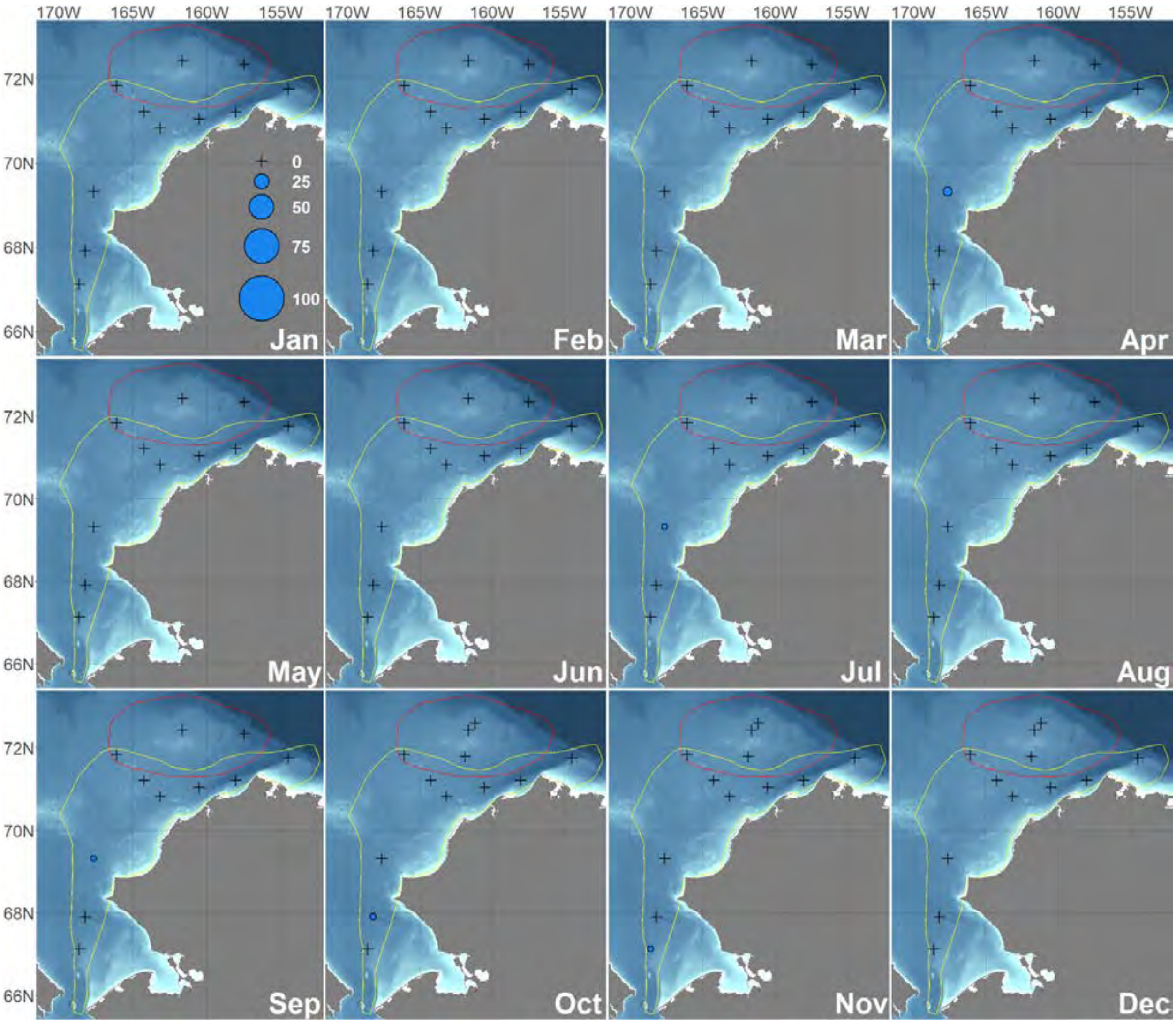


Figure 65. Monthly minke whale ('boing' call) distribution, 2014. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 11 for numbers used to generate figure.

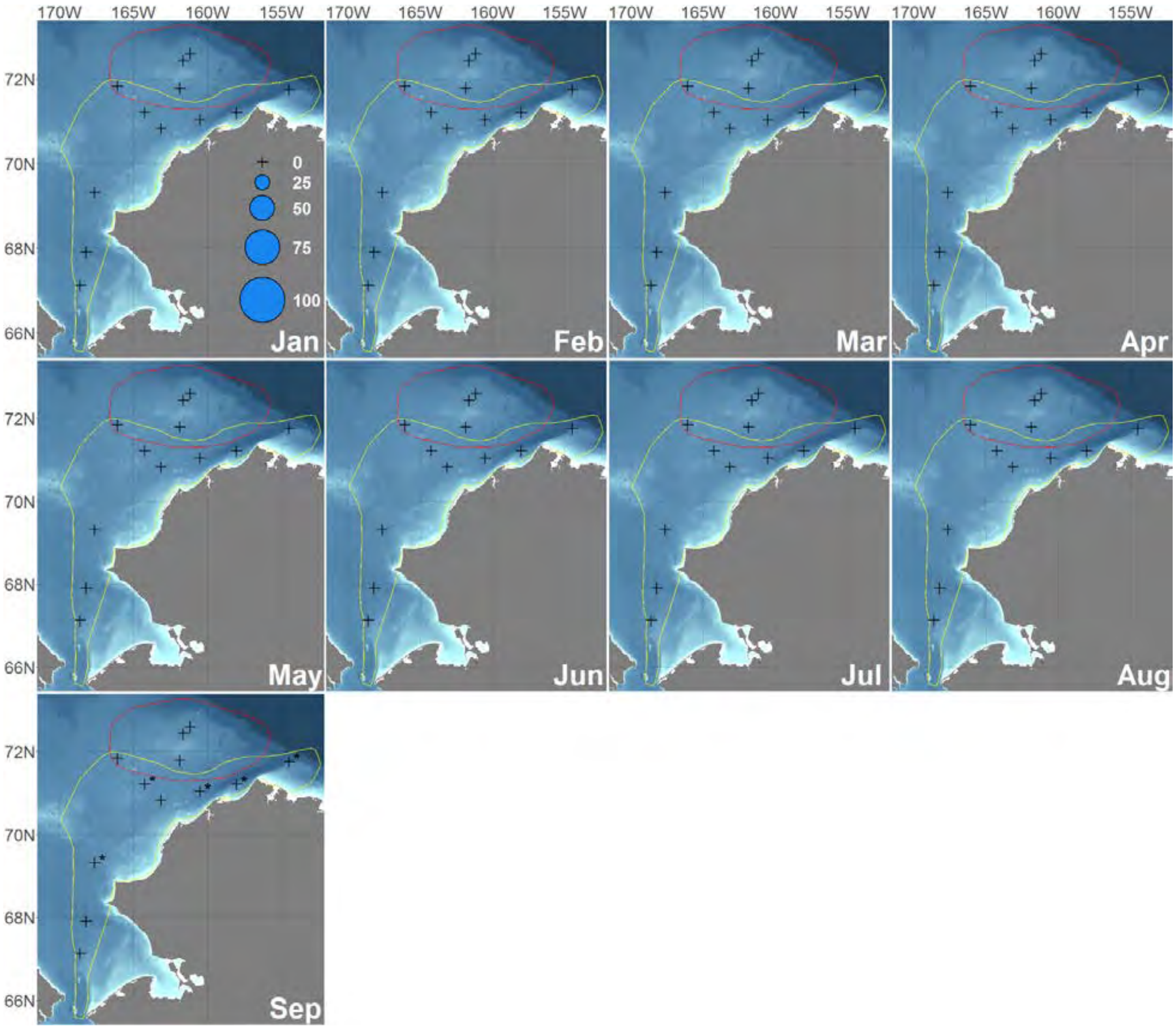


Figure 66. Monthly minke whale ('boing' call) distribution, 2015. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 11 for numbers used to generate figure.

<u>Ribbon seals</u>

Ribbon seals are the last subarctic species to be detected in the ARCWEST study area. Ribbon seal calling activity was present at all mooring sites, but not consistently across years (Figure 67; Table 30). The mooring site with the greatest proportion of days with calling activity was the BF2 site on the eastern flank of Barrow Canyon, with calls detected on 7 % of the analyzed days. The PH1 and CL1 mooring sites in the southern Chukchi saw 3-4% of days with detections, and the rest were ≤ 1% (Table 30). No moorings showed peak calling activity levels greater than 1%. Most moorings showed calling activity between October and December, although BF2 ranged from August through November (Figures 68-73; Table 31). In addition, several sites (KZ1, PH1, IC1, PB1) also had a small number of days with detections in April and

May, and IC3 had one day with detections in August (Table 31). The majority of ribbon seal calling activity occurred during the open water season immediately prior to ice formation, which suggest this is a migratory pulse calling, although a handful were present overwinter. No consistent trends were seen with the start and end dates of the calling pulses.

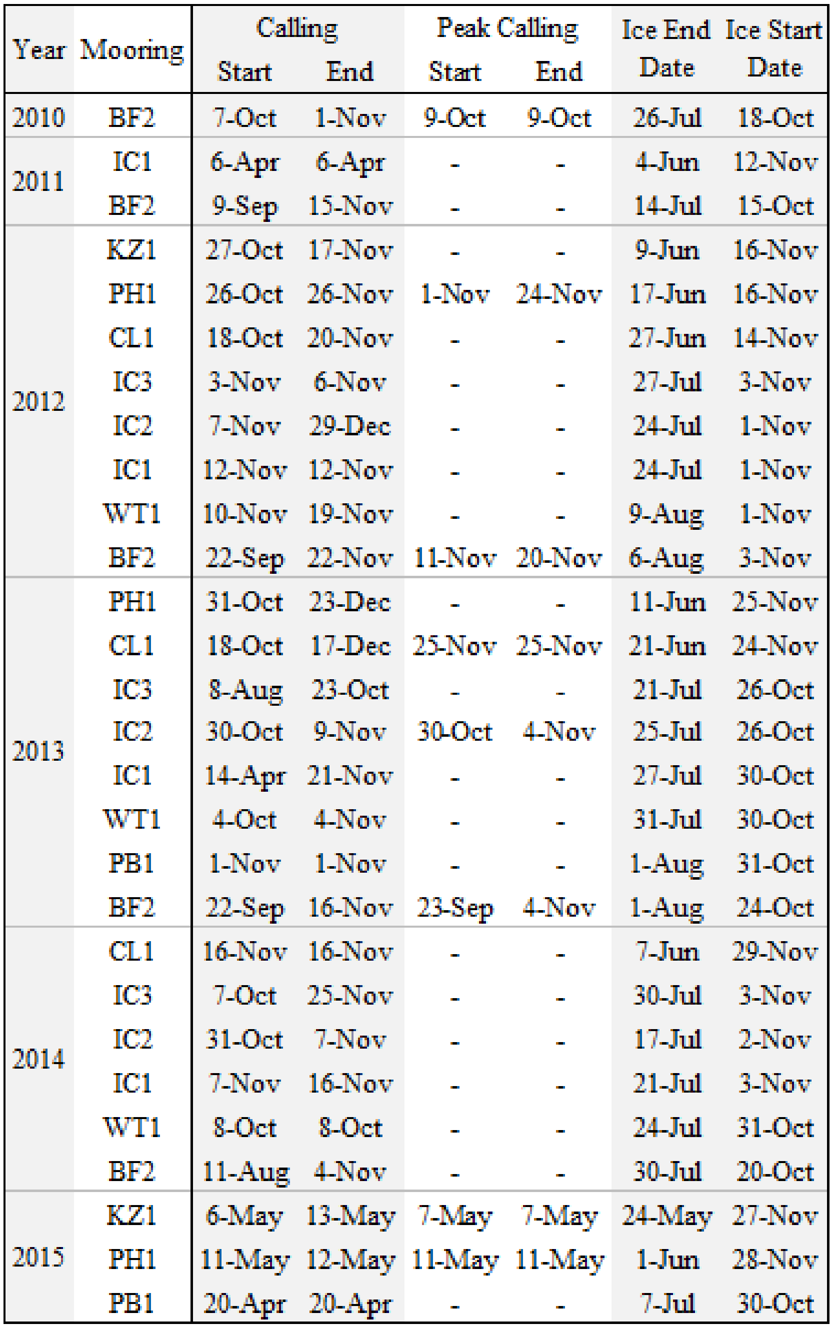
Table 30. Total ribbon seal calling activity, 2010-2015, for all ARCWEST mooring locations. Number of days with recordings (Eff), number of days with calling activity (#), number of days with calling activity > 50% (#pk), percent of days with calling activity (%)percent of days with calling activity > 50% (%pk).

Mooring	Eff	#	# pk	%	% pk
KZ1	1126	10	1	1	<1
PH1	1124	41	6	4	1
CL1	1114	36	1	3	<1
IC3	1647	10	0	1	0
IC2	1636	14	4	1	<1
IC1	1765	11	0	1	0
WT1	1103	7	0	1	0
PB1	742	2	0	<1	0
BF2	1784	118	26	7	1

Table 31. Average monthly ribbon seal calling activity, 2010-2015, for all ARCWEST mooring locations. Number of days with calling activity (#), number of days with recordings (Eff), percent of days with calling activity per month (%).

Month	KZ1			PH1			CL1			IC3			IC2			IC1			WT1			PB1			BF2		
	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%	#	Eff	%
Jan	0	93	**0**	0	93	**0**	0	93	**0**	0	155	**0**	0	155	**0**	0	155	**0**	0	93	**0**	0	62	**0**	0	155	**0**
Feb	0	84	**0**	0	84	**0**	0	84	**0**	0	141	**0**	0	141	**0**	0	141	**0**	0	84	**0**	0	56	**0**	0	141	**0**
Mar	0	93	**0**	0	93	**0**	0	93	**0**	0	155	**0**	0	155	**0**	0	155	**0**	0	93	**0**	0	62	**0**	0	155	**0**
Apr	0	90	**0**	0	90	**0**	0	90	**0**	0	150	**0**	0	150	**0**	2	150	**1**	0	90	**0**	1	60	**2**	0	150	**0**
May	7	93	**8**	2	93	**2**	0	93	**0**	0	138	**0**	0	143	**0**	0	155	**0**	0	93	**0**	0	62	**0**	0	155	**0**
Jun	0	90	**0**	0	90	**0**	0	90	**0**	0	98	**0**	0	111	**0**	0	147	**0**	0	90	**0**	0	60	**0**	0	150	**0**
Jul	0	93	**0**	0	93	**0**	0	93	**0**	0	93	**0**	0	93	**0**	0	124	**0**	0	89	**0**	0	62	**0**	0	153	**0**
Aug	0	103	**0**	0	103	**0**	0	102	**0**	1	99	**1**	0	74	**0**	0	121	**0**	0	94	**0**	0	62	**0**	2	123	**2**
Sep	0	111	**0**	0	109	**0**	0	100	**0**	0	158	**0**	0	154	**0**	0	157	**0**	0	102	**0**	0	72	**0**	19	142	**13**
Oct	1	93	**1**	5	93	**5**	7	93	**8**	4	155	**3**	3	155	**2**	0	155	**0**	3	93	**3**	0	62	**0**	51	155	**33**
Nov	2	90	**2**	30	90	**33**	26	90	**29**	5	150	**3**	10	150	**7**	9	150	**6**	4	90	**4**	1	60	**2**	46	150	**31**
Dec	0	93	**0**	4	93	**4**	3	93	**3**	0	155	**0**	1	155	**1**	0	155	**0**	0	92	**0**	0	62	**0**	0	155	**0**

Table 32. Key timing events for ribbon 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 67.



Year	Mooring	Calling		Peak Calling		Ice End Date	Ice Start Date
		Start	End	Start	End		
2010	BF2	7-Oct	1-Nov	9-Oct	9-Oct	26-Jul	18-Oct
2011	IC1	6-Apr	6-Apr	-	-	4-Jun	12-Nov
	BF2	9-Sep	15-Nov	-	-	14-Jul	15-Oct
2012	KZ1	27-Oct	17-Nov	-	-	9-Jun	16-Nov
	PH1	26-Oct	26-Nov	1-Nov	24-Nov	17-Jun	16-Nov
	CL1	18-Oct	20-Nov	-	-	27-Jun	14-Nov
	IC3	3-Nov	6-Nov	-	-	27-Jul	3-Nov
	IC2	7-Nov	29-Dec	-	-	24-Jul	1-Nov
	IC1	12-Nov	12-Nov	-	-	24-Jul	1-Nov
	WT1	10-Nov	19-Nov	-	-	9-Aug	1-Nov
	BF2	22-Sep	22-Nov	11-Nov	20-Nov	6-Aug	3-Nov
2013	PH1	31-Oct	23-Dec	-	-	11-Jun	25-Nov
	CL1	18-Oct	17-Dec	25-Nov	25-Nov	21-Jun	24-Nov
	IC3	8-Aug	23-Oct	-	-	21-Jul	26-Oct
	IC2	30-Oct	9-Nov	30-Oct	4-Nov	25-Jul	26-Oct
	IC1	14-Apr	21-Nov	-	-	27-Jul	30-Oct
	WT1	4-Oct	4-Nov	-	-	31-Jul	30-Oct
	PB1	1-Nov	1-Nov	-	-	1-Aug	31-Oct
	BF2	22-Sep	16-Nov	23-Sep	4-Nov	1-Aug	24-Oct
2014	CL1	16-Nov	16-Nov	-	-	7-Jun	29-Nov
	IC3	7-Oct	25-Nov	-	-	30-Jul	3-Nov
	IC2	31-Oct	7-Nov	-	-	17-Jul	2-Nov
	IC1	7-Nov	16-Nov	-	-	21-Jul	3-Nov
	WT1	8-Oct	8-Oct	-	-	24-Jul	31-Oct
	BF2	11-Aug	4-Nov	-	-	30-Jul	20-Oct
2015	KZ1	6-May	13-May	7-May	7-May	24-May	27-Nov
	PH1	11-May	12-May	11-May	11-May	1-Jun	28-Nov
	PB1	20-Apr	20-Apr	-	-	7-Jul	30-Oct

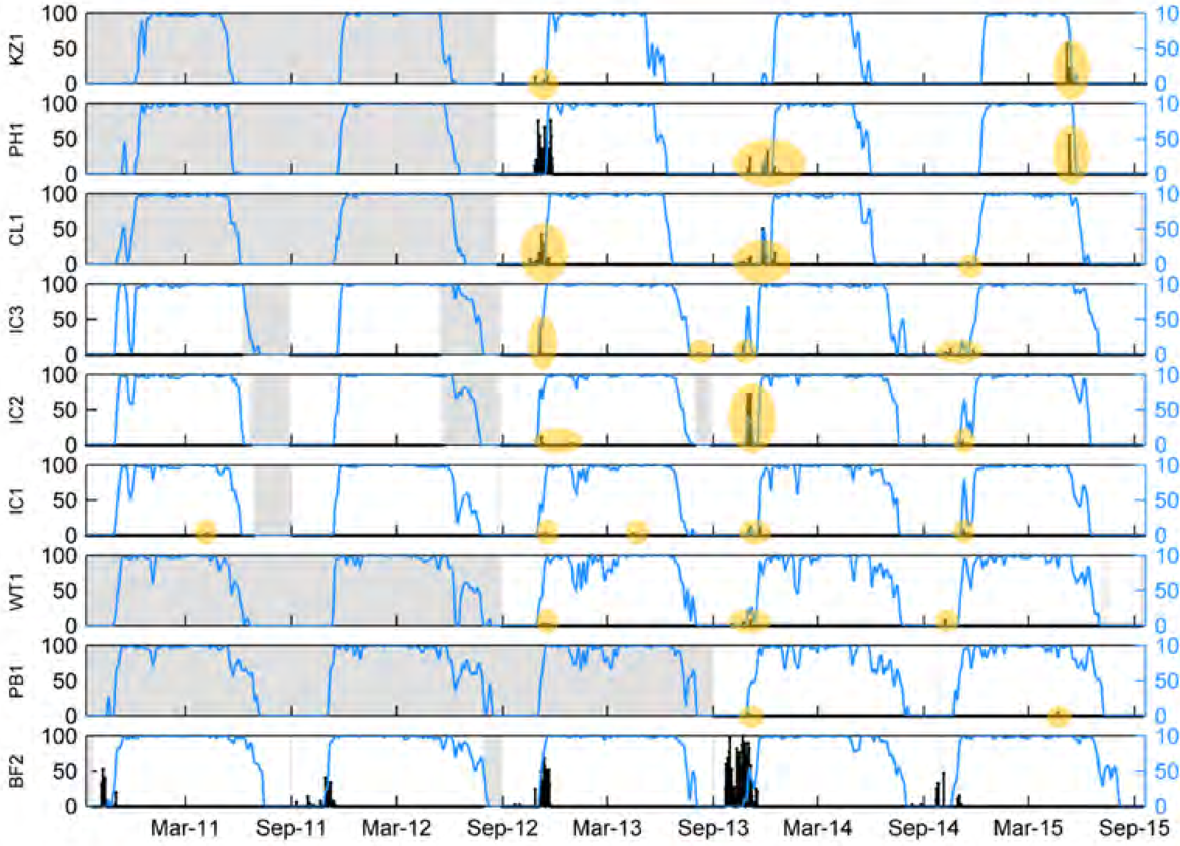


Figure 67. Ribbon seal calling activity (presented as the percentage of ten-minute time intervals with calls) for the nine ARCWEST locations (see Figure 2A), 2010-2015. Blue line indicates percent ice cover (zero-phase, three-day moving average). Yellow shading highlights low level detections. Gray shading indicates no data.

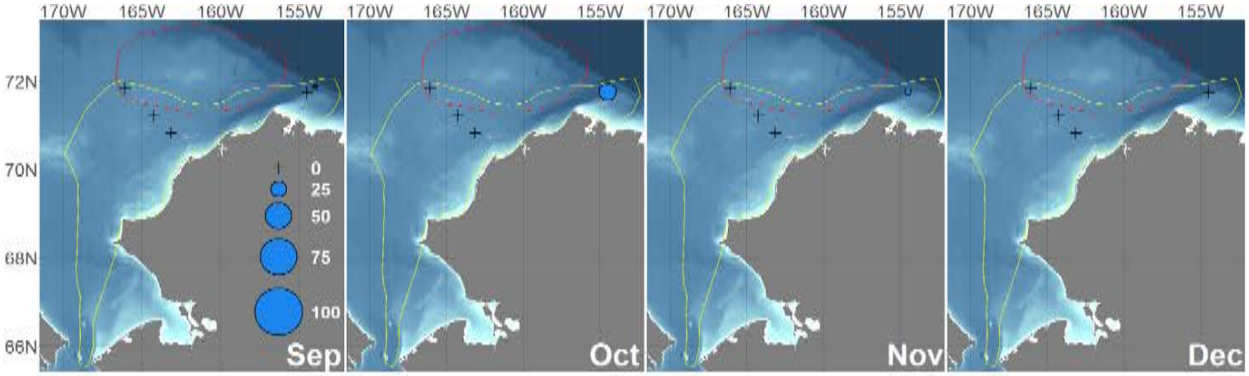


Figure 68. Monthly ribbon seal calling distribution, 2010. Graduated scale in the September panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 12 for numbers used to generate figure.

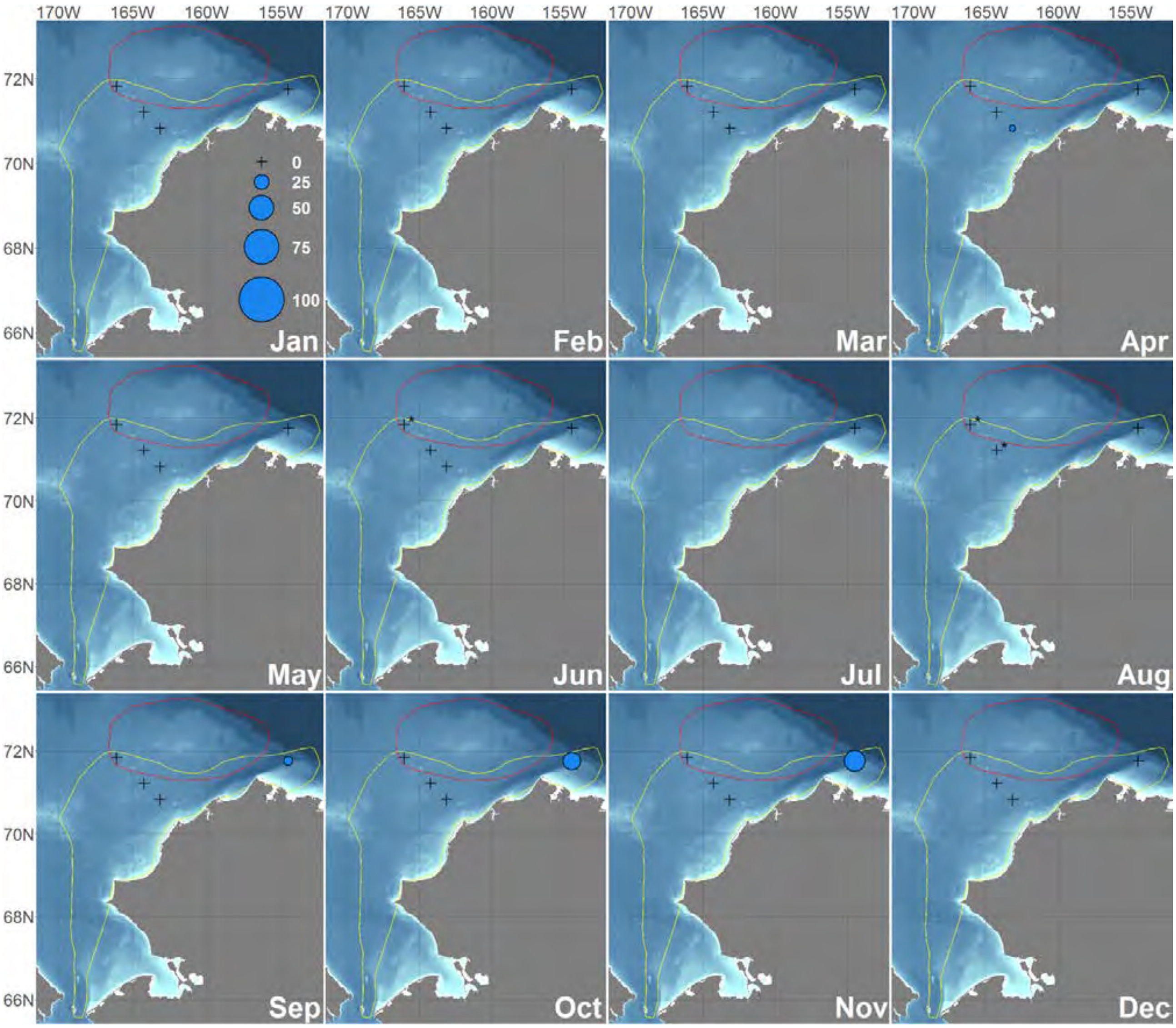


Figure 69. Monthly ribbon seal calling distribution, 2011. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 12 for numbers used to generate figure.

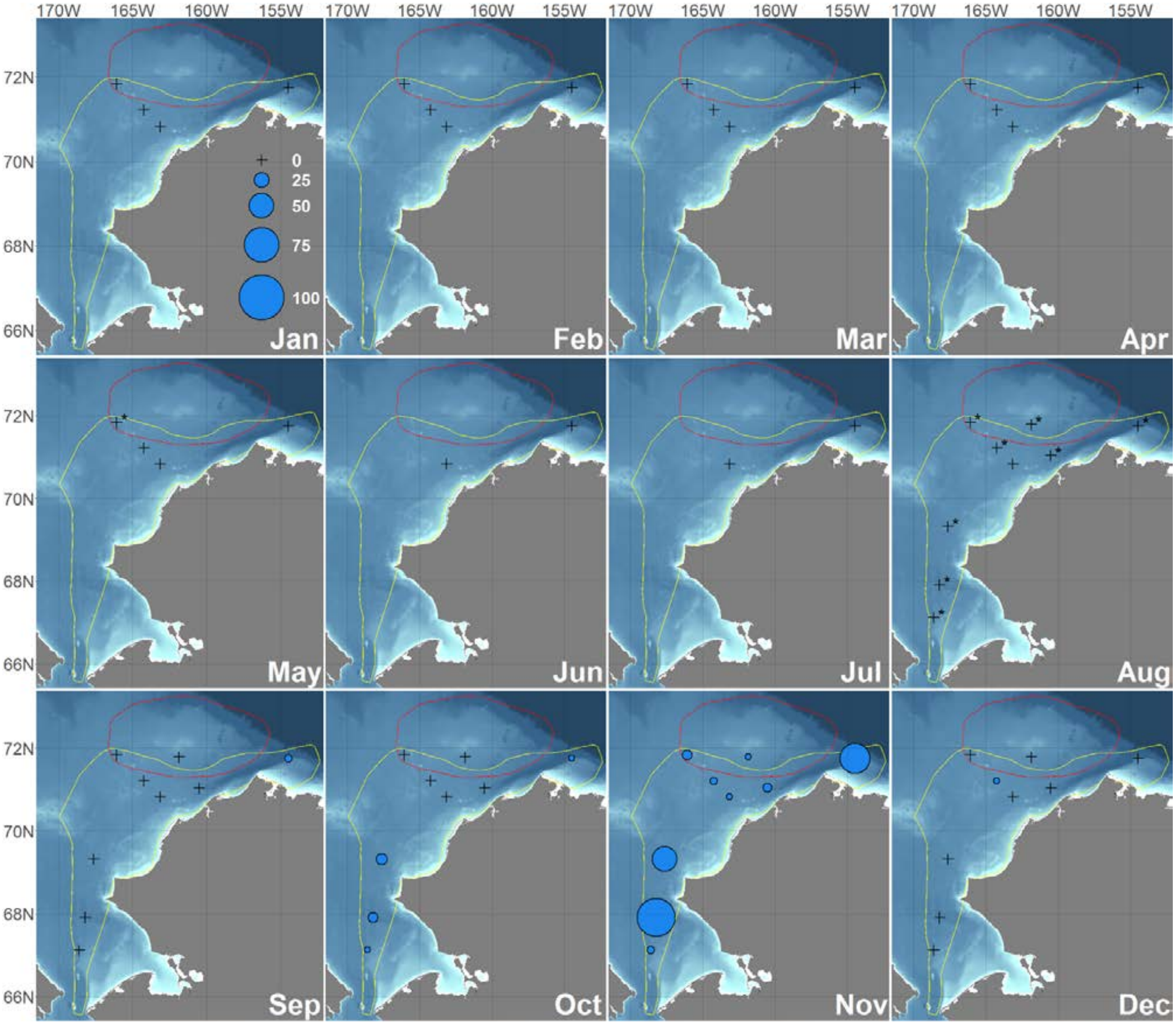


Figure 70. Monthly ribbon seal calling distribution, 2012. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 12 for numbers used to generate figure.

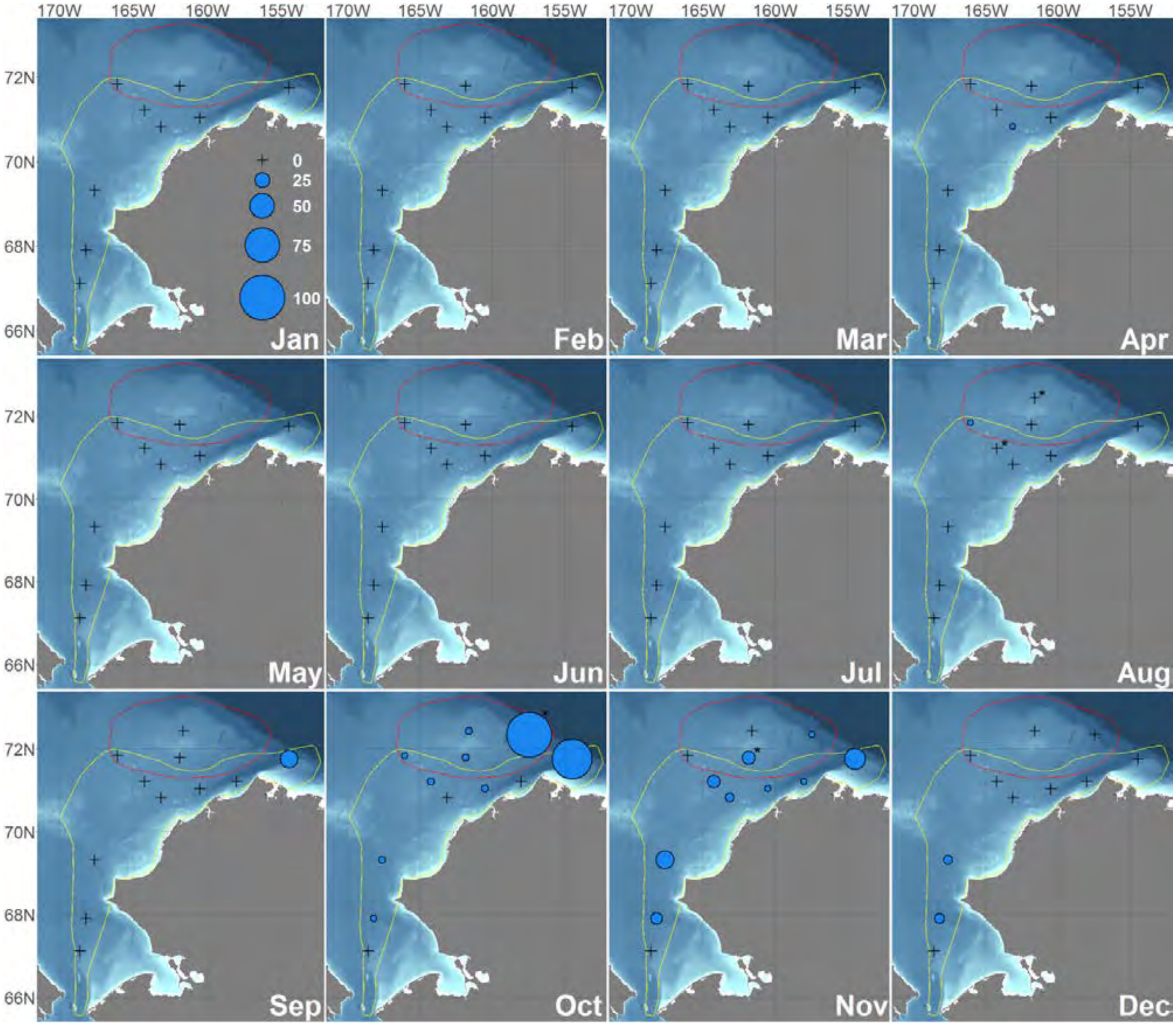


Figure 71. Monthly ribbon seal calling distribution, 2013. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 12 for numbers used to generate figure.

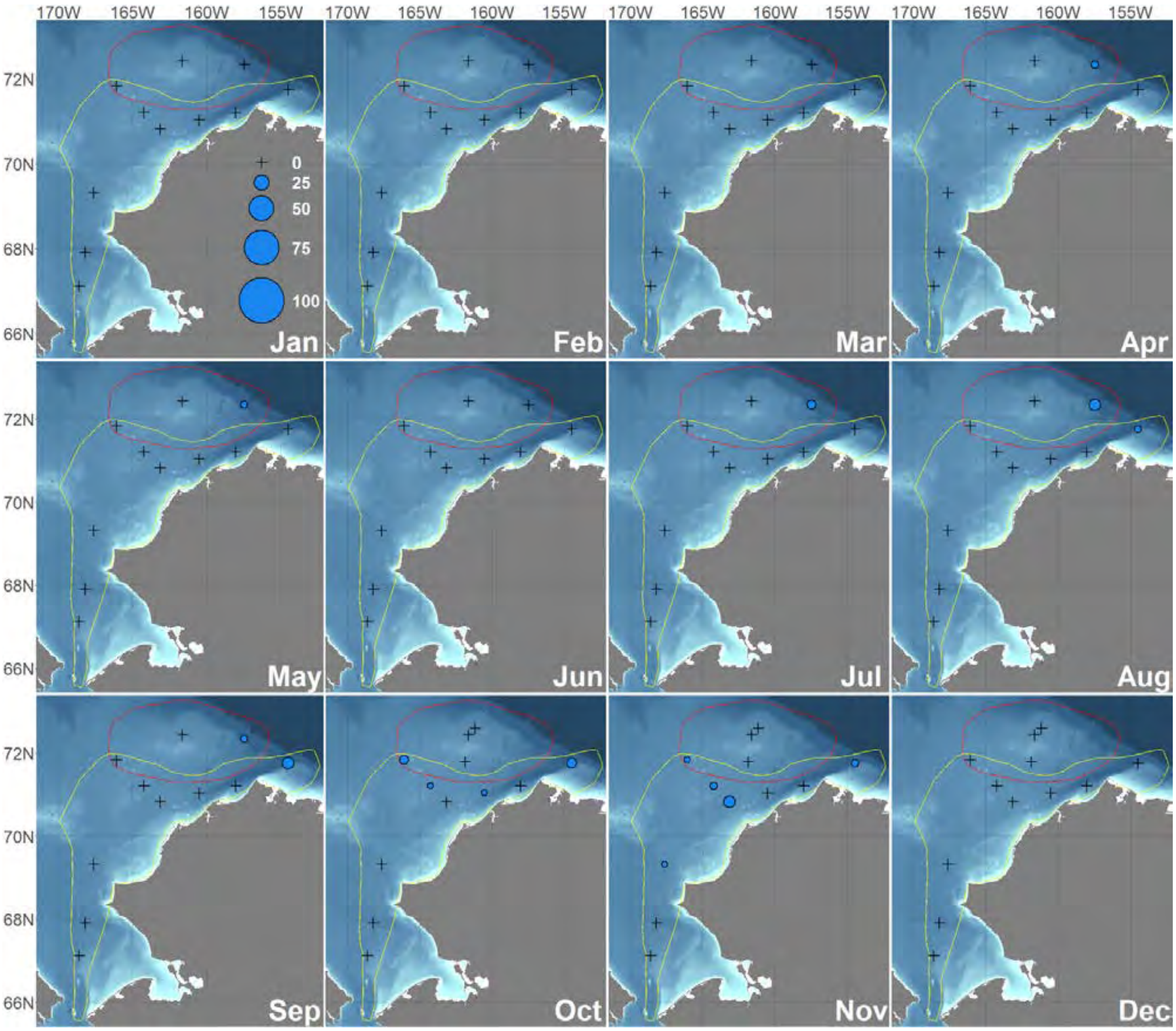


Figure 72. Monthly ribbon seal calling distribution, 2014. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 12 for numbers used to generate figure.

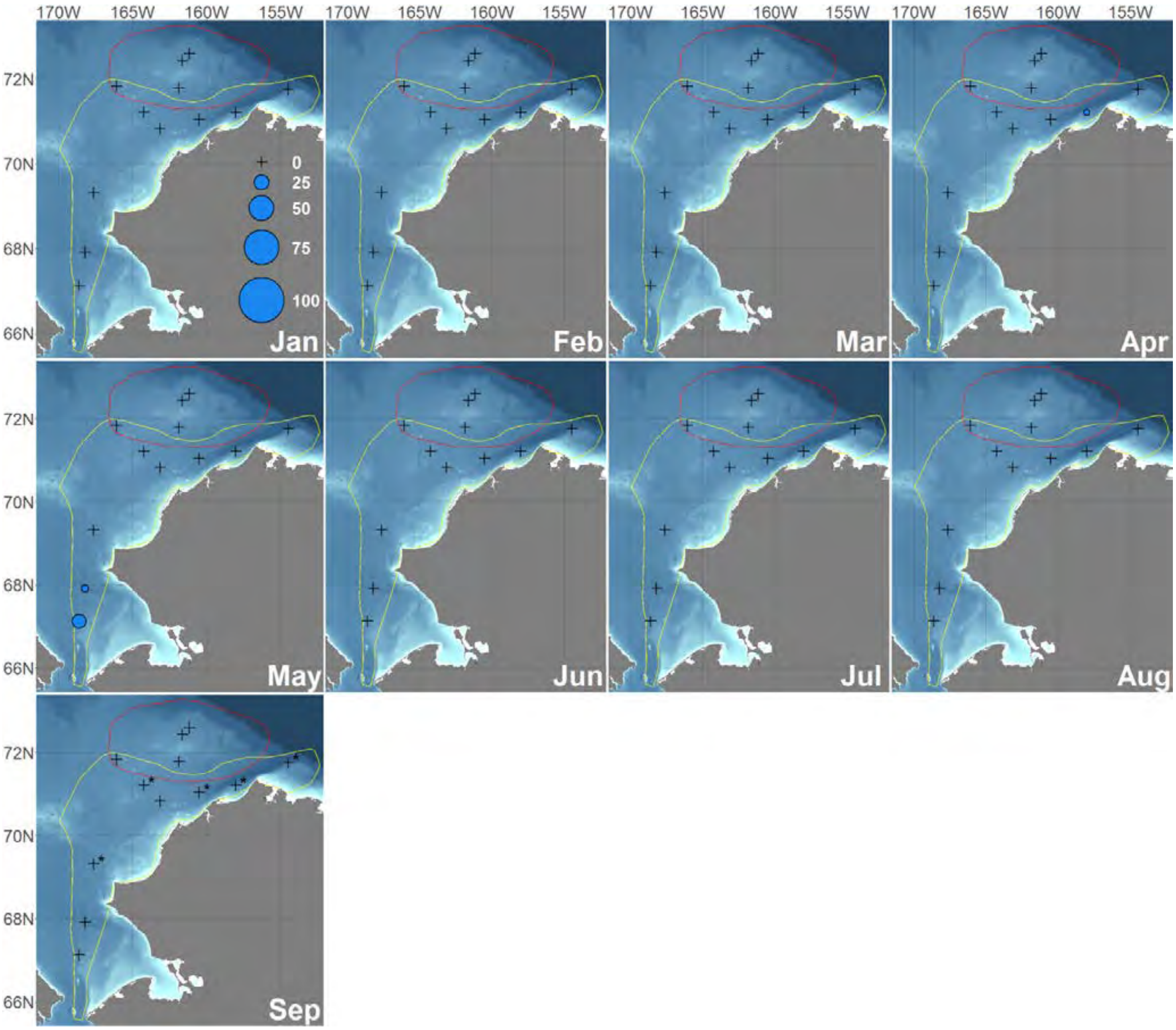


Figure 73. Monthly ribbon seal calling distribution, 2015. Graduated scale in the January panel indicates % days per month with calling. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 12 for numbers used to generate figure.

Note on double knocks:

In the process of analyzing the large data set for the ARCWEST and CHAOZ-X 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 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 608 of 3468 days with recordings (~17%). At this point in time, the seasonality of this sound seems to align best with that of beluga whales (Figure 74). However, further investigations are on hold until a larger sample size of results from multiple moorings and years is obtained from the Chukchi, Beaufort, and Bering Seas and more robust spatial and temporal trends can be determined.

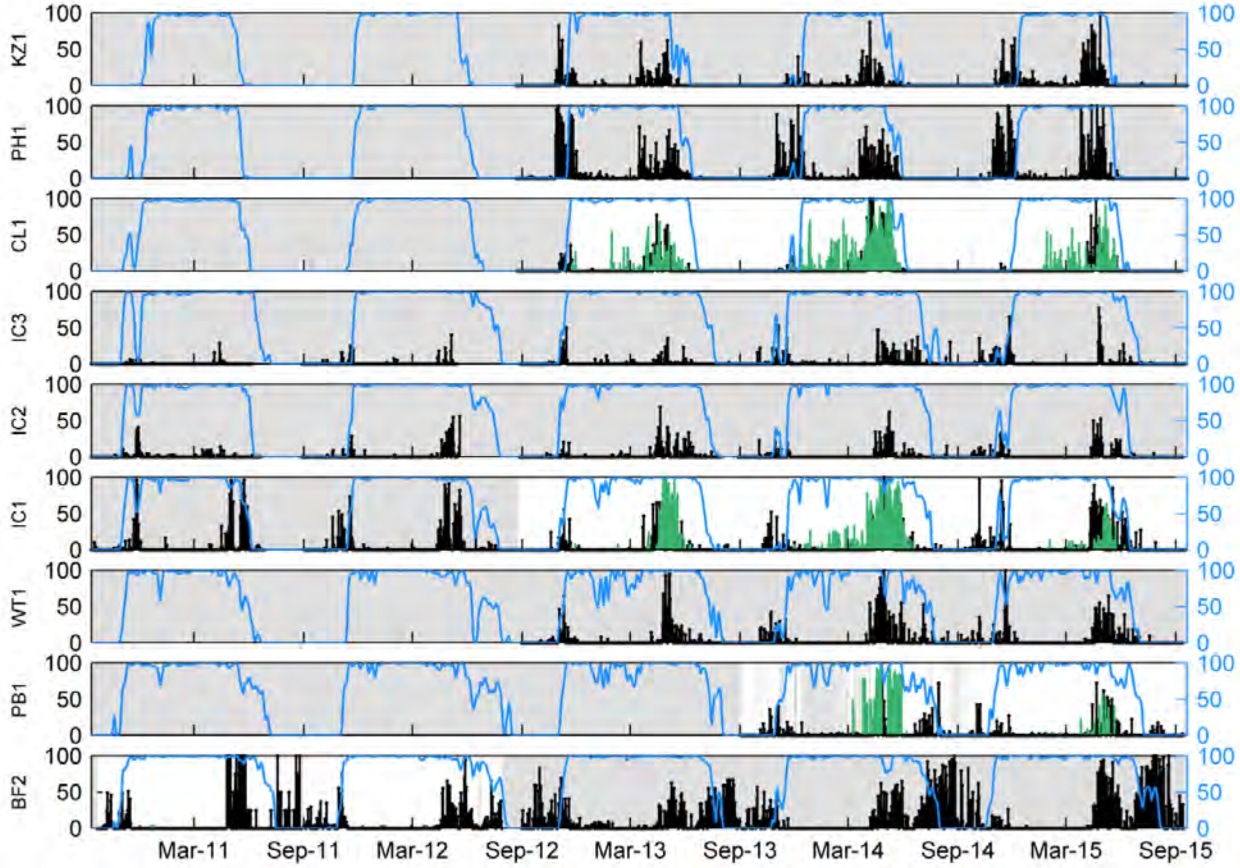


Figure 74. Double knock sound activity (green) overlaid on beluga whale calling activity (presented as the percentage of ten-minute time intervals with calls) for the nine ARCWEST locations (see Figure 2A), 2010-2015. Blue line indicates percent ice cover (zero-phase, three-day moving average). Gray shading indicates no data or data not yet analyzed.

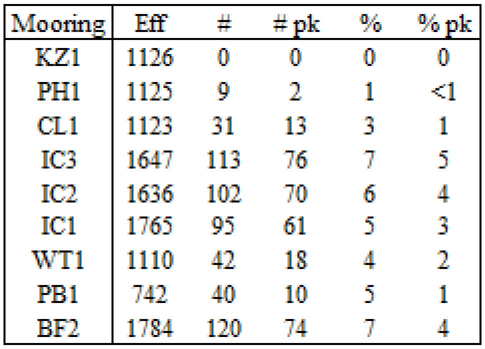
Environmental and anthropogenic sources

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

Seismic airguns

Seismic airgun noise activity was present in all six open water seasons from 2010 to 2015 (Figure 75). It was detected at most of the mooring sites in the ARCWEST study area, with the exception of KZ1, the southernmost site (Figure 75; Table 33). Mooring sites along the Icy Cape Line (IC1-3) and those furthest east (PB1, BF2) had the greatest proportion of days with airgun noise activity, although all had less than 10 %. They also had the highest proportion of days with peak noise activity levels (Table 33). 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 across the most mooring sites (Figures 76-81, Figure 81).

Table 33. Total airgun noise activity, 2010-2015, for all ARCWEST 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
KZ1	1126	0	0	0	0
PH1	1125	9	2	1	<1
CL1	1123	31	13	3	1
IC3	1647	113	76	7	5
IC2	1636	102	70	6	4
IC1	1765	95	61	5	3
WT1	1110	42	18	4	2
PB1	742	40	10	5	1
BF2	1784	120	74	7	4

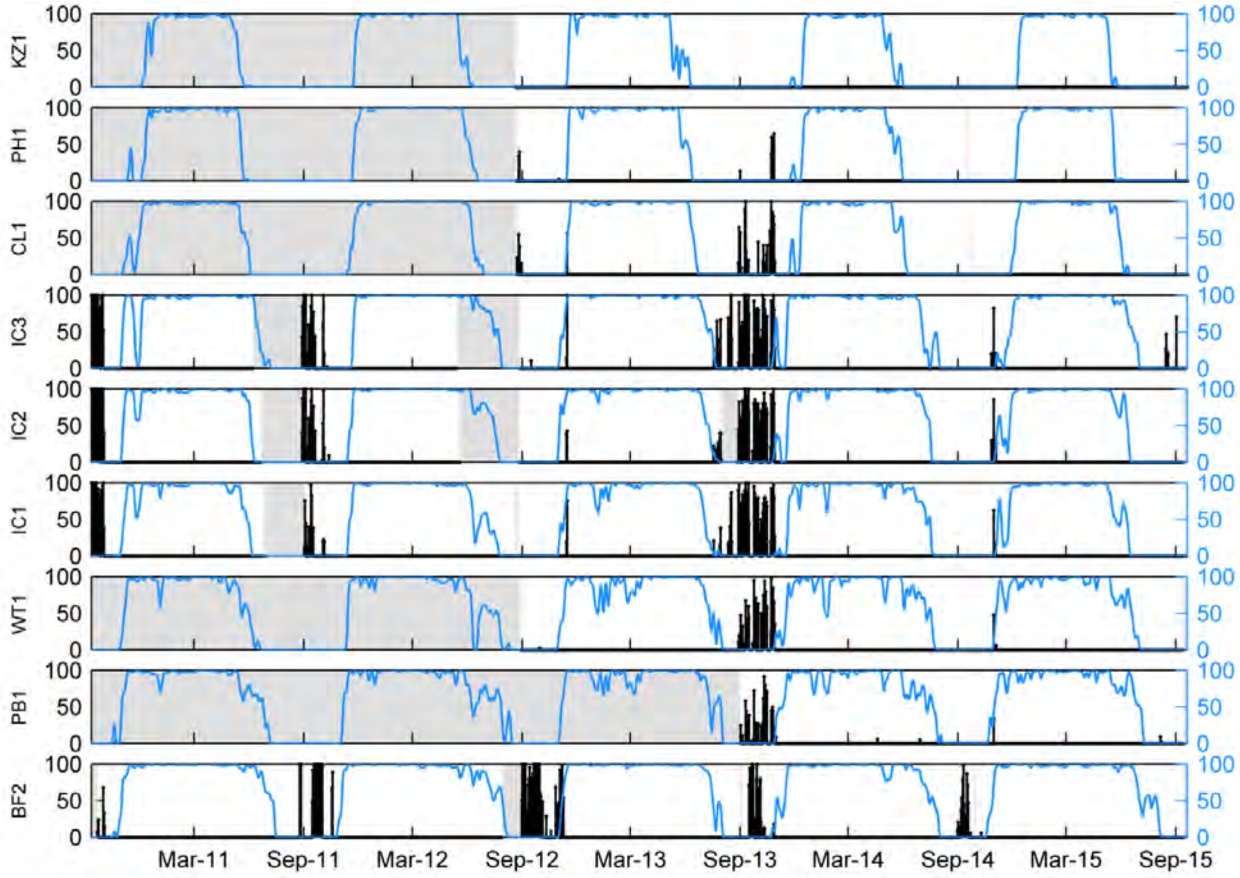


Figure 75. Airgun noise activity (presented as the percentage of ten-minute time intervals with airguns detected) for the nine ARCWEST locations (see Figure 2A), 2010-2015. Blue line indicates percent ice cover (zero-phase, three-day moving average). Gray shading indicates no data.

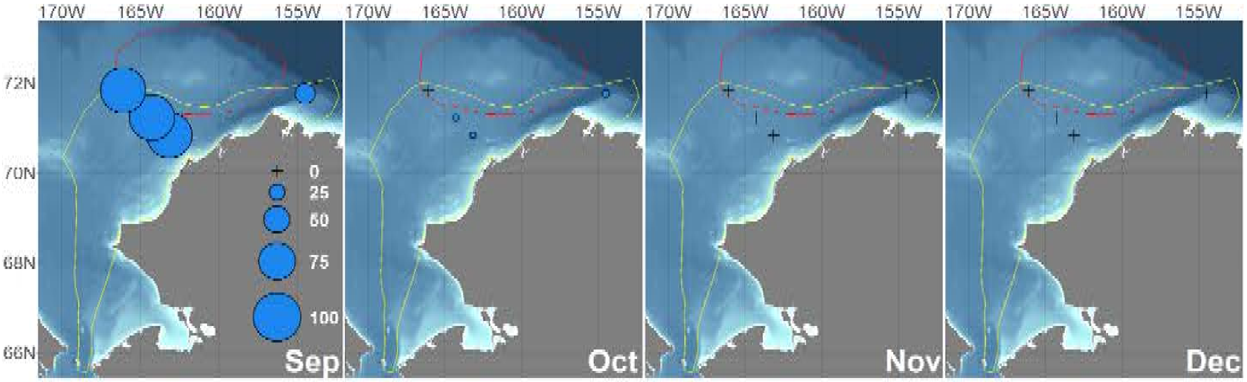


Figure 76. Monthly airgun noise distribution, 2010. Graduated scale in the September panel indicates % days per month with airgun noise. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 13. for numbers used to generate figure.

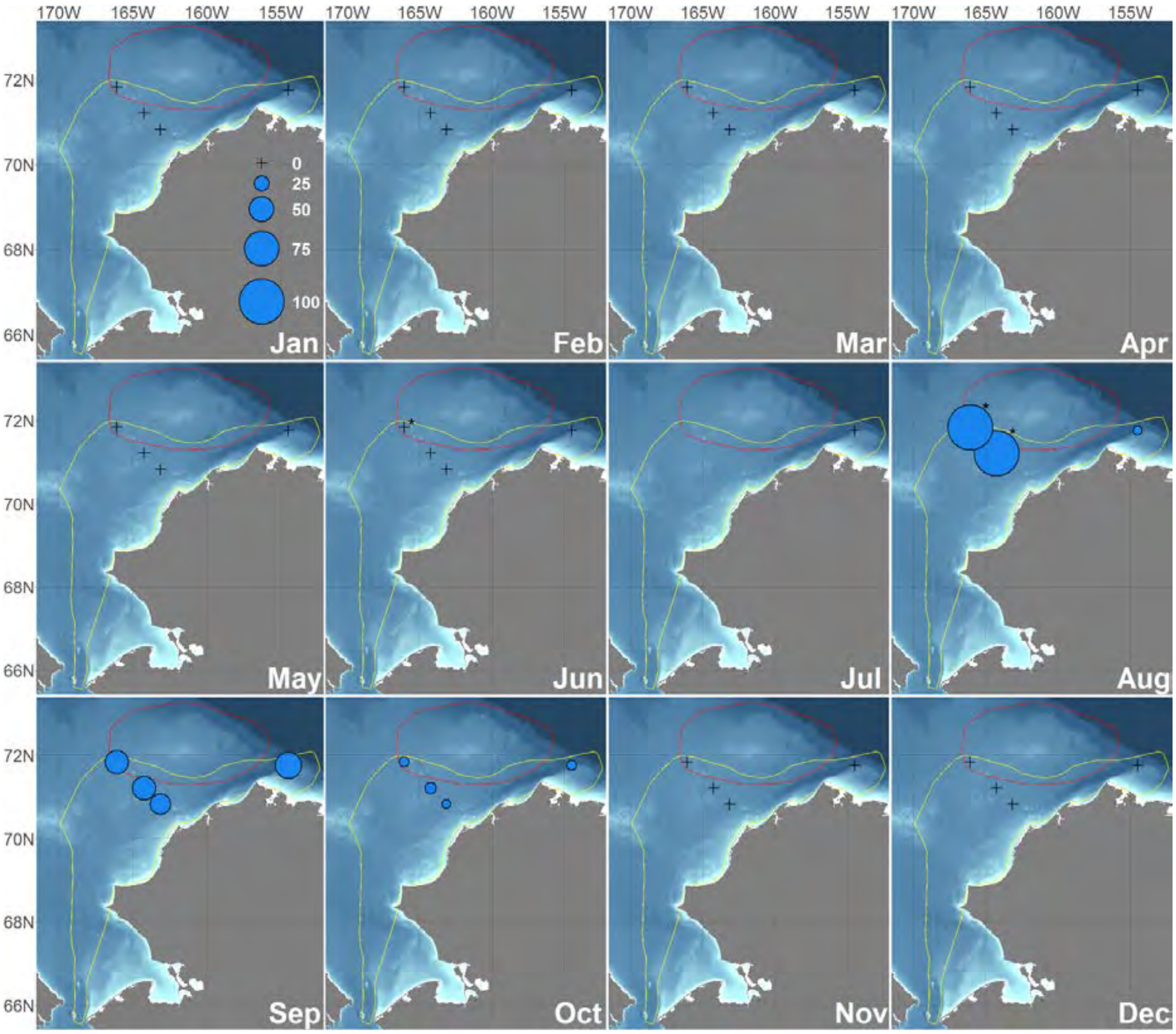


Figure 77. Monthly airgun noise distribution, 2011. Graduated scale in the January panel indicates % days per month with airgun noise. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 13. for numbers used to generate figure.

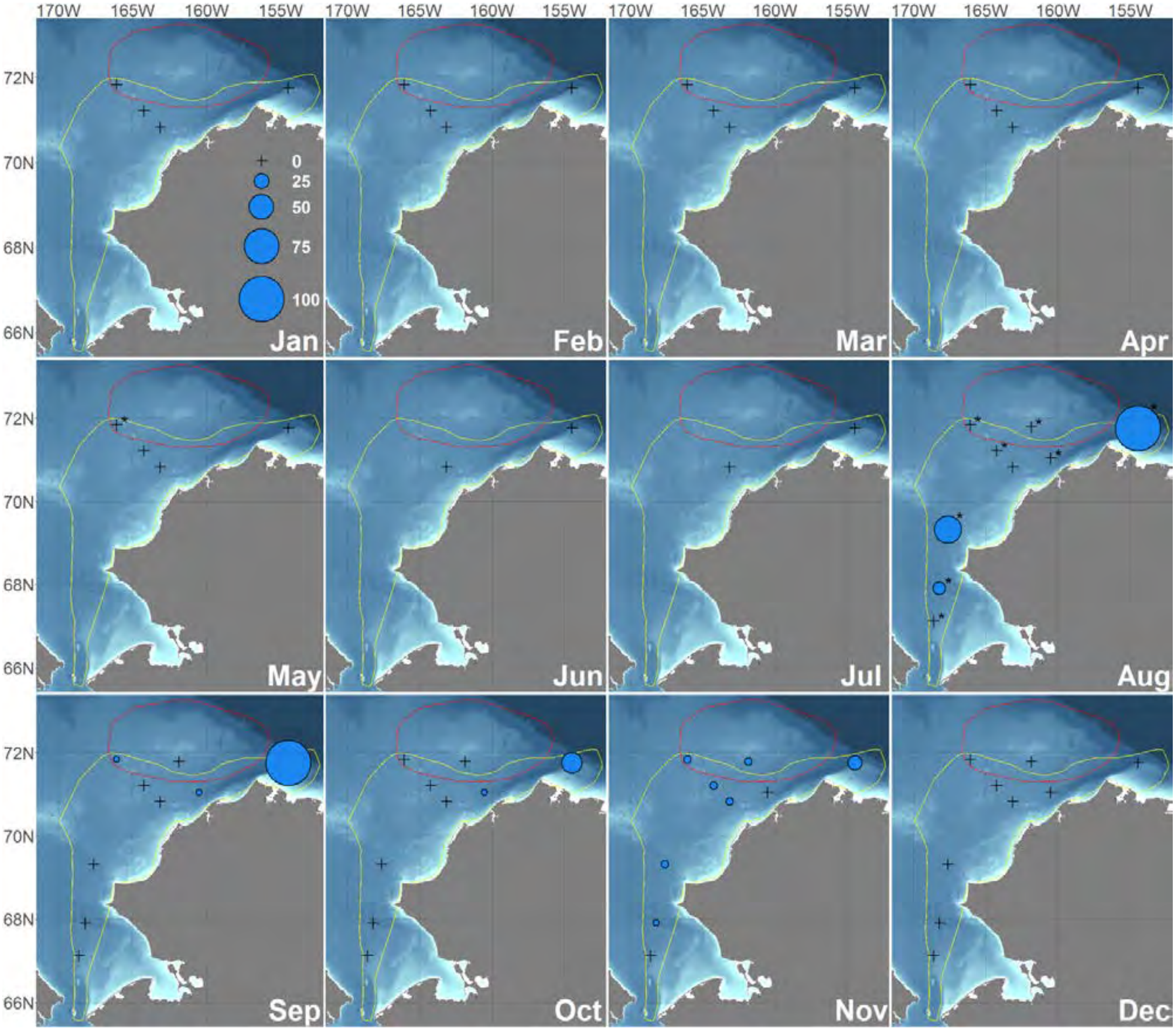


Figure 78. Monthly airgun noise distribution, 2012. Graduated scale in the January panel indicates % days per month with airgun noise. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 13. for numbers used to generate figure.

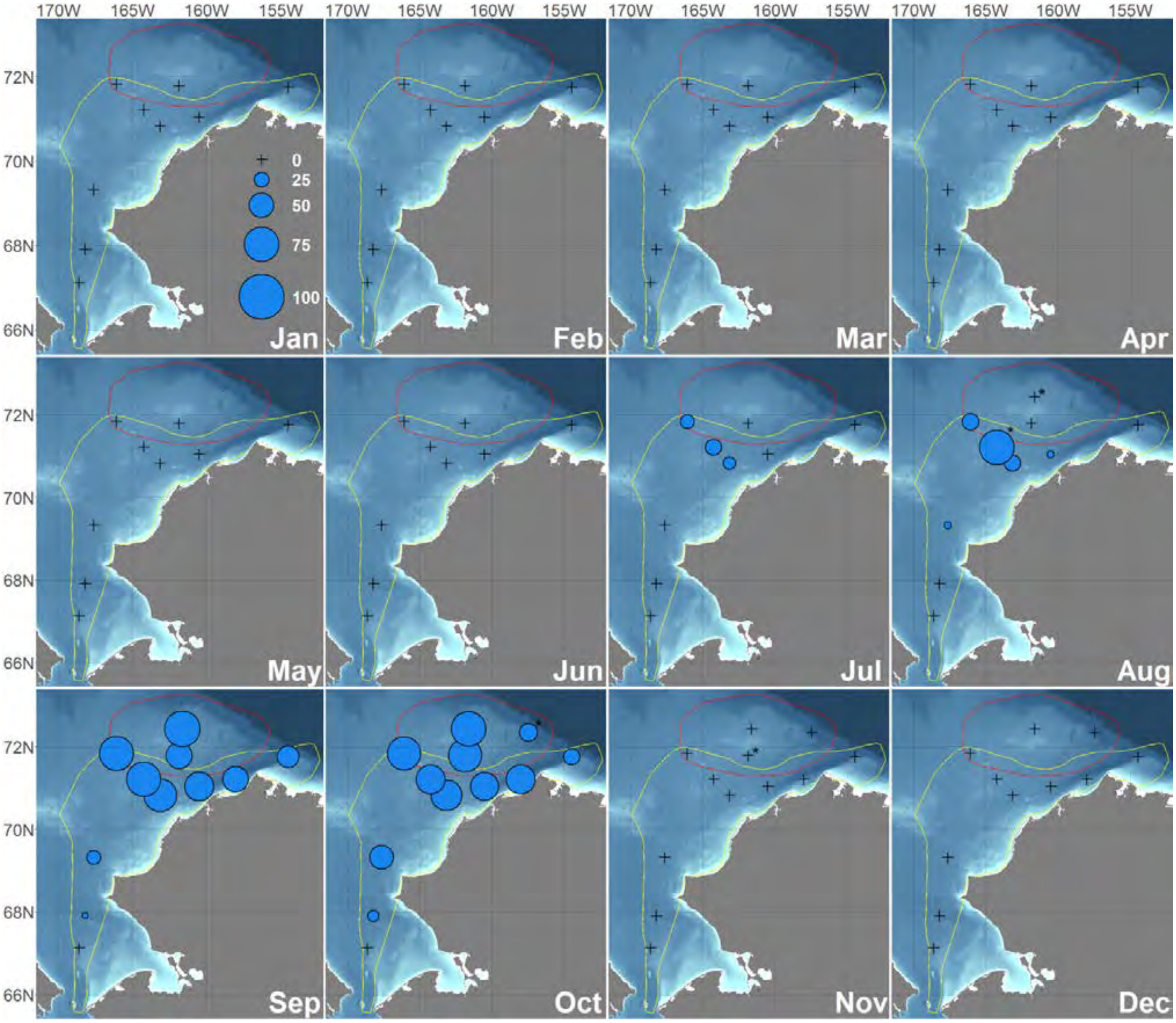


Figure 79. Monthly airgun noise distribution, 2013. Graduated scale in the January panel indicates % days per month with airgun noise. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 13. for numbers used to generate figure.

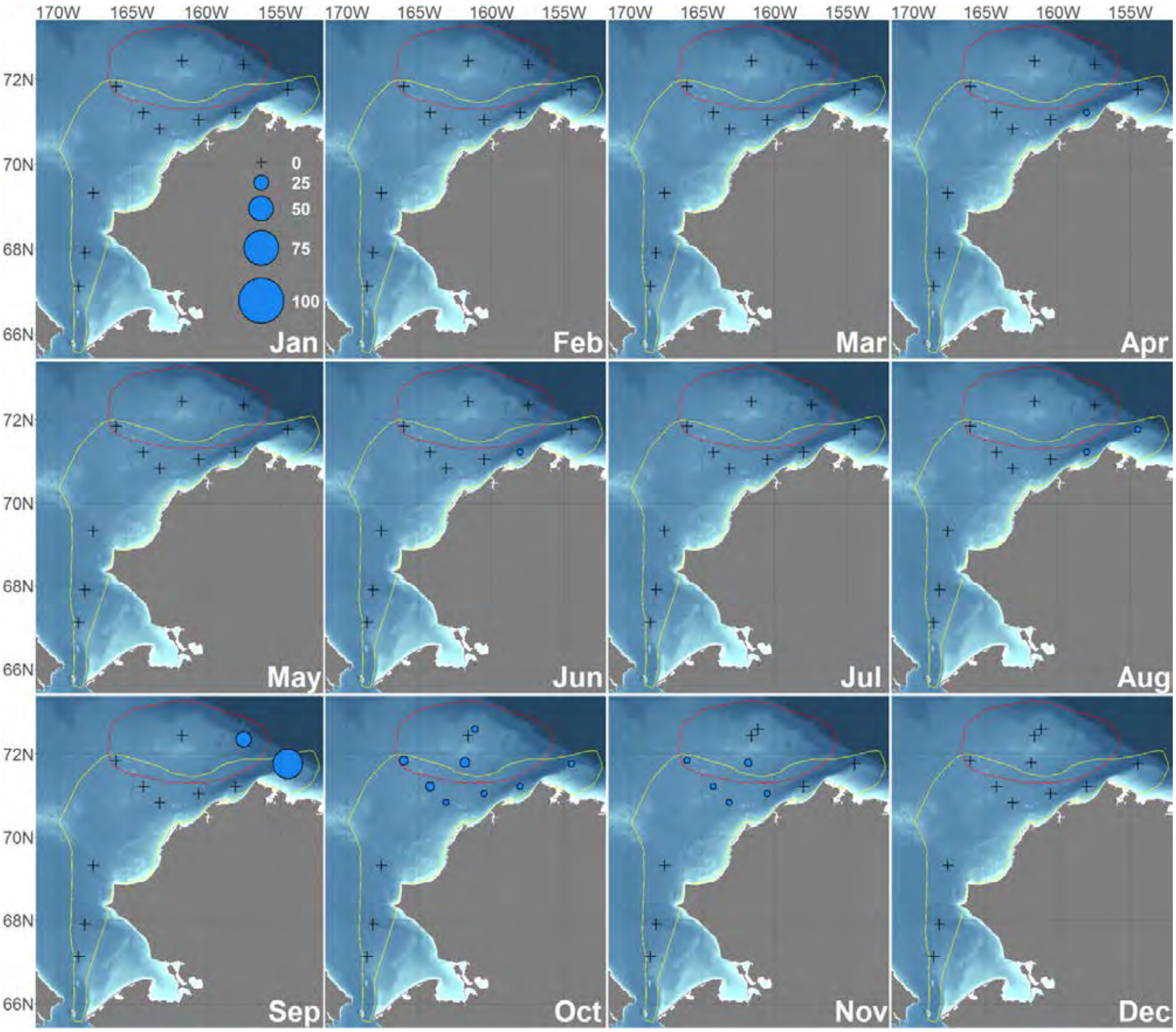


Figure 80. Monthly airgun noise distribution, 2014. Graduated scale in the January panel indicates % days per month with airgun noise. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 13. for numbers used to generate figure.

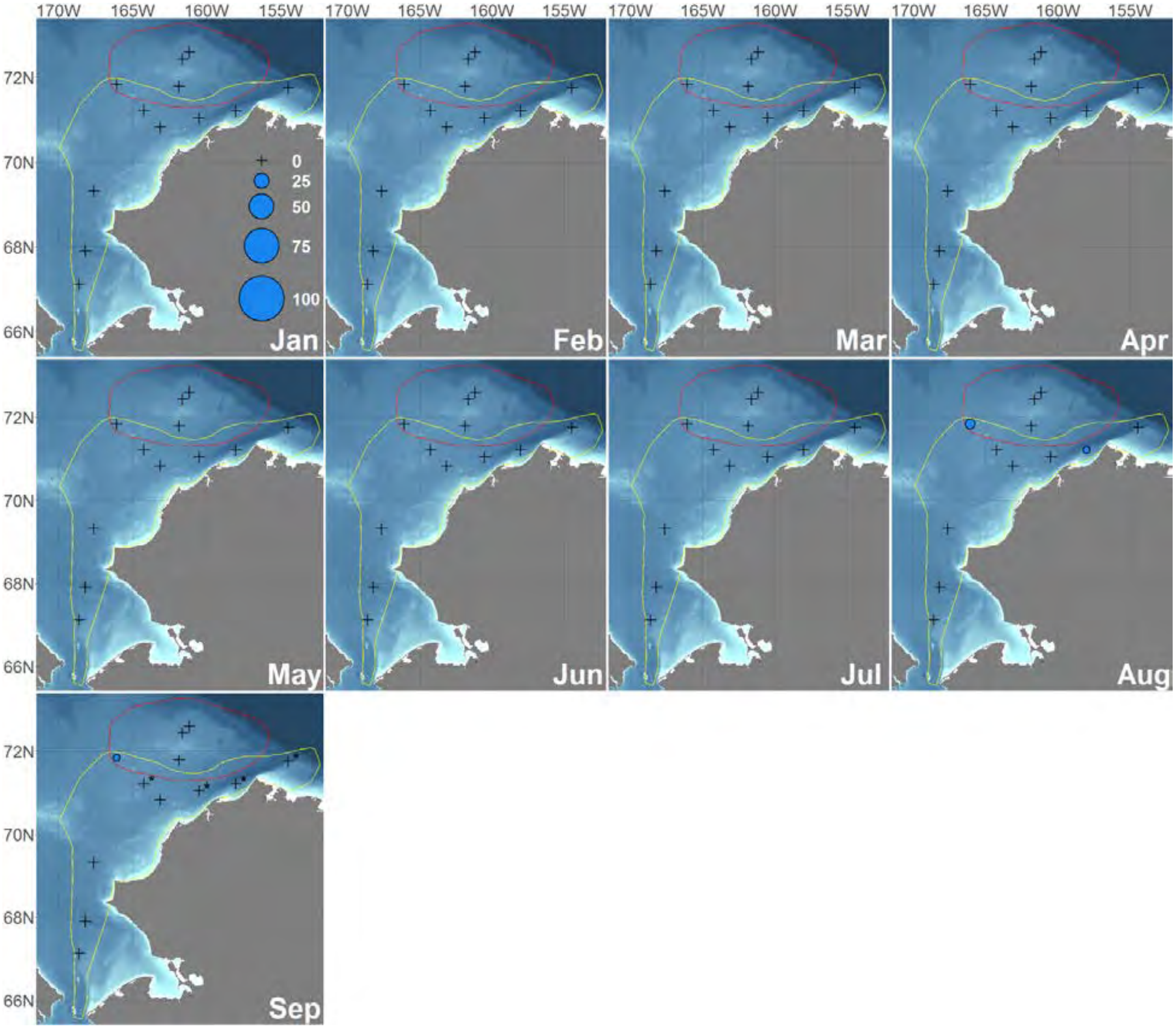


Figure 81. Monthly airgun noise distribution, 2015. Graduated scale in the January panel indicates % days per month with airgun noise. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 13. for numbers used to generate figure.

Vessel noise

Vessel noise activity was also present in all six open water seasons from 2010 to 2015 (Figure 82). It was detected at all of the mooring sites in the ARCWEST study area (Figure 82; Table 34). The southernmost mooring site (KZ1) had the highest percentage (i.e., ~20%) of days with vessel noise detected, while the easternmost (BF2) and furthest offshore (IC3) moorings had the lowest percentage (i.e., < 10%; Table 34). The inshore Icy cape mooring (IC1), however, had the highest sustained levels of peak vessel noise activity. The open water seasons of 2012, 2013, and 2015 had the highest (saturated) levels of vessel noise activity, with 2015 having the longest sustained period with saturated levels across the most mooring sites (Figures 83-88).

Table 34. Total vessel noise activity, 2010-2015, for all ARCWEST 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
KZ1	1126	216	31	19	3
PH1	1125	165	36	15	3
CL1	1123	131	16	12	1
IC3	1647	100	27	6	2
IC2	1636	166	73	10	4
IC1	1765	261	150	15	8
WT1	1110	181	59	16	5
PB1	742	112	23	15	3
BF2	1784	140	23	8	1

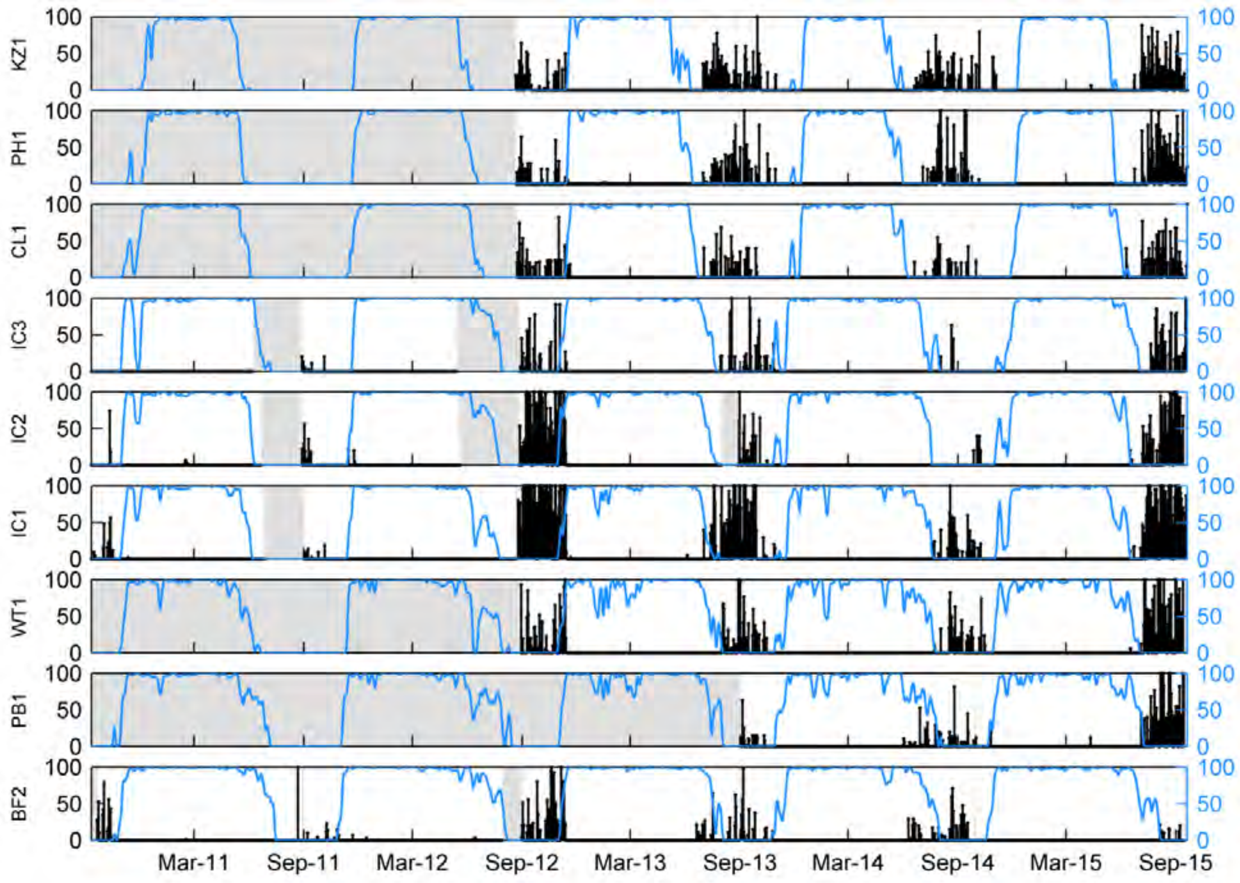


Figure 82. Vessel noise activity (presented as the percentage of ten-minute time intervals with vessels detected) for the nine ARCWEST locations (see Figure 2A), 2010-2015. Blue line indicates percent ice cover (zero-phase, three-day moving average). Gray shading indicates no data.

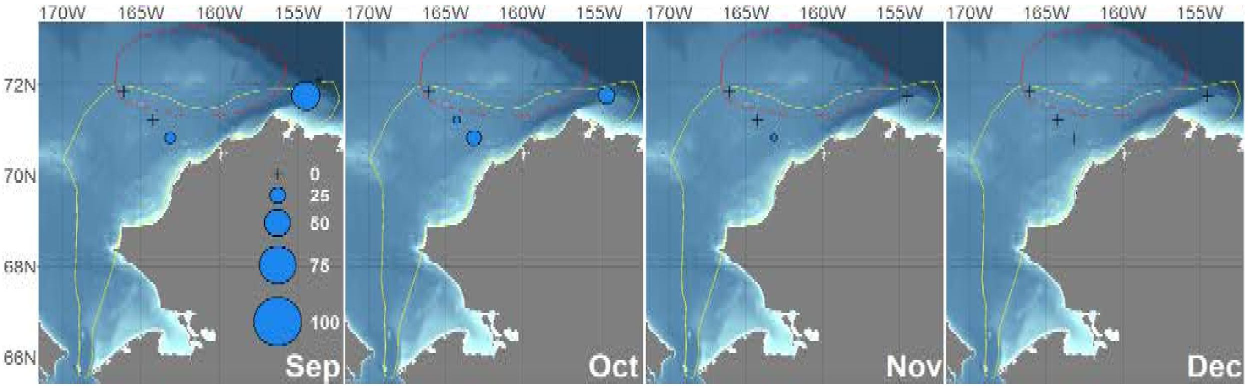


Figure 83. Monthly vessel noise distribution, 2010. Graduated scale in the September panel indicates % days per month with vessel noise. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 14 for numbers used to generate figure.

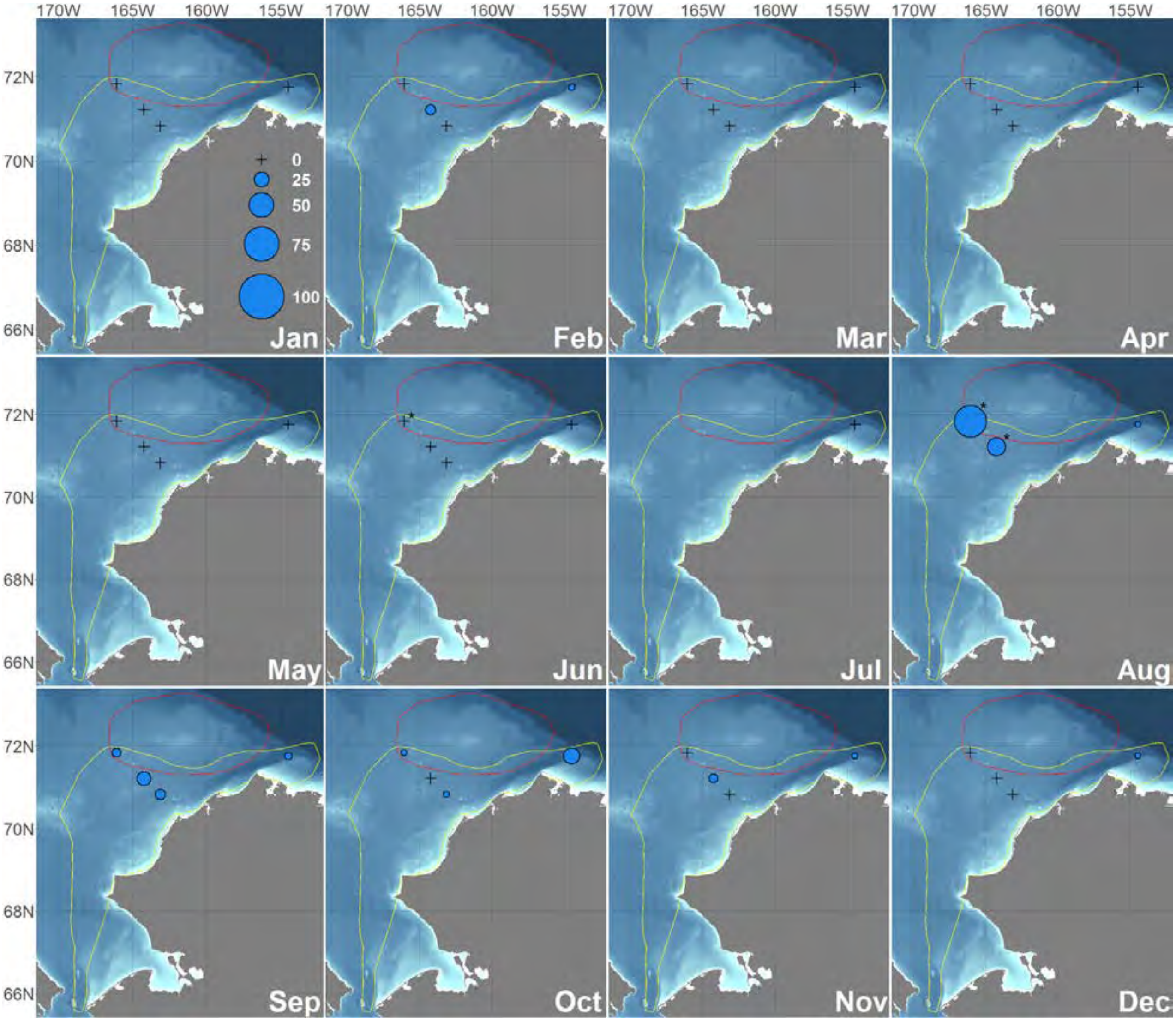


Figure 84. Monthly vessel noise distribution, 2011. Graduated scale in the January panel indicates % days per month with vessel noise. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 14 for numbers used to generate figure.

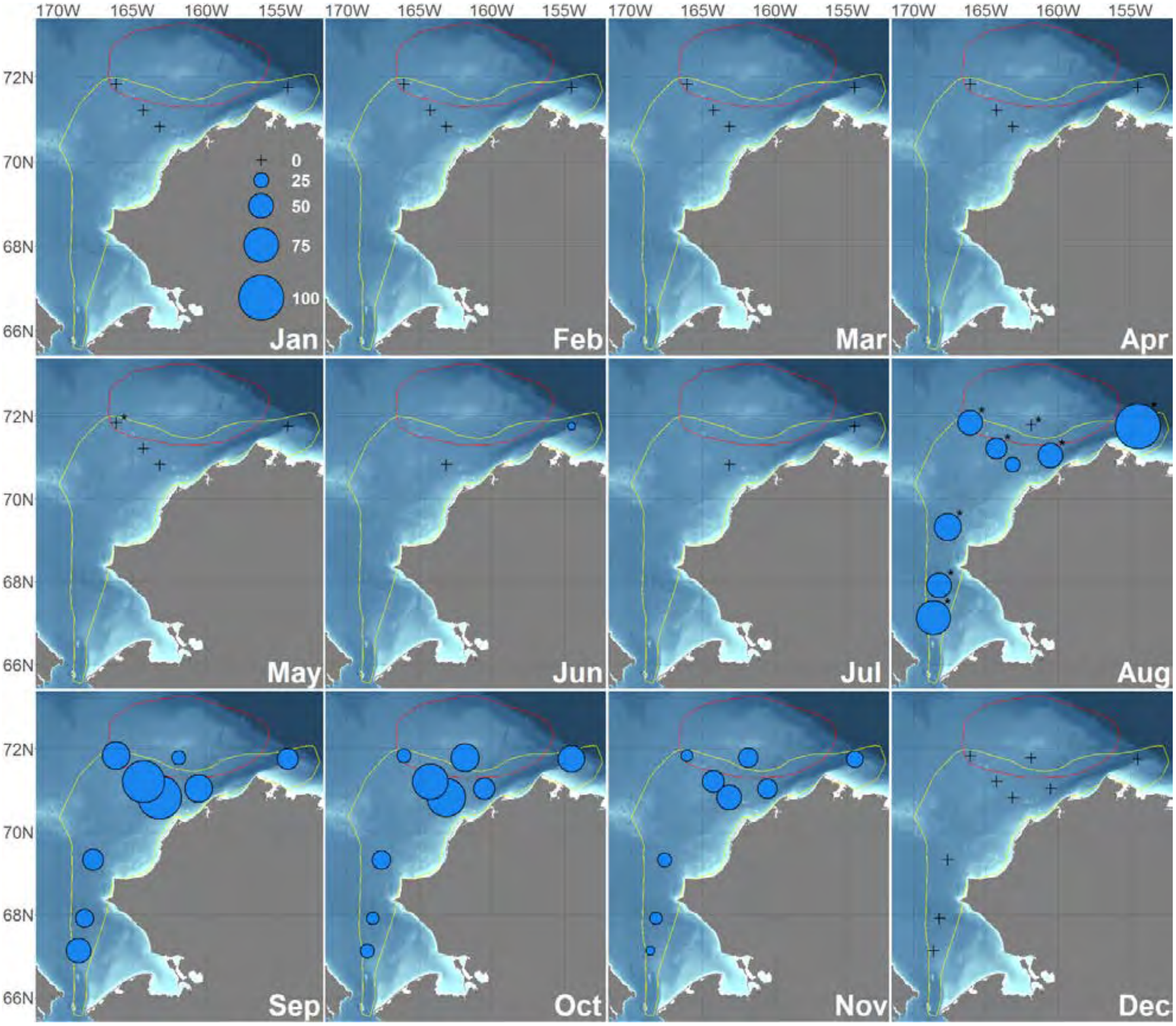


Figure 85. Monthly vessel noise distribution, 2012. Graduated scale in the January panel indicates % days per month with vessel noise. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 14 for numbers used to generate figure.

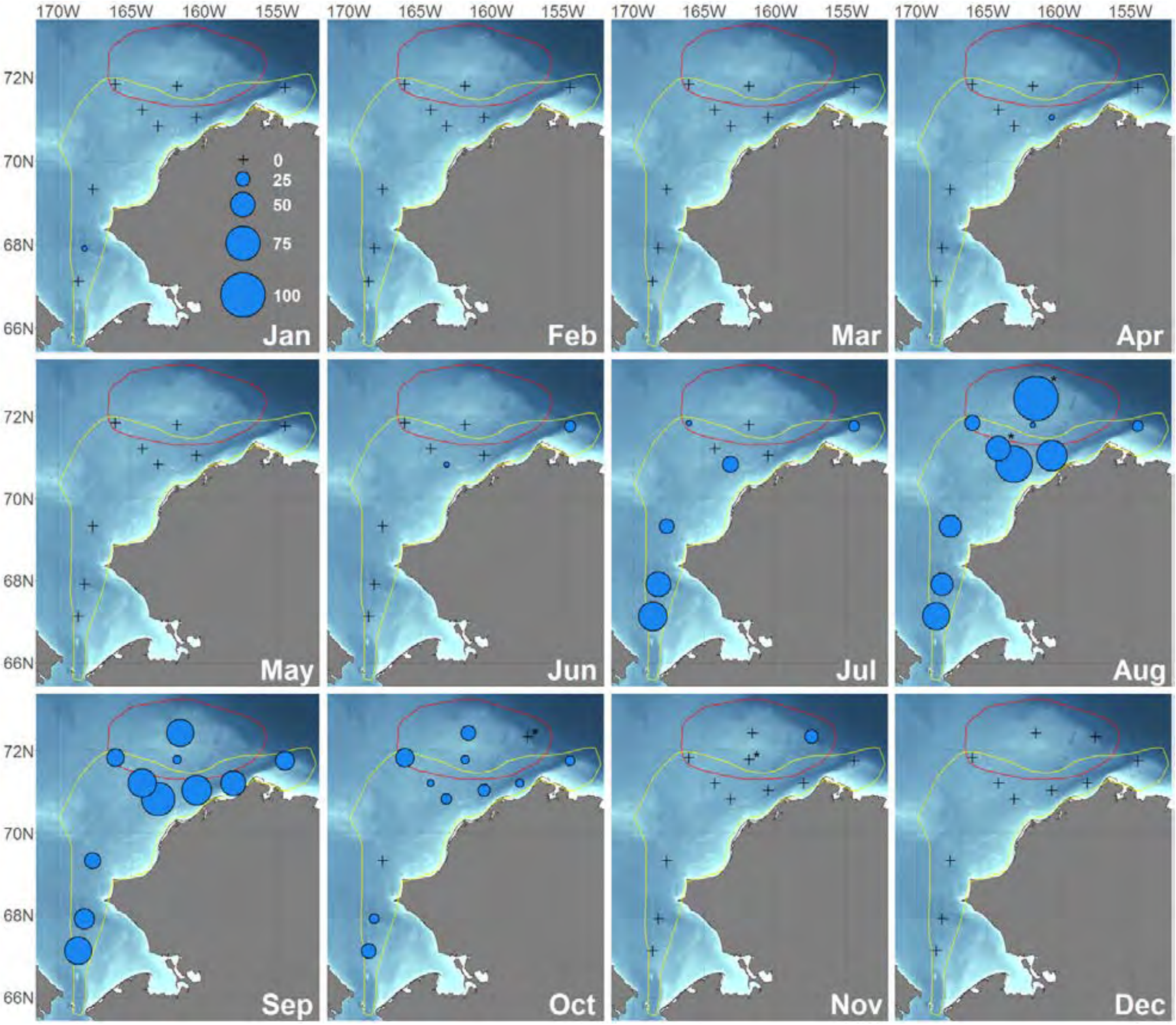


Figure 86. Monthly vessel noise distribution, 2013. Graduated scale in the January panel indicates % days per month with vessel noise. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 14 for numbers used to generate figure.

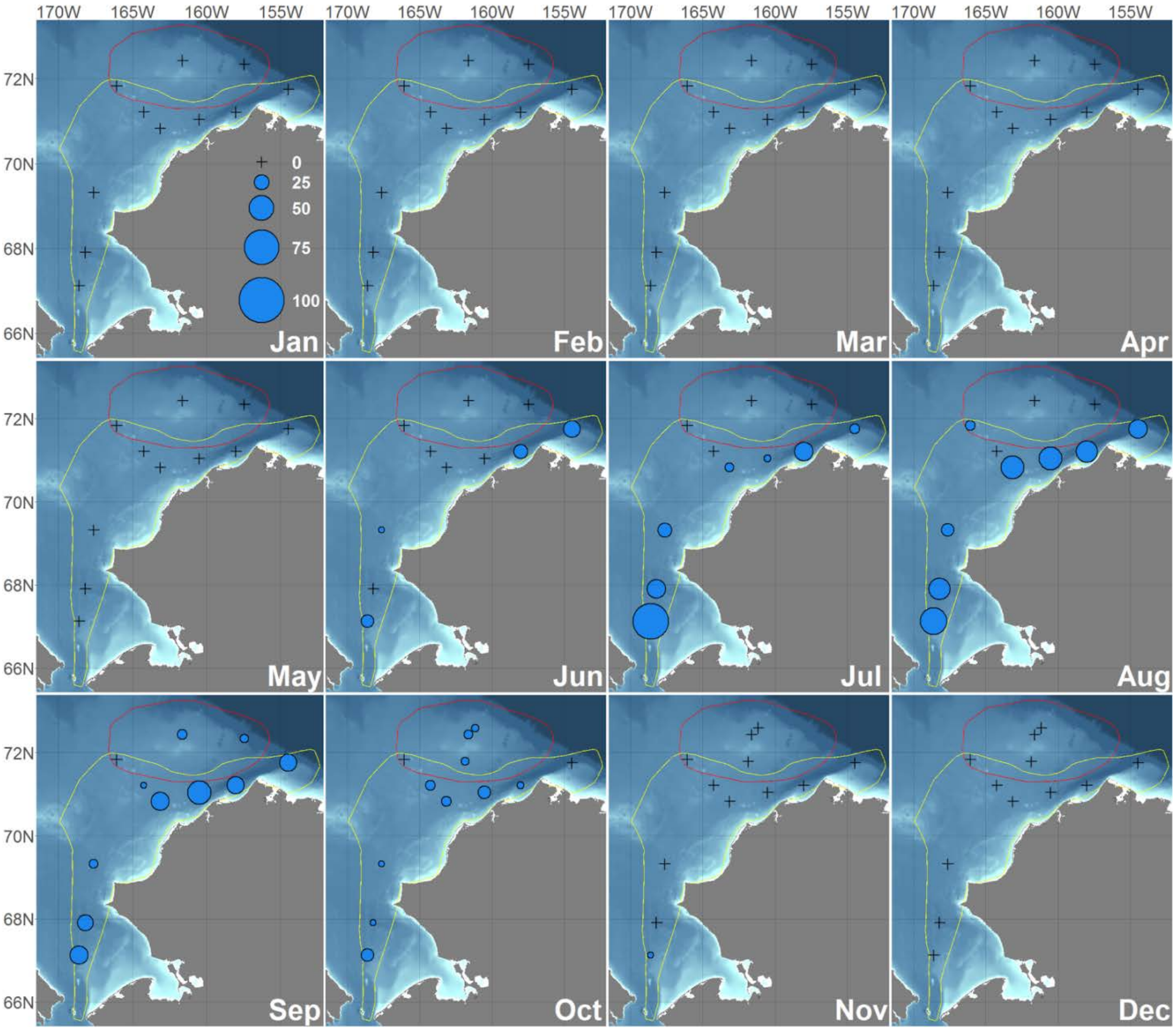


Figure 87. Monthly vessel noise distribution, 2014. Graduated scale in the January panel indicates % days per month with vessel noise. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 14 for numbers used to generate figure.

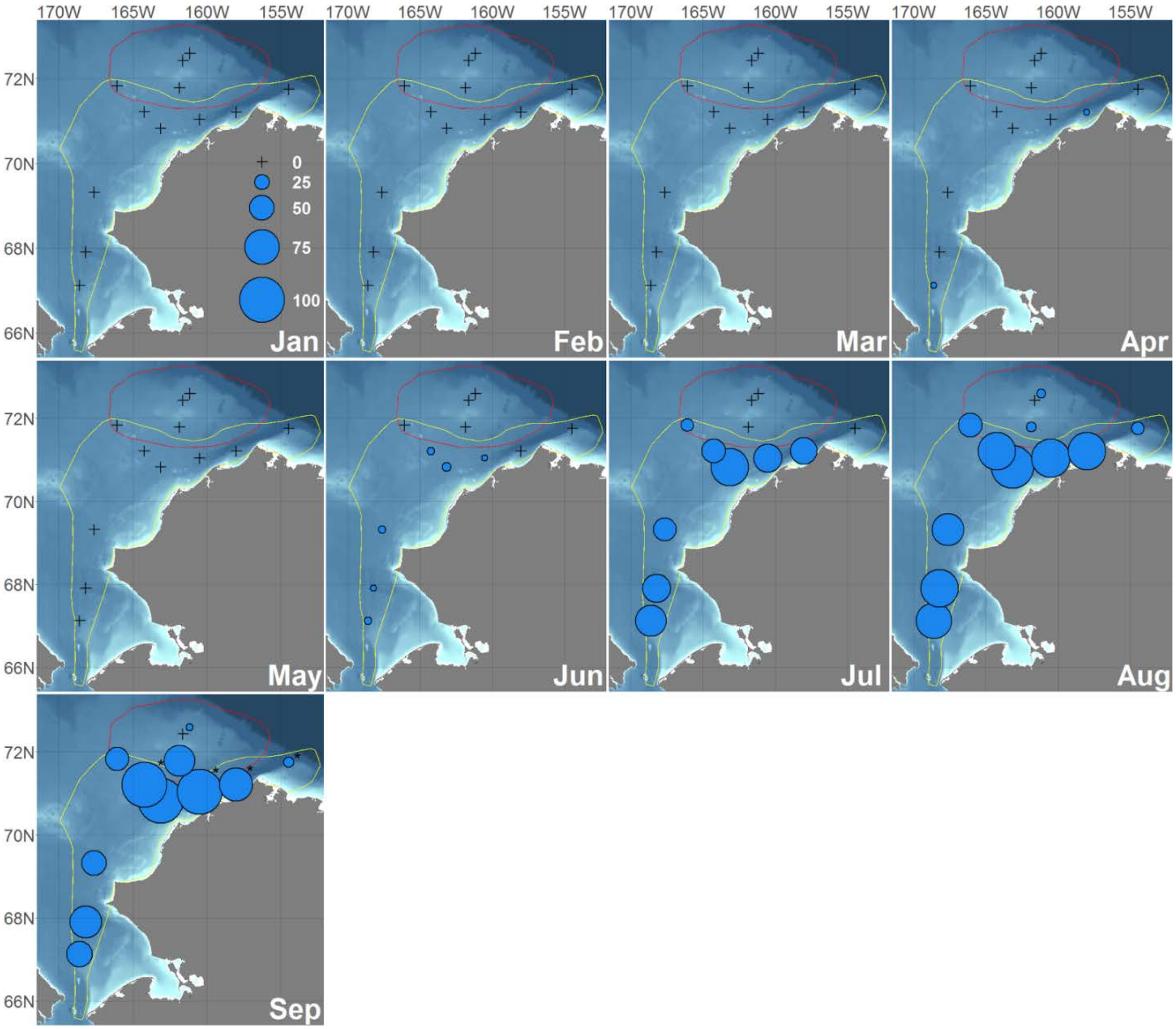


Figure 88. Monthly vessel noise distribution, 2015. Graduated scale in the January panel indicates % days per month with vessel noise. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 14 for numbers used to generate figure.

Ice noise

A substantial source of noise on the year-long recordings was from ice, 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 89; Table 35). Among sites, the easternmost (BF2) and offshore Icy Cape (IC2-3) sites had the highest percentage of days with ice noise detected, and those sites also had the highest proportion of days with peak noise activity levels. However, please note that 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 D1-6.

Table 35. Total ice noise activity, 2010-2015, for all ARCWEST 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
KZ1	1126	376	69	33	6
PH1	1124	446	104	40	9
CL1	1114	472	154	42	14
IC3	1647	891	289	54	18
IC2	1636	879	424	54	26
IC1	1765	728	219	41	12
WT1	1103	445	177	40	16
PB1	742	379	120	51	16
BF2	1784	1233	611	69	34

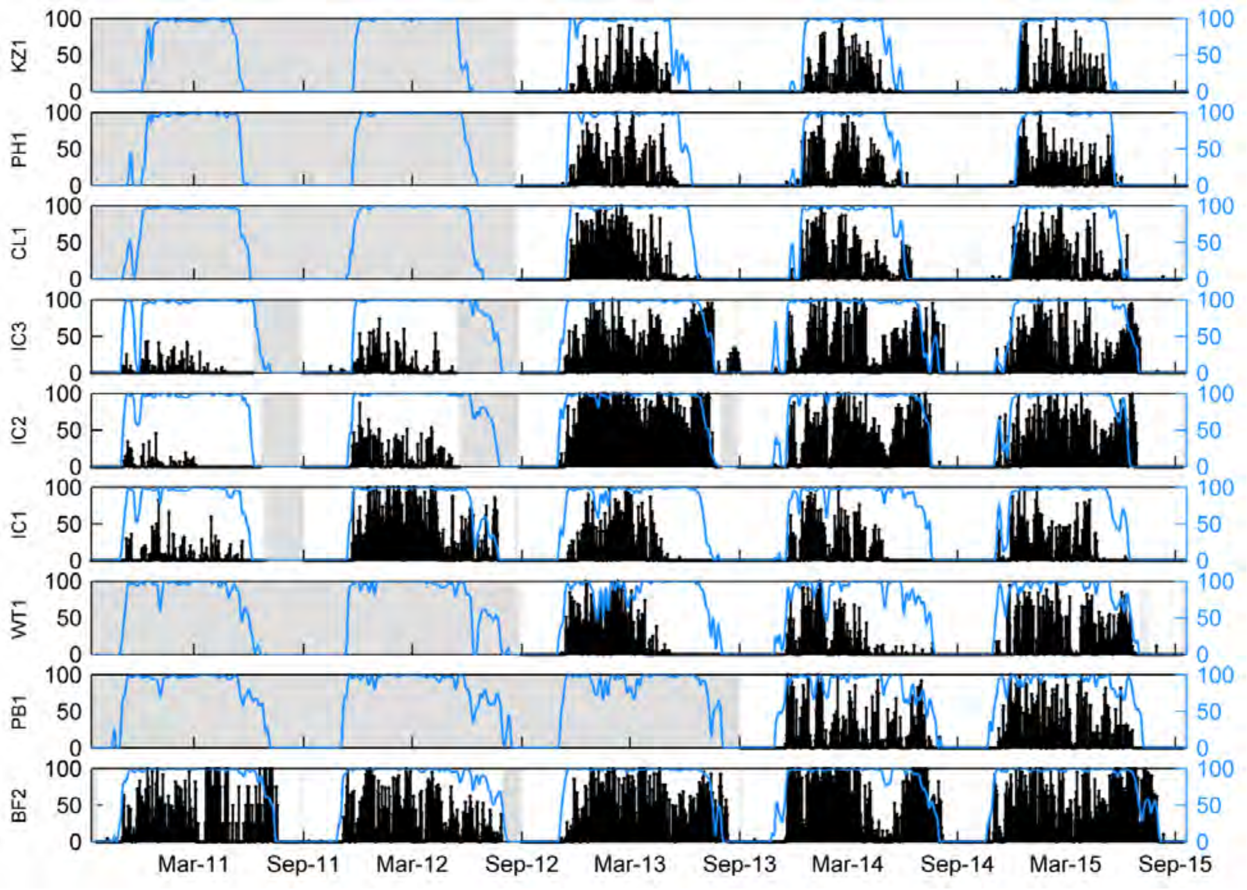


Figure 89. Ice noise activity (presented as the percentage of ten-minute time intervals with vessels detected) for the nine ARCWEST locations (see Figure 2A), 2010-2015. Blue line indicates percent ice cover (zero-phase, three-day moving average). Gray shading indicates no data.

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 included in this discussion section, key findings for each species or signal will also be presented as concise, bulleted highlights in the Conclusions (Section VII.A.4) that follows.

Bowhead whales

The annual pattern of spring and fall pulses of bowhead whale calling activity described in the results above for the ARCWEST 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 Bering Sea along the Chukotka or Alaskan coasts through the Bering Strait, then following 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 it cannot be considered a Biologically Important Area (BIA) designated migratory corridor (Clarke et al., 2015a). Because the ARCWEST study area included some offshore mooring sites, 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.

Although the timing of the fall migratory pulse in calling activity for the ARCWEST study area is not consistent among years, its general movement among mooring sites follows the same east-to-west trend. For all years, the fall pulse was first seen east off Barrow, moving southwestward toward the southern Chukchi sites (Figures 7-12). This trend is also seen in Figure 6 where the fall 2013 pulse begins in September at the BF2 mooring site and this start date angles up later in time to the KZ1 mooring, where it begins in November. Furthermore, the divergence of the fall migration once past Point Barrow is evident in the similarity of the fall pulse in calling activity between the three Icy Cape mooring sites that range from 40 to 110 nm offshore (Figure 6-11).

For the most part, a distinct end to the fall pulse of calling activity was evident in region to the east of Cape Lisburne; very few days with bowhead calling were detected from January through March, and most of those occurred in the initial ice formation period. In general, these results fit for a population that is currently not believed to overwinter in the Arctic (Braham et al., 1984a). They are also 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. However, overwintering calling activity was present at peak levels in the southern Chukchi. This continued presence of bowhead whales north of the Bering Strait overwinter challenges the assumption that all bowhead whales pass through the strait during the fall migration. Investigation of bowhead calling activity on moorings in the northern Bering Sea will help elucidate whether these overwinter detections are due to a delayed fall migration, or one that never reached the Bering Sea.

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 the Icy Cape sites (Figure 6), where three distinct peaks or modes were seen. 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 fall pulses is needed to determine whether there is a difference in call characteristics among them, which might 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. Finer scale analysis that includes the bowhead whale gunshot call is shown in Figure 13. This call type occurs near the end of the fall migration pulse in calling activity for almost 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.).

The spring pulse in calling activity also followed the expected west-to-east trend, although the difference in timing between the southern and northeastern study areas was less than that seen with the fall pulse. Also unsurprising was the reduction of the spring pulse inshore-to-offshore along the Icy Cape line, with extremely low levels of calling activity at the offshore (IC3) site in all years (Figure 6). As it was expected that most of the spring migration would occur closer to shore in the leads of the shorefast ice, the surprising finding here is that any spring calling was detected at the mooring sites of this ARCWEST offshore study area. However, TEK describes another migration path in a lead approximately 75 miles from shore (Huntington and Quakenbush, 2009), approximately even with the IC2 mooring site. In addition, satellite tag (Quakenbush et al., 2013) and passive acoustic data (Clark et al., 1986; Hannay et al., 2013) have shown that not all whales are confined to the lead system.

For the moorings to the northeast of Cape Lisburne, it is difficult to determine where the spring pulse ends and the fall pulse starts. This is especially true the further east the mooring site is located. In contrast, the moorings in the southern Chukchi have a clear separation between the spring and fall pulses. Correspondingly, calling activity was present at all the northeastern

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

mooring sites/years during the open water (summer) season, while it was absent at the southern Chukchi Sea moorings. The BF2 mooring, located just to the east of Pt. Barrow (Beaufort Sea), is a known summer feeding ground for bowheads; a particular set of physical factors including the flow of ACC 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). The sustained high calling activity levels in the open water period at the BF2 mooring site, while most of the population is summering in the main feeding ground in the eastern Canadian Beaufort, supports its current designation as a biological hotspot for feeding.

Although calling activity during the open water season for the northeast Chukchi Sea moorings is not as pronounced or continuous as was seen in the Beaufort Sea, it is still present (Figure 6). The Chukchi Sea is used primarily as a migratory corridor by the BCB stock. It is also identified as a 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. 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 X.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 the field cruises, it was found that bowhead whales are equally likely to be visually sighted as acoustically detected. 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 ARCWEST 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., 2015b). 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, the start of which was seen around March in the southern Chukchi and around April in the northeastern Chukchi/western Beaufort, is consistent with the spring migration. Unlike the bowhead spring migration, beluga whale spring calling activity was seen at all moorings including those offshore (IC2, IC3). At first glance, these results are puzzling, given the location of these moorings offshore (70-110 nm respectively), 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). They have also been seen to break through ice up to 20 cm thick (Fraker, 1979).

Although not discussed, there are satellite ice data in Fraker (1979) that show the presence of leads offshore on the Chukchi Sea shelf (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 15-19) provides a bit more context. The March through June panels of Figure 19 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 eastward 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[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, however, 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 ARCWEST mooring locations adds the possibility that a proportion of individuals from either population overwinter in the area. The association between belugas and ice conditions is discussed in detail in Section X.A.

The presence of calling activity in the open water season, particularly the high levels seen at the Beaufort Sea site (BF2) is consistent with the summer range of the Eastern Chukchi Sea population of beluga whales (Hauser et al., 2014). This population has been reported to feed on saffron cod, cephalopods, crustaceans, and marine worms (Seaman et al., 1982; Braham et al., 1984a; Lowry et al., 1985). Other studies suggest that this population also feeds on Arctic cod (Citta et al., 2013; Stafford et al., 2013; Hauser et al., 2014, 2015). Current data from Quakenbush et al. (2015) found that shrimp were the predominant prey type; however, their results are from the spring migration and potentially do not represent sampling from prime beluga feeding grounds. The diet of the Beaufort Sea population is reported to be primarily Arctic cod, along with other fish, cephalopods, and shrimp (Moore et al., 2000; Hauser et al., 2015).

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 possibility that the double knock call type could be attributed to fish, and its apparent co-occurrence with beluga whale calling activity (Figure 74), has potential for investigating whether beluga are foraging for fish in the CHAOZ-X study area.

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[14] 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.

For all but the most southern mooring sites (KZ1, PH1) beluga calling activity in the fall was less prominent than 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 have 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 have 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).

Multiple peaks are seen in some of the calling activity pulses. These are the most evident during the fall pulse at the PH1 mooring site, and were also seen in the Hannay et al. (2013) data (e.g., their Figure 6, W35). These peaks might be caused by the two populations moving by at different times (Garland et al., 2015b), sex/age segregation (Hauser et al., 2014), or simply, in the case of the spring migratory pulse, 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., 2015a) 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 ARCWEST mooring that, quite frankly, they were considered an annoying source of background noise to the analysts (Figure 21-27). 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 ARCWEST mooring sites and in all years with recordings, calling activity increased from September through February, reaching sustained and saturated levels from March through May in the southern Chukchi, and February through June in the northeastern Chukchi/western Beaufort, when calling ceased abruptly. July and August had the lowest calling activity levels of the year. At most sites and in most years, a smaller, less sustained pulse of calling occurs prior to the main ramp-up of calling activity (tracking southwestward and immediately preceding ice arrival, suggestive of a fall migration). This pulse is much larger and defined in the southern region. Bearded seals give birth to their pups on the ice from 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). 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 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. Regardless, the fact that calling activity ceased within about a week among all moorings in a particular year *and* do not appear to be related to changes in ice concentration (see Figure 21) suggests further investigation is warranted into the environmental or biological factors behind these similar trends. This, and the role these factors also play in the variation of calling activity levels (including the small pulse of calling occurring before the main pulse) during the ramp up period among mooring sites and years will be discussed in Section X.A below.

The presence of high levels of calling activity in the ARCWEST 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 (Jones et al., 2014; Frouin et al., 2016), 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 also 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 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 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 ARCWEST study area 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[15]; Jones et al., 2014; Frouin 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. 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 might be possible that the precursor pulse of calling activity represents this migration, as its timing seems to indicate it moves southward from CL1 to KZ1. 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

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[15] These two papers used data from the CHAOZ and/or BOWFEST studies.

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. It is also interesting that the region of the ARCWEST study area that is supposed to have most of the population in the spring (i.e., the Southern Chukchi), does not show saturated calling until March, while the more northeastern sites (WT1, PB1, BF2) reach saturation in February. Are more animals passing more quickly through the Bering Strait into the Arctic; and if so, why? Is the calling heard in the Arctic actually attributable to sub-adults, who are merely practicing for the mating season, while mature adults are down in the southern Chukchi waiting for pupping to end so that the females are available for mating? Whatever the reason, a multitude of passive acoustic recorders distributed throughout the Arctic have all detected the substantial acoustic presence of bearded seals over winter. Although it is noted that bearded seals do overwinter in the Chukchi Sea (Cameron et al., 2010), these winter passive acoustic data should be included on future Status Reviews to emphasize their overwinter use of the northeastern Chukchi Seas.

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 (>90%) 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, rather than within 20 nm of shore (Burns and Frost, 1979; Burns, 1981a). They are primarily benthic feeders and eat mainly crustaceans, mollusks, cephalopods, worms, and fish. Males and females eat the same items, but a higher proportion of the diet is composed of shrimp for the younger seals (Lowry et al., 1980). 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.

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, therefore, does not imply absence of animals. As seen in 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. This high level of calling activity did not continue in the subsequent years for the ARCWEST study, but instead declined at a steady rate from the winter of 2012 to the winter of 2015 (Figure 28). Only low-levels of calling activity, less than or equal to those seen in winter 2015 at IC3, were seen at the other ARCWEST mooring locations.

Still, the presence of walrus calling activity overwinter in the ARCWEST 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). 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 calling activity was present in the ARCWEST study area. Historical sightings, however, of walrus off Point Hope from January through April are not uncommon (Fay, 1982), and could help explain the overwinter walrus calling activity at the southern Chukchi sites (especially the peak calling levels seen at KZ1).

For walrus to be present overwinter, some form of open water (e.g., polynya, leads) has to be available. 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 ice image from this time (Figure 90) provides compelling evidence that cracks forming in the Bering Strait progressed to the ARCWEST study area by mid-March, 2012.

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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.

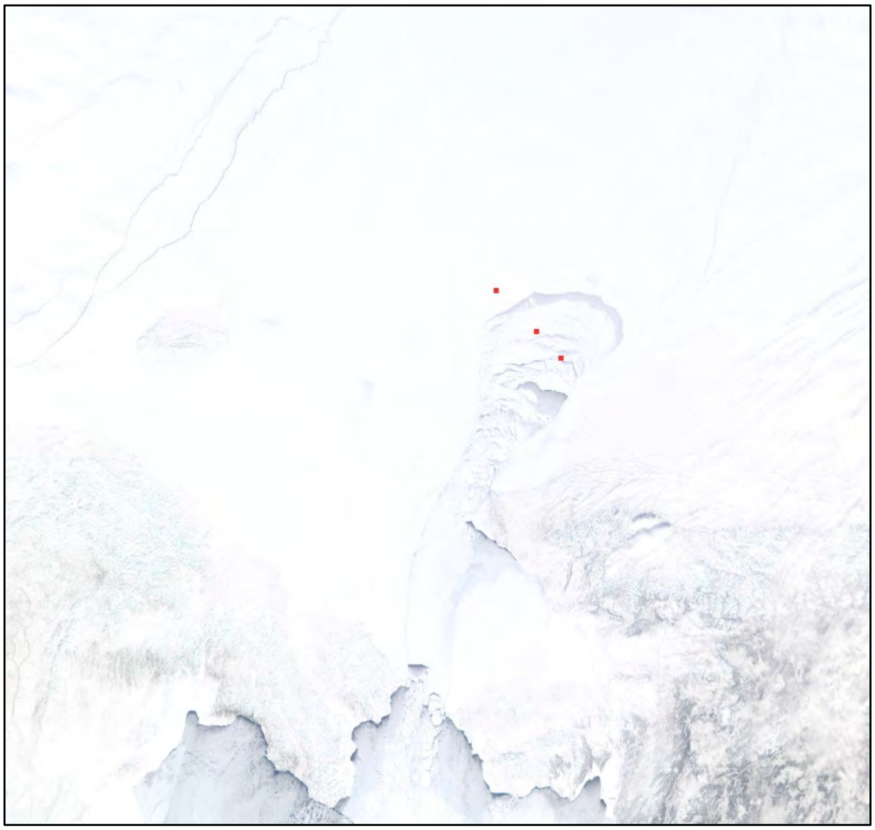

Figure 90. Ice cover in the northeastern Chukchi Sea. MODIS infrared-band image from mid-March, 2012. The three red dots mark the locations of the offshore (IC3), midshore (IC2), and inshore (IC1) mooring locations. Image recolored to emphasize open water.

It is not unreasonable to assume that the walrus heard overwintering on the ARCWEST 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 animals are, in fact, subadults. Since the mating season for walrus occurs mid-winter, between December and March, peripheral subadults practicing reproductive displays seems a highly plausible explanation for the presence of walrus calling activity at the KZ1 site, which is the closest ARCWEST mooring to the known Bering Sea overwintering grounds. Incorporating Bering Sea walrus calling activity distribution into the analysis would help to determine if the KZ1 site is, in fact, on the periphery of the core use area. Even if this is the case, however, it is possible that, as with bearded seals, a subset of walrus (regardless of age) overwinter in the Chukchi Sea. Finer scale analyses into the call types present in these peripheral areas, versus the core use area, could also help to elucidate whether there is any cohort segregation occurring.

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 May through October for the southern Chukchi moorings and June through September for those east of the Icy Cape Line, and agreed with the findings of Hannay et al. (2013). Summer calling among the ARCWEST mooring sites was most saturated and sustained at the Icy Cape moorings. However, when the full set of Chukchi/Beaufort data are included (especially in the August and September panels of Figure 31-33), it is obvious that the Hanna Shoal area is their core use area. This result was expected, given the importance of Hanna Shoal as a feeding area for this species (Jay et al., 2012). Walrus are benthic feeders and prefer to remain in areas where the water depth does not exceed 100 m (Fay, 1982). This includes all of the ARCWEST mooring sites (that are typically in water depths of 40-50 m) with the exception of BF2 (right at their preferred limit of 100 m), which had the lowest proportion of days with calling activity detected. Their diet varies spatio-temporally, and they forage opportunistically (Seymour et al., 2014), but feed primarily on bivalve mollusks (Fay, 1982; Jay et al., 2014) and other invertebrates such as worms, snails, and crabs.

Although it is typically thought that all walrus need to always be in close proximity to ice, the truth is that differences in distribution 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 summer in the Bering Sea (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. 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.

It is important to note, however, that this model of age/sex class segregation might change as the number of ice-free months increases. When the ice leaves Hanna Shoal early in the season, moving out over waters too deep to forage in, large aggregations of walruses 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). These aggregations could also deplete the local benthic community so that foraging excursions become further and more energetically taxing (Sheffield and Grebmeier, 2009).

However, Jay et al. (2012) also found that June/July is currently a time period with walrus ranging further north than in the past, which may explain their acoustic presence along the offshore portion of the Icy Cape line in those months. Which age/sex class is there? 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. This is counter to the ARCWEST results as well as 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 producing the high level of calling at this time on the shoal; 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 walruses (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. Comparison with satellite tracks of tagged individuals might help determine if female walrus typically make underwater sounds in the wild, but tagging females with suction cup acoustic tags (e.g., DTAGs) would be by far the best method to quickly verify that the original, male-only, assumption is correct.

Calling activity was not detected equally on all ARCWEST 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. Inter-annual differences are also apparent. For example, all of the central-most moorings, CL1 and IC1-3, showed a bimodal distribution in the summer of 2013, while the summer 2014 showed a single pulse at these same sites (Figure 28). Factors influencing these spatio-temporal differences will be investigated further in Section X.A.

Gray whales

While the CHAOZ and CHAOZ-X projects did not find substantial gray whale calling activity present on any of their sites, the ARCWEST project did. This is primarily due to the inclusion of the southern Chukchi Sea within the ARCWEST study area, and the PH1 site in particular, a known gray whale hotspot (Moore et al., 2000; Clarke et al., 2015a). However, detections at the IC1, WT1, and PB1 fit with the feeding Biologically Important Area designation of the area within 90 km of shore between Point Lay and Point Barrow (Clarke et al., 2015a).

Gray whales have the longest migration of any Arctic species, overwintering in the breeding/calving lagoons of Baja California and feeding in the Bering and Chukchi Seas in the summer and fall (Swartz, 1986). Departure from the breeding grounds in the spring is bimodal, with adults leaving in February/March and cow/calf pairs following in March/May. The spring migration reaches Unimak Pass mid-March to mid-June. The feeding season spans from June through September in the northeastern Chukchi Sea and June through October (and sometimes into late November (Rugh et al., 2001)) in the southern Chukchi Sea between Cape Lisburne and Point Hope (Clarke et al., 2015a), before the whales begin their southward migration with the pregnant females in the lead (Swartz, 1986). This timing fits well with summer pulses in calling activity that occurred on the northeastern ARCWEST moorings from August through October and in the southern sites from June through November. These dates also fit with the overall sighting rates from recent aerial surveys, which show an increase of sightings in July and August

(Clarke and Ferguson, 2010). The sporadic detections from recent passive acoustic monitoring efforts in the northeastern Chukchi Sea have also fallen into this timeframe (Hannay et al., 2013).

The lack of calling on the offshore Icy Cape (IC2 and IC3) and Beaufort (BF2) sites was also expected. 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). In addition, only a handful of gray whales have been sighted east of 155°W, near the BF2 site (Clarke et al., 2015a). Furthermore, in agreement with the results presented by Stafford et al. (2007b), who found gray whale calls present from October 2003 to May 2004 at a mooring located northeast of Barrow, AK, a few days with calling activity were detected overwinter on the IC1 and PB1 mooring sites. Additional overwintering detections were made on the southernmost ARCWEST mooring (KZ1) in both 2014 and 2015, as well as at the CL1 mooring site in 2013. Incorporating gray whale calling activity distribution from the Bering Sea recorders will help investigate whether these detections are isolated instances or part of a larger distribution of detections south of the Strait.

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 ~65 nm between calls; the chance that a recorder will be recording when a whale is calling nearby is low. Additionally, gray whales are in the Arctic to feed. Although there is information on gray whale calling behavior on their breeding grounds and during their migration, little exists on the sounds they make while feeding. They are presumed to be silent when feeding (e.g., Ljungblad et al., 1983), but 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.2) 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, 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. (2013b) 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, analyses of the passive acoustic recordings extended to a number of subarctic marine mammal species. Some of these species, 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 ARCWEST 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.

Humpback whales

Humpback whales were another species, like gray whales, that were detected with greater frequency during the ARCWEST project than in the CHAOZ and CHAOZ-X projects. Again, this was primarily due to the inclusion of the southern Chukchi Sea within the ARCWEST study area. They are common in the Bering Sea in certain areas during summer months: north of the Aleutians and Alaskan Peninsula, in Bristol Bay, and near Pervenets Canyon along the northern Bering Slope (Friday et al., 2013). They were also found, through a compilation of results from vessel-based and aerial surveys as well as through passive acoustic monitoring via sonobuoys, to be the most common subarctic cetacean found throughout the southern Chukchi Sea (Clarke et al., 2013b). However, few sightings or detections have been made using comparable methods in the northeastern Chukchi/western Beaufort Seas (Aerts et al., 2013; Clarke et al., 2013b; Berchok et al., 2015; this study - see Section VII.B.2).

Results for the long-term passive acoustic moorings were similar. Over the five years of data analyzed for the ARCWEST project, only seven days had humpback whale detected in the northeastern Chukchi Sea (at the IC3 and WT1 sites); there were zero days with detections at the western Beaufort Sea mooring site (BF2). This is similar to the findings of Hannay et al. (2013), who reported only two days of humpback whale detections on their vast array of passive acoustic recorder moorings in the northeastern Chukchi Sea from 2007-2011.

In contrast, nearly 400 days had humpback whale detections in the southern Chukchi Sea. The majority of these were found on the two southernmost sites (PH1, KZ1) which are both located in a highly productive area (Grebmeier et al., 2015). Humpback whales are feeding generalists, and will take advantage of the numerous prey types found in this hotspot area. The Hannay et al. (2013) study did not include any recorders to the south of Cape Lisburne and so it is not surprising that they did not have any detections in this area. The timing of the humpback whale calling activity agrees with what has been found from recent vessel-based and aerial survey methods: calling was present from June through November (peaking in September and October with ~50% of days having calling activity) in the southern Chukchi, and June through October in the northeastern Chukchi.

The question remains, however, whether the recent uptick in sightings/detections is real or an artifact. As pointed out by Clarke et al. (2013b), this increase could be due to an increase in survey/monitoring effort, a range expansion post-whaling, environmental changes, or a combination of all three. The passive acoustic results included here show that, although there are some inter-annual differences, the presence of humpbacks in the southern Chukchi Sea has been constant for at least four open water seasons. Starting in the fall of 2015, oceanographic moorings were deployed at the PH1 site; a closer look into the factors influencing these spatio-temporal differences will therefore be investigated in the future, once those data can be incorporated.

Fin whales

Like the gray and humpback whales mentioned above, the fact that fin whales were detected for ARCWEST and not for either CHAOZ or CHAOZ-X is due to the inclusion of the southern Chukchi in the ARCWEST study area. 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). Short-term sonobuoy results (Berchok et al. 2015; Crance et al. 2015; this study Section VII.B) show fin whales to be distributed more often in the southern Chukchi Sea from Cape Lisburne to Bering Strait. Although fin whales are more easily detected acoustically than sighted visually (Berchok et al., 2015), their distribution in the southern Chukchi is still supported by visual sighting results from vessel-based and aerial surveys (Clarke et al., 2013b). Other long-term mooring efforts have also found fin whales to range not much farther past the Cape Lisburne area (Delarue et al., 2013a; Hannay et al., 2013).

The only moorings in the northeastern ARCWEST study area analyzed for fin whales were those deployed and analyzed for the CHAOZ study (i.e., IC1-3 2010-2012)[17]. No calling activity was detected on those moorings, however. Fin whales detected on sonobuoys during the research cruises were also mainly concentrated in the area off Cape Lisburne and south. The one exception is a series of about 30 fin whale calls detected on a sonobuoy deployed in late August 2012, approximately 50 nm off the coast near Barrow, AK (Crance et al., 2015). There is the possibility that fin whales are present in the area but are not vocalizing. However, sightings of fin whales on ship and aerial surveys are rare in the U.S. Arctic and have not occurred outside the southern Chukchi Sea (Aerts et al., 2013; Clarke et al., 2017).

We found fin whale calling activity in the southern Chukchi Sea from June through November. This range is larger than the July through September range reported by Clarke et al. (2013b); however, their data were compiled from field efforts that were biased toward the open water season. Recent long-term monitoring off the Point Hope area by Tsujii et al. (2016) has reported fin whale detections from July through early November. Their presence throughout most of the open water season demonstrates the importance of the southern Chukchi as a feeding ground. Fin whales, like humpbacks, are feeding generalists that can take advantage of whatever prey is available in the hotspots of this region, and perhaps impact the success of the Arctic

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[17] As mentioned earlier, attempts at autodetection of fin whale calls on this dataset did not yield satisfactory results. We have been working with Cornell to revisit the efficacy of using autodetectors for fin whales. The ARCWEST 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.

species that have utilized these resources in the past (Sigler et al., 2012; Clarke et al., 2013b; Grebmeier et al., 2015).

It is unclear whether the increase in occurrence of fin whales in the southern Chukchi is real or an artifact of the increased passive acoustic monitoring effort. Fin whales are typically more easily detected acoustically than visually (Berchok et al., 2015), and outside of opportunistic sonobuoy deployments, passive acoustic monitoring in this area did not begin until 2007 (Hannay et al., 2013). Furthermore, if their occurrence is, in fact, increasing, it is unclear whether this is due to a population increase or range expansion of a single or multiple population(s), and whether these changes are due to natural population recovery from whaling pressures or from changes to the environment. Additional investigations into the call types present throughout this pulse of calling activity may help to track the general movements of the different populations throughout this area (Delarue et al., 2013a). Current passive acoustic methods also cannot determine whether the increase in fin whale occurrence is due to an increase in the number of animals using the area or just an increase in time spent in the area. Future work with density estimation techniques (e.g., Marques et al., 2009) may provide the means to help answer this question. At any rate, a closer look into the factors influencing fin whale presence throughout the ARCWEST study area will be pursued once the autodetection algorithms have been improved and the rest of the mooring sites have been analyzed.

Killer whales

Killer whale calling activity was detected at every site in the ARCWEST study area, but levels were highest in the southern Chukchi Sea, followed by the PB1 mooring site in between Wainwright and Point Barrow. Calls were detected from June through October which aligns perfectly with the timing and distribution of gray whales in the ARCWEST study area, which suggests the latter are an important prey item. In fact, one attack by a pod of killer whales on a gray whale calf in the nearshore waters near Wainwright happened during the ARCWEST field survey in September 2013 (see Section VII.C.2). The results in the southern Chukchi match with those from Hannay et al. (2013), who had occasional detections of killer whales in the Point Lay/Cape Lisburne recorders annually between late July and October. Detections at the other mooring sites in the ARCWEST area were infrequent and sporadic. This agrees with shipboard (Aerts et al., 2013; Berchok et al., 2015; this study - see Section VII.B.2) and aerial surveys results (Clarke et al., 2013b), which have found killer whale sightings to be rare. Opportunistic sightings (George and Suydam, 1998) are also uncommon.

Not much is known about killer whales in the Arctic other than it seems likely they are the transient ecotype. See Clarke et al. (2013a) for references that support this assumption. The transient ecotypes are mammal eaters, who stalk their prey silently (Deecke et al., 2005) and so it is unlikely that many calls would be detected in the study area. However, the lack of visual sightings suggests that it is not just a matter of them being present and not heard, but rather a combination of low presence and low calling activity. At any rate, they are typically very vocal 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-foraging calling bouts.

Minke whales

The story for the minke whale mirrors that of the humpback; they are sighted infrequently in the northeastern and southern Chukchi Sea by visual and vessel surveys (Aerts et al., 2013; Clarke et al., 2013b; this study - see Section VII.B.2), and passive acoustic detections are rare. Although analyses included the minke whale pulsed call, this call type can be difficult to attribute to species, especially in the presence of other vocalizing species, and so is most likely missed (or marked as 'maybe'). However, the repertoire of minke whales also includes the 'boing' call (Rankin and Barlow, 2005) that is quite unmistakable.

In the northeastern Chukchi Sea, there were only two days where minke whale boing calls were detected, both in October on the IC1 mooring site. The majority of the minke whale boing call detections were made in the southern Chukchi, primarily at the CL1 mooring site. Delarue et al. (2013b) found minke whale boing calls offshore between Cape Lisburne and Wainwright in 2009 and 2011. All but one of their call detections occurred in October, while visual sightings occurred throughout the summer and fall, leading them to hypothesize that boing calls are produced seasonally as a reproductive display (Delarue et al., 2013b). The ARCWEST detections were not limited to October, however (Figures 61-66). Although the majority of days with detections occurred in October, the main pulse in the southern Chukchi lasted from September through November, with other detections made in March, April, and July. More fine-scale analysis of the pulse repetition rate of the individual boing calls will help identify whether they are the eastern or central boing call type, which could be useful in future stock structure assessments, especially because there is debate on whether the minke whales found in the Bering Sea and north are a separate migratory stock from those in the North Pacific (Clarke et al., 2013b). As with the other subarctic cetacean species discussed previously, minke whales are feeding generalists that can take advantage of whatever prey is available.

Ribbon seals

The last of the subarctic species detected was the ribbon seal, whose calling activity was again present at low levels at all mooring sites in the ARCWEST study area. The BF2 mooring site had the most consistent and highest levels, which is unsurprising given its proximity to the Beaufort slope. As summarized by Boveng et al. (2013), 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. Including the full set of Chukchi/Beaufort Sea data (Figures 68-73) shows that the CHAOZ-X study site (HS3), which is closest to the Beaufort slope, has the most sustained presence of Ribbon seals.

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. Jones et al. (2014) found ribbon seal calling on their slope site in late September. In this study, calling activity ceased concurrently with ice formation at all sites and in all years (Figure 67). This agrees with what is known about ribbon seals: they are highly dispersed during the open-water season, returning to the Bering Sea with the advance of the ice edge (Boveng et al., 2013). 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, however, 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. Inclusion of Bering Sea passive acoustic mooring data in the ribbon seal analyses will allow for an independent verification of this finding.

Ribbon seal calling activity was additionally detected during April/May at half of the ARCWEST mooring sites. This coincides with the reproductive season, when the seals are thought to remain in the Bering Sea. As summarized in Boveng et al. (2013), ribbon seals are strongly associated with pack ice in the Bering and Okhotsk Seas during the whelping/nursing season, which extends from mid-March through June. Ribbon seals do not form dense breeding aggregations, as females tend to be solitary. Molting occurs during the breeding season from late-April/early May to as late as July (Tikhomirov, 1961). 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).

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 springtime presence of these sounds in the Chukchi Sea could be indicative of juvenile male practice sessions, as was proposed for both bearded seals and walruses above. Finer scale analyses on the individual call types produced during this time period compared with those produced in the Bering Sea may help determine if any differences exist.

The overall lack of ribbon seal calling activity on our recordings over the summer 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 ARCWEST study area over the past decade (i.e., Hannay et al. (2013) and Jones et al. (2014)). It is, however, 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).

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 was attributed to 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 in 2012 was conducted in the Beaufort Sea, which explains the higher levels of detections at the BF2 mooring site compared with the others in the Chukchi Sea portion of the

ARCWEST study area. Those November detections corresponded 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 the most persistently during the 2013 open water season, where they were heard on all sites except the southernmost (KZ1; Figure 75). These detections aligned 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 91, Cate et al., 2014), and was evident in the spatial distribution map (Figure 79). 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 explained the lack of airgun activity in the western/southern part of the ARCWEST study area. It is possible that the Beaufort activity was detected on the eastern ARCWEST mooring sites, but otherwise these detections could not be attributed to permitted activities on the U.S. OCS (i.e., listed on the website[18]) at that time. The same was true for 2015, where seismic activities occurred 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 ARCWEST study area that could not be attributed to known permitted activities on the U.S. OCS.

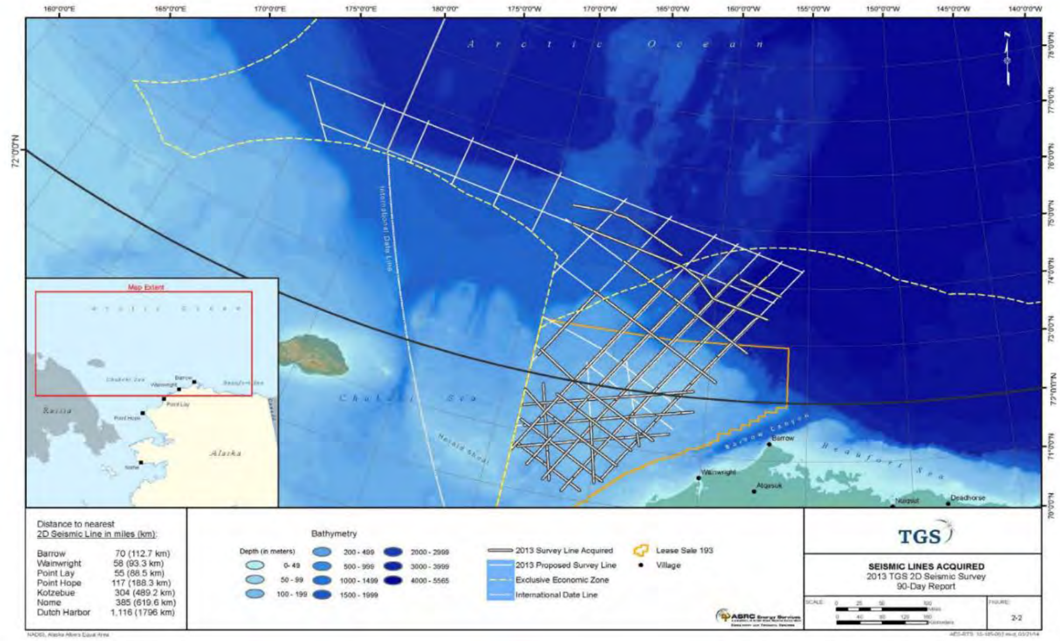

Figure 91. Survey lines acquired during TGS seismic survey August-October, 2013 (Figure from Cate et al. 2014, Figure 2-2).

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[18] https://www.fisheries.noaa.gov/national/marine-mammal-protection /incidental-take-authorizations-oil-and-gas

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 Icy Cape sites (Figure 82), although high levels were also present at all other sites except BF2. The 2013 vessel activity was 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 and Bisson, 2016) Seas that required the presence of many support vessels. In addition, the 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 (i.e., 'white noise') 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. Not surprisingly, ice noise was present when ice was present (Figure 89). 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.2 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 (humpback, fin, killer, and minke whales, and ribbon seals), anthropogenic sources (airguns and vessel), and environmental (ice) sources in the ARCWEST 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 possible. Maintaining this broad-scale, and near-decade long, set of passive acoustic time series provides the important year-round component of the best available science needed by 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 ARCWEST study area is provided as bullet points below (with *italicized text* highlighting interesting or unexpected findings). *[Note: there were two main regions in the ARCWEST study area: the southern region which extends from Cape Lisburne south, and the northeastern region from Icy Cape and east; there were often distinct differences in the distribution and timing of animals in these two regions and so key findings will be described separately for each region as needed].*

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 the spring and fall migrations throughout the ARCWEST area, during the open water season in the northeastern region, and during the ice season in the southern region.

- Bowheads were detected from April/June through December in the northeastern region and from October through May in the southern region.
    - Bowheads leave the northeastern region in the winter. No calling activity was present from January to March.
    - *Some bowheads overwinter in the southern region.* Not all bowheads pass through Bering Strait or remain south of the Strait.
    - The mooring with the highest level of calling activity was BF2; this provides supporting evidence that *the waters off Barrow are a biological hotspot for bowhead whales.*
    - Low levels of calling activity indicate that *bowheads are also present in the northeastern Chukchi Sea during the open water season.*
- The timing of the fall migration was not consistent inter-annually, but generally progressed from the northeast to southwest.
    - The fall migratory pulse is similar among the three Icy Cape mooring sites (ranging from 40 to 110 nm offshore), supporting a broad divergence of whales across the shelf once they are 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 fall migration pulse* for the majority of moorings and all years.
    - A distinct end to the fall migration pulse was evident in the northeastern region, but not the southern region where it blended into the spring migratory pulse.
- The timing of the spring migration also was not consistent among years; but generally progressed from southwest to northeast.
    - *The spring migration does not appear to be contained entirely in the nearshore lead*.
- A distinct end to the spring migration pulse was evident in the southern region, but not the northeastern region where it blended into the fall migratory pulse.

Beluga whales: Two populations can pass through ARCWEST 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 during the spring and fall migrations and during the ice season throughout the ARCWEST area, and during the summer open water season in the northeastern region.

- Belugas were detected from September through July in the southern region and in all months in the northeastern region.
- Fall calling activity is generally low compared to the spring.
    - This fits with the theory that *belugas are broadly distributed across the Chukchi shelf in fall.*
    - The fall pulse of calling progressed southwestward.
- *A presence of calling activity overwinter* at most ARCWEST mooring locations and years suggests some belugas overwinter in both the southern and northeastern regions.
- The pulse of spring calling activity was detected at all mooring locations including those offshore - far away from the inshore lead.
    - This supports the theory that *belugas are not limited by high ice concentrations.*
    - The timing of the pulse progressed northeastward.
- *The highest levels of calling were seen at BF2*, consistent with the summer range of the Eastern Chukchi Sea population.
- *Multimodal calling was evident* - this could be different populations, age/sex class segregation, and/or ice impeding migration. Ongoing work with repertoires may help differentiate between the populations.
- A double-knock sound that is thought to be produced by fish occurs simultaneously with beluga whale calling activity. It is not a known beluga sound. Analyses of additional mooring sites and years are needed before further investigation is possible.

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 compared to visual survey and tagging results. Bearded seals were detected year-round throughout both regions of the ARCWEST area.

- High and sustained levels of fall-through-spring calling activity are present on every mooring in every year, providing evidence that *bearded seals are present in the Chukchi year-round* instead of overwintering in the Bering.
    - Calling activity increased from September through February.
    - Calling activity reached sustained and saturated levels in March/May in the southern region and February/June in the northeastern region, corresponding with the whelping/mating/molting season.
    - The lowest calling activity levels were in July and August.
- *Calling ceased abruptly in the spring*.
    - This could be an artifact of binned analysis; another study that counted individual calls reported a gradual decrease in calling activity.
- *The end of calling in spring is extremely consistent among years/moorings.*
    - The average date among all years for the southern and northeastern sites was 1 July and 16 June, respectively, both with standard deviations of less than 1 week.
- A smaller, less sustained pulse occurs prior to each main ramp-up of calling activity.
    - This is much larger and more defined in southern region.

  - This smaller pulse occurs immediately preceding the ice arrival, and its start date progresses southwestward. Is this evidence of a southbound migration?

Walrus: Walrus have high rates of calling activity which can be used as a proxy for presence. Winter and summer calling activity was seen in most ARCWEST locations in every year.

- Combining all years and mooring sites, calling activity was detected in all months for both ARCWEST regions.
- *Overwinter calling was detected at most ARCWEST sites/years.*
  - *High levels of mid-winter walrus calling activity occurred at the offshore Icy Cape site* (IC3) in 2011 and 2012, which declined at a steady rate from 2012 through 2015.
  - *High levels of overwinter calling occurred at the southernmost site* (KZ1), which may indicate an expansion of their core wintering area.
  - Sporadic and low levels of overwinter calling activity were present throughout the rest of the ARCWEST sites.
  - This indicates leads or polynyas exist in those areas with detections; so *these overwinter detections may be used as a proxy for open water presence.*
  - This overwinter calling may be due to subadults practicing reproductive displays; finer-scale analyses of call characteristics are needed to investigate whether differences exist.
- The summer pulse in calling ranged from May through October and from June through September for the southern and northeastern regions, respectively.
  - *The most saturated and sustained summer levels were on the Icy Cape sites*, the closest ARCWEST sites to the Hanna Shoal area.
  - The low levels of summer calling that occurred BF2 was unsurprising given its location at the limit of their preferred diving depth (100m).

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. Gray whales were detected in the open water and ice seasons in both the northeastern and southern ARCWEST regions.

- Calling was detected from March through November in the southern region and May through November at the northeastern region.
- Summer calling occurred between June and November in the southern region and August through October in the northeastern area.
  - *There were high and sustained levels of summer calling activity at the PH1 site, a known benthic hotspot.*
  - *Some detections occurred at sites within the designated Biological Important Area for feeding: PB1, IC1, and WT1.*
  - There was a lack of calling at the offshore (IC2, IC3) and Beaufort (BF2) sites, as expected from aerial survey data.
- Winter detections occurred between November and July.
  - *Low levels of calling activity were present overwinter:* ten or less days per mooring had detections over five years of study.

  - These detections occurred in both the northeastern and southern ARCWEST regions.

Subarctic species: Because of the inclusion of the southern Chukchi Sea in the ARCWEST region, several subarctic species (humpback, fin, killer, and minke whales, and ribbon seals) were detected in varying levels over primarily the open water season.

- Humpback whales
  - Humpback whales were seen more frequently (50x more days) in the southern region than in the northeastern Chukchi Sea. None were detected in the Beaufort Sea.
  - Calling levels decreased northward in the southern region.
  - Calling was present from June through November in the southern region and June through October in the northeastern region.
- Fin whales
  - Analyses are incomplete and pending improvements to autodetectors.
  - There were no detections in the northeastern region.
  - Calling was present from July through November in the southern region.
  - *Finer-scale analyses on song structure may help understand which population(s) use the ARCWEST region.*
- Killer whales
  - Visual observations indicate Arctic whales are of the transient ecotype; which may explain the low calling levels detected. Investigations into call repertoires can possibly confirm which ecotype is present.
  - Calling activity was detected at every site in the ARCWEST study area.
  - Calling was present from June through October at all locations.
  - Calling activity levels were highest in the southern region, followed by the PB1 site between Wainwright and Pt. Barrow.
  - *Their timing and distribution aligns well with that of gray whales*.
- Minke whales
  - Detections included the 'boing' calls only.
  - There were only two days with calls (at IC1) in the northeastern region.
  - Most detections occurred in the southern region at the CL1 site.
  - The main pulse of detections was from September through November, with the majority in October. Sporadic detections occurred in March, April, and July.
  - *Further fine-scale analyses are needed to differentiate between stocks using boing call characteristics*.
- Ribbon seals
  - Calling activity was present at low levels at all mooring sites in the ARCWEST area.
  - The highest and most consistent levels were at the BF2 site in the Beaufort Sea; this site is closest to their preferred slope region.
  - The majority of calling at all sites was centered in October/November; beginning prior to and ceasing concurrently with ice formation at all sites and years. Perhaps this is evidence of a fall migration.
  - *Calling was also detected during April/May at half of the sites; this coincides with the reproductive season when seals are thought to be in the Bering Sea.*

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.
    - Airguns were 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 on the U.S. OCS.
    - Lower levels were detected in the southern region, although none occurred at the KZ1 site.
- Vessels were also detected during 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 is present overwinter when ice is present.
    - Ice makes different sounds during formation versus breakup.

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 (or may just provide a more complete understanding of the phenology) 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 minimal, making continued maintenance of this very valuable long-term dataset quite cost effective. Passive acoustic data do not have an expiration date; they can sit unprocessed until funds are available for their analysis. However, they can never be recollected if the opportunity is missed; 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 National Science Foundation 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.

One thing that was apparent during analyses of this data set is that information is limited 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 three years for the presence of North Pacific right, bowhead, humpback, gray, and minke whales, walrus, vessel and airguns[19]. *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 Bering Sea 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[20] 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 and autonomous gliders. For these reasons *we recommend further funding of auto-detection techniques and equally important – comparison of these results with datasets fully reviewed by experienced analysts.* We will continue to collaborate with C. Clark (Cornell Bioacoustics Research Program), 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, Saildrone, etc.) presents an important avenue for future research. Future surveys of the Chukchi will likely include passive acoustic data collected from both Eulerian (moorings) and Lagrangian (moving) platforms. Researchers will need spatial and temporal analytical techniques to merge both types of data. Furthermore, 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 density estimation 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, stock and ecotype differentiation using call characteristics for minke, beluga, and killer whales, 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 has been collocated with active fish echosounders, which will provide additional information to direct that investigation. There was only one site with data from both the active fish and the passive acoustic recorders and those data are currently being compared. These moorings were redeployed in 2018 and will

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[19] Final reports have been written for the IFAW (Wright, 2015), MMC (Wright, 2017a), and NFWF (Wright, 2017b projects.

[20] The real reason behind the naming of the CHAOZ project!

be retrieved in the summer of 2019. The recordings from the captive Arctic cod study included just grunts (Riera et al., 2018); however, the authors reference a paper (Nahrgang et al., 2016) that reports that the arctic cod breeding season occurs between January and April. This fits the seasonality of the double-knocks recorded during ARCWEST. 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: BS, DBO3, CL, LB, CkA, CkB, CkC, IC, WT, BX, BC, BfA)

1. Methods

Sonobuoys

During the 2013-2015 ARCWEST 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 Very High Frequency (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 92). 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.

Four types of sonobuoys were used over the four field seasons: 77C, 53F, 53D, and 77B. The 77C sonobuoys were all manufactured by Sparton (SPW), the 53F sonobuoys were manufactured by either SPW or Undersea Sensor Systems Inc. (USS), the 53D sonobuoys were manufactured by USS, and the 77B sonobuoys were manufactured by Magnavox (MAG). 53F sonobuoys have either omnidirectional or DiFAR (Directional Frequency Analysis and Recording) capabilities, and the 53D and 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.

Figure 92. A) Modifications of a 77C (SPW) sonobuoy (top row, left to right): Tying up the top housing; taping up the bottom array of sensors; a 77C sonobuoy fully modified. B) 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. C) Modifications of a 53D (USS) sonobuoy to shorten deployment depth by tying the main spool housing to the top float to prevent cable from unspooling. D) Modifications of a 77B (MAG) sonobuoy (bottom row, left to right): Tying the elastic cable to the middle housing; tying the float to the top housing to prevent spool of cable from deploying; taping up the bottom array of sensors.

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 YA150-9-5 antenna was attached to the highest possible location on the vessel (i.e., crow's nest) with the directional antenna facing astern (Figure 94). 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 93a) located in the bridge[21] 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[22]. 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 93b) allowed for real-time plotting of the vessel and sonobuoy locations, as well as bearing and location coordinates of calling whales. 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. Average underwater detection range of baleen whale calls on

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[21] 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.

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

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 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[23]. All species were identified using the same acoustic cues and parameters as those listed in Section VII.A.1 above.

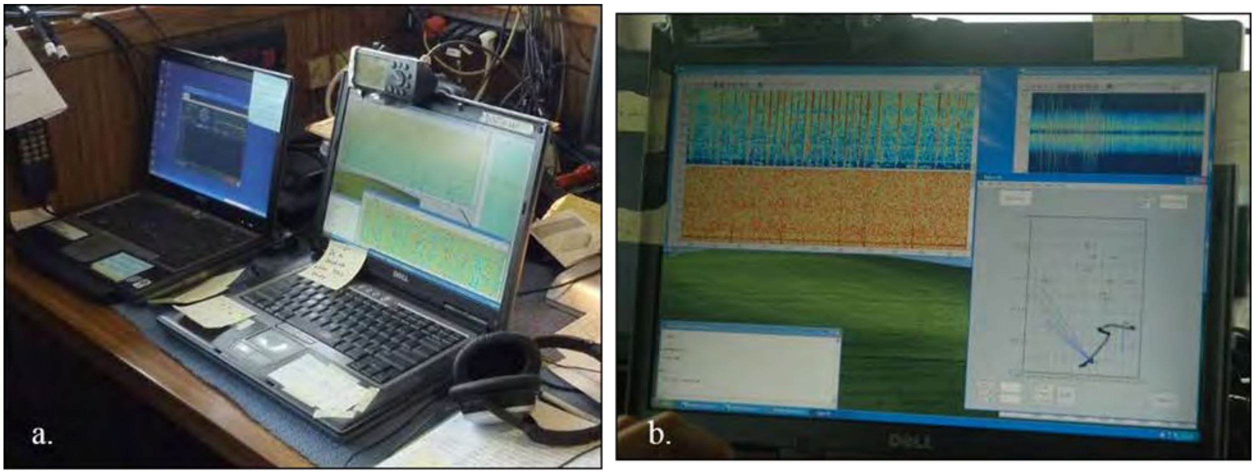

Figure 93. Sonobuoy monitoring station (a). Custom designed DiFAR tracking and monitoring program (b).

Figure 94. Omnidirectional and YAGI antenna placement (left) in relation to the R/V Aquila and (right) in relation to each other on the crow's nest.

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[23] The detection range for higher-frequency species, such as beluga, is much smaller (i.e., 5-10 km).

Visual surveys

Vessel surveys were conducted in the 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, sampling stations, and while searching for animals for satellite tag deployment. Photographs of marine mammals during the visual surveys were collected on an opportunistic basis. Given the remote location and paucity of survey effort in a large portion of the survey 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 2 nm 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 95) 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)[24] 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 2 nm and/or sea state 6 or greater), surveying continued in an off-effort status. When weather deteriorated (visibility ≤ 0.5 nm 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.

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[24] https://swfsc.noaa.gov/uploadedFiles/Divisions/PRD/WinCruz.pdf

Figure 95. Marine mammal observer using 25x “big-eye” binoculars.

2. Results

A summary of the combined visual and passive acoustic effort during the 2013-2016 ARCWEST field surveys is shown in Figure 96, Table 36 - 37. Because funds from NOAA/Oceanic and Atmospheric Research (with supplemental funds from ARCWEST) were available to conduct a fourth field season in 2016, results from this year will be included in the report. In addition, although ARCWEST 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 E).

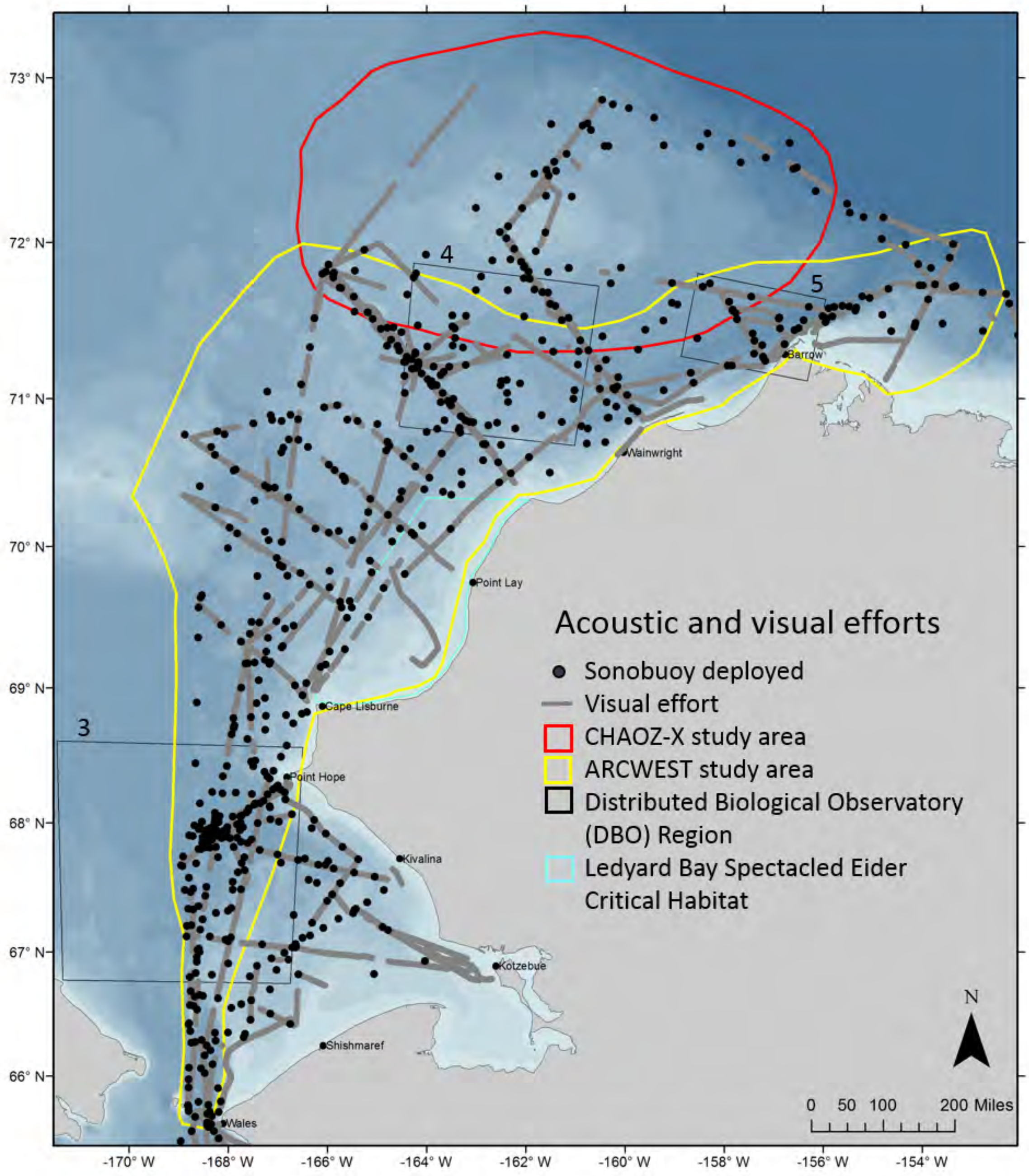

Figure 96. Summary of combined visual and acoustic effort, 2010-2016. Gray lines = visual effort, black dot = successful sonobuoy deployment.

Table 36. Total number of sonobuoys deployed per year in the ARCWEST study area, the number of successful deployments (sonobuoy functioned properly), and the success rate, 2013-2016.

Year	**Total deployed**	**# successful deployments**	**Success rate**
2013	110	99	0.9
2014	177	139	0.79
2015	58	46	0.79
2016	82	74	0.9
TOTAL	**427**	**358**	**0.85**

Table 37. Summary of visual trackline effort for ARCWEST (in bold), CHAOZ-X, and all waters, 2013-2016.

Year	**ARCWEST**		**CHAOZ-X**		**All waters**	
	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 427 sonobuoys were deployed in the ARCWEST study area during the four survey years (2013-2016). The total number of sonobuoys deployed per year, the number of successful deployments (sonobuoy functioned properly), and their success rate is shown in Table 36; species detected each year are presented in Table 38, and Figure 97-103. For a complete listing of each sonobuoy deployment and species detected, contact the NCEI[25]. In total, six cetacean species (bowhead, gray, humpback, fin, killer, and beluga whales), and two pinniped species (walrus and bearded seal) were acoustically detected in the study area (Figures 97-103; Table 39).

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[25] https://data.nodc.noaa.gov/cgi-bin/iso?id=gov.noaa.nodc:0138863

Table 38. Total number of successful sonobuoys (total number deployed) and number of species acoustically detected per year in the ARCWEST study area, 2013-2016.

Year	Total buoys	# Bowhead	# Gray	# Walrus	# Bearded	# Fin	# Humpback	# Killer Whale	# Beluga
2013	99 (110)	8	12	2	2	11	3	8	0
2014	139 (177)	27	31	8	9	34	18	14	3
2015	46 (58)	3	3	1	1	2	1	0	0
2016	74 (82)	2	4	7	8	1	1	0	0
TOTAL (% of buoys)	**358 (427)**	**40 (11%)**	**50 (13%)**	**18 (5%)**	**20 (6%)**	**48 (13%)**	**23 (6%)**	**22 (6%)**	**3 (1%)**

Over the four year study, a total of 2,553 nm (4,727 km) of on-effort trackline was surveyed in ARCWEST study area and a total of 4,593 nm (8,507 km) for all waters combined (Figure 96; Table 37). For all six years of surveys (including the 2010 and 2011 CHAOZ surveys) eight cetacean species, four pinniped species, and polar bears were documented within the ARCWEST study area (Figures 97-103). Although bearded and ribbon seals can be acoustically identified to species, visual sightings of all ice seals (bearded, ringed, ribbon, and spotted) were left as unidentified due to difficulty in identifying animals in the water to species.

The most commonly sighted and/or acoustically detected species were gray whales, walrus, and bowhead, fin, and humpback whales, in that order (Figures 97-101). Gray whales were sighted and/or acoustically detected in all years in two main concentrations: nearshore from Wainwright to Barrow, AK, and in the southern Chukchi Sea (Figure 97). No visual sightings, and only one acoustic detection occurred (2015) between Point Hope and Wainwright, despite heavy effort in that area. Walrus were visually and acoustically detected throughout the study area in all years (Figure 98). Most sightings and detections were in the northeastern Chukchi Sea, off Icy Cape, Wainwright, and Barrow, while scattered sightings and detections were documented in the southern Chukchi, with detections as far south as the Bering Strait. In 2010 and 2016, there were large concentrations of walrus sightings approximately 70 nm off Icy Cape, southwest of Hanna Shoal. Bowhead whales were seen and/or acoustically detected in all seven years, although there were no visual sightings in 2011 or 2015 (Figure 99). Most detections and sightings were north of Icy Cape, and the majority of visual detections were concentrated around the Barrow Arch area. However, in 2014 (when the survey occurred in late September/mid-October) bowheads were visually and acoustically detected from Point Lay to Wainwright. No bowheads were visually or acoustically detected south of Point Lay (Figure 99). Gunshot calls, produced by bowheads, were detected in three different years in the ARCWEST study area. Those gunshot detections that occur north of Point Lay coincide very nicely with bowhead whale detections and visual sightings. As such, we are confident these gunshots were produced by bowheads. However, there are gunshot calls that occur south of Point Hope, in an area with no bowhead acoustic detections or visual sightings. Because these gunshot detections occur far south of where we would expect bowheads to be at that time of year, we cannot definitively attribute these signals to bowhead whales. It is possible that the impulsive sounds were not gunshots, but were in fact flipper slaps or breaches by other species. In addition, it is possible, though highly unlikely given their location, that these gunshot calls were produced by North Pacific right whales.

Although fin whales were acoustically detected in all seven years, they were only visually sighted in the study area in 2010-2012 (Figure 100). The acoustic detections and visual sightings were concentrated in the southern Chukchi (Bering Strait to Point Hope); however, there were a few acoustic detections in the northern Chukchi. In 2010, two acoustic detections occurred north of Cape Lisburne, and far offshore of Wainwright, AK. In 2012, there was one detection off Point Lay, AK, as well as one detection in the northeastern Chukchi, off Barrow, AK (Figure 100). Humpback whales were acoustically and/or visually detected in all years in the study area except 2012 (Figure 101). All humpback whale sightings and acoustic detections were concentrated in the southern Chukchi (Bering Strait to Point Hope) with the exception of one acoustic detection offshore of Point Lay in 2011. Killer whales were acoustically detected in 2010, 2011, 2013, and 2014, and visually sighted in 2013 and 2016 (Figure 102, circles). Although most sightings and acoustic detections were documented in the southern Chukchi, there were a handful of sightings and detections in the northern portion of the study area as well. One group of killer whales was sighted and acoustically detected in 2013, ~40 km WNW of Wainwright (photo documentation was obtained, see Section VII.C.2), and one group was acoustically detected in 2014 approximately 200 km off Point Lay. In 2016, one group was documented 120 km off Icy Cape (Figure 102).

Bearded seals were acoustically detected in the study area from 2012 to 2016 (Figure 103). Most detections were in the northeastern Chukchi Sea between Icy Cape and the Barrow Arch, although there were a handful of sightings in 2014 between Cape Lisburne and Icy Cape. Ribbon seals were acoustically detected on two sonobuoys (2014; Figure 103, stars), both of which were in the far northeastern portion of the study area along the slope. There were no visual sightings of ribbon seals. There was one sighting of a northern fur seal in the far southern portion of the study area near the Bering Strait in 2010 (Figure 103, diamond). Although northern fur seals were identified to species, visual sightings of all other seals were categorized as unidentified due to the difficulty identifying animals in the water; however, unidentified seals are most likely bearded, spotted, and ringed seals (Figure 103, triangles and stars).

Harbor porpoise sightings were concentrated in two areas: in the southern Chukchi (Bering Strait to Point Lay) in 2010 and 2013, and nearshore off Barrow, AK (2011, 2013; Figure 102, squares). No Dall's porpoises were sighted in the study area; however, there was one sighting near the Bering Strait (2010; Figure 102, star). There were no acoustic detections of harbor or Dall's porpoises, as their vocalizations are too high in frequency (110-150 kHz) to be detected on sonobuoys. Belugas were acoustically detected in only one year (2014) offshore of Point Lay (Figure 102, diamonds). They were not visually sighted during any of the surveys. One polar bear was sighted in 2013 (Figure 102, triangles), and four separate sightings of polar bears were documented in 2016, three occurring on the same day. Bear sightings from both years occurred north and northwest of Wainwright (Figure 102, triangles). There were no acoustic detections of polar bears.

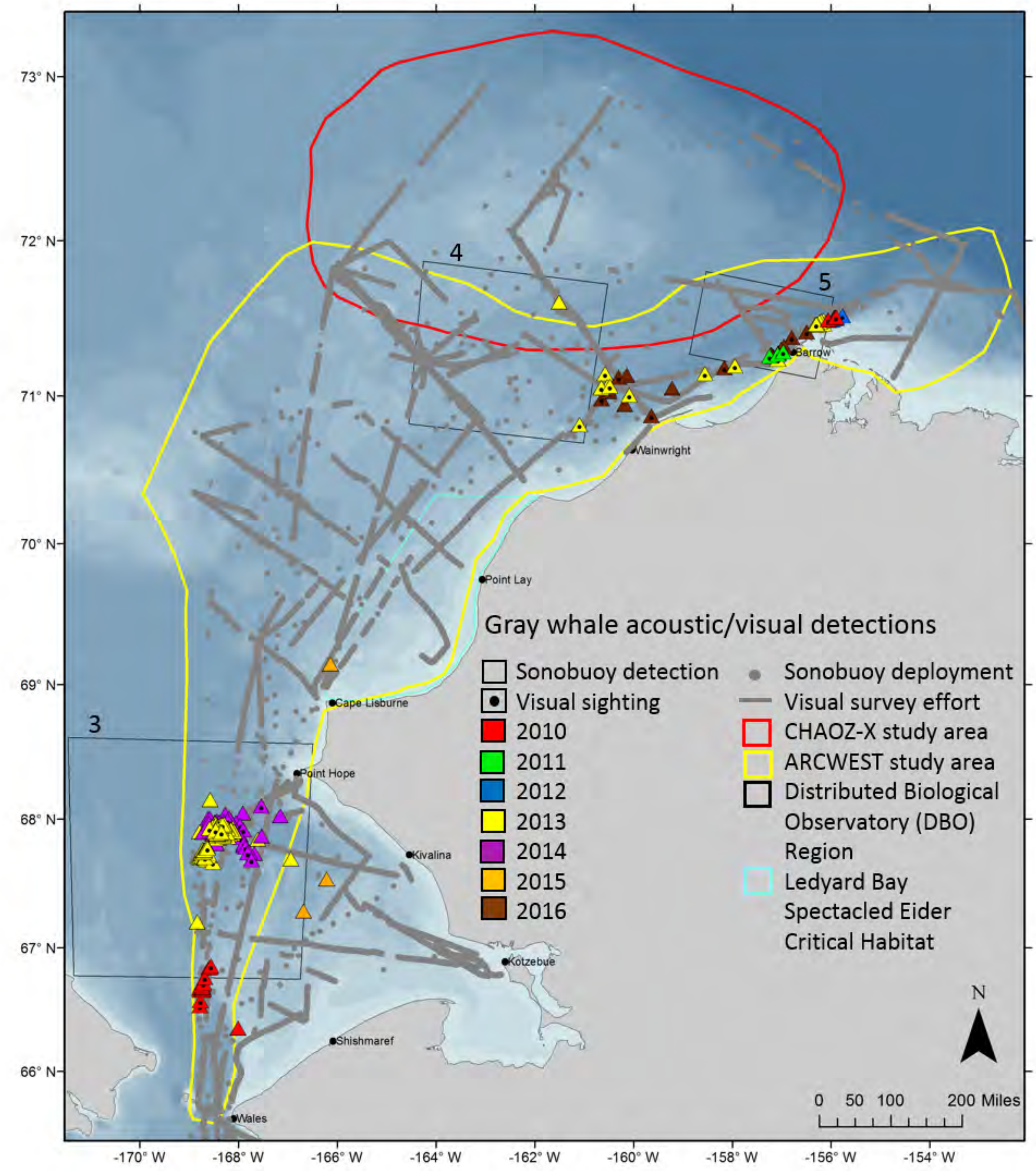


Figure 97. Gray whale acoustic and visual detections during the 2013-2016 ARCWEST surveys.

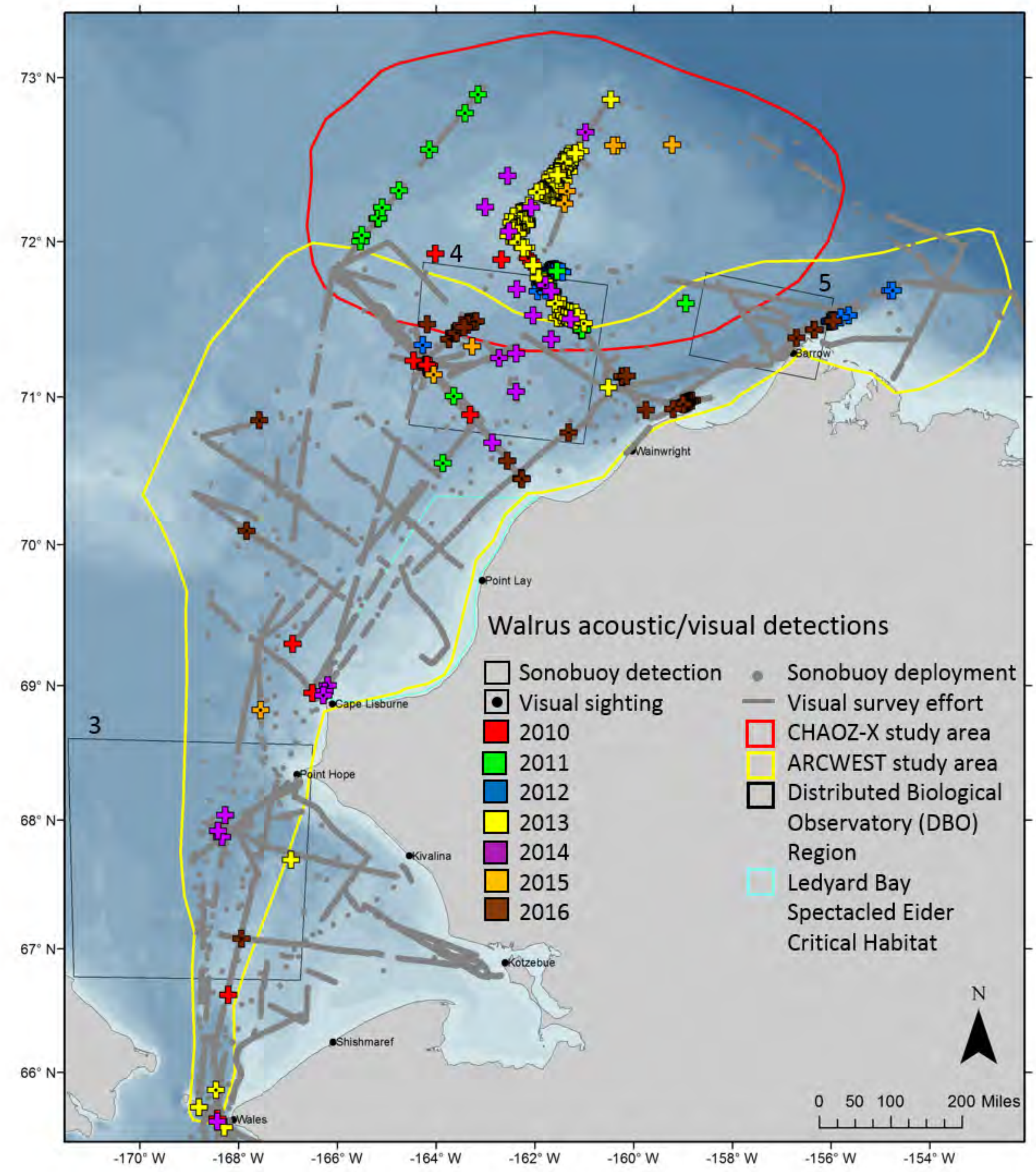


Figure 98. Walrus acoustic and visual detections during the 2013-2016 ARCWEST surveys.

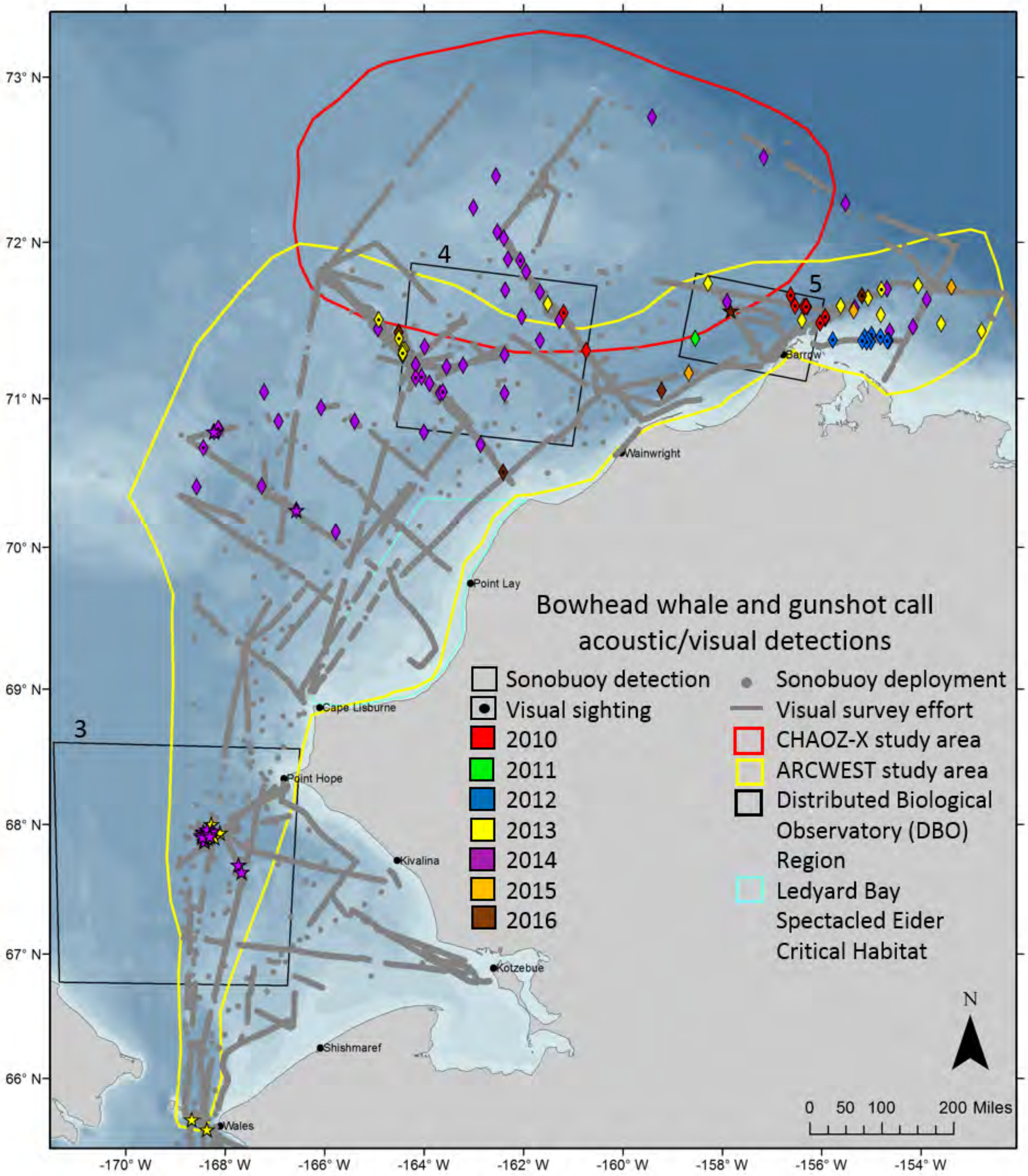


Figure 99. Bowhead whale acoustic and visual detections during the 2013-2016 ARCWEST surveys. Diamonds denote bowhead whale sightings or calls; stars denote gunshot call detections.

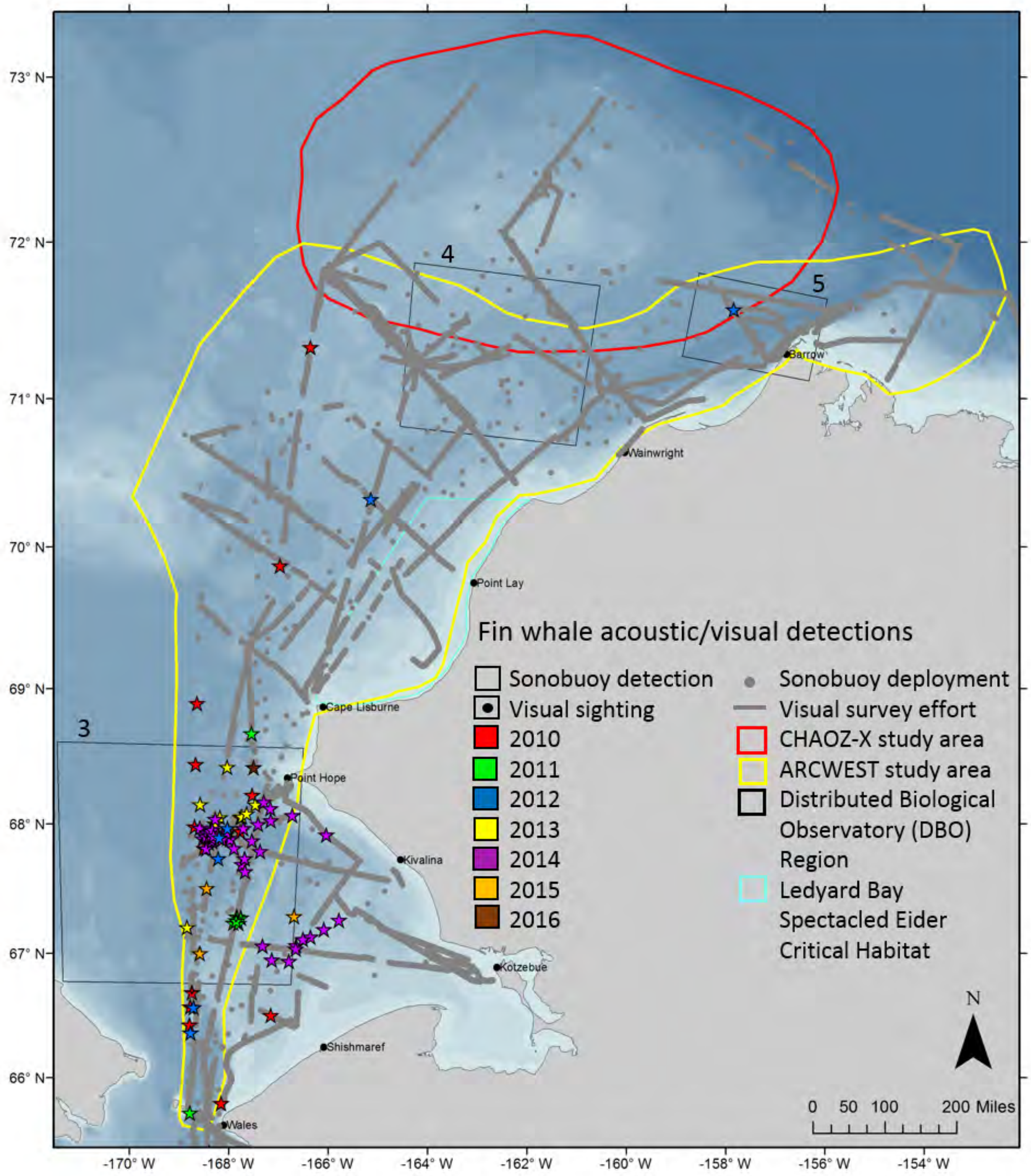


Figure 100. Fin whale acoustic and visual detections during the 2013-2016 ARCWEST surveys.

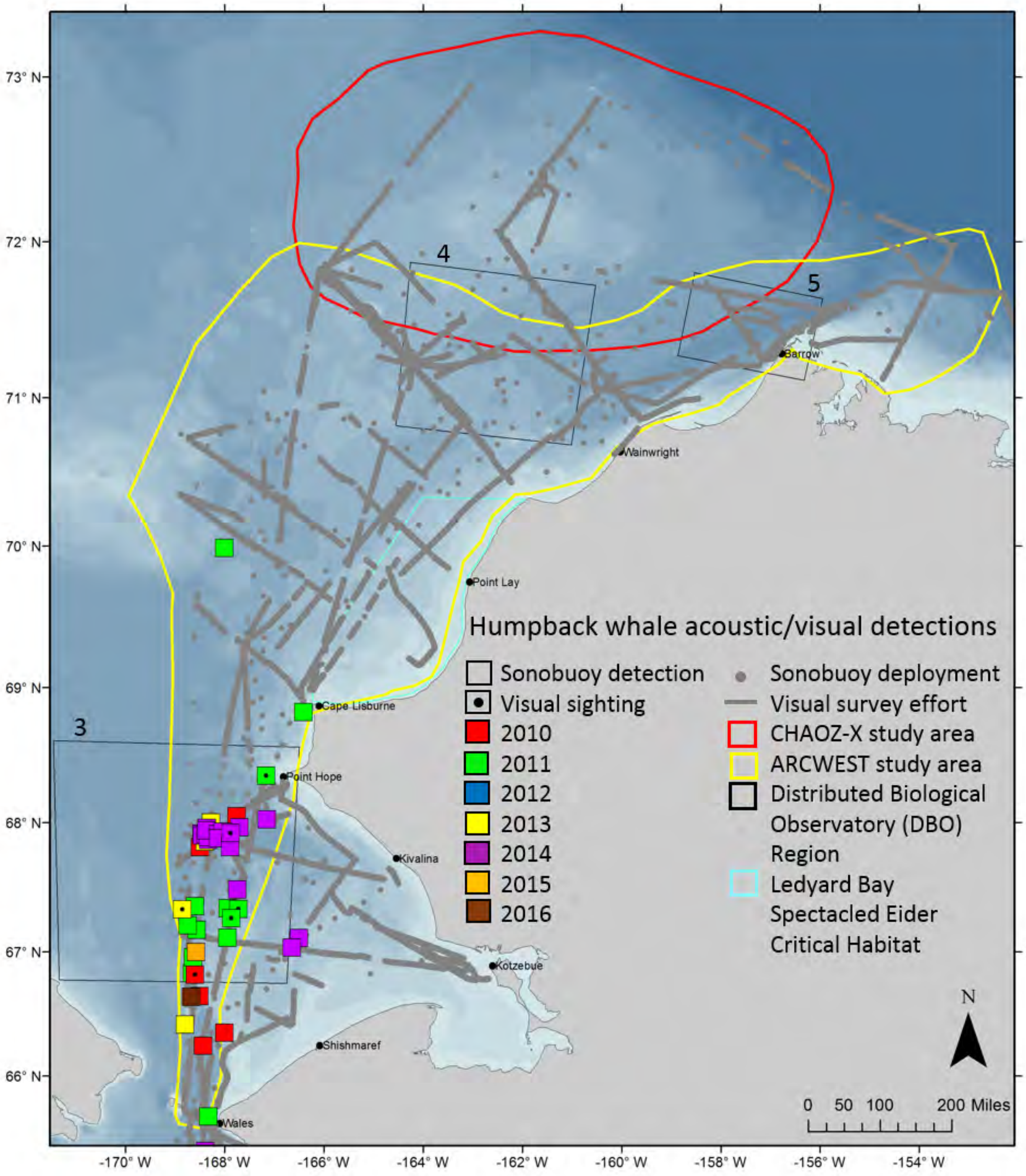


Figure 101. Humpback whale acoustic and visual detections during the 2013-2016 ARCWEST surveys.

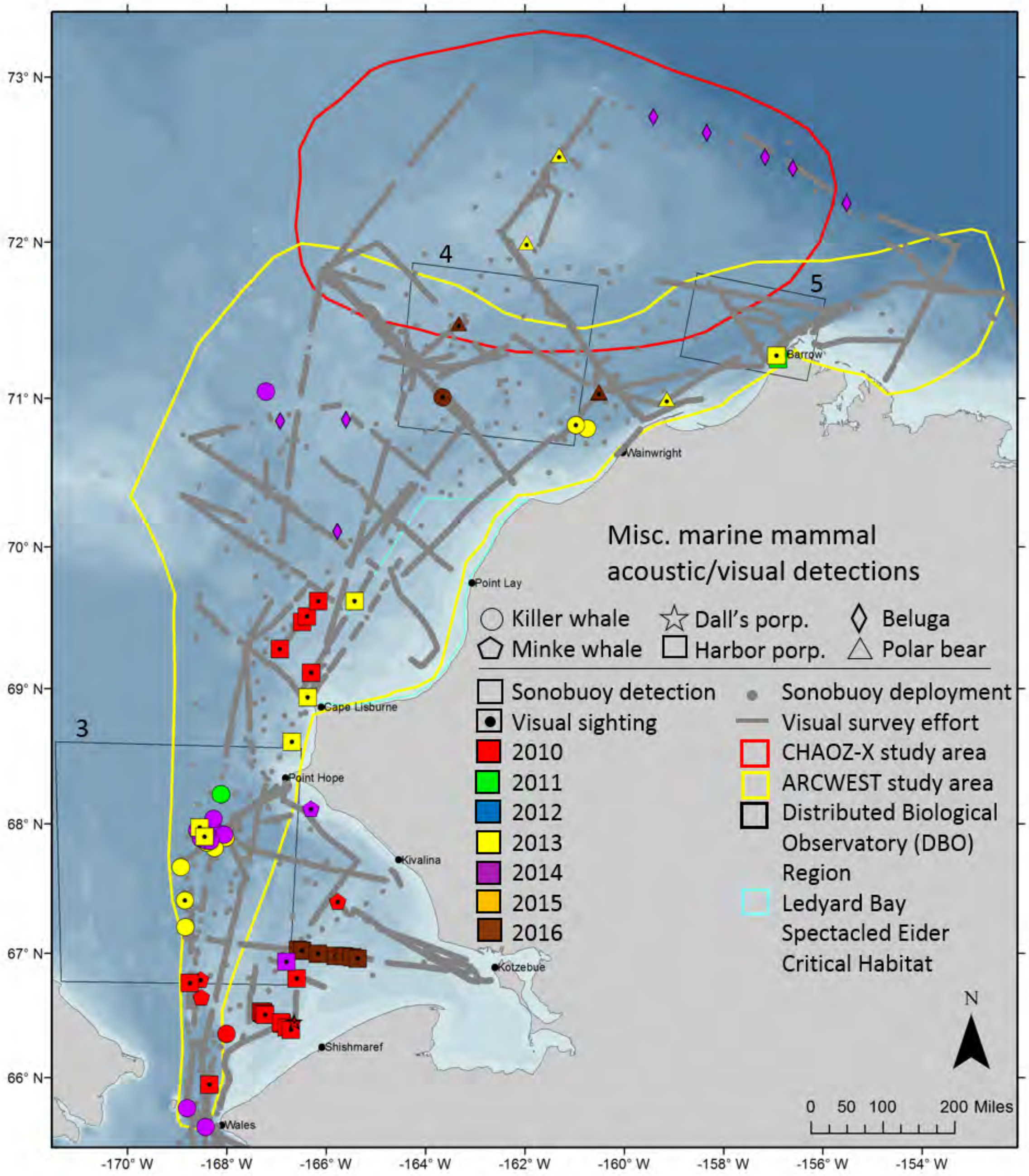


Figure 102. Acoustic and visual detections of miscellaneous marine mammals during the 2013-2016 ARCWEST surveys. Killer whale = circle; Minke whale = pentagon; Dall's porpoise = star; harbor porpoise = square; beluga whale = diamond; polar bear = triangle.

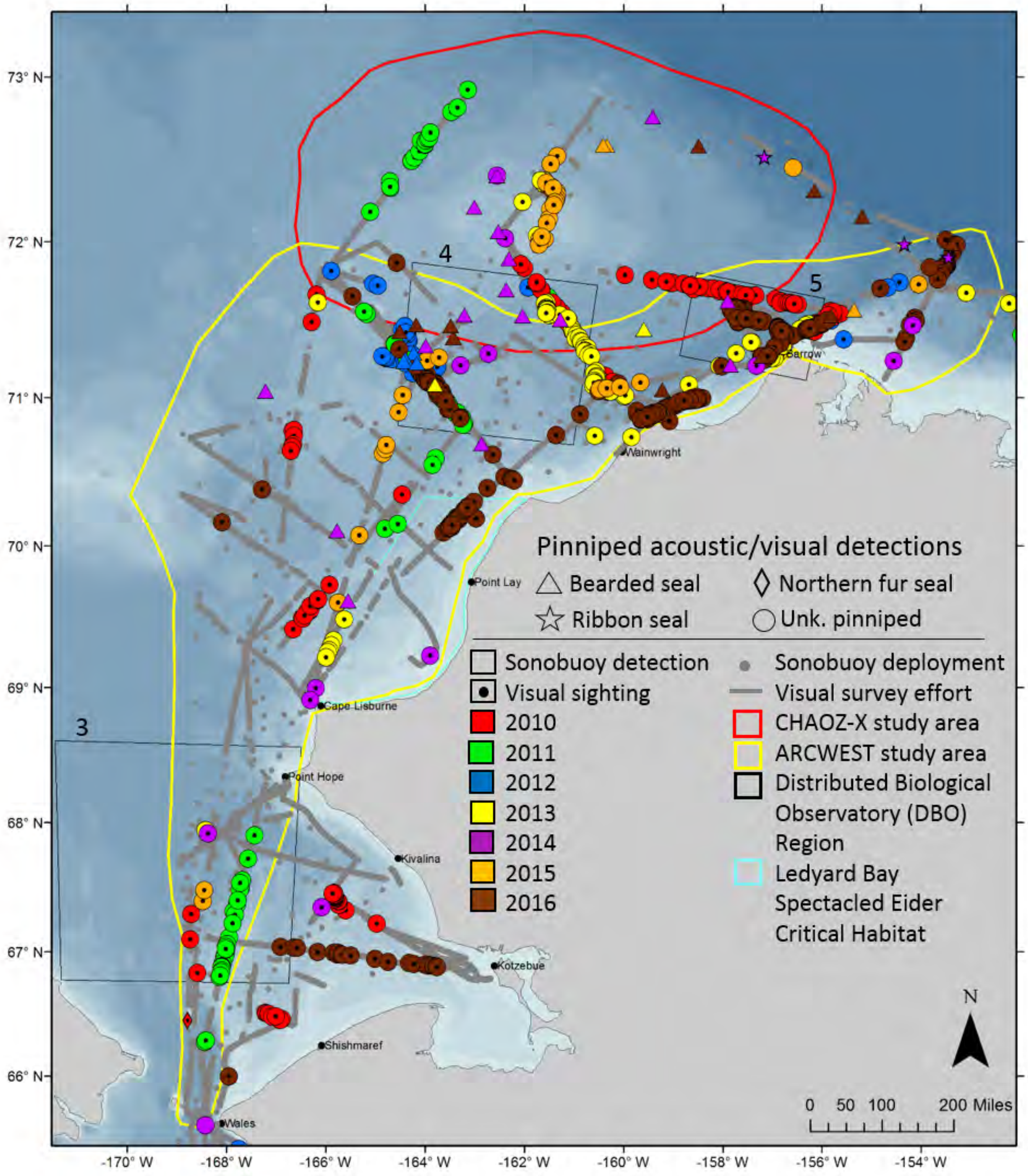


Figure 103. Acoustic and visual detections of all pinnipeds during the 2013-2016 ARCWEST surveys. Bearded seal = triangle; ribbon seal = star; northern fur seal = diamond; unknown pinniped = circle.

Table 39. Summary of sightings (number of individuals) for ARCWEST (in bold), CHAOZ-X, and all waters (including Bering Sea), 2013-2016.

	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)*

$^{+}$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 considerable number of duplicate sightings and should be considered artificially high. A large portion of the unidentified large whales were in these same areas. Scientists plotted all sightings to keep track of animals in the area prior to and during small boat operations.

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 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.

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 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 near Barrow, AK, as is expected from numerous studies (e.g., Moore et al., 2000; Shelden and Mocklin, 2013; Clarke et al., 2016). However, in 2014 there were numerous acoustic detections and visual sightings from Point Lay to Wainwright. 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. The distribution of the bowheads from these surveys, with whales seen/heard predominantly in the eastern part of the study area near Barrow, suggests that the whales were just beginning their fall migration south during this time period. In fact, with the exception of 2014, these data were generally collected during the period with low calling activity preceding the first peak in bowhead whale calling activity seen on the long-term recorders, though there were a few exceptions (e.g., WT1 location).

Based on the long-term results which show that the gunshot calling occurs near the end of the pulses of regular bowhead calling activity, it would not be expected that gunshot calls would be frequently detected during the field seasons. There were only three gunshot detections that coincided with other bowhead whale acoustic detections and visual sightings, all of which occurred in the northern portion of the study area (e.g., north of Point Lay). However, there were some gunshot detections that occurred in the southern portion of the study area, near the Point Hope mooring and in the Bering Strait (Figure 99), which corresponds to the long-term data (Section VII.A.3). Given the distribution of bowhead whales during this time of year and the southern location of these detections, we cannot confidently attribute these gunshots to bowhead whales. Additionally, because of the high numbers of other large whale species sighted in that area (e.g., gray, humpback, and fin whales), it is possible that these gunshots are in fact flipper slaps, breaches, or other impulsive sounds from surface impact activities, and not the internally-produced gunshot. As such, these southern gunshot detections should be treated with caution, and not definitively attributed to the bowhead whale.

Beluga whales

There were no visual sightings of belugas during any of the four field seasons, and there were only three acoustic detections of belugas, all of which occurred in 2014, which occurred later in the year than the other field seasons. This corresponds with the long-term mooring results, which have detections during the September time frame only at BF2, with the exception of 2014, where beluga were detected at WT1 in early September (Section VII.A.2). However, these results only slightly correspond with satellite tagging results that show that the Barrow Canyon area is a core area in August and September for both male and female beluga whales (Hauser et al., 2014). However, aerial survey data (summarized in Clarke et al., 2015b) 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 102).

Clarke et al. (2015a) suggested that the beluga whales are north of our study area as they migrate west in the fall. A bifurcation of their fall migration path is supported by the acoustic detections presented here; acoustic detections of belugas were split between those detections outside of the study area to the north along the slope, and those few detections that were offshore of Point Lay in the study area. This is also supported by data from Moore et al. (2012) that showed a large pulse of beluga whale calling activity from May to August 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 Bering 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 lack of both call detections and visual sightings during our four years of field surveys suggests that the low levels of calling activity, for this highly vocal species, correspond to low beluga whale densities in that area. The results also suggest that passive acoustics may be a 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, a finding that supports the low calling rate reported by Crane and Lashkari (1996) for migrating gray whales and assumed throughout the discussion on the long-term recorder results (Section VII.A.3). The vast majority of sightings and acoustic detections occurred in two main areas: nearshore from Wainwright to Barrow, and in the southern Chukchi Sea, from Point Hope to the Bering Strait, which corresponds with the long-term recorder results. Both of these areas were deemed gray whale BIAs for feeding and reproduction for the summer and fall (Clarke et al., 2015). In the northeastern Chukchi/western Beaufort Seas, most sightings/detections occurred within 25 nm of shore. This is expected from the narrow extent of the defined BIAs, and fits extremely well with the calling activity results of the long term moorings (and the calling being mainly concentrated at inshore locations). In the southern portion of the study area, sightings and acoustic detections were concentrated around the Point Hope mooring location, an area known for having high benthic biomass, and as such, is a well-known gray whale hotspot (Moore et al., 2003; Bluhm et al., 2007; Berchok et al., 2015).

Studies have shown that gray whales are silent when feeding (Ljungblad et al., 1983), with sounds heard only when socializing was observed (S. Moore, pers. comm.). This was also observed during the field surveys, in which gray whales that were feeding near Point Hope (evidenced by extensive mud plumes) were predominantly silent, while gray whales that were exhibiting socializing behavior (e.g., rolling around, spy hopping, body contact) were very vocal (C. Berchok, pers. observation). Given that the Chukchi Sea is a known feeding ground, it is expected that the vocal activity of gray whales would be low. As a result, visual surveys are often more effective at detecting gray whales than passive acoustics in their known feeding grounds.

Results from the satellite telemetry data show tagged individuals remaining in a very limited area for long periods of time. A satellite tagged whale, Platform Terminal Transmitter (PTT) ID 84484, had been photographed 14 days prior, only 4.5 nm away from the tagging location. This animal then spent 46 out of the 50 transmission days within a restricted range around this tagging location. The combination of photo-ID and tagging results demonstrates the protracted duration of restricted summertime foraging for at least some of the individuals in this population. The match of Cascadia Research Collective (CRC) 1503 is interesting. In 2012, this animal was sighted just north of San Francisco, CA on 5 September and in the following year was photographed in the Chukchi Sea on 22 August. It's likely that this animal had a protracted migration in 2012 rather than making the complete migration into the Bering/Chukchi Seas. No biopsy sample was obtained from this individual and it was not observed with a calf so the sex remains unknown.

Walrus

There was good consistency between the shipboard survey results and the long-term mooring results (see section VII.A.3). Most sightings/detections occurred offshore between Icy Cape and Wainwright, near Hanna Shoal, with a secondary grouping near Barrow Canyon. These results are consistent with what is currently known about walrus distribution (Jay et al., 2012). Walrus distributions were consistent among the four field seasons of this study. The distribution of walrus as determined from Aerial Surveys of Arctic Marine Mammals (ASAMM) 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 to open water 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 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).

There was good consistency between the visual and acoustic results for walrus detections in the northeastern Chukchi Sea. 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. However, in the southern Chukchi, most of the detections of walrus were acoustic detections, with only a handful of visual sightings. This suggests that outside their major haul-out areas or feeding grounds, passive acoustics may be a better tool for detecting walrus presence.

Bearded seals

Bearded seals were acoustically detected in all four years; however, with the exception of 2014, there were very few detections each year. The vast majority of the detections were north of Icy Cape. 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, on mostly northern mooring locations. 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).

Other species

There were several records of subarctic cetaceans detected and/or sighted during our survey cruises in the Chukchi Sea. Most were located in the southern Chukchi Sea, but a few were found north of Point Hope. Three species; fin whales, humpback whales, and killer whales (Figure 100-101), were both visually sighted and acoustically detected. Although passive acoustic monitoring generally performed better than the visual surveys, minke whales, harbor and Dall’s porpoise, and polar bears (Figure 102), had only visual sightings.

Fin whales

Fin whale detections were concentrated in the southern Chukchi Sea, south of Point Hope; there were no detections or sightings of fin whales north of Point Hope during the four field surveys. The vast majority of detections were acoustic detections; there were only a handful of visual sightings. The low number of detections of fin whales in the northeastern Chukchi Sea, but high number of detections in the southern Chukchi Sea are consistent with results presented by other passive acoustic studies (Delarue et al., 2013a; Hannay et al., 2013), aerial survey results (Clarke et al., 2015b, 2017), and from the results obtained from our long-term recorder data (section VII.A.2). There have been very few sightings of fin whales in the Chukchi Sea over the years from aerial survey efforts and none from vessel surveys. No fin whales were documented during aerial surveys conducted from 1982-1991. However, since 2008, aerial surveys have documented fin whales in the Chukchi Sea each year, predominantly in August and September in the southern Chukchi Sea. Feeding was documented during multiple encounters in the southern Chukchi Sea in August and September, 2008-2016 (Brower et al., 2018). Additionally, passive acoustic studies suggest a possible increase in fin whale presence in the Arctic. This evidence of increased presence may be due to the increased use of passive acoustics to monitor for this species; as a loud, low-frequency species, fin whale calls can travel large distances, making them highly detectable using passive acoustics. 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.

Although not detected during the ARCWEST survey years, the acoustic detection of fin whale calling activity so far to the northeast (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, or it could be a response to the changing climate and ecosystem (Clarke et al., 2013b; Crance et al., 2015, Brower et al., 2018). In either 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).

Humpback whales

Like fin whales, humpback whales are another subarctic species that were detected frequently in the southern Chukchi, but were not detected north of Point Hope during the field surveys. There was good consistency between the passive acoustic and the visual sighting data, as well as between the short-term and long-term mooring data (Section VII.A.2). The lack of sightings or detections in the northern Chukchi corresponds nicely with the data from the long-term moorings, which had only a few detections at the near-shore northern location (WT1). As mentioned previously (Section VII.A.2), ASAMM aerial survey efforts have also determined that humpback whales occur infrequently in the northeastern Chukchi Sea. No humpback whales were documented during aerial surveys conducted from 1982-1991. However, since 2008, humpback whales have been documented by ASAMM surveys in the Chukchi Sea each year, with the majority of sightings occurring in September. The greatest numbers of sightings from aerial surveys were documented in 2014, which is consistent with the results presented here. Feeding was documented in the southern Chukchi Sea in August, September, and October (Brower et al., 2018). It is suggested that multiple factors may explain the increase in sightings, including population recovery, climate change, and increased survey effort (Clarke et al., 2013b; Brower et al., 2018). However, humpbacks are opportunistic feeders, just like fin whales, and are currently well positioned to penetrate into the BIA feeding areas of bowhead and gray whales, if conditions continue to change.

Killer whales

Killer whales were visually and/or acoustically detected in every year except 2015. Generally, there were more passive acoustic detections than visual sightings, suggesting passive acoustics may be a better method for detecting killer whale presence. The vast majority of killer whale detections occurred in the southern Chukchi Sea, south of Point Hope, in the same area as the concentrations of gray whales. However, there were a handful of sightings/acoustic detections in the northern portion of the study area, between Point Lay and Wainwright.

The low number of sightings or detections in the Chukchi Sea are similar to reports from other aerial and vessel surveys (e.g., Clarke et al., 2013a, 2015b, 2017). Clarke et al. (2013b) combined results from aerial surveys and three separate vessel surveys from 2009 to 2012. During those four years, killer whales were visually sighted only six times, and acoustically detected only twice. Similarly, aerial survey data show that killer whales have only been sighted north of Point Hope in two years, 2012 and 2016, in September. In 2012 a group of 13 individuals were sighted 10 km northwest of Barrow, AK (Clarke et al., 2013b). In 2016, there were 5 sightings of 30 killer whales, all in the northeastern Chukchi Sea (Clarke et al., 2017), All five sightings occurred between 40 km west of Icy Cape and 265 km northwest of Icy Cape. One group was observed hunting a seal, suggesting they are of the transient ecotype.

During the CHAOZ project, the only killer whale sightings were located south of Point Hope, in approximately the same areas as the concentrations of gray whales (Figures 27 and 22, respectively, in Berchok et al., 2015). It was hypothesized that those killer whales were also the transient ecotype, which eat marine mammals like gray whales. Results from the predation event during the ARCWEST 2013 survey support this hypothesis that killer whales in the Arctic are of the transient ecotype. 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 low number of sightings and detections north of Point Lay during the four years of field surveys supports the long-term recorder findings that killer whales are rare in the northeastern Chukchi Sea.

Minke whales

There were no records of minke whales in the study area during the four field surveys. The only acoustic detection (1 in 2010; CHAOZ) and visual sightings (two in 2010 (CHAOZ), one in 2014 outside the study area) were in the southern Chukchi Sea, south of Point Hope. Since 2011, minke whales have been documented in the Chukchi Sea each year by the ASAMM aerial survey (Brower et al., 2018). Minke whales had the most extensive distribution with distances ranging from <1 km to 170 km offshore. Sightings occurred in July and August with a majority of the southern sightings occurring in August 2016 and northeastern Chukchi Sea in 2011 and 2012 (Brower et al., 2018). The increase in sightings in the northern Chukchi in recent years may indicate that the species is encroaching on more northerly territories. While reasons for the increase in sightings is unknown, it may be due to post-whaling population increase, increased survey activities, or climate change. These results also indicate that visual surveys are a better method than passive acoustics for detecting this species.

Harbor and Dall's Porpoise

Harbor porpoise were visually sighted within the survey area in 2013, with the majority of sightings occurring between the Bering Strait and Point Lay and one sighting off Barrow, AK (Figure 102). They were not seen in any other year during this project. Harbor porpoise were documented in previous years in the Chukchi Sea off Barrow and Cape Lisburne, and near the Bering Strait during the CHAOZ project (Berchok et al., 2015). Dall's porpoise were not visually sighted in the study area during the four field surveys. However, during the CHAOZ project, one Dall's porpoise sighting occurred just north of the Bering Strait (Berchok et al., 2015). See Appendix E for sightings of harbor porpoise outside of the survey area.

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, because of their small size, are difficult to identify during aerial surveys at the altitudes typically flown in the Arctic; 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.

Small ice seals

There are numerous unidentified pinniped sightings in the study area in each year; it is likely that many of these are small ice seals (spotted, ringed, ribbon). However, due to the difficulty in positively identifying these species when in the water, they were all categorized as 'unidentified' to avoid mis-identification. Like the two species of porpoise, small ice seals are difficult to sight during aerial surveys at altitudes flown by ASAMM and therefore, those records are also saved as 'unidentified pinnipeds'. Only two acoustic detections of ribbon seals occurred in the far northeastern portion of the study area (2014). This corresponds with the long-term recorder data, in which the only detections in September were at the BF2 location (Section VII.A.2). 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-September time period.

Polar bears

In 2013, one polar bear was sighted swimming in open water ~ 40 km from shore just NE of Wainwright. In 2016, there were 4 sightings located NW of Wainwright at ~145 and ~470 km from shore on ice floes. Ice was encountered during all four survey years, and 2016 had a larger number of ice seals hauled out on ice floes than previous years. This may explain the larger number of 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 of the marine mammal species. The results of this four year shipboard survey have shown that the northeastern Chukchi Sea is an important area for several resident species in the August/September time period, including bowhead and gray whales, and walrus. Although there was some inter-annual variability in detection locations, all three of these species were detected visually or acoustically in large numbers in all three years of surveys. The southern Chukchi Sea also appears to be an important area for both Arctic species (i.e., bowhead whales) and subarctic species (e.g., fin and humpback whales, and harbor porpoise). Clarke et al. (2013)

suggest there may be an increase in these cetaceans within this region, which is evidenced by the number of killer whale detections in the northeastern Chukchi Sea in this study. This increase 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 each species. 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 to be sighted or detected during the August/September time period of these cruises. For gray whales, bearded seals, minke whales, and the two porpoise species, call detections cannot be used as a proxy for presence of these species at this time of the year. However, for highly vocal species like killer whales and belugas, passive acoustics may be a better method for detecting species presence than visual surveys. 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 possibly 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 (see Section VII.B.1). This then allows us to obtain estimates of call detectability that are necessary for future calculations of relative abundance.

C. Photo-Identification

1. Methods

At the cruise leader's discretion, survey effort was temporarily suspended to allow closer approaches to sightings for the collection of photo-identification data. Photographs were obtained to potentially evaluate movements of animals individually identified during the survey and for comparison to existing catalogs. Photographs were taken using Canon 50D, 7D, and Nikon D200 digital cameras equipped with a 100-400 and 80-200 mm zoom lens set to autofocus. All photographs were reviewed, and the highest quality identification photograph(s) of each animal were selected to be compared to existing photo-identification catalogs. Photo-identification efforts focused on species for which catalogs are available in other areas of the North Pacific and the Bering Sea, particularly humpback, gray and killer whales.

2. Results

Over the four year study, opportunistic photographs were collected of humpback, gray, and killer whales. One humpback whale was photographed on 16 September 2014, 55 nm southeast of Point Hope, Alaska. The animal was observed performing surface active behaviors including breaching, flipper slapping, and lob-tailing. This animal was compared to the MML and SPLASH catalogs. There was no match, and the fluke was added to the MML catalog.

Gray whales were photographed in 2013 and 2014. Thirty-six and fifteen animals, respectively, had photographs of acceptable quality for matching. These animals were matched to the North Pacific Gray Whale catalog curated by Cascadia Research Collective (CRC). One individual photographed on 22 August 2013, located 55 nm southeast of Point Hope, Alaska was matched to CRC 1503. This animal was sighted the previous year on 5 September 2012, 6 nm north of Bodega Bay, California. There was one intra-annual match of a gray whale tagged on 7 September 2013 (PTT ID 84484; see Section VII.D.2). This animal was photo documented 14 days prior on 24 August 2013 at a location that was 4.5 nm away from the tag deployment location (Figure 104). No animals photographed in 2013 were re-sighted in 2014; all photographed animals in 2014 were new individuals. All gray whales have been added to the catalog curated by CRC.

On 2 September 2013, a group of transient killer whales were photographed during a predation event on a gray whale calf located 22 nm northwest of Wainwright, Alaska. The gray whale was estimated at ~20 ft in length. No other gray whales were sighted in the area; the calf was abandoned. Twelve kiler whales were photographed during this event, including four bulls and one calf. Two of the twelve whales were identified from the Western Transient Killer Whale Catalog curated by MML. Of these two, one female, WT0142, was previously sighted off Cape Lutke on the Pacific Ocean side of the Alaska Peninsula on 7 June 2007. The second identified killer whale, WT0059, was first sighted on 14 May 2005. This individual (WT0059) was conducting a majority of the attacks on the calf. By the time the vessel departed due to darkness and increased sea state, the gray whale calf was floating belly up and would only intermittently right itself to take a breath. Throughout the encounter, no calls were detected, although calls were detected prior to the vessel arriving on scene.

All other photographs were collected in the Bering Sea and along the Alaskan Peninsula in the Gulf of Alaska (see Appendix E for plots of sighting and sonobuoy locations of these species detected outside of the official study area).

Figure 104. Intra-annual match of gray whale PTT ID 84484 photographed in late summer, 2013. Top: First sighting of whale 84484 on 24 August 2013. Bottom: photograph of whale 84484 during tagging event on 7 September 2013.

3. Discussion

Photo-identification is an invaluable tool to understand seasonal and temporal habitat use and to understand population structure. The match of a western transient killer whale in the Chukchi Sea confirms the presence of the transient ecotype along with evidence of predation within Arctic waters. The intra-annual match of the tagged gray whale (PTT ID 84484) combined with the tag data contributed to a more extensive picture on habitat use during the summer- fall. The gray whale match, CRC 1503, is an interesting match. It was sighted in the Chukchi Sea in mid-August in 2013 and off Bodega Bay, California in 2012 at the beginning of September. We can’t say for sure why this animal would be in two very different geographic locations during the same time of year. It does underscore the fact that there is a lot we don’t know, even for species like the gray whale that has been extensively studied.

4. Conclusions

Given the objectives of this project, we did not have sufficient time to dedicate to photo-identification studies. Although we only had 3 matches to catalogs, those few matches proved to be important to our knowledge on Arctic species. Dedicating effort to more extensive photo-identifications studies could prove invaluable to understanding habitat use and movements, particularly in this time of changing climate.

5. Recommendations

Obtaining photographs for photo-identification purposes typically requires the survey to suspend operations when feasible and approach the animal(s). As a rule, we attempt to collect photographs opportunistically as the vessel continues on its course when we don't have time to stop. However, dedicated time would need to be allocated to conduct robust photo-identification studies.

D. Satellite Telemetry

1. Methods

Satellite telemetry was conducted at the discretion of the Chief Scientist after considering weather, time of day, and planned oceanographic operations. Once a tagging candidate species (humpback, fin or gray whale) was located, two 23' rigid-hulled inflatable boats (RHIB) were launched; the tagging vessel had a coxswain, tagger, data recorder and photographer on board and the support vessel had a coxswain and crew member on board. Satellite transmitters were attached to the body of the whales using the Air Rocket Transmitter System (ARTS, Heide-Jørgensen et al., 2001), which is a modified marine safety pneumatic line thrower. Tagging took place from a platform at the bow of the RHIB with the boat positioned approximately 6-10 m perpendicular from the animal.

Whales were tagged with the implantable configuration of the Smart Position and Temperature version 5 (SPOT 5, Figure 105) and MK10A transmitters produced by Wildlife Computers (Redmond, WA). These instruments are cylindrical in shape and contain an Argos satellite PTT (SPOT5) tag or an Argos PTT and time-depth recorder instruments (MK10A). When deployed, approximately 2-4 cm of the tag remains external to the body of the whale, with an antenna extending out of the distal end of the tag. The two tag types were duty-cycled to transmit from 02:00-08:00 and 14:00-20:00 GMT daily to maximize battery life and transmission rate. This sampling design was expected to provide extensive data while the whales were on their feeding grounds. Beginning in November, when large whales are likely migrating out of the area, the MK10A transmitters were programmed to transmit every other day, following the same alternating 6 hr. on/off periods. Follow-up photo-documentation of tag placement and animal behavior was attempted for 20-30 min after deployment. Tag deployment and follow-up photo-documentation were performed according to regulations and restrictions specified in the existing permits issued by the National Marine Fisheries Service to MML (permit #14245) and the International Animal Care and Use Committee assurance issued to MML.

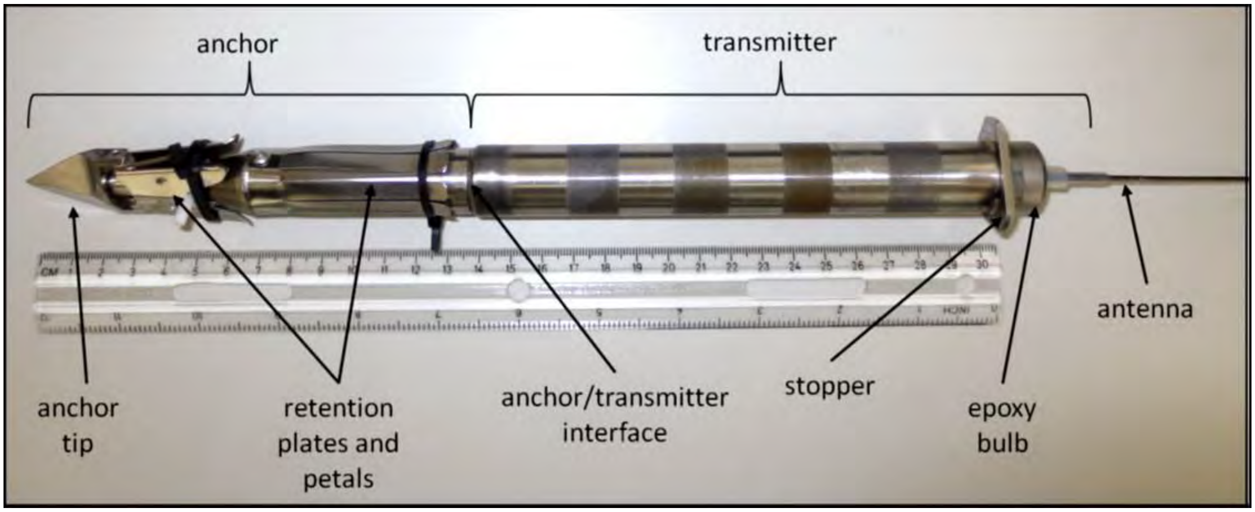


Figure 105. An example of a SPOT 5 satellite transmitter that was deployed in 2012.

Satellite tags were monitored by Argos Data Collection and Location Service receivers on NOAA TIROS-N weather satellites in sun-synchronous polar orbits (Argos, 1990). Locations were calculated by Argos from Doppler-shift data when multiple messages were received during a satellite's passage overhead. Argos codes locations into quality classes (LQ) labeled B, A, 0, 1, 2, 3, in order of increasing accuracy. Fadely et al. (2005) verified accuracies of 0.4 km (±0.3) for LQ3, 0.7 km (±0.6) for LQ2, 1.5 km (±1.5) for LQ1, 4.9 km (±5.3) for LQ0, 2.9 km (±5.2) for LQA, and 17.4 km (±26.2) for LQB.

The Speed-Distance-Angle Argos filter (Freitas et al., 2008) was applied to all location qualities in software R in order to remove locations that implied unlikely deviations from the track's path as well as unrealistic travel rates. This filter requires two main parameters: turning angles and maximum speed of travel. The default value of turning angles (Freitas et al., 2008) was used and the maximum speed was assumed to be 15 km/h, as a reasonable upper limit for large whales (e.g., Mate et al., 1997). Exploratory analysis showed that the use of different maximum speed limits (12 and 18 km/h) did not influence the filter results. Distances between filtered locations were calculated assuming a great circle route.

A Bayesian switching first-difference correlated random walk state space model (hereafter referred to the SSSM) (Jonsen et al., 2005) was fit to the filtered Argos data. As this approach has been extensively described elsewhere (Jonsen et al., 2005, 2007; Patterson et al., 2008; Jonsen, 2016) we will only briefly describe the procedure. Because Argos satellite tags provide location information with error in space and at irregular time intervals (Argos), SSSM integrates a process model that predicts the future state of an animal given its current state, and an observation model that relates the unobserved location states (true locations) predicted by the process model to the observed data (locations obtained from Argos). As animals are expected to switch their behavior along their paths, the process model to describe movement dynamics allows movement parameters to change between two discrete behavioral states by including a process model for each one (Morales et al., 2004). In order to quantify discrete behavioral modes, the model incorporates an index based on mean turning angle and speed/direction autocorrelation parameters. Behavioral modes are estimated from the means of Markov Chain Monte Carlo (MCMC) samples within the model, producing continuous variables between 1 and 2; higher values represent higher turning angle and speed/direction variability. Modes are then classified (conservatively) as follows: behavioral mode 1 (1−1.25) assumes a low turning angle and speed/direction variability and is classified as transit behavior, which in this case is associated to migratory behavior. Behavioral mode 2 (1.75−2) corresponds to higher turning angles and speed/direction variability, and is classified as Area-Restricted Search (ARS), which might be associated with foraging activities. Unclassified behavior mode values fall between 1.25 and 1.75. State variables related to true locations and behavioral states were estimated at the individual level but assuming individuals share identical movement parameters using a joint estimation multi-level structure variant of the previously described model (Jonsen, 2016). While it is impossible to definitively characterize feeding behavior without real-time confirmation, in this study ARS was considered analogous to foraging behavior on an animal's feeding ground (Kareiva and Odell, 1987; Mayo and Marx, 1990; Jonsen et al., 2007; Kennedy et al., 2014).

The SSSM was used to estimate a position and behavioral mode every 24 hours (Jonsen et al., 2005; Kennedy et al., 2014), using the package 'bsam' in R (Jonsen et al., 2013; R Core Team, 2017). The SSSM estimates two behavioral modes assumed to represent transiting (mode 1) and 'area restricted search (ARS) behavior (mode 2). The 'bsam' package fits the SSSM using MCMC simulations via software rJags (Plummer, 2003). For the present analysis, two MCMC chains were run in parallel, each for a total of 30,000 samples with the first 10,000 samples discarded as burn-in. The posterior distribution of the model parameters were approximated by retaining every 20th sample in the remaining chain to reduce auto-correlation.

Temperature and bathymetry data from the Global 1-km Sea Surface Temperature (http://ourocean.jpl.nasa.gov/SST/) dataset and the 1-km global relief surface model (ETOPO1) (Amante and Eakins, 2009) were extracted for each modeled position using the package xtractomatic (https://coastwatch.pfeg.noaa.gov/xtracto/) in R. To quantify the area used by tagged gray whales in 2012 and 2013, we used the least-squares cross-validation method as implemented in the adehabitat package for R (Calenge, 2006) to create utilization distributions. The 90% home range and 50% core use area (CUA) polygons were produced for the entire track of each whale, excluding the extensive travel period undertaken by whale # 87636 (which lasted only 10 days but artificially inflated the animal's home range beyond realistic limits) (Irvine et al., 2014).

2. *Results*

In 2012, one gray whale was tagged (PTT ID 112713) approximately 16 miles offshore from Wainwright, Alaska. Results from this tagged animal were reported in the CHAOZ final report (Berchok et al., 2015); they are also included here in order to consolidate our Arctic gray whale tagging results. The whale was judged to be a juvenile based on size (Figure 106). The tag transmitted for 49 days, until 11 October 2012 (

Table 40). The animal remained within 140 km of the deployment site for the duration of the tag and occupied relatively shallow waters (20-50 m) to the south of Hanna Shoal with a predicted 90% home range of approximately 420 km^2 (Figure 107). Results from the switching state-space model show that all but one uncharacterized position fell within the area restricted search (ARS) criteria threshold (Figure 108).

Figure 106. Satellite tagged gray whale

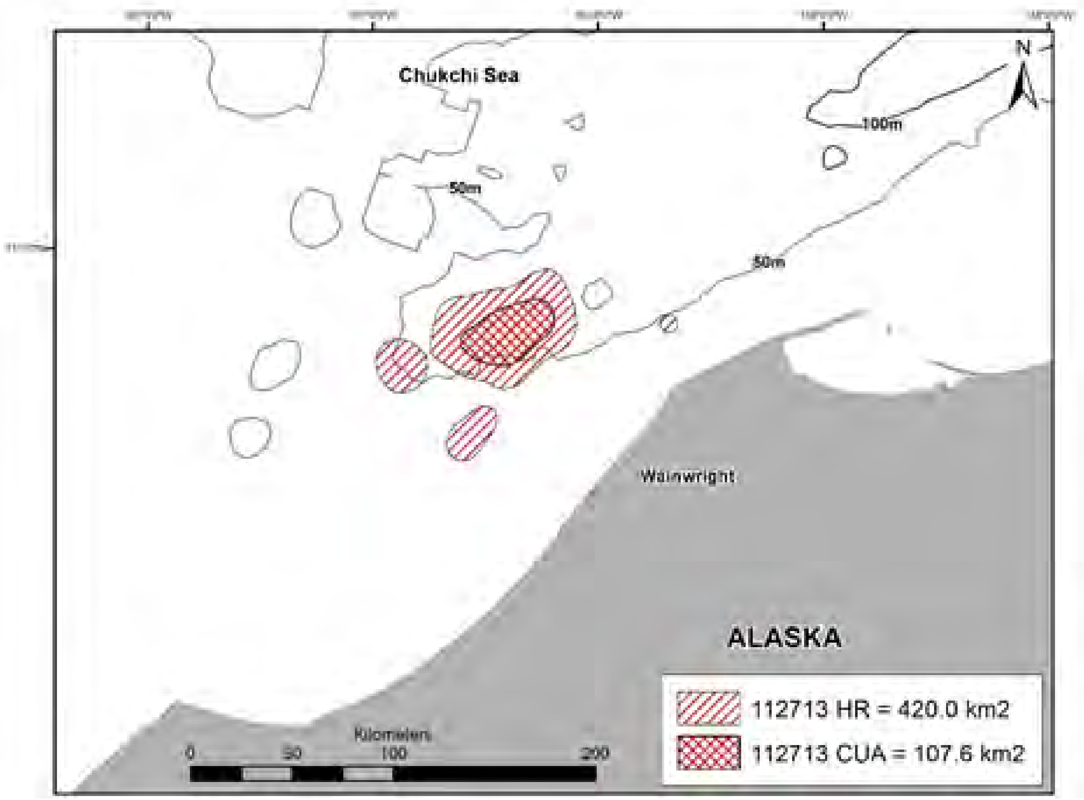


Figure 107. 90% home range (HR) and 50% core use area (CUA) for the 49 day tag transmission of PTT ID 112713.

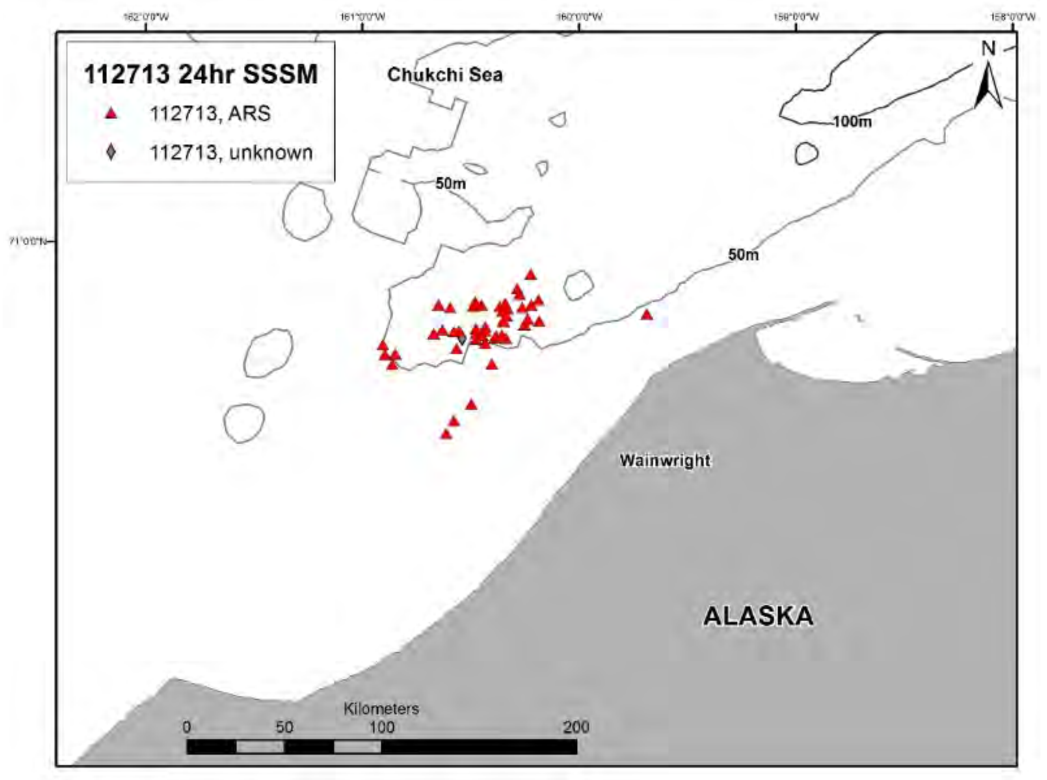


Figure 108. Switching state-space modeled locations (24 hour time-step) of the gray whale tagged off Wainwright during 2012 (PTT ID 112713). Red triangles indicate area restricted search (ARS).

Table 40. Tag performance and habitat-use summary table. HR=Home range area, estimated as 90% of the animal's utilization distribution. CUA= core use area, estimated as 50% of the animal's utilization distribution. *does not include long-distance travel data which artificially inflate the HR and CUA beyond realistic limits.

PTT ID	Deployed	End	# Days	90% HR (km^2)	50% CUA (km^2)	Mean SST (C)	Mean Depth (m)	Mean SST (C)	Mean Depth (m)
112713	8/25/2012	10/11/2012	48	420	107.6	2.46±1.41	-49.98±2.92	2.36±1.23	-49.97±2.95
84482	9/8/2013	10/18/2013	41	635.2	185.3	2.90±0.74	-56.76±3.99	2.84±0.66	-56.78±8.99
84484	9/8/2013	10/27/2013	50	2508.1	355.7	2.37±1.2	-53.84±3.72	2.48±1.00	-54.07±3.74
84485	8/24/2013	9/3/2013	11	61,724.90	21,628.00	5.63±1.83	-50.50±4.82	n/a	n/a
87636	9/7/2013	11/12/2013	67	1556.6*	476.5*	2.36±1.55	-63.79±11.27	2.32±1.50	-65.12±11.19

In 2013, 4 gray whales were tagged ~125 nm southwest of Pt. Hope (PTT IDs 84482, 84484, 84485, and 87636; Table 40, Figure 109). 81% of the positions fell within a narrow band from 66.8°N and 68.4°N in the Chukchi Sea. Of the 169 total transmission days in 2013, an overwhelming 84% of those days were categorized as ARS, 8% were transit and 8% were uncategorized (Figure 110).

Whale 84482 spent the entire 41 day tag duration within a 90% home range that covered a mere 635.2 km^2. Whale 84484 spent 46 out of 50 days of tag transmission within a 2,500 km^2 home range (Figure 112) before it began heading south from 27 to 27 October (end transmission). Whale 84485 had the shortest tag duration, but also the largest home range

(61,724 km^2, Table 12, Figures 111, 112). This whale initially headed west after tagging then turned towards the northern Chukotka Peninsula (Russia) and eventually began moving southeast before transmissions ceased. Whale 87636 spent a month in the same general area as whales 84482, and 84484, before heading south on 11 October (Figure 109). Once the whale was directly west of St. Lawrence Island on 16 October, it slowed and engaged in ARS southwest of St. Lawrence for nearly a month before the tag stopped transmitting (12 November). With the exception of 84485, all whales tagged in this study had a remarkably small home range of 2,508 km^2 or less, and a CUA of 477 km^2 or less (Figure 113).

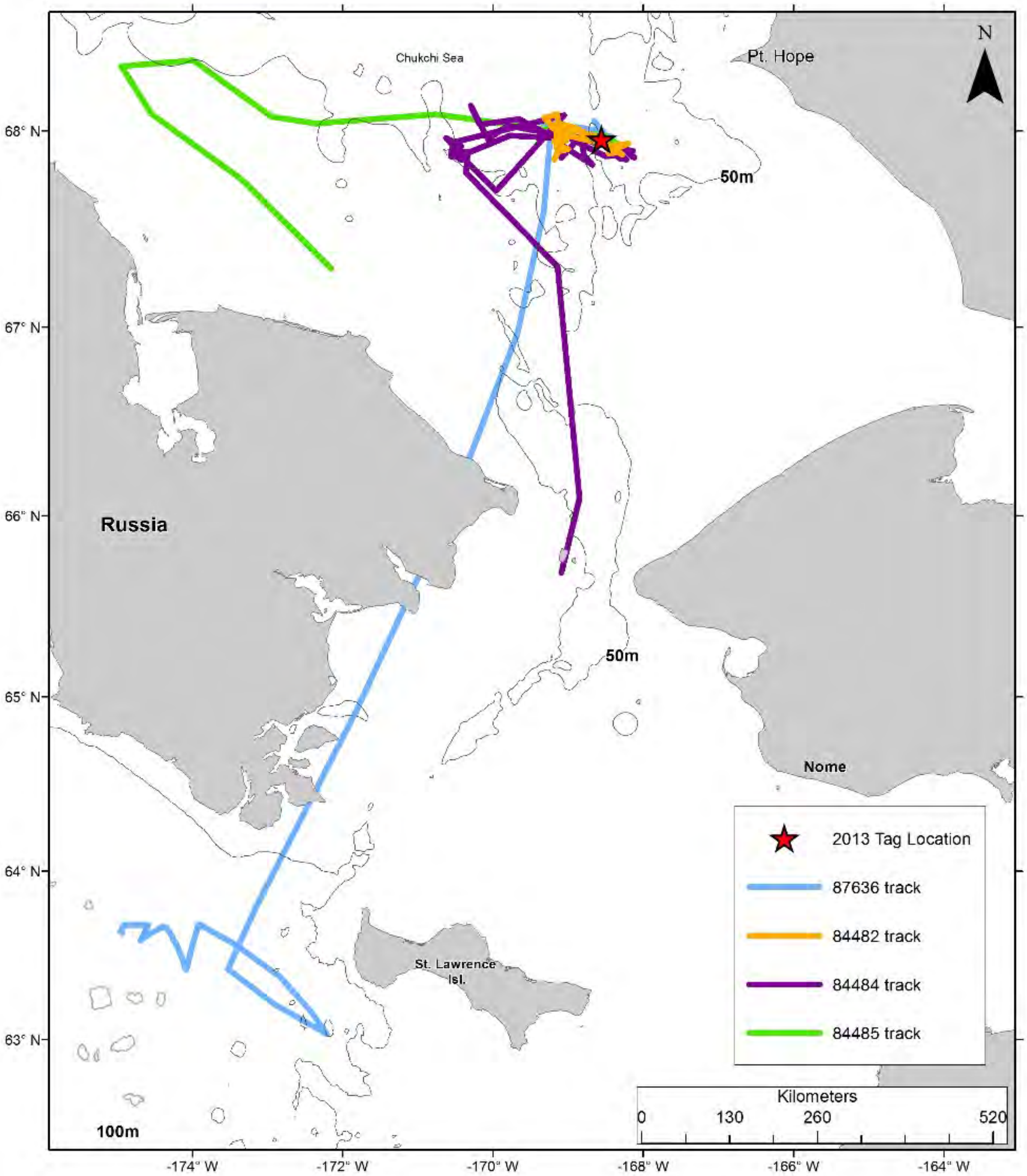


Figure 109. Tracks from 4 gray whales satellite tagged ~125 nm southwest of Pt. Hope in 2013

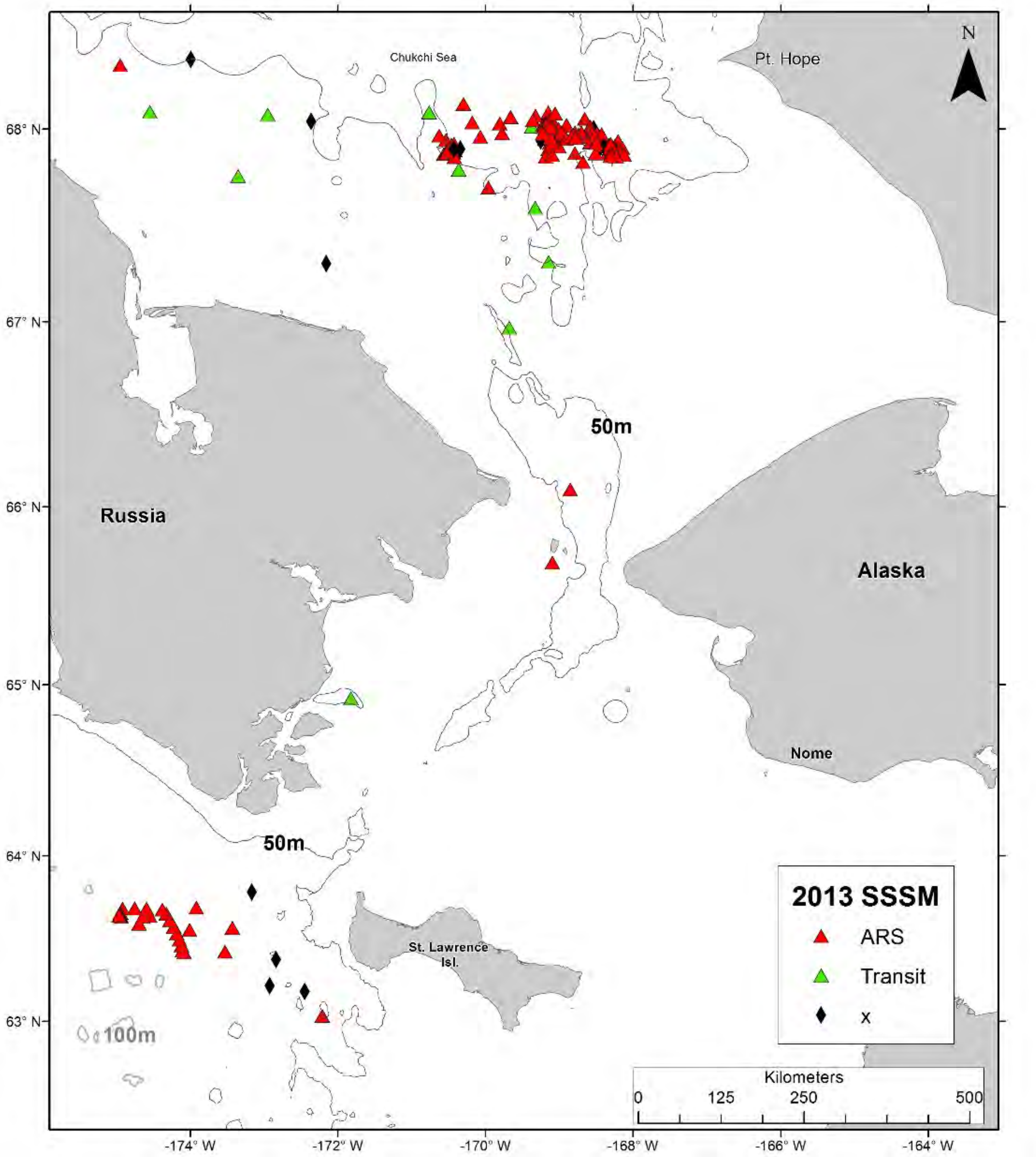


Figure 110. Area Restricted Search (ARS), transit, and Uncategorized (x) behavioral modes for all gray whales tagged in 2013.

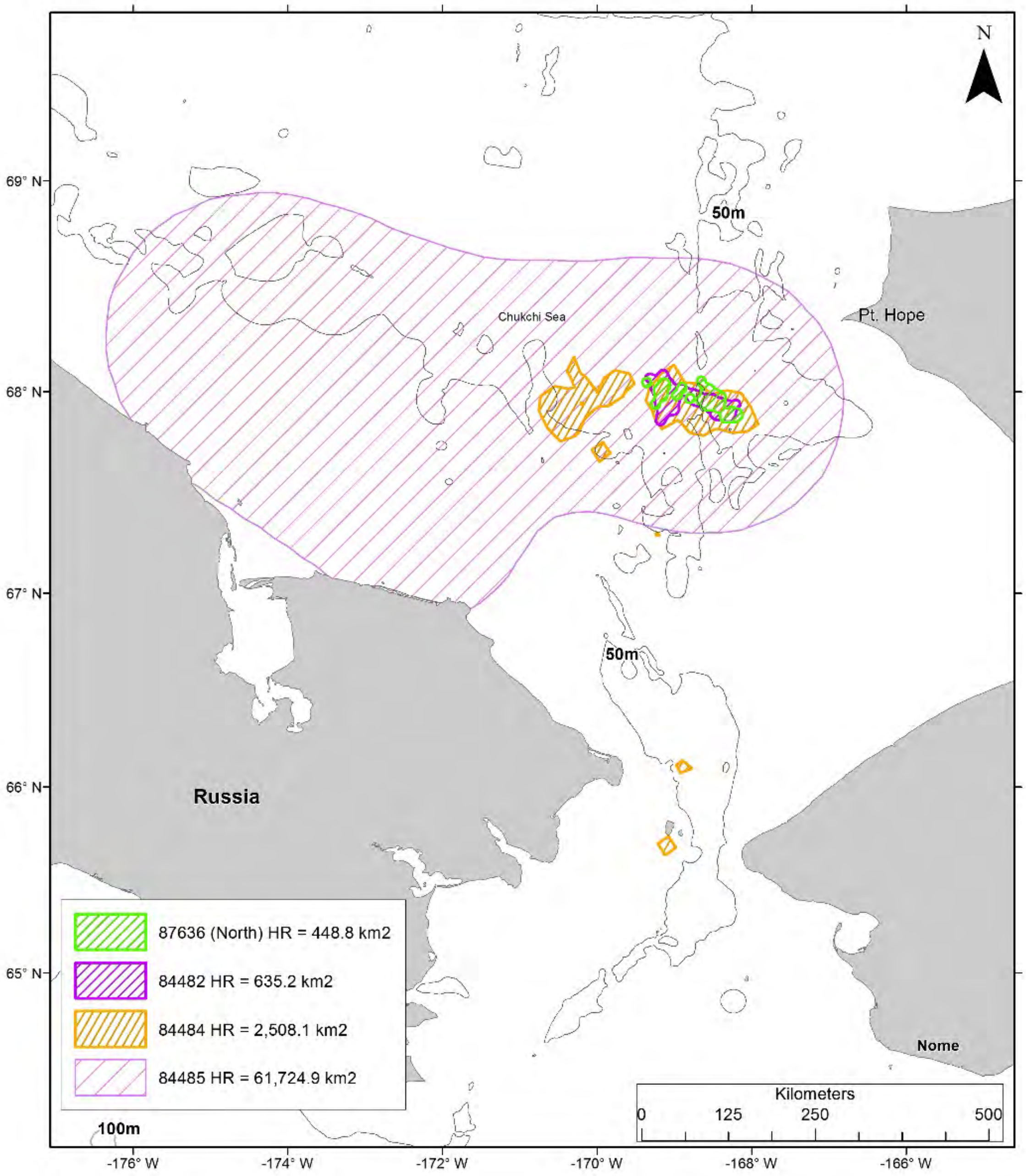


Figure 111. 90% home range (HR) and 50% core use area (CUA) for all gray whales tagged in 2013, excluding 87636 southbound travel.

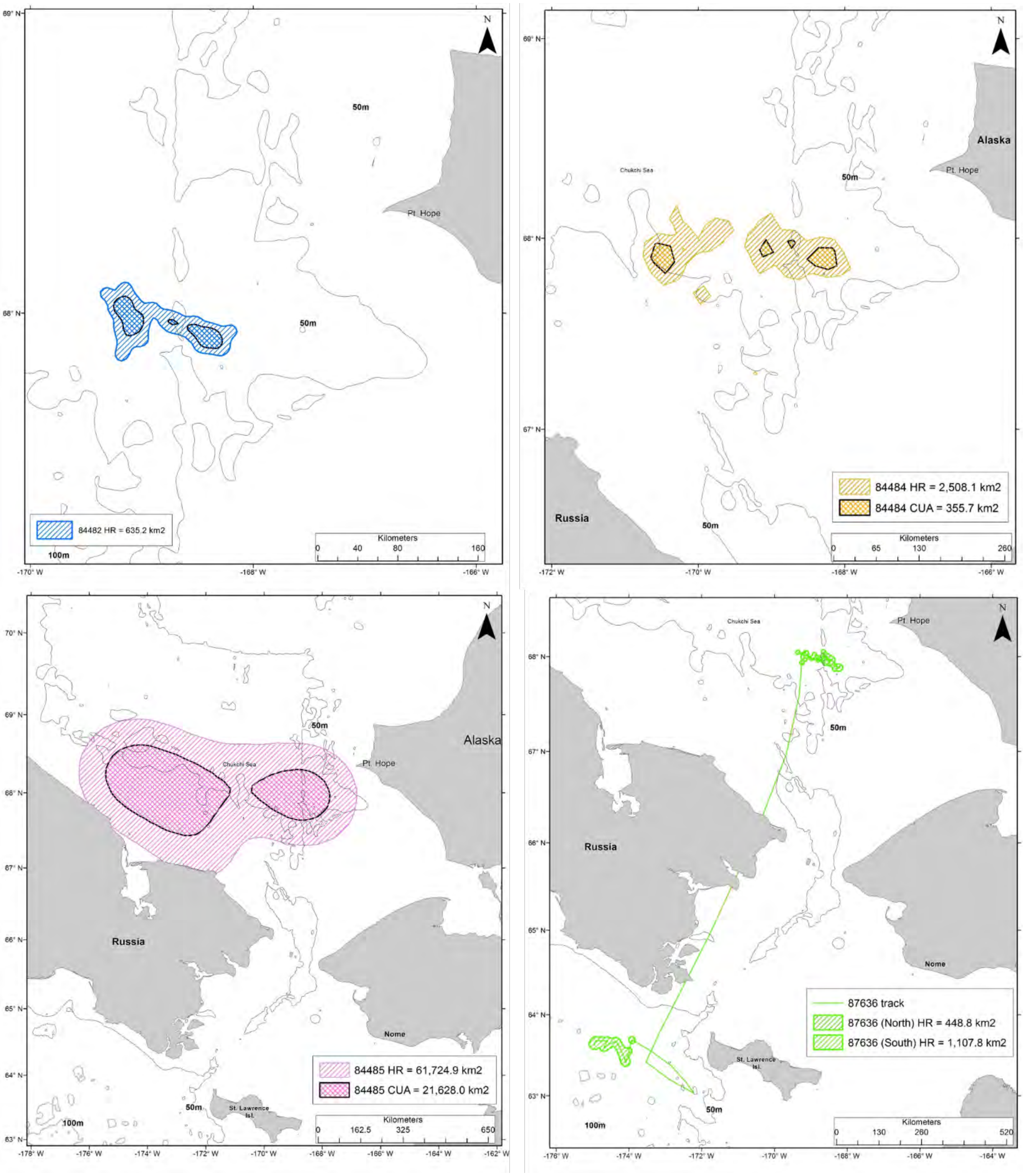


Figure 112. 90% home range (HR) and 50% core use area (CUA) for individual whales tagged in 2013.

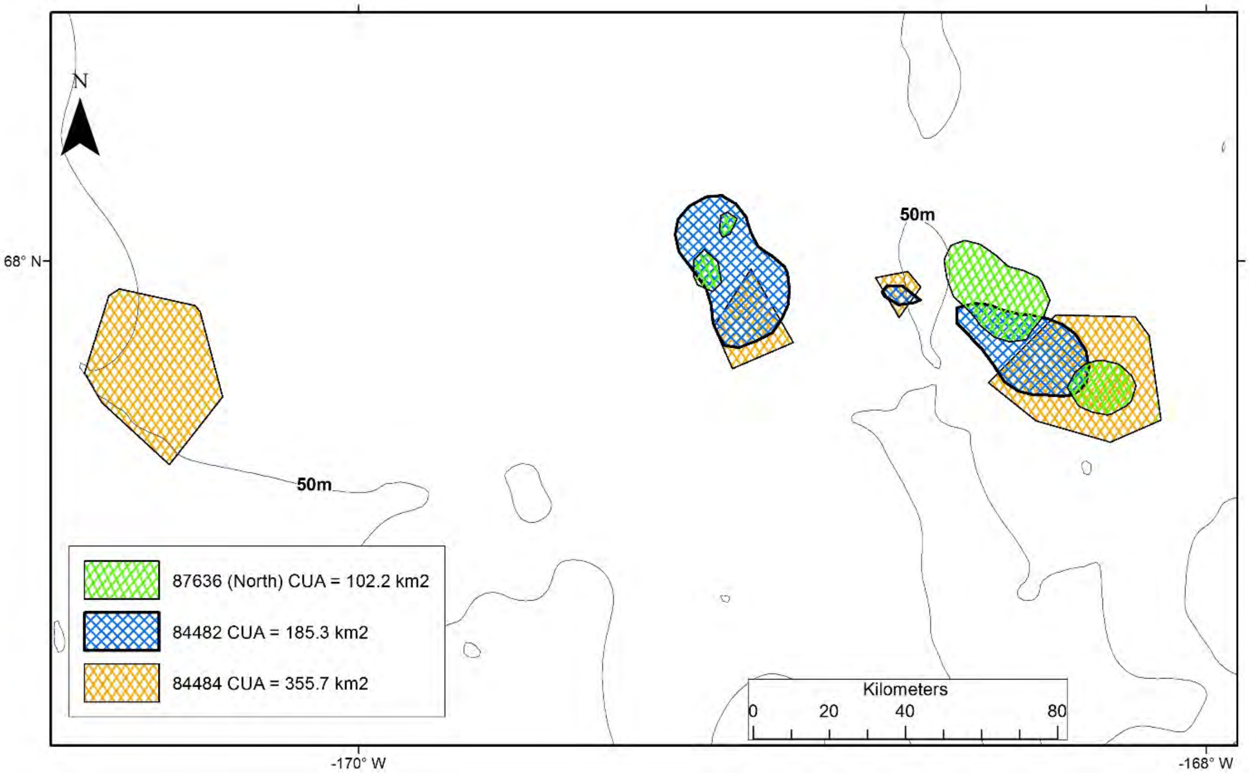


Figure 113. Closer look at the 50% core use area (CUA) of 3 whales tagged off Pt. Hope showing remarkable distribution overlap at a very fine scale.

Whale 87636 was equipped with a MK10a tag, which recorded dive depth as well as position (Figure 114). During periods of ARS, the whale recorded dive depths consistent to charted bottom depth. During periods of transiting behavior, dive depth was variable. While 87636 was the only whale with a depth recording tag, we extracted the charted depth (ETOPO1; Amante and Eakins, 2009) for each daily modeled position (Figure 114) and show that, while in ARS behavior, the whales were using an average depth of -56.9 ± 8.9 m (range = -89.9 to -40.2 m) (Figure 114). Depths at ARS locations north of the Bering Strait ranged from -61.8 m to -44.5 m (mean = -55.7 ± 3.4 m) (Figure 115).

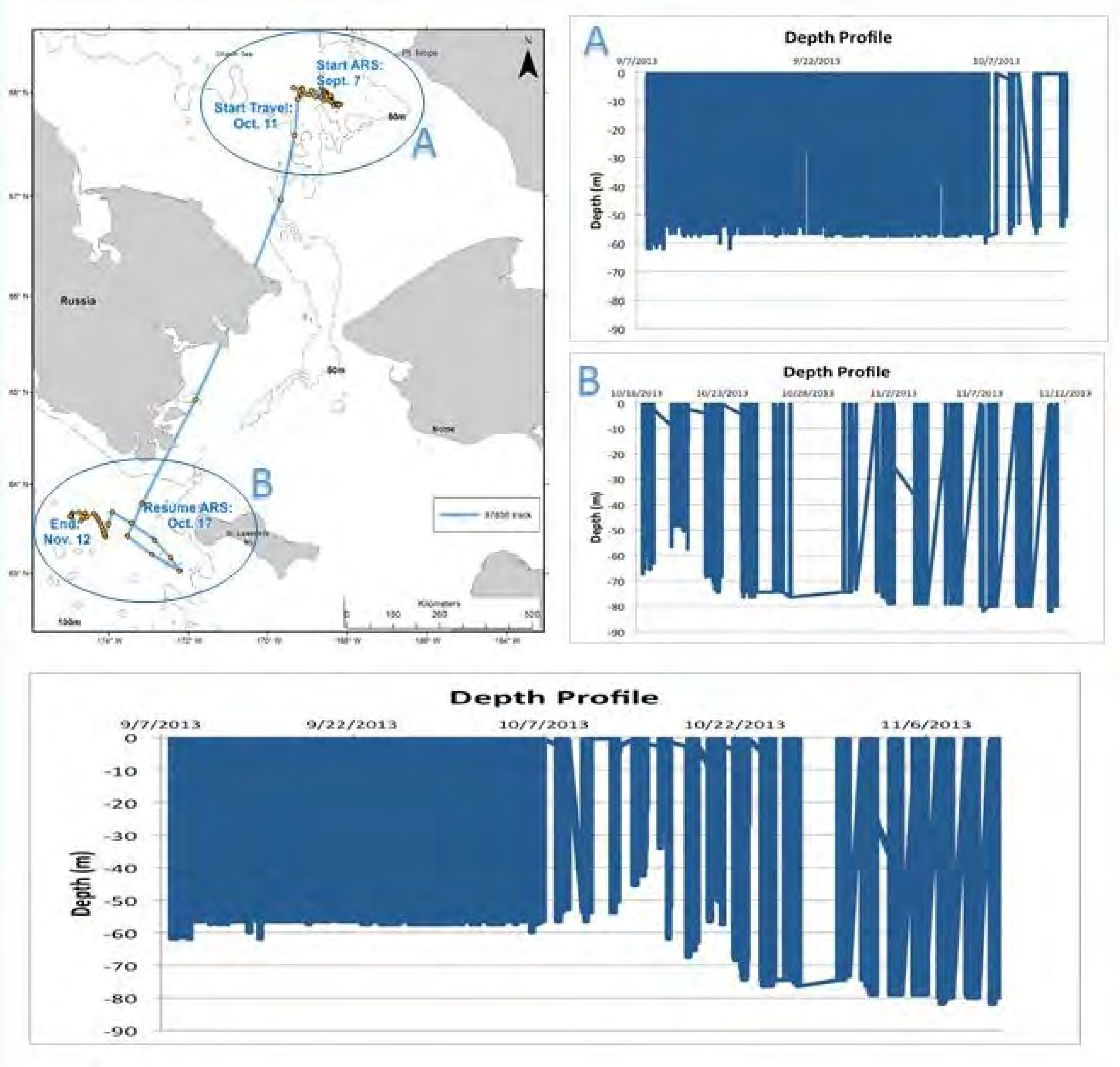


Figure 114. Full track of whale 87636 with corresponding dive depth profiles. Gaps in data indicate a change in duty cycle, from daily transmissions to every other day.

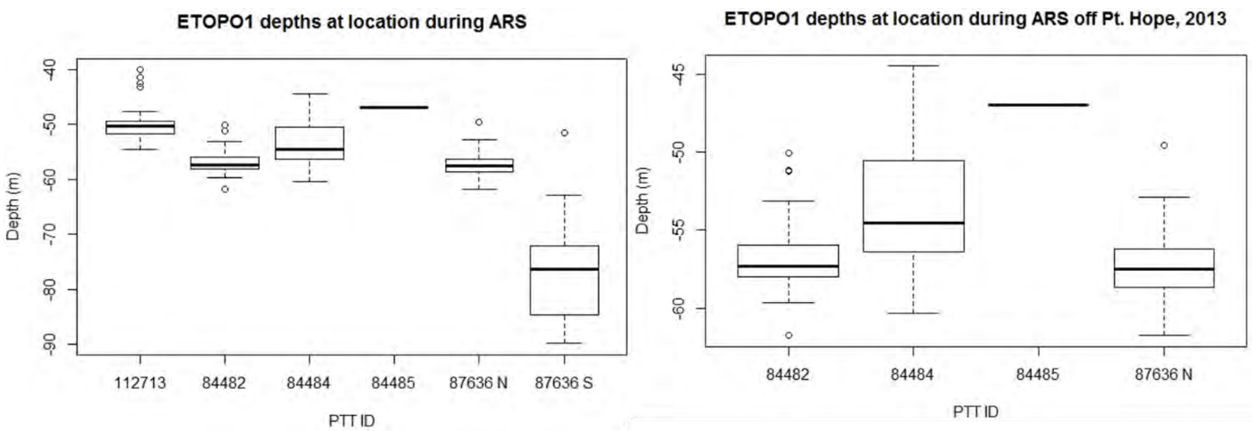


Figure 115. Left: Boxplot of charted depth at daily whale location while in area restricted search (ARS) by individual. 87636 was split into separate sessions corresponding to a period of ARS off Pt. Hope (north) and a second period of ARS off St. Lawrence Island (south). Right: Boxplot of charted depth at daily whale location while in ARS off pt. Hope in 2013.

3. *Discussion*

The area between Pt. Hope and St. Lawrence Island is a well-known hot-spot for gray whale aggregations (Moore et al., 2000; Clarke et al., 2016; Brower et al., 2017), and benthic samples have shown very high amphipod, filter-feeding clam, and polychaete biomass in this region (Grebmeier et al., 2006; Bluhm et al., 2007). Results from the 5 gray whales satellite tagged in 2012 (n=1; for the CHAOZ study) and 2013 (n=4; this study) show a very high proportion (84%) of ARS behavior in three distinct areas: approximately 16 nm northwest of Wainwright, approximately 125 nm southwest of Pt. Hope, and approximately 130 nm west of St. Lawrence Island. ARS, characterized by slower speeds and higher turning angles, is often synonymous with foraging behavior (Kareiva and Odell, 1987; Mayo and Marx, 1990; Kennedy et al., 2014), particularly in a well-known feeding ground similar to the region studied here. The dive-depth profile collected from whale 87636 (Figure 114) showed strong correlation between dive-depths at or near the charted bottom depth and ARS, further strengthening our assumption that ARS aligns with foraging in this study.

Interestingly, most gray whales tagged in this study showed remarkably small home ranges and CUA areas. For example, whale 112713's predicted HR was only 420 km^2 for the entire 48 day telemetry period, or roughly 8.8 km^2 per day. One animal tagged in 2013 (PTT ID 84484) was first photographed on 24 August and was sighted and tagged 15 days later on 7 September, just 4.5 nm away from the first sighting. This animal remained within a 2500 km^2 home range before heading south underscoring the importance of this area as a critical summertime feeding habitat.

In contrast to the small home range areas used by gray whales, humpbacks are known to travel over 100 km per day in their Bering Sea (Kennedy et al., 2014) and the Antarctic (Zerbini et al., 2006; Dalla Rosa et al., 2008) feeding grounds. Gray whales tagged off Chukotka (Russia) in 2006 also used a very small home range, although it was larger than the animals tagged in this study (roughly 84.5 to 295 km^2 per day for a 95% kernel home range in 2006) (Heide-Jorgensen et al., 2012).

Studies have shown that prey density, rather than taxonomic composition, is a better predictor for gray whale aggregations (Darling et al., 1998; Moore et al., 2003). The extremely small HR used by eastern North Pacific gray whales is almost certainly a response to concentrated, yet spatially limited, benthic biomass between Pt. Hope and St. Lawrence Island. Telemetry results from this study underscore previous research showing that the northern Bering and Chukchi Seas are critical foraging habitat for eastern North Pacific gray whales (Moore et al., 2000; Brower et al., 2017; Clarke et al., 2016). In addition, these results highlight the remarkably small home-ranges, spanning weeks and months that some individual gray whales occupy. This may suggest that high concentrations of prey are stable for long periods of time, even though they are spatially restricted.

4. *Conclusions*

Satellite telemetry is a powerful tool for describing fine-scale cetacean behavior and habitat use, particularly in remote, inaccessible, or under-studied areas. Combining telemetry results with data from long-term studies of the target species and with temporally relevant biological and physical oceanographic measurements would greatly increase our knowledge of fine-scale animal behavior in a changing Arctic.

5. *Recommendations*

Conducting satellite telemetry operations in Arctic waters is a challenging, but not impossible, endeavor. In addition to the difficulties associated with tagging large whales in general, gray whales in the Arctic are highly sensitive to boat presence and can be aggressive in some situations. It is our strong opinion that only the most highly qualified boat drivers, crew, and tagging specialists should attempt to deploy large whale satellite tags in this region. Inclement weather, low concentrations of whales, highly evasive and/or unapproachable animals, and international border restrictions all factor into the amount of time needed to successfully deploy a satellite tag on a large whale in the Chukchi Sea. Dedicated operations with sufficient time around large groups of whales is essential to ensure successful telemetry projects in the Arctic.

VIII. BIOPHYSICAL PATTERNS AND TRENDS (OBJECTIVES 3, 4)

A. *Moored Observations (Moorings: KZ1, C12/PH1, CL1, C1/IC1, C2/IC2, C3/IC3, C4/WT1, C5/PB1, BF1, BF2, BF3)*

1. *Methods*

Moorings (moorings: KZ1, C12/PH1, CL1, C1/IC1, C2/IC2, C3/IC3, C4/WT1, C5/PB1, BF1, BF2, BF3)

Each year, year-long biophysical moorings were deployed at each of four sites (C1, C2, C4, C5) (Figure 1) and one mooring (C9) was deployed in 2014 and 2015 on the slope. To avoid ice keels, the top of each shelf mooring was only ~10 m off the bottom (or ca. 30 m from the ocean surface). Mooring designs were identical for each year (Figure 116; Table 41) and the instruments that successfully collected data are listed in Table 44. Data were collected at least hourly, and all instruments were calibrated prior to deployment. The physical and chemical data were processed according to manufacturer's 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. CTD and water bottle casts 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, photosynthetic active radiation (PAR), dissolved oxygen, chlorophyll fluorescence, and nitrate).

Nitrate sensors

Nitrate time series are from optical sensors purchased from Satlantic (ISUS or 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, 2014-C5, 2013-C6) 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 through the water column, and deliver temperature and pressure sensor data, and range and amplitude data for conversion to ice draft. Five instruments were deployed each year (Figure 116). 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. National Center for Environmental Prediction (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 Coordinated Universal Time (UTC) each day. Averaging and statistics were done within the MATLAB environment. These daily ice draft data include ice cover and exclude waves and ice-free data segments.

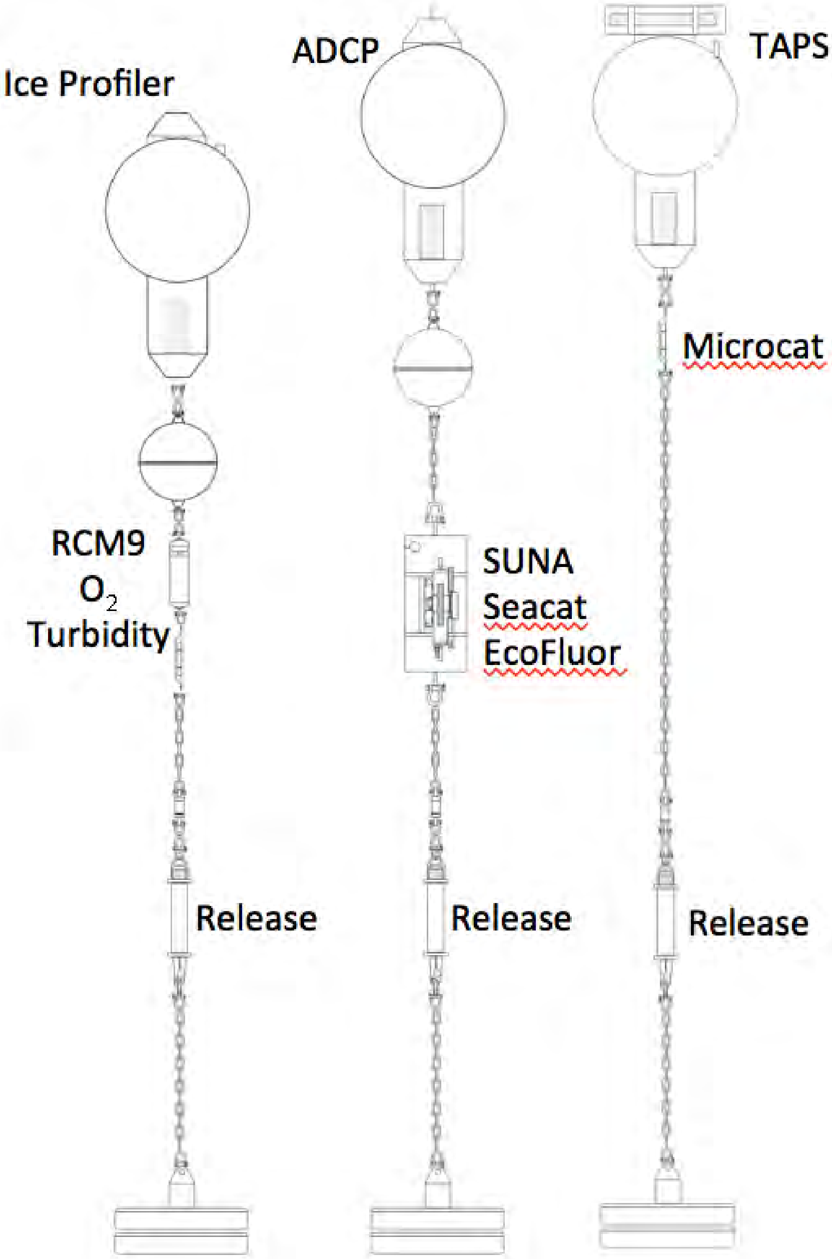


Figure 116. Schematic of the three different moorings types deployed. All moorings were less than 10 m tall.

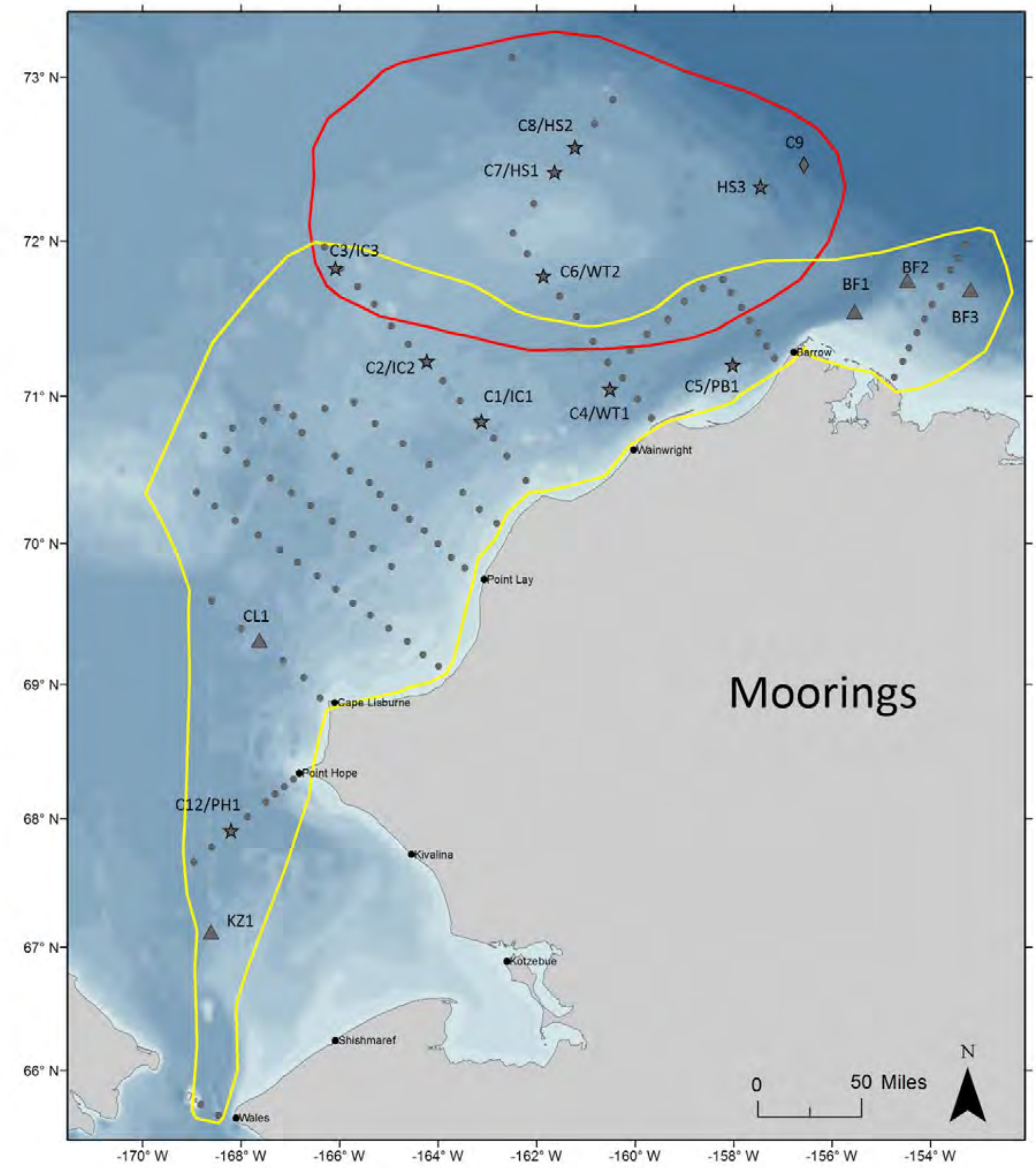


Figure 117. **Bathymetry in the study area, the eleven mooring sites, and the twelve hydrographic transects occupied.**

Table 41. The instruments deployed at each site, each year. X means at least some data were collected, F means that the instrument failed completely and no data were collected. Blanks indicate that no instrument was deployed. Two types of nutrient sensors were deployed – the ISUS and the SUNA. The mooring at C8 was not deployed in 2013 because of technical difficulties.

Site	Year	Temp	Sal	Chl	O_2	Turb	PAR	Nut	Ice	RCM	ADCP
C1	2013	X	X	X	X	X	X	ISUS	X	X	X
	2014	X	X	F	F		X	ISUS	X	X	X
C2	2013	X	X	X	X		X	ISUS	X	X	X
	2014	X	X	X	X		X	ISUS	X	X	X
C3	No biophysical mooring was funded as part of CHAOZ-X and ARCWEST										
C4	2013	X	X	X	F	F	X		X	F	F
	2014	X	X	X			X	SUNA	X	X	X
C5	2013	X	X	X	X	X	F	ISUS	X	X	X
	2014	X	X	X	F	F	X			X	X
C12	No biophysical mooring was funded, however, a SeaCat was deployed on the marine mammal mooring in 2014										

Total transport at Icy Cape

Total transport past Icy Cape was calculated using the current meter data from available instruments from the three moorings (C1, C2, C3) at Icy Cape. The available instruments varied from year-to-year and are listed in Table 42. Average transport over the five years was ~0.4 Sverdrup (1 Sverdrup = 10^6 m^3 s^{-1}) or ~40% of the northward transport measured through Bering Strait (Woodgate et al., 2012). A significant ($P < 0.01$) correlation exists between the local daily winds and transport, with southwestward winds associated with southwestward transport and northwestward winds associated with northwestward transport.

There is strong seasonal variability in the monthly mean transport at Icy Cape, with the maximum transport occurring in the summer months (June – August) (Figure 118). In contrast, the monthly mean transports during winter and fall were more variable and on average are weaker. Comparing the average monthly transports at Icy Cape with those through Bering Strait shows a similarity in the temporal pattern, with maximum transport occurring in the summer months at both sites. Each mooring deployment was for approximately one year. The annual transports varied among years, with the greatest transport occurring in 2014-2015 deployment and transport during 2013-2014 only 60% of what occurred in 2014-2015.

Table 42. Data used each deployment cycle to calculate transport at Icy Cape. The mean transport for each deployment ± the standard error of the mean (SE = [Standard deviation]/$N^{.5}$, where N is the number of independent estimates). The bottom row is the average over all five years. The 2010-2012 were part of CHAOZ. Wind velocity was obtained from the North American Regional Reanalysis (NARR) and interpolated to C2. These winds are an extension to the NCEP 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). See Mesinger et al., 2006 for details.

Start & End Time	Instruments	Mean ± SE (Sv)	Min/Max (Sv)	Wind Cor. R^2
9/3/2010- 8/20/2011	ADCP – C1, C2, C3	0.45±0.08	-0.5481928	0.22
8/29/2011- 8/19/2012	ADCP – C2, C3 RCM9 – C1	0.24±0.08	-1.2343324	0.28
8/26/2012- 8/24/2013	RCM9 – C2	0.46±0.08	-1.1451613	0.21
8/30/2013- 9/22/2014	ADCP – C1, C2	0.33±0.07	-1.7760736	0.25
9/28/2014- 9/10/2015	ADCP – C1 RCM9 – C2	0.55±0.17	-1.007984	0.39
Average		0.39±0.03	-1.1556886	0.25

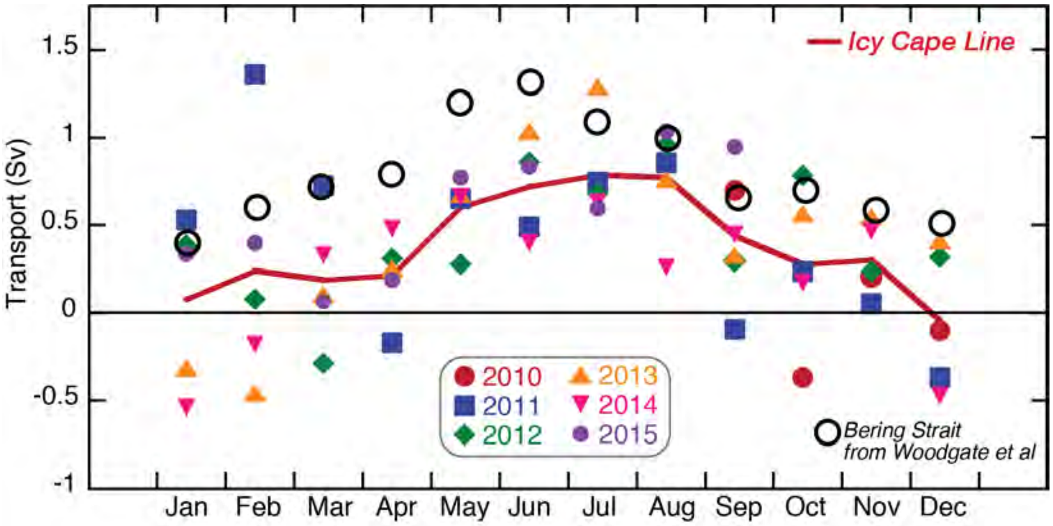


Figure 118. Monthly mean total transport calculated at the Icy Cape from mooring data (colored symbols) for each month. The red line is the average transport at Icy Cape averaged over the five deployment cycles. The open circles is the monthly average transport through Bering Strait (from Woodgate et al., 2012).

Transport calculations

Estimates of total transport were obtained following application of the approach previously applied in the Gulf of Alaska (Schumacher et al., 1989; Stabeno et al., 1995, 2016). In this approach the current data were low-pass filtered and the component of velocity perpendicular to the mooring line was calculated. This normal component of velocity at each current meter or ADCP bin was multiplied by the cross-sectional areas defined by the midpoints located halfway between two adjoining moorings or total distance between the mooring and the shore, as appropriate. The outer edge of the mooring lines were defined as the same half distance as between the outer mooring and its nearest more coastal neighbor. The vertical boundaries were the surface, the bottom or the halfway point between instruments/bins, as appropriate. The individual mooring transport time series were summed. Unfortunately, only in 2010 – 2011 (as part of CHAOZ) were ADCP data collected at each mooring site (C1, C2, and C3) at Icy Cape. Available data for calculating total transport are listed in Table 41.

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 ADCPs at each mooring site (Table 41). 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 + 10log10((Tx+273.16)R2) – LDBM – PDBW + 2αR + 10log10(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).

Zooplankton volume backscatter estimates derived from multi-frequency measurements

A 6-frequency (50, 78, 115, 200, 420, 735 kHz) Tracor Acoustic Profiling System - Next Generation (TAPS6-NG) was used to estimate the size and abundance of zooplankton for each survey year. The TAPS6-NG is comprised of a PVC block containing the 6 individual transducers (Transonics, Inc.) mounted on the top of an ADCP syntactic foam float (Deep Water Buoyancy, Inc; Figure 119). The controller electronics case is clamped inside the float where the ADCP instrument would normally reside, and several pressure cases containing lithium ion batteries are mounted below the float in a custom-designed, stainless steel frame. The instrument collects measurements between the range of 1-35 m, with data bin centers every 0.37 m. Sample volumes for each frequency were from ca. 0.5-50 m^3 at a range of 2-30 m, respectively, from the transducer faces. Raw data from each frequency of the TAPS6-NG were recorded during these intervals as mean integrated echo intensities (W/m^2) computed over 24 individual pings per ensemble. System electronics optimization was obtained by tuning each transducer in the freshwater dive tank (30’ x 15’) at the NOAA Western Regional Center. System calibration consisted of determining the source and receiver levels for each frequency before and after deployments, using a standard calibrated transducer. Calibration was accomplished at the Hydroacoustic Technology Inc. calibration barge in Seattle, Washington.

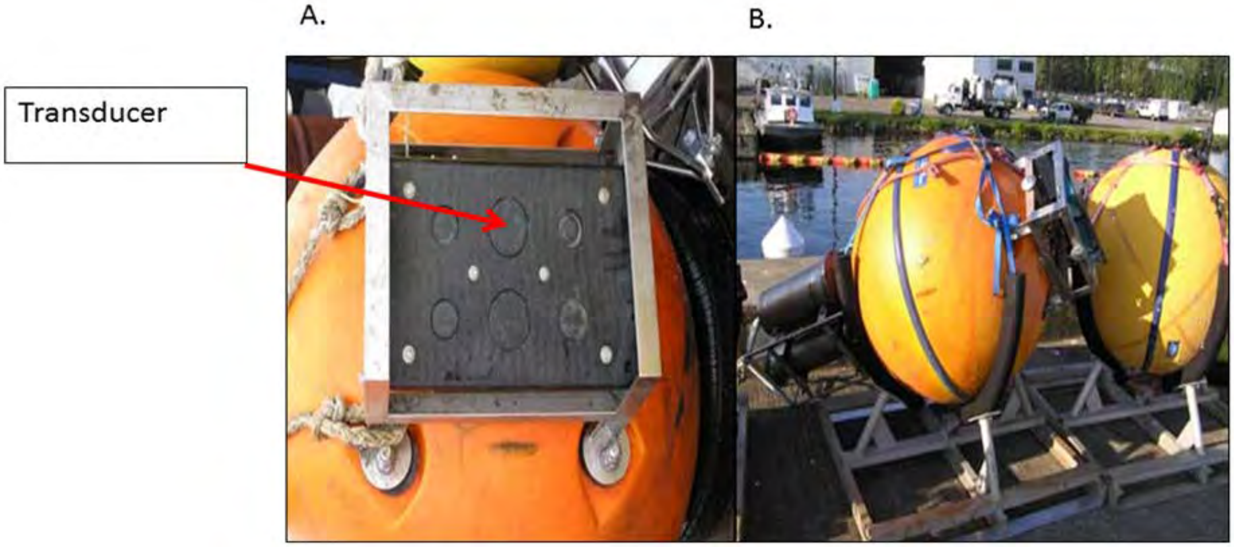


Figure 119. TAPS6-NG. A) A PVC block containing the 6 individual transducers is mounted on the top of an ADCP syntactic foam float. B) The entire assembly showing the transducer block above the float and the battery cases below the float.

The TAPS6-NG acoustic instrument was programmed to sample every 30 minutes April-September, and at 60 min intervals October-March. This mooring was placed nearby two other moorings, one of which contained a 600 kHz ADCP, ISUS nitrate analyzer, chlorophyll fluorometer, CTD, and PAR light meter (Table 41). The other mooring contained a mechanical current meter and an ice profiler (Figure 116).

Matlab™ (R2012b) was used to process the acoustic data. Background and instrument noise was defined as the weekly minimum intensities for each frequency. Those values were then subtracted from each measurement for that week. The intensities were then converted to volume-scattering strength (Sv, dB re 1 m^{-1}) followed by correction with calibration constants. Signal-to-noise ratios of <10 dB were used as a threshold to reject Sv values that were not used in further analyses.

Inverse methods were used to estimate the abundance of scatterers as a function of size (Holliday, 1977; Greenlaw, 1979; Greenlaw and Johnson, 1983). Abundances were estimated for near-bottom (10 m from the transducer head) and near-surface (25 m from the transducer head). Near-surface data were only analyzed until the end of September due the possibility of ice affecting the backscatter.

The truncated fluid sphere (TFS) and distorted-wave Born approximation (DWBA) scattering models were used in the inverse calculation to estimate scattering from small, spherical organisms (e.g., copepods, eggs, nauplii) and elongate organisms (e.g., euphausiids, mysids), respectively (Holliday, 1992; Holliday et al., 2003). The assumed values used in the models, included the animal orientation, sound speed (H) and density contrast (G), Levenberg-Marquardt factor, number of size classes, and size range, are provided in Table 43. Euclidian norms were computed as a goodness-of-fit statistic between measured Sv and the inverse model fit to verify that the inversion could adequately explain the measured Sv values.

Table 43. Material properties and other parameters used in the scattering models and inverse solutions.

Parameter	TFS	DWBA
G	1.00	1.018
H	1.003	1.006
Levenberg-Marquardt	1.0x10-3	1.0x10-3
Orientation	random	broadside/horizontal
Size classes	48	48
Size Range	1.0-11.25 mm	10.0-24.0 mm

2. Results

*Time series of physical and chemical data from biophysical moorings (*Figure 121-128)

Currents

Except for the ADCPs (which measure currents throughout the water column) and the ice profilers (which measure the depth of the ice keels), all biophysical measurements are in the bottom 10 m of the water column. To accommodate all of the biophysical sensors at each site and keep the tops of the moorings below the ice required as many as three moorings to be deployed at a site: an ADCP mooring, an ice profiler mooring, and a TAPS mooring (Figure 116). Sites C1, C4 and C5 were all in the freshwater core of the ACC. While C2 was ~70 km farther offshore from C1 and outside of the freshwater core, it was, however, still in the high speed part of the ACC.

Time series of near bottom variables (temperature, salinity, oxygen, fluorescence, turbidity, and PAR) for moorings C1, C2, C4 and C5 are shown in Figures 121-128. The mean bottom currents were largely eastward with the strongest flow (7.3±0.9 [mean ± standard error of the mean] cm s^{-1}; 4-year average) found at C1; the currents decreased with distance from the coast to 5.3±0.5 cm s^{-1} (5-year average) at C2. Seasonally, the strongest mean flow was in the spring/summer, but the strongest daily averaged currents were found in the fall and winter when the system was largely ice covered (Figures 121-122). Horizontally the low-pass filtered currents at C1 and C2 were in phase and well correlated ($p<<0.001$).

The strongest flows occurred at the three mooring sites (C1, C4, and C5) nearest the coast, with strongest (12.1± cm s^{-1}; 2-year average) mean flow occurring at C5, slightly weaker (9.1±3.0 cm s^{-1}; 1-year average) flow at C4 and the weakest (7.3±0.9 cm s^{-1}; 4-year average) at C1 (Figure 120). The greatest daily average velocities occur during the winter (Figures 121-128), with the strongest daily average flow at C5 (~100 cm s^{-1} in January), slightly weaker velocity at C4 (~80 cm s^{-1} in December) and weaker still at C1 (~60 cm s^{-1} in December). In addition, strong reversals of flow occur at each mooring site, primarily in fall and winter. Ladd et al. (2016) observed that the propagation of the identifiable AtlW events observed at C1, C4, and C5 indicated that C5 led C4 by ~1 day and C1 by ~4 days, suggesting that the source of AtlW was upwelling via Barrow Canyon.

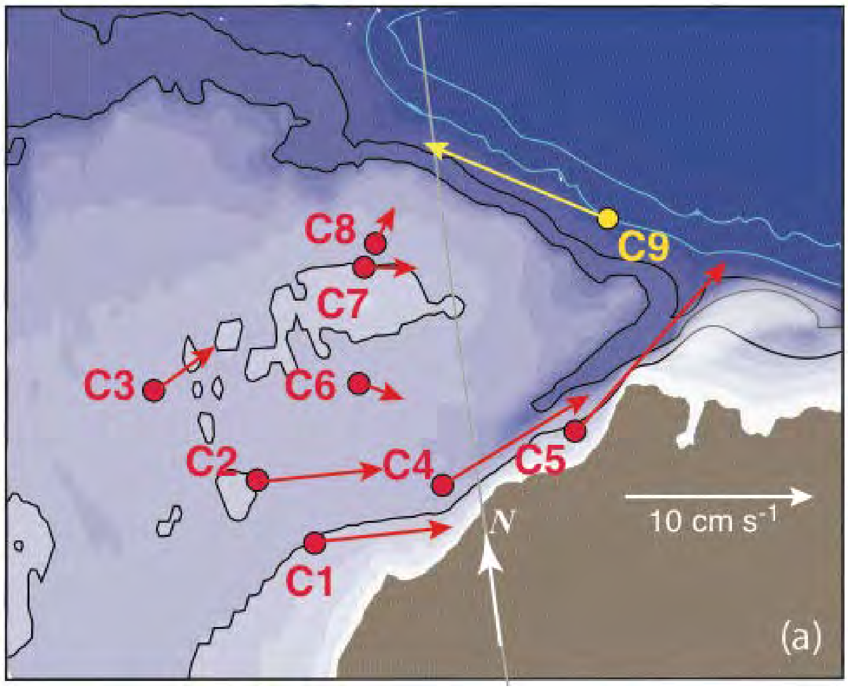


Figure 120. Relative annual mean bottom velocity at each mooring site deployed for all three BOEM-funded projects (C1-C8) and at 48 m at C9 (yellow indicates the slope mooring).

Temperature, salinity, dissolved oxygen, PAR, chlorophyll fluorescence

At all the mooring sites (Figures 121-128) the warmest temperatures occurred in the late summer and fall, when storms mix the water column introducing heat to the bottom. Salinity is much more complex, with high salinities occurring throughout the year. Sometimes these increases in salinity are associated with warmer temperatures and southwestward flow (especially for C1, C4, and C5). This often was the result of intrusion of AtlW. In contrast, at other times the higher salinities were associated with slight cooling, which is likely associated with brine rejection. Other high salinity events did not appear to be related to either of these mechanisms.

Typically, increased fluorescence occurred in the fall (phytoplankton bloom) and in the late spring and early summer with the retreat of ice (likely the flux of ice algae to the seafloor). Increases in PAR occurred after the spring equinox, with the highest values occurring after the retreat of sea ice. Dissolved oxygen was typically below 100% saturation, except in the summer when periods of high fluorescence were observed.

Sea ice typically arrives in late October or early November. As the year progresses the daily median ice thickness increases. Ice cover often begins to decline in May and by June or July the sea ice is gone.

Temperature and salinity variability during cold period (December-June)

A careful examination of the temperature during the period when the region is largely ice covered, shows small-scale variability in the record (Figure 129). This is most evident at near coastal moorings, C1, C4, and C5. Here we examine the record at C1, where four years of data exist (including the time series collected as part of CHAOZ). When the temperature scale is expanded, the variability in temperature becomes evident. An event of apparent brine rejection (colder more saline water) is evident in late January and early February in 2015 (blue). Ladd et al. (2016) identified episodes of relatively warm more saline water as AtlW. Two such periods of AtlW are evident here: the increase in temperature and salinity in early January 2011 and again in January 2014. Ladd et al. (2016) noted that both of these periods were associated with southwestward flow based on current meter data. The greatest increase in salinity, however, occurred in late January through late February. This high salinity was associated with colder temperatures, an indicator of brine rejection.

The variability of the temperature and salinity, even during the period of ice cover when temperatures are expected to be near the freezing point, is indicative of considerable spatial variability in this region. In addition, there is inter-annual variability. For instance, Ladd et al. (2016) noted that the number of times AtlW was detected at the moorings varied seasonally (usually occurring between October and May) and among years, with 2010–2011 having more events (3) than the other years.

Time series of nutrients and salinity from biophysical moorings (Figures 130-133)

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, excretion and decomposition, nitrification) processes that vary in space and time. Many of the time series show an increase in nitrate during the ice-covered months. All of the time series showed nitrate drawdown and periods in the summer when nitrate was undetectable (Figures 130-133). During the spring ice retreat, large amounts of ice-associated algae sink to the bottom. When bottom PAR is sufficient to support net photosynthesis, in-situ growth near the bottom can occur and result in the drawdown of nitrate and increase in oxygen. Increases in percent oxygen at the mooring sites were often associated with increased fluorescence (e.g., Figures 130-133). 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 during late summer/early fall storms, mixes nitrate-depleted (and fresher) water to the bottom. A slower, and temperature-dependent mechanism is the generation of nitrate from ammonia by bacteria. So the overall timing and extent of nutrient drawdown in bottom waters is related to the timing of ice retreat, the amount of light reaching the bottom, the bottom temperature, and storm events.

In the time series, nitrate drawdown occurred earlier (June-July) at moorings C1, and C5, and later (July-August) at mooring C4. At mooring C2 there were two periods of drawdown in 2014, one in late June and another a month later in late July/early August. Nitrate replenishment usually commences with the arrival of ice and a thoroughly mixed water column, and often periods, or pulses, of higher nitrate are associated with increases in salinity. These are related to advection of different water masses past the mooring, or salt rejection during ice formation. For example, in 2014 at C1, C2 and C4, pulses of nitrate and salinity were related to ice-formation during a polynya event off Icy Cape (cold and salty water), and also the arrival of AtlW upwelling in Barrow Canyon (warmer, salty water). The patterns of replenishment varied among the mooring sites.

Time series of ice keel depths (Figures 134-136)

A comparison between the 15-day running average of the median keel depth at the different mooring sites is shown in Figure 134 for 2013/14 (a) and 2014/15 (b). The steady deepening of ice keels in November 2014 - January 2015 was evident (Figure 135). Note that the time series for 2013-4 begins later and misses this period. Both time series (Figure 135a, b), showed considerable variability in keel depth over the winter and spring months, especially in May.

Maximum depths of the ice keels were greater in 2015 than they were in 2014 (Figure 134-136). At both C1 and C4, in 2015, there were keels that reached a depth of 30 m in May and April, respectively (Figure 136). The data at C6 (collected as part of CHAOZ-X) are shown for comparison. The greatest variability occurred at C5 (Figure 135). In contrast, C6, especially in 2014, had the least variability. Keel depth of > 20 m were common every year at some sites. Periods when the ice draft was < 1 m were common at C1, C4 and C5 – the coastal moorings where polynyas often occurred. Farther from the coast, C2 and C6, rarely showed periods of thin ice in the winter.

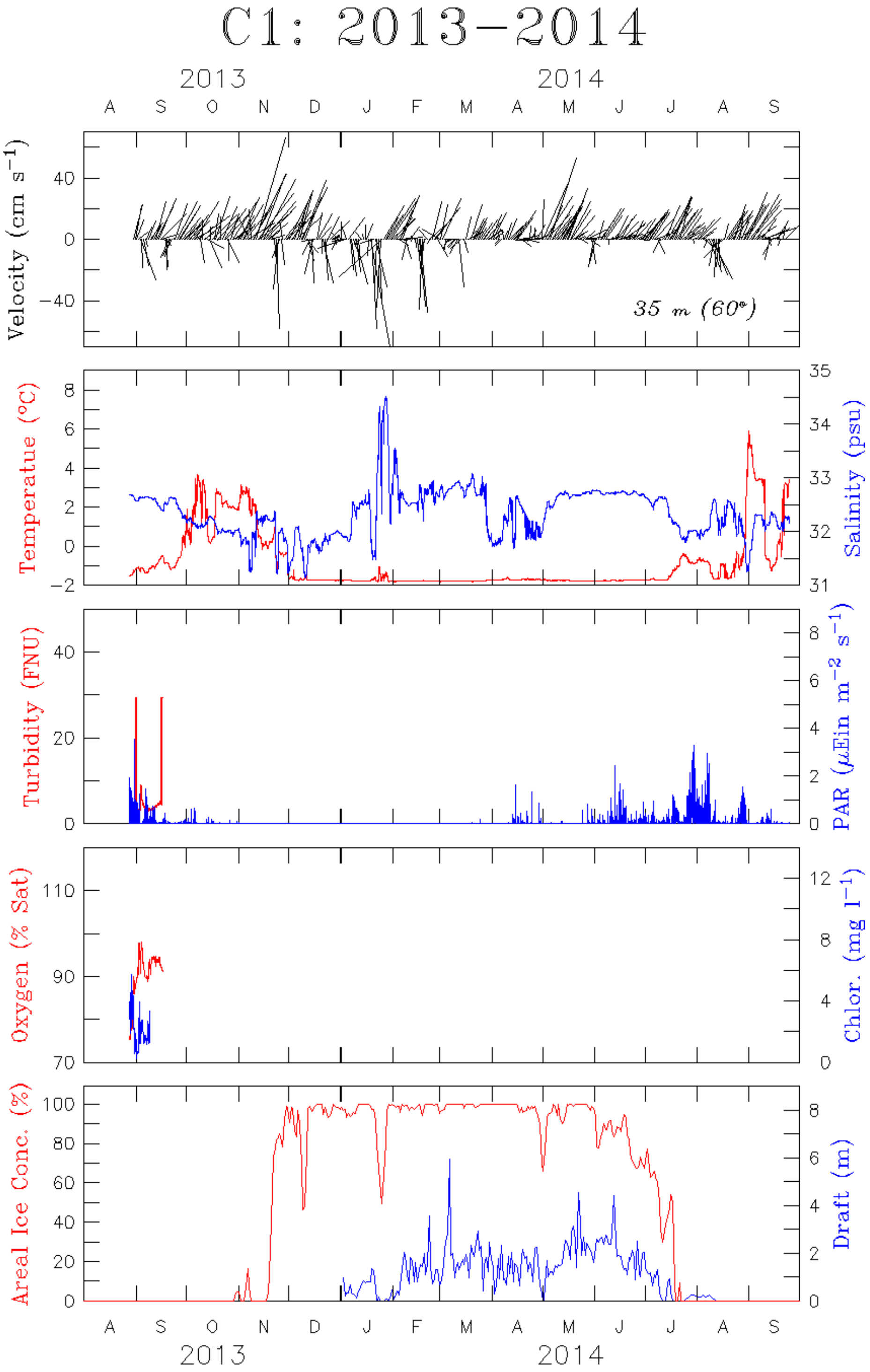


Figure 121. Times series from the inshore mooring (C1) on the Icy Cape line for 2013-2014. From top panel to bottom panel: near bottom currents (low pass filtered and rotated 60°); near bottom temperature and salinity; turbidity and PAR; dissolved oxygen and chlorophyll fluorescence; and daily median depth of ice keels and percent areal ice cover in 25 km x 25 km box around the mooring site.

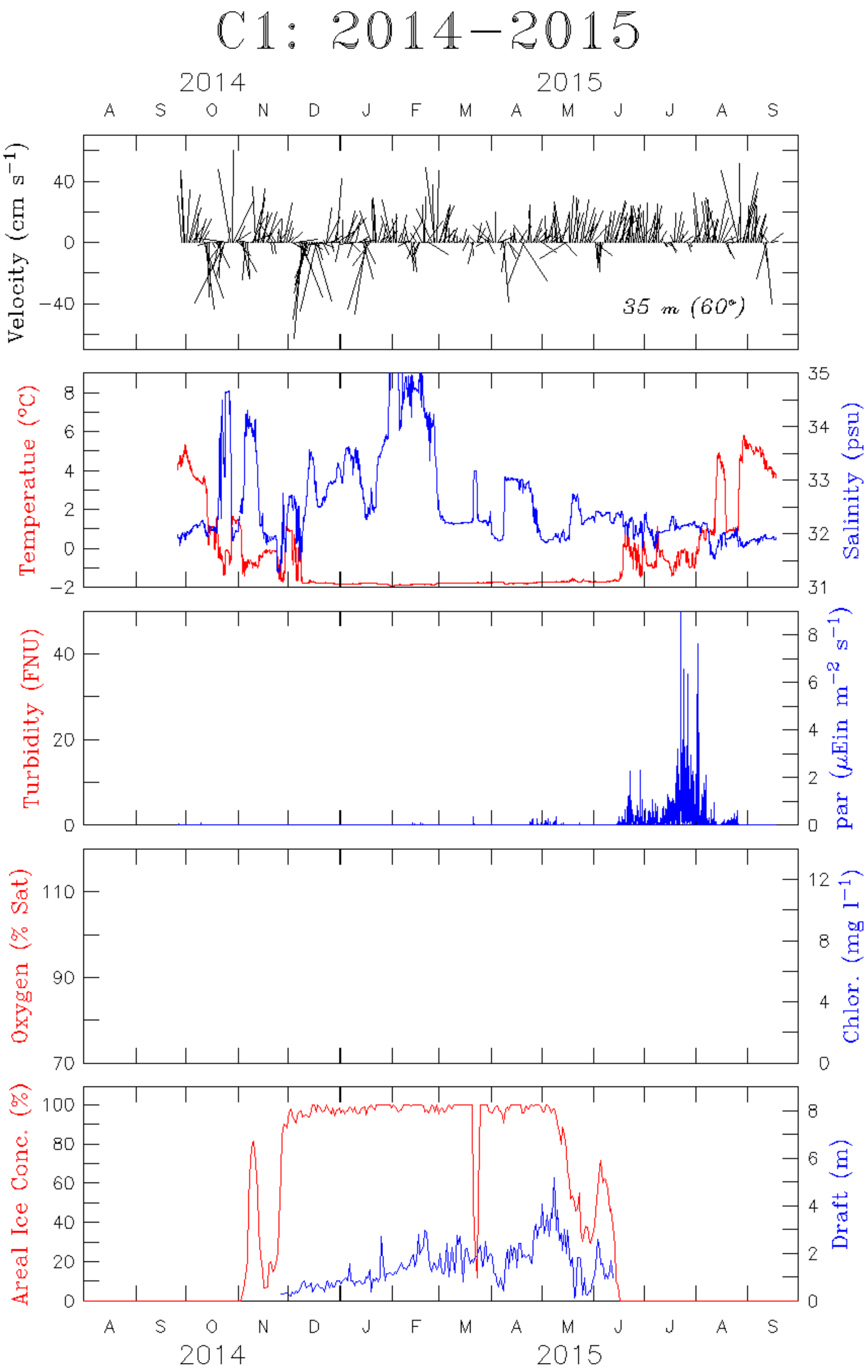


Figure 122. Times series from the inshore mooring (C1) on the Icy Cape line for 2014-2015. From top panel to bottom panel: near bottom currents (low pass filtered and rotated 60°); near bottom temperature and salinity; turbidity and PAR; dissolved oxygen and chlorophyll fluorescence; and daily median depth of ice keels and percent areal ice cover in 25 km x 25 km box around the mooring site.

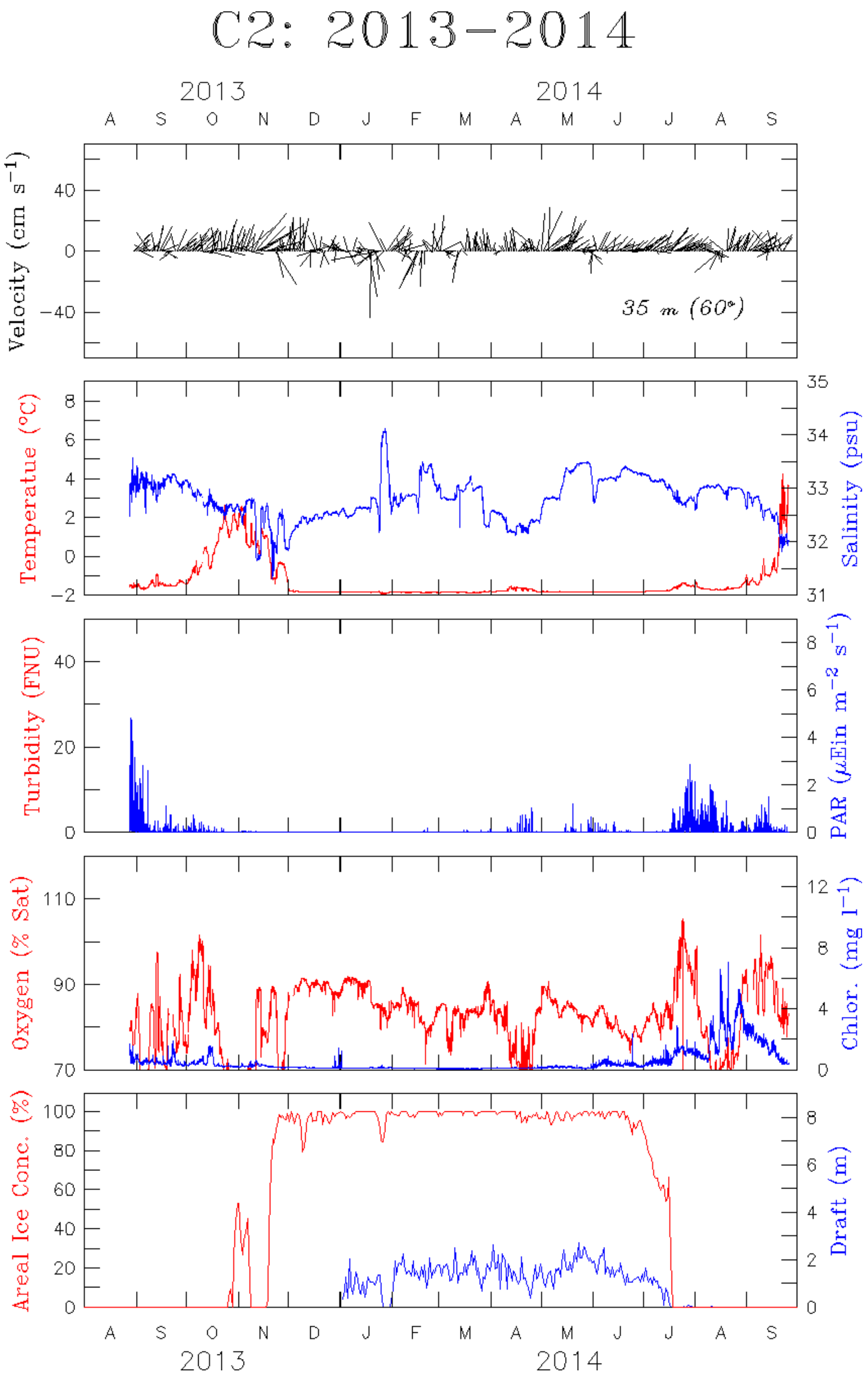


Figure 123. Times series from the midshore mooring (C2) on the Icy Cape line for 2013-2014. From top panel to bottom panel: near bottom currents (low pass filtered and rotated 60°); near bottom temperature and salinity; turbidity and PAR; dissolved oxygen and chlorophyll fluorescence; and daily median depth of ice keels and percent areal ice cover in 25 km x 25 km box around the mooring site.

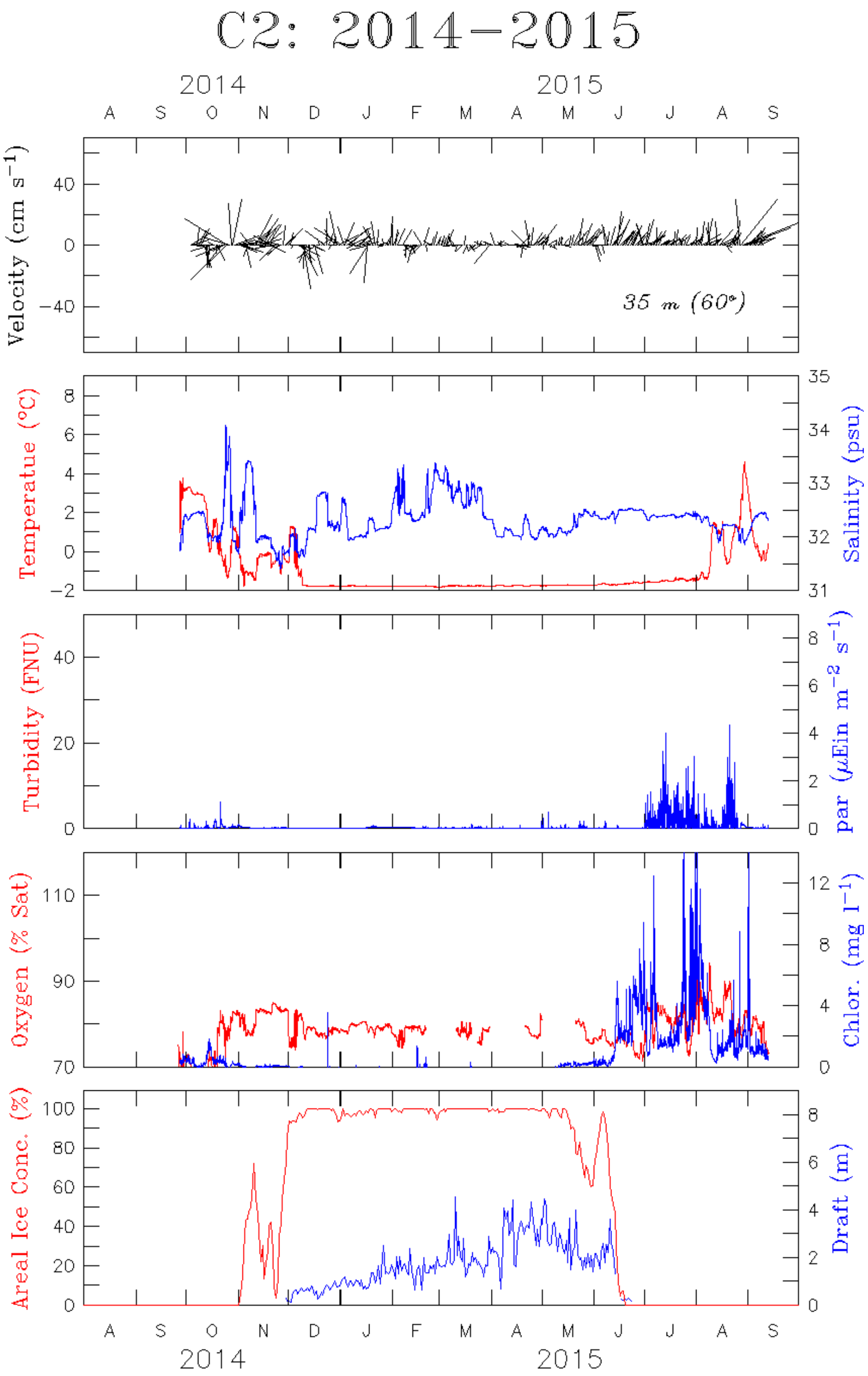


Figure 124. Times series from the midshore mooring (C2) on the Icy Cape line for 2014-2015. From top panel to bottom panel: near bottom currents (low pass filtered and rotated 60°); near bottom temperature and salinity; turbidity and PAR; dissolved oxygen and chlorophyll fluorescence; and daily median depth of ice keels and percent areal ice cover in 25 km x 25 km box around the mooring site.

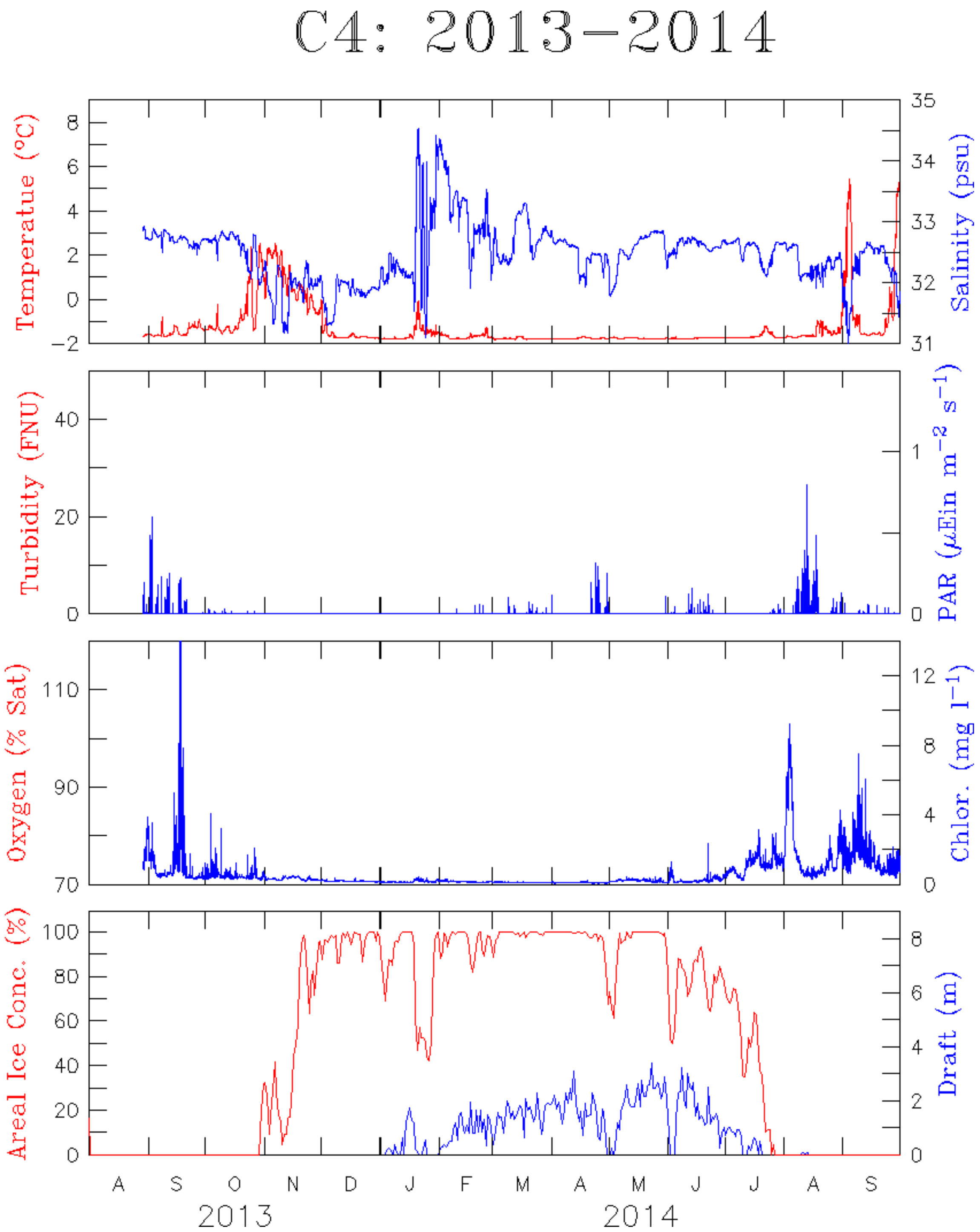


Figure 125. Times series from the Wainwright mooring (C4) for 2013-2014. From top panel to bottom panel: near bottom currents (low pass filtered and rotated 60°); near bottom temperature and salinity; turbidity and PAR; dissolved oxygen and chlorophyll fluorescence; and daily median depth of ice keels and percent areal ice cover in 25 km x 25 km box around the mooring site.

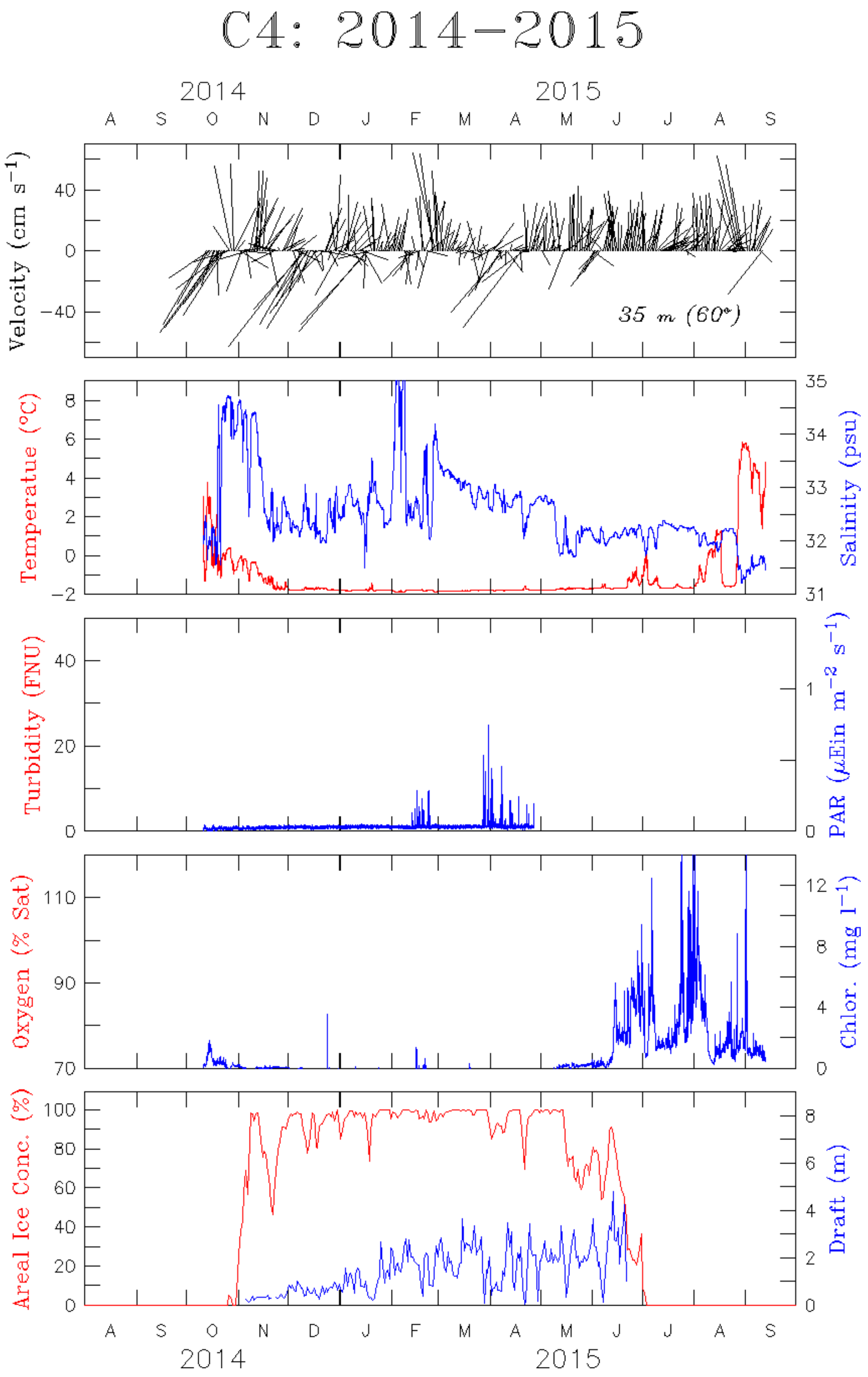


Figure 126. Times series from the Wainwright mooring (C4) for 2014-2015. From top panel to bottom panel: near bottom currents (low pass filtered and rotated 60°); near bottom temperature and salinity; turbidity and PAR; dissolved oxygen and chlorophyll fluorescence; and daily median depth of ice keels and percent areal ice cover in 25 km x 25 km box around the mooring site.

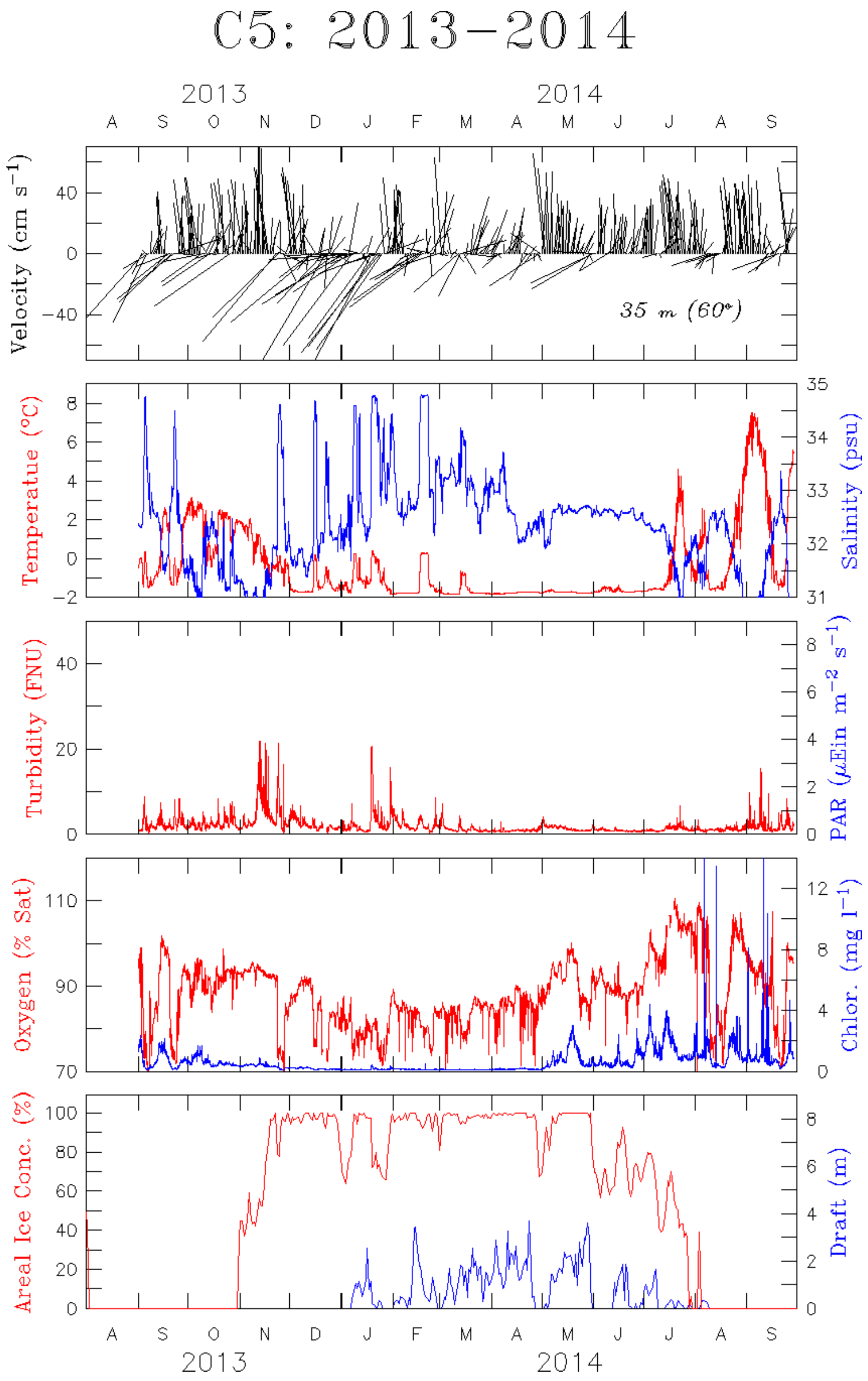


Figure 127. Times series from the Peard Bay mooring (C5) for 2013-2014. From top panel to bottom panel: near bottom currents (low pass filtered and rotated 60°); near bottom temperature and salinity; turbidity and PAR; dissolved oxygen and chlorophyll fluorescence; and daily median depth of ice keels and percent areal ice cover in 25 km x 25 km box around the mooring site.

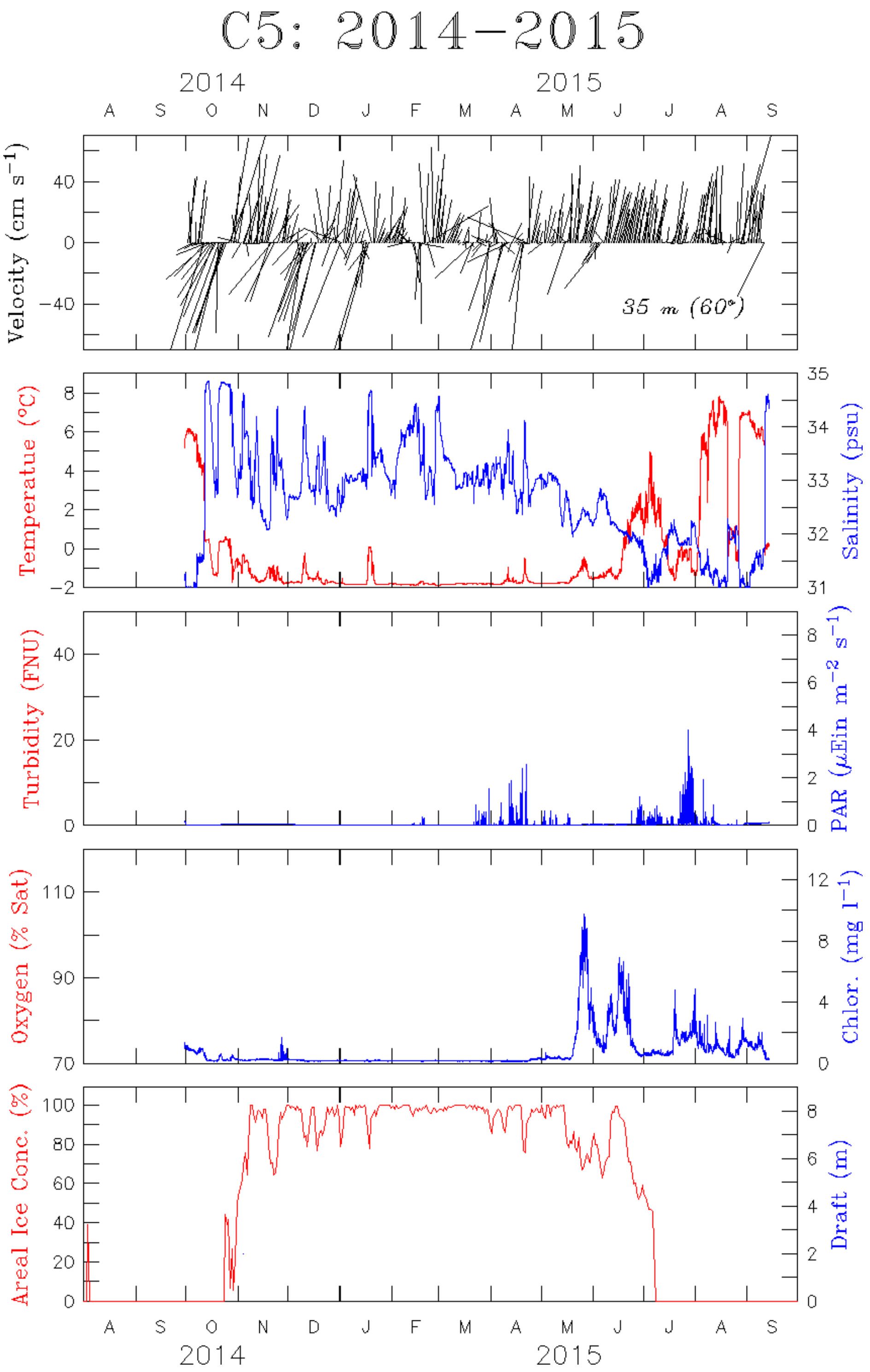


Figure 128. Times series from the Peard Bay mooring (C5) for 2014-2015. From top panel to bottom panel: near bottom currents (low pass filtered and rotated 60°); near bottom temperature and salinity; turbidity and PAR; dissolved oxygen and chlorophyll fluorescence; and daily median depth of ice keels and percent areal ice cover in 25 km x 25 km box around the mooring site.

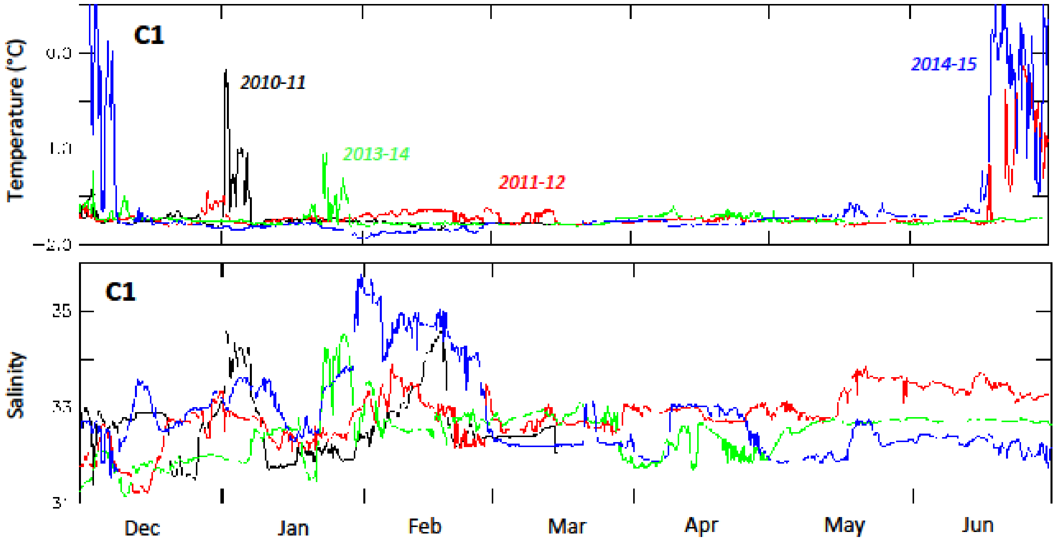


Figure 129. Time series of (top) temperature and (bottom) salinity at mooring C1 during December through June of each year.

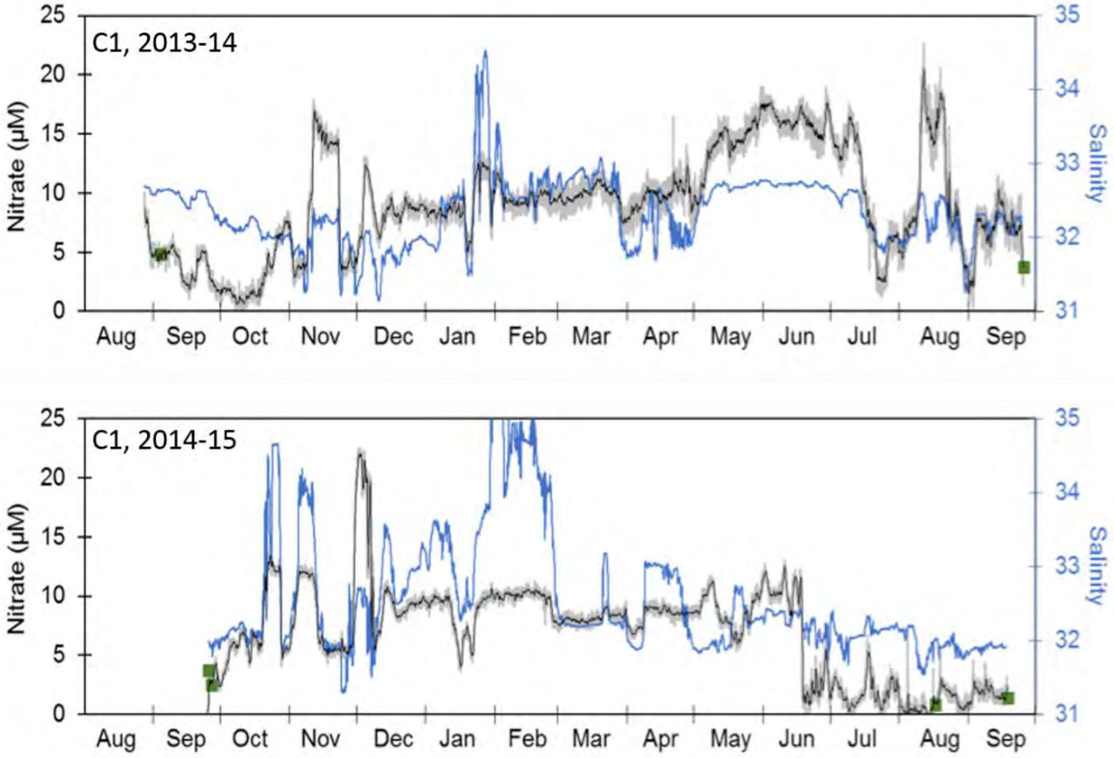


Figure 130. Time series of nitrate (black, gray) and salinity (blue) at mooring C1 from 2013-2014 (top) and 2014-2015 (bottom). Salinity data are identical to data shown in Figure 121 and Figure 122. Nitrate data include hourly data (gray) overlaid with a 12-hour running mean (black). Nitrate samples collected in the field were used to calibrate the data (green squares).

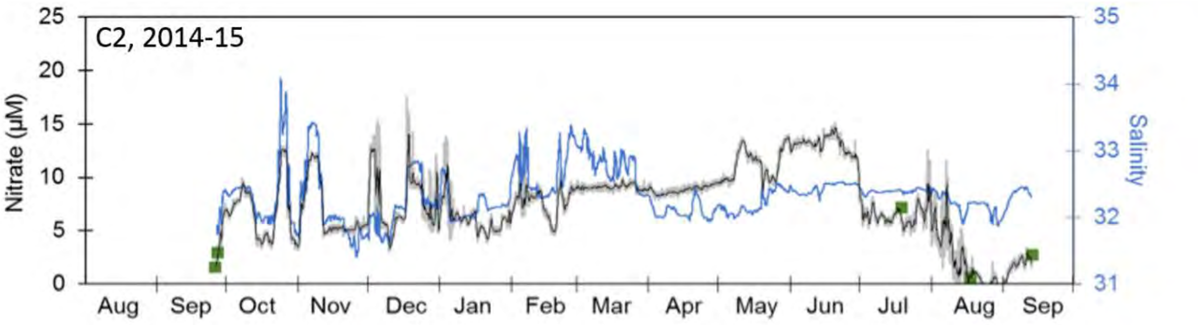


Figure 131. Time series of nitrate (black, gray) and salinity (blue) at mooring C2 from 2014-2015. Salinity data are identical to data shown in Figure 124. Nitrate data include hourly data (gray) overlaid with a 12-hour running mean (black). Nitrate samples collected in the field were used to calibrate the data (green squares).

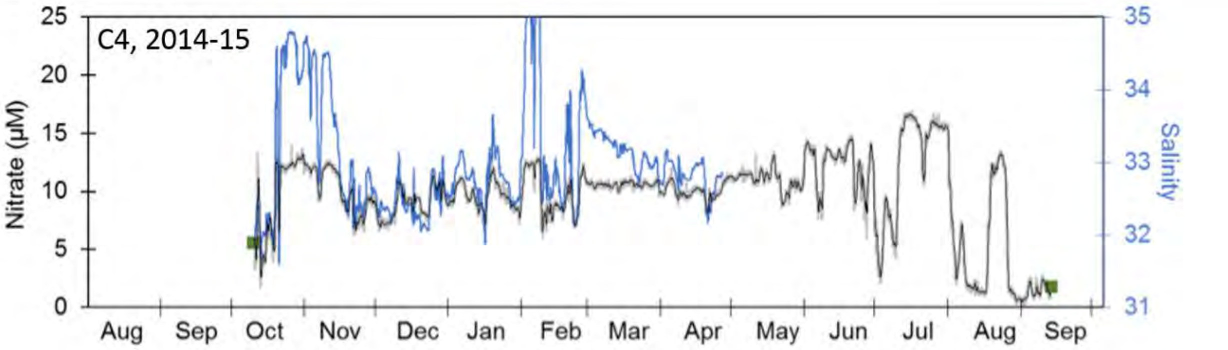


Figure 132. Time series of nitrate (black, gray) and salinity (blue) at mooring C4 from 2014-2015. Salinity data are identical to data shown in Figure 126. Nitrate data include hourly data (gray) overlaid with a 12-hour running mean (black). Nitrate samples collected in the field were used to calibrate the data (green squares).

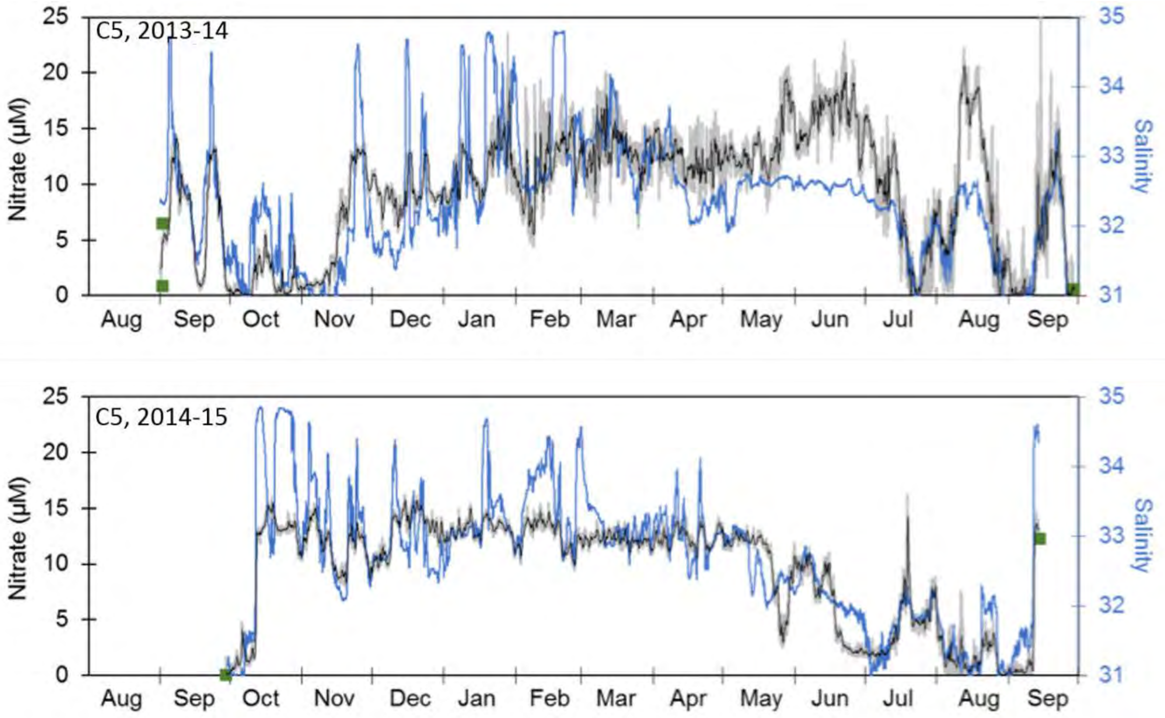


Figure 133. Time series of nitrate (black, gray) and salinity (blue) at mooring C5 from 2013-2014 (top) and 2014-2015 (bottom). Salinity data are identical to data shown in Figure 127 and Figure 128. Nitrate data include hourly data (gray) overlaid with a 12-hour running mean (black). Nitrate samples collected in the field were used to calibrate the data (green squares).

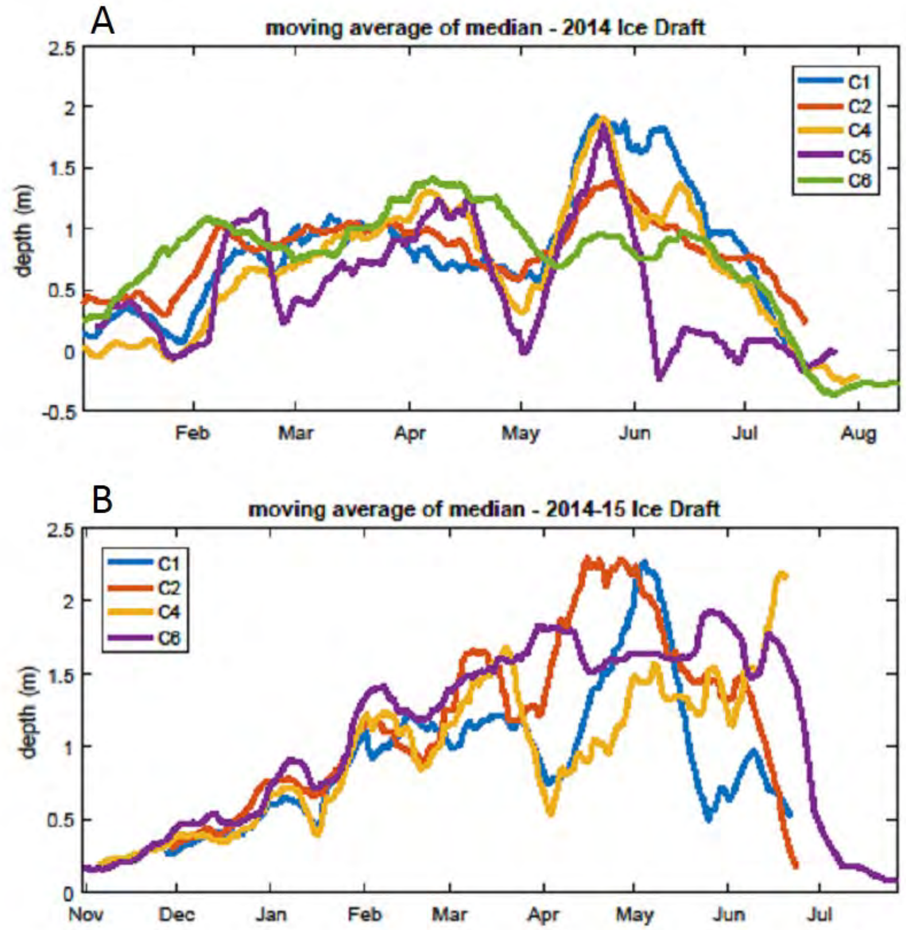


Figure 134. Time series of daily median ice keel draft in A) 2014 (from the 2013-2014 data set) at five mooring sites; and in B) 2014-2015 at four mooring sites.

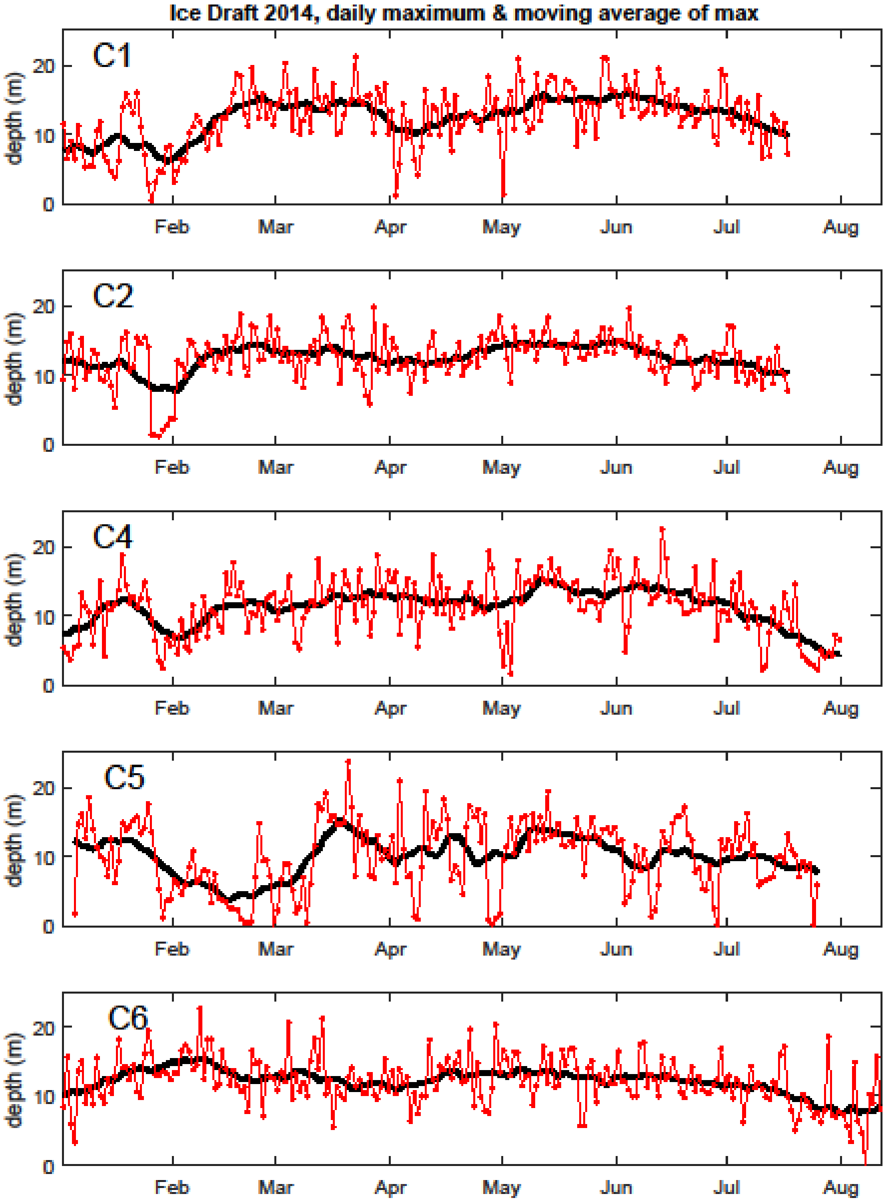


Figure 135. Time series of the daily maximum ice keel draft in 2014 (from the 2013-2014 data set) at each mooring site. The 15-day running average is shown.

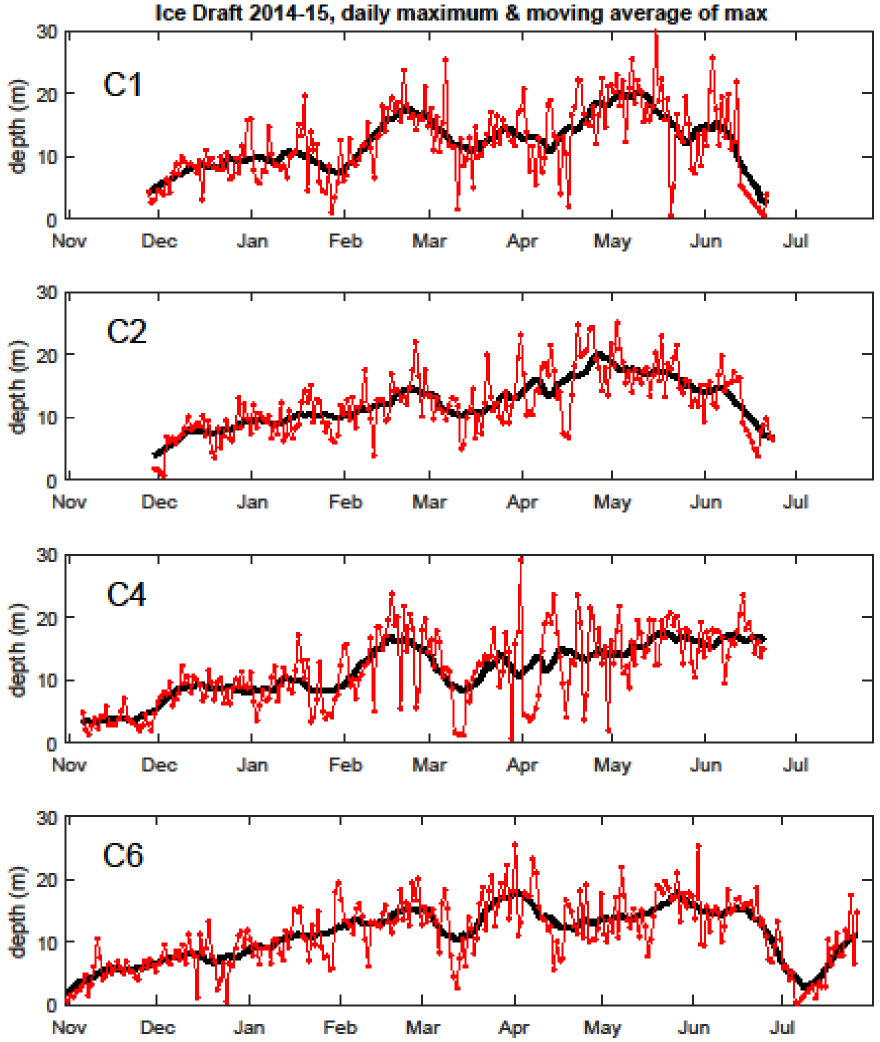


Figure 136. Time series of the daily maximum ice keel draft in 2014-2015 at each mooring site. The 15-day running average is shown.

Time series of zooplankton backscatter estimated from ADCP instruments

When we first examined the temporal patterns in ADCP-derived zooplankton volume backscattering from CHAOZ, we found evidence for 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 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 (Table 44). 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. Analyses in 2013 were the most extensive, with measurements from 6 sites.

Table 44. Locations and depths of ADCP backscatter (echo count) measurements during 2013-2015 in the ARCWEST and CHAOZ-X regions. Water mass indicates the source of water generally found in that region. ACC = Alaska Coastal Current Water; BSW = Bering Sea Water.

Mooring	Location	Depths	Project	Water Mass
2013				
C1	Icy Cape, Inshore	11, 31	ARCWEST	ACC
C2	Icy Cape, Mid shelf	11, 31	ARCWEST	ACC/BSW
C4	Wainwright, Inshore	10, 30	ARCWEST	ACC
C5	Peard Bay	10, 30	ARCWEST	ACC
C6	Wainwright, Mid shelf	11, 31	CHAOZ-X	BSW
C7	Hanna Shoal, South flank	14, 32	CHAOZ-X	BSW
2014				
C1	Icy Cape, Inshore	10, 30	ARCWEST	ACC
C5	Peard Bay	11, 31	ARCWEST	BSW
C8	Hanna Shoal, North flank	10, 30	CHAOZ-X	BSW
2015				
C1	Icy Cape, Inshore	12, 28	ARCWEST	ACC
C2	Icy Cape, Mid shelf	12, 33	ARCWEST	ACC/BSW
C4	Wainwright, Inshore	11, 31	ARCWEST	BSW
C9	Continental Slope	51, 99, 203, 307	CHAOZ-X	BSW

In general, we did not observe a strong annual DVM signal (Figures 137-144). In 2013 there was evidence for periods of DVM at C1 (31 m fall, spring, and summer) and C2 (11 and 31 m, winter under the ice; Figure 137). Seasonal DVM was much less prevalent farther downstream in the ACC at C4 and C5 (although there was again some evidence for DVM under the ice at Mooring C4 (10 m, Figure 138). At Hanna Shoal there was little evidence for DVM on the south flank (Mooring C6; Figure 139), but some indications of DVM over the top of the shoal (Mooring C7) mostly during the ice covered period.

In 2014 we had far fewer instruments available to us. There was again evidence of DVM at C1 during both the ice-free and the ice covered periods (Figure 140), but not farther downstream (Mooring C5). Mooring C8 over the NE flank of Hanna Shoal had some evidence of DVM in the fall, winter, and late summer (Figure 141).

We observed the strongest DVM in 2015. As in other years, there was some evidence of DVM at Mooring C1, particularly in the fall and late summer (12 m, Figure 142). The strongest signal, however was over deep water at Mooring C9 on the NE flank of Hanna Shoal (Figure

144). Here we observed a strong signal at all 4 depths examined (51, 99, 203, 307 m). The signal was strongest in the late fall/early winter (at all depths) and during the winter (99 and 203 m). The deepest depth (307 m) appeared to have migratory behavior occurring in fall, winter and late summer.

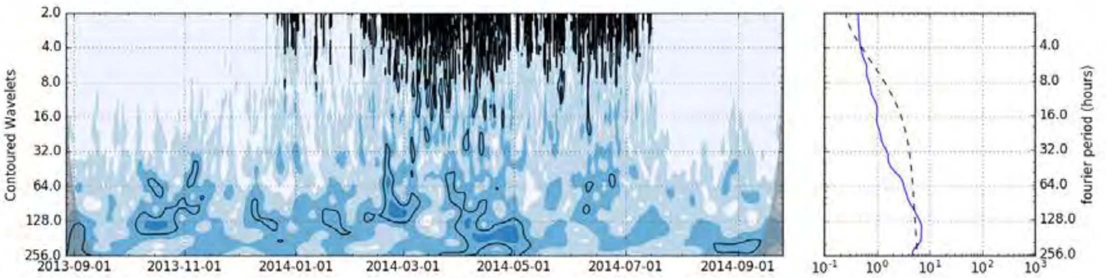
Only at the deepest mooring, 2015 C9, over the continental slope did we see strong evidence for diel vertical migration over the course of the annual deployment. This could have been plankton or small fishes. There were a number of cases where there appeared to be weak migration either as expected in the 24 hr period band or in the 12 hr band (for example, Icy Cape C1 in most years). Conversely, the spectra from the most inshore station, Peard Bay (C5), which was expected to be mostly comprised of small zooplankters from the coastal waters, never showed any evidence of diel vertical migration.

Vertical migration

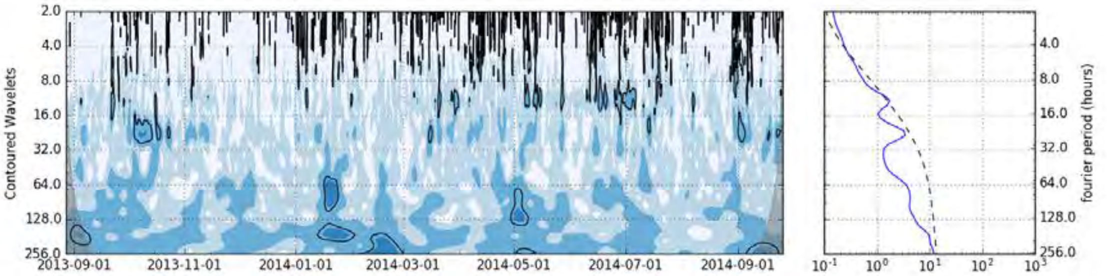
ADCP results showed intermittent DVM behavior on the shelf and much stronger behavior over the shelf break north of Hanna Shoal. This was consistent with our results from the previous CHAOZ study (Berchok et al., 2015). Previous Arctic studies have confirmed that because of the extreme environment, DVM can become intermittently synchronized or even completely unsynchronized, where individuals vertically migrated in an uncoordinated way (Cottier et al., 2006; Berge et al., 2009; Wallace et al., 2010). We did observe that over the shelf, there was evidence for DVM when ice was believed to be present and light levels are assumed to be low. There did not appear to be a strong association over the shelf between areas where *C. glacialis* was present during late summer/early fall surveys (Figures 137-138 and Figures 142-143, Moorings C2 and C4) and the ADCP data from those regions.

The strongest DVM was observed near the shelf edge, particularly over the slope with some of the strongest signals being below 200 m. This points to the importance of a mesopelagic community of sound scatterers most likely euphausiids, but possible also are Arctic cod.

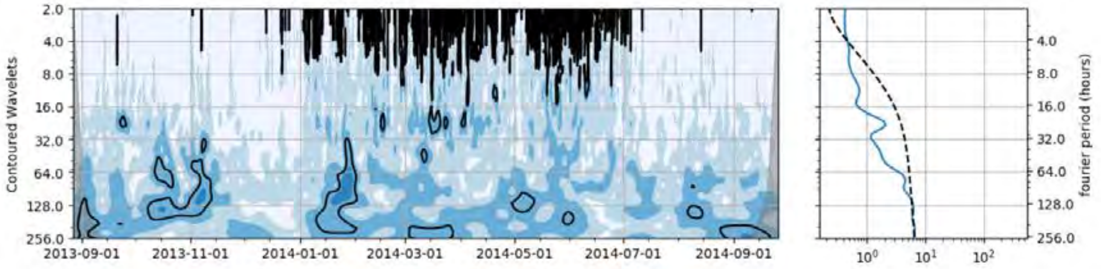
A) C1 2013-14, 11m



B) C1 2013-14, 31 m



C) C2 2013-14, 11m



D) C2 2013-14, 31m

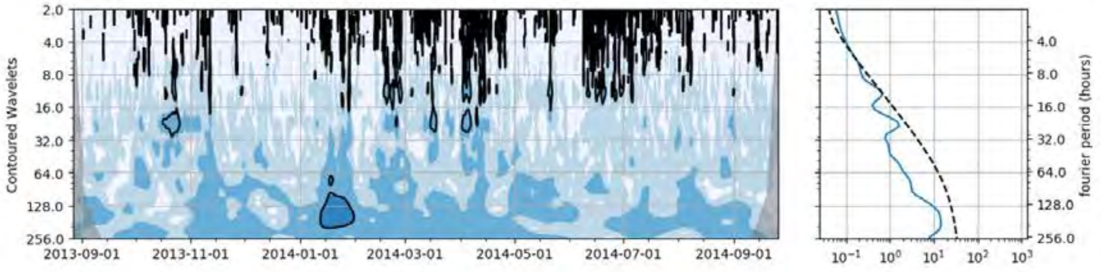
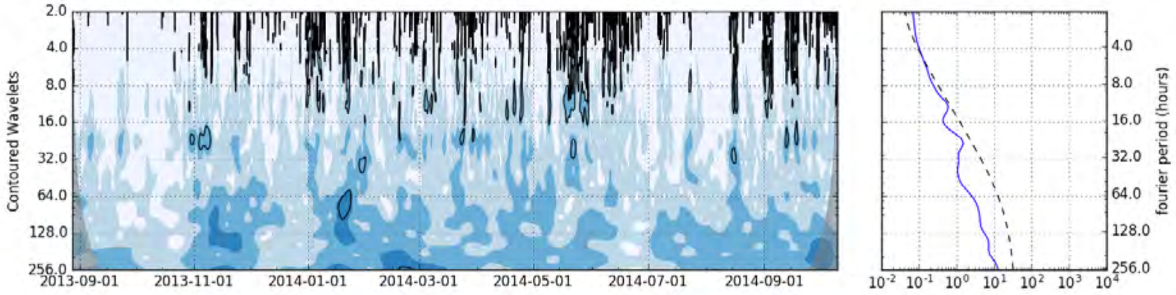
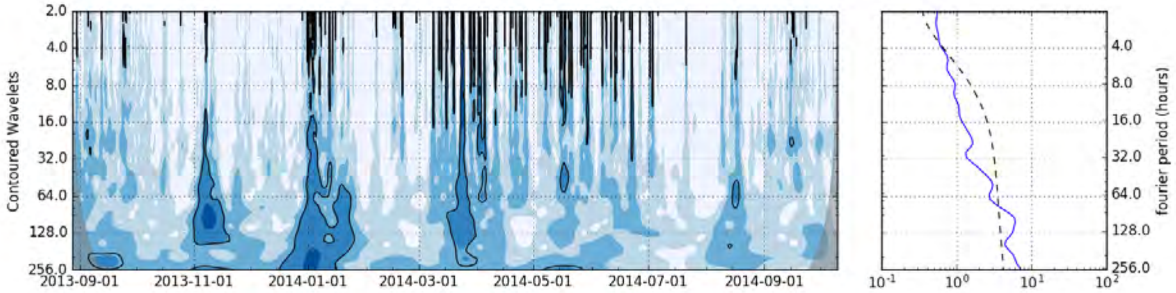


Figure 137. Wavelet analysis of 2013 - 2014 at Moorings C1 and C2. A) C1, 11 m; B) C1, 31 m, C) C2, 11 m, D) C2, 31 m. Left plots show contoured wavelet values as a function of date. Right plots show the average magnitude of temporal signal as a function of period. Dotted line is P = 0.05 such that when the peaks on the blue line are to the right of the dotted line, variability in that period is considered to be statistically significant.

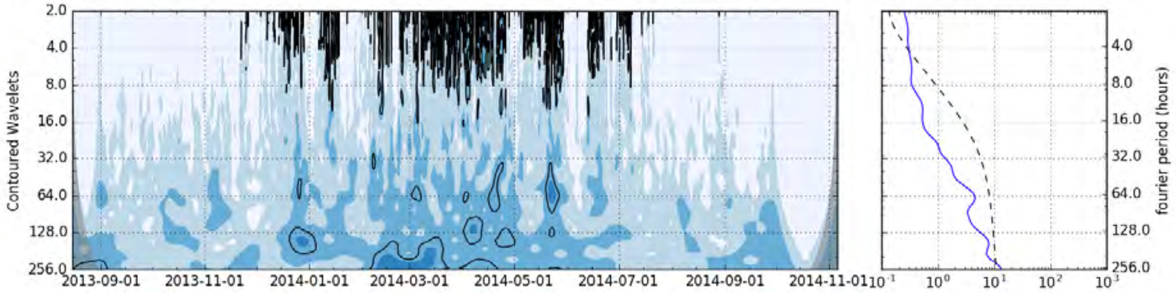
A) C4 2013-14, 10m



B) C4 2013-14, 30 m



C) C5 2013-14, 10m



D) C5 2013-14, 30m

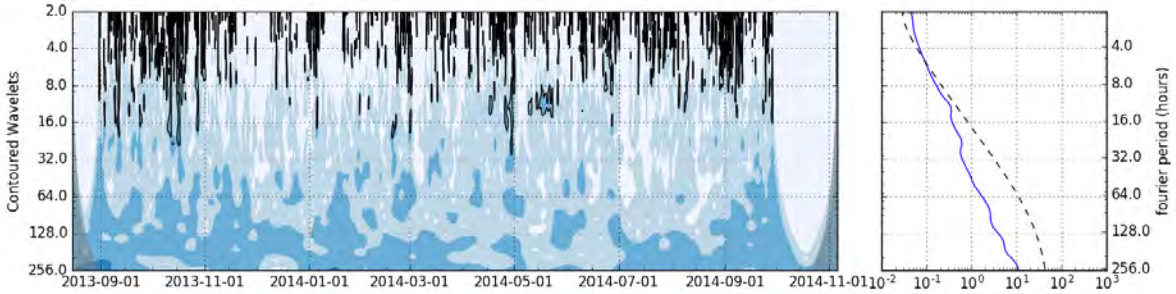
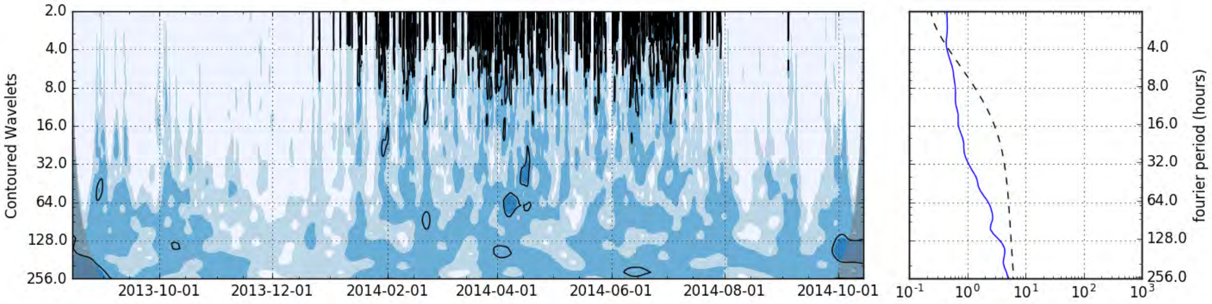
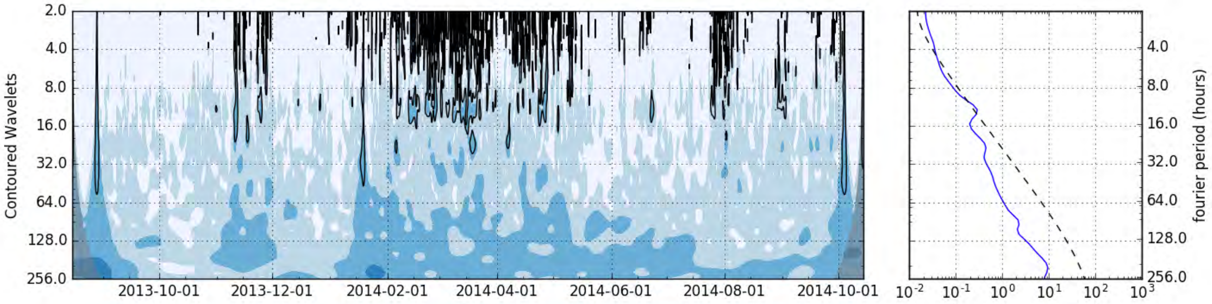


Figure 138. Wavelet analysis of 2013 - 2014 at Moorings C4 and C5. A) C4, 10 m; B) C4, 30 m, C) C5, 10 m, D) C5, 30 m. Details of plots are the same as in the previous plot.

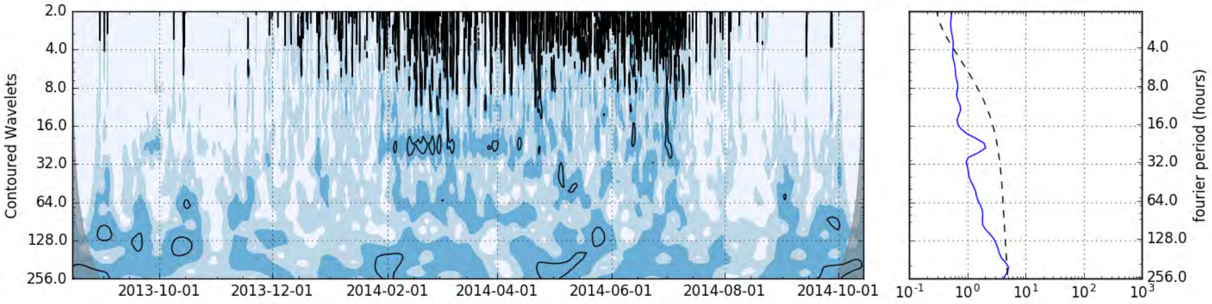
A) C6 2013-14, 11m



B) C6 2013-14, 31 m



C) C7 2013-14, 14m



D) C7 2013-14, 32m

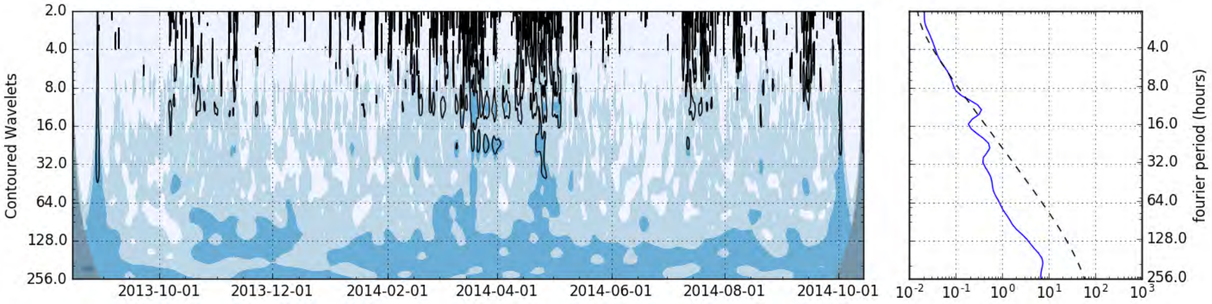
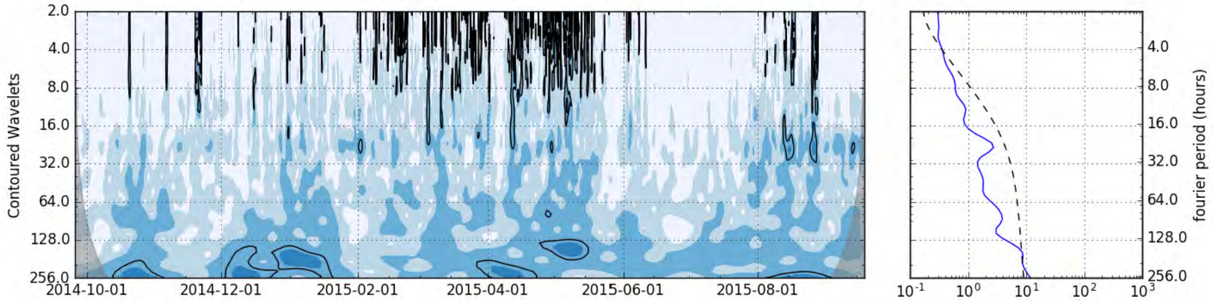
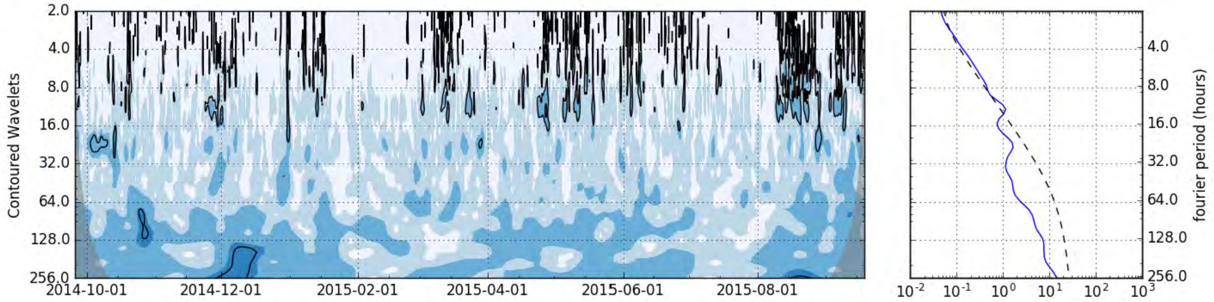


Figure 139. Wavelet analysis of 2013 - 2014 at Moorings C6 and C7. A) C6, 11 m; B) C6, 31 m, C) C7, 14 m, D) C7S, 32 m. Details of plots are the same as in the previous plot.

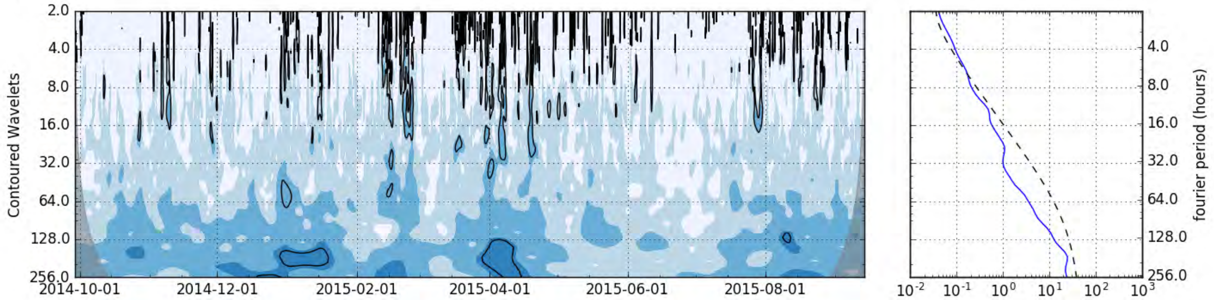
A) C1 2014-15, 10m



B) C1 2014-15, 30 m



C) C5 2014-15, 11m



D) C5 2014-15, 31m

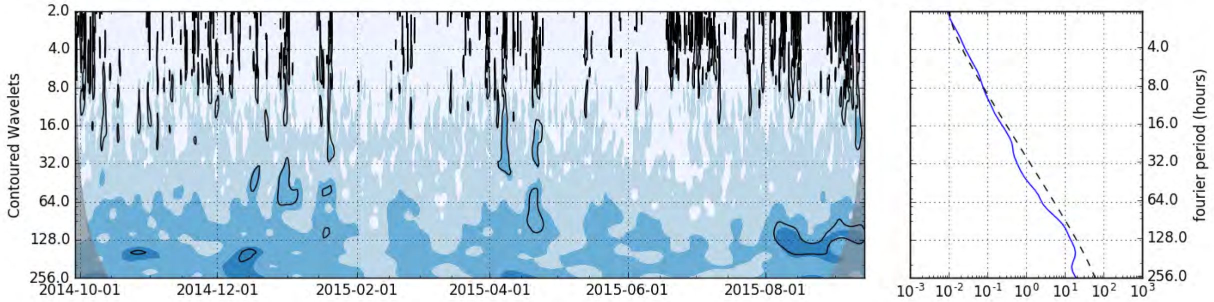
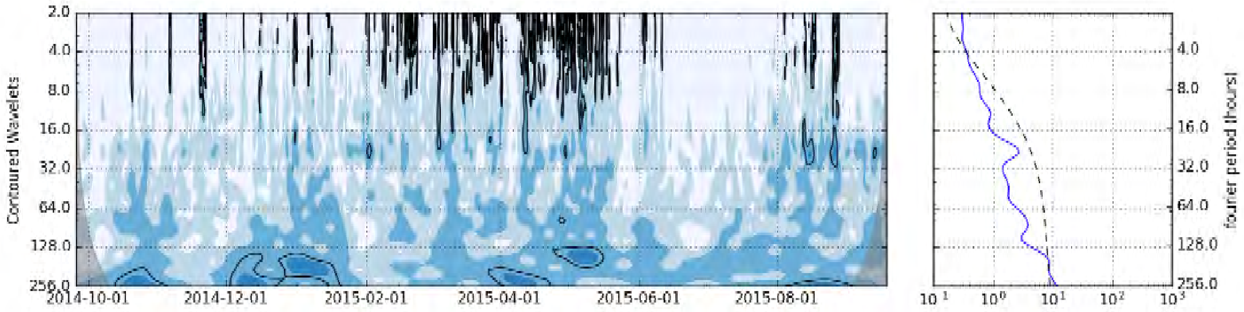


Figure 140. Wavelet analysis of 2014 - 2015 at Moorings C1 and C5. A) C1, 10 m; B) C1, 30 m, C) C5, 11 m, D) C5, 31 m. Details of plots are the same as in the previous plot.

A) C8 2014-15, 10m



B) C8 2014-15, 30m

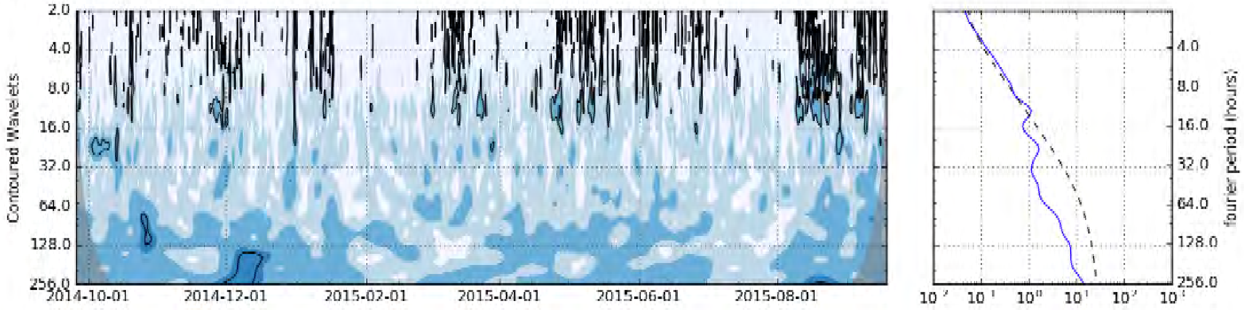
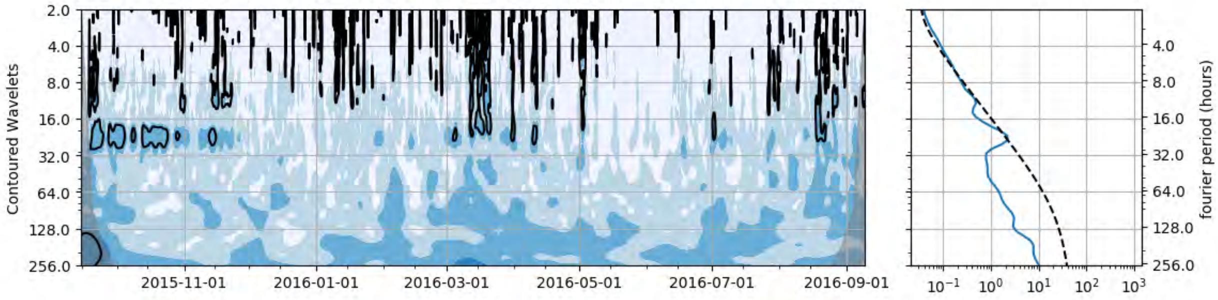
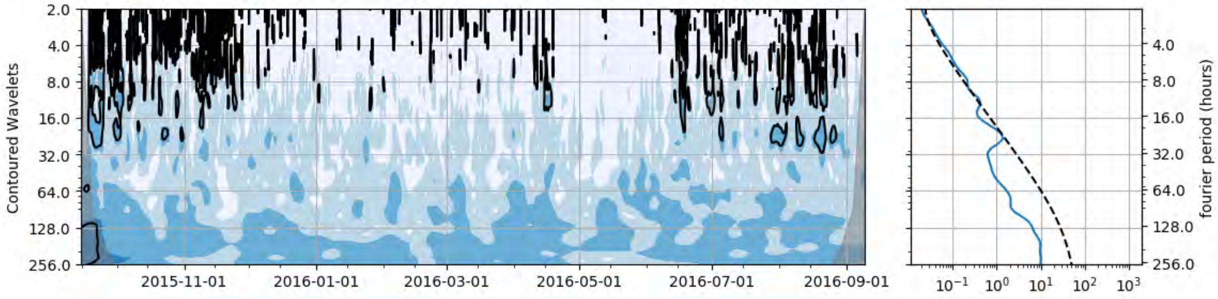


Figure 141. Wavelet analysis of 2014 - 2015 at Mooring C8. A) C8, 10 m; B) C8, 30 m. Details of plots are the same as in the previous plot.

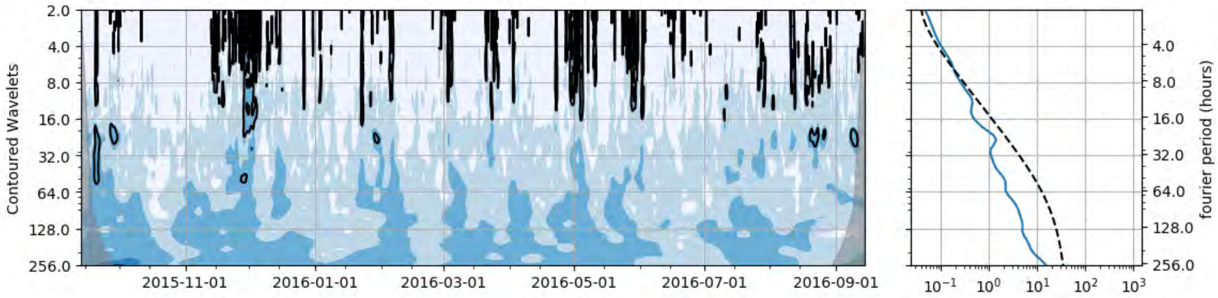
A) C1 2015-16, 12m



B) C1 2015-16, 28 m



C) C2 2015-16, 12m



D) C2 2015-16, 33m

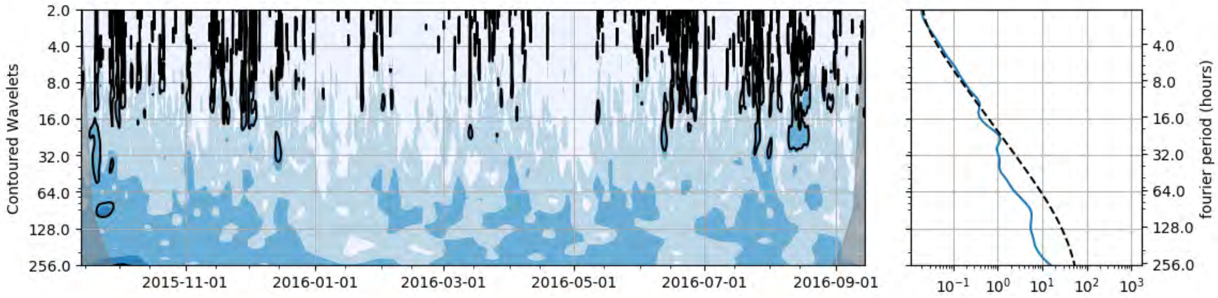
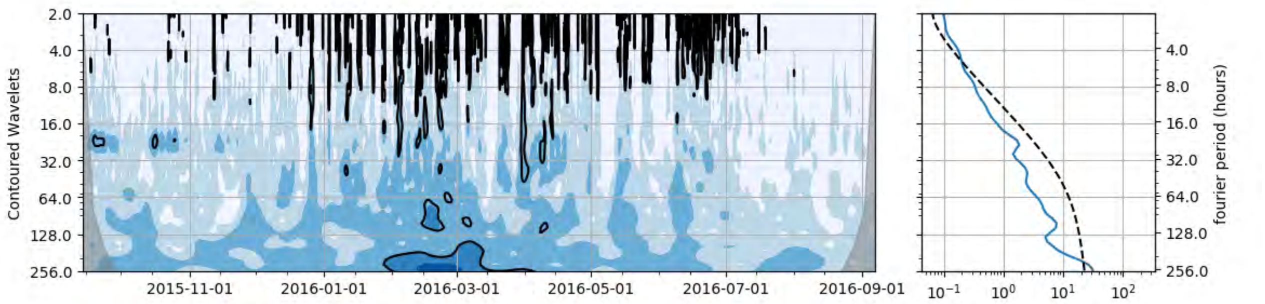


Figure 142. Wavelet analysis of 2015 - 2016 at Moorings C1 and C2. A) C1, 12 m; B) C1, 28 m, C) C2, 12 m, D) C2, 33 m. Details of plots are the same as in the previous plot.

A) C4 2015-16, 11m



B) C4 2015-16, 31 m

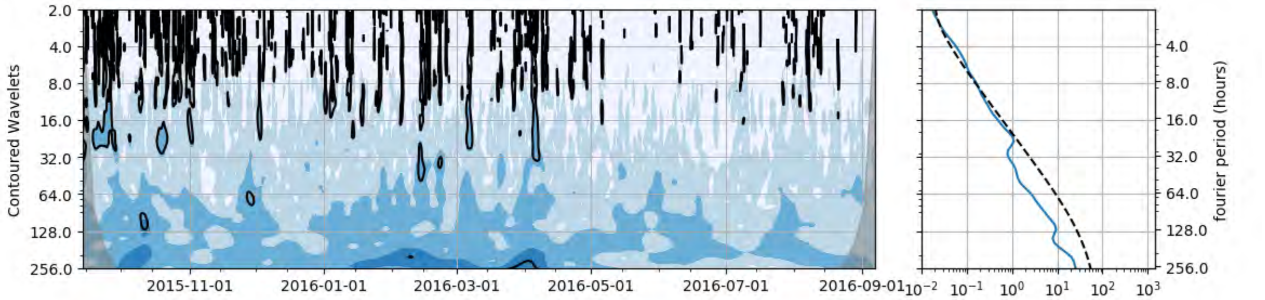
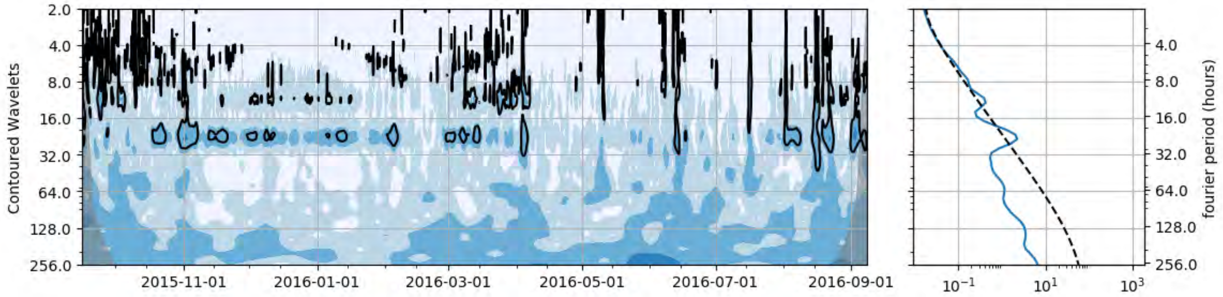
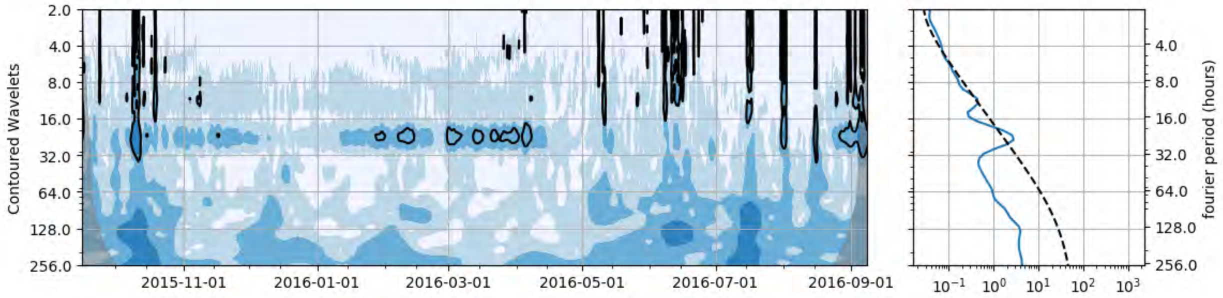


Figure 143. Wavelet analysis of 2015 - 2016 at Mooring C4. A) C4, 11 m; B) C4, 31 m. Details of plots are the same as in the previous plot.

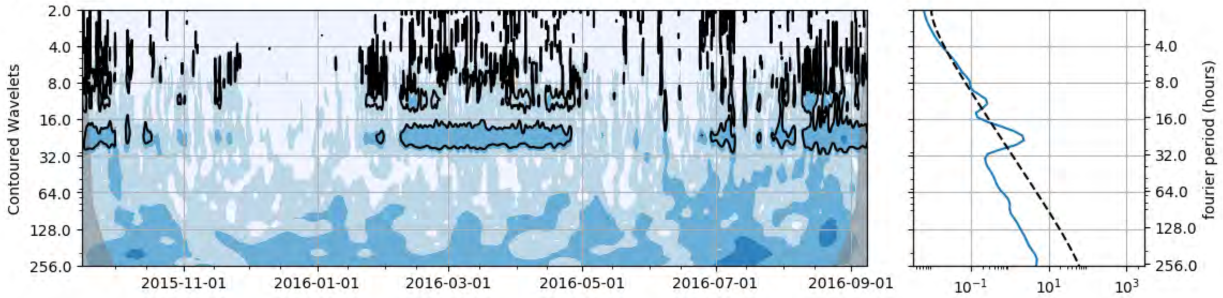
A) C9 2015-16, 51m



B) C9 2015-16, 99 m



C) C9 2015-16, 203m



D) C9 2015-16, 307m

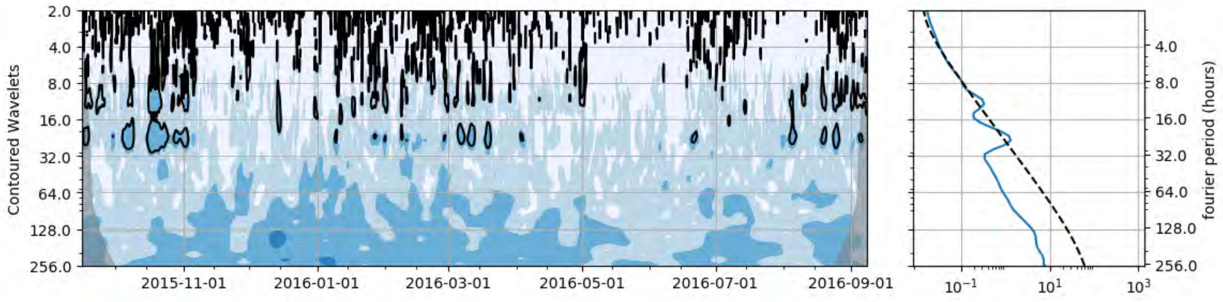


Figure 144. Wavelet analysis of 2015 - 2016 at Mooring C9. A) 51 m; B) 99 m, C) 203 m, D) 307 m. Details of plots are the same as in the previous plot.

Zooplankton volume backscatter estimated from multi-frequency acoustic measurements (TAPS6-NG)

One of the goals of the biological oceanography component was to adapt existing technology to acoustically measure plankton (particularly krill) backscatter year round using tethered sensors. This would help to achieve several of our goals such as: determine the spatial and temporal variability of zooplankton biomass in the region, and help to evaluate the "conveyor belt" hypothesis proposed by others to explain the presence of krill in the area (Berline et al., 2008). At the time the first project began (CHAOZ; Berchok et al., 2015) acoustic technology for remotely estimating plankton backscatter was not readily available and tested. We chose to partner with a research and development team from Tracor Associates (later BAE Systems) which had been supported for many years by the Office of Naval Research to develop and apply acoustic technology for this and other purposes.

Scientists from BAE Systems provided us with the plans/schematics for instrument electronics and sources to obtain other system components. They also helped us to determine battery power requirements, manufacture electronic boards, assemble systems, and correctly calibrate the individual acoustic transducers. In essence we began to create our own acoustic research and development group.

The initial design, although somewhat modified from 20 year old technology BAE Systems previously used, did not work reliably in the Arctic. In particular, the instrument did not reliably turn itself on and off. Thus we developed our own controller board for this harsh environment. The in-house development was necessary because one of our two initial collaborators died and the other retired. 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 levels. Although our development of a brand new acoustic sensor did not succeed, by the time the ARCWEST ended, commercial sensors had become much more available and other researchers had accomplished sufficient testing such that these sensors could be used in future applications in the Arctic.

3. Discussion and Conclusion

Time series of physical and chemical data from biophysical moorings

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 later ice arrival in the fall, warmer ocean temperatures during summer, and changes in weather patterns (Wood et al., 2015). These physical changes will continue to have profound impacts on this ecosystem. Long-term observations are necessary to quantify the changes in the ocean.

The Chukchi Sea 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 Arctic basin through Barrow Canyon.

The northward flow on Chukchi shelf is a product of the pressure head that forces the northward flow of Pacific water through Bering Strait. Like Bering Strait, local winds modify the northwestward transport over the Chukchi Shelf, at times (especially in the winter) even reversing it. The currents and transport are significantly ($p = 0.01$) correlated with winds. The total transport at Icy Cape varies seasonally, with highest monthly transport in the summer and the lowest in the winter. However, the monthly mean transports vary the most during the winter. The highest monthly mean transport (~1.5 Sverdrup) occurred in February 2011 (Figure 118).

Reversals of flow at the coastal moorings result in upwelling of AtlW onto the shelf that is warmer, more saline water and has higher nutrient content (Ladd et al., 2016). The number and strength of these flow reversals vary seasonally (more common November - May) and inter-annually. These reversals can be an important source of nutrients to the northern shelf. In addition, these intrusions bring heat which can delay freezing of the polynyas that can occur during these events (Ladd et al., 2016).

Our hydrographic data set with transects normal to the coastline provide insight into the physical and chemical oceanography of the Chukchi shelf. These data, drifter trajectories and data from the moorings enable us to refine previous summaries of Chukchi Shelf currents (Figure 146). They also allow us to quantify transport and flux of heat, salt, and nutrients during the sampling period. High ammonium concentrations between Pt. Hope and Barrow Canyon indicate the effects of active remineralization and regeneration of nutrients in the cold Arctic. Subsurface maxima of chlorophyll fluorescence were common during the late summer cruises. It was not determined whether or not these regions were due to higher fluorescence per cell (photo-adaptation) or if there was increased phytoplankton biomass there. However these regions were sometimes associated with high percent saturation of oxygen. In those cases it is presumed that the cells were actively photosynthesizing and contributing to the total primary production. Sinking cells from this subsurface region would continue to seed the benthos and add carbon to support secondary production.

Ice is a primary forcing mechanism on this shelf. Ice typically appears sometime in November and disappears in July. The biggest ice keels appear spring (often exceeding 20 m). The largest keel observed during this program was 30 m at mooring C4 in early spring 2015.

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. An interesting feature of the mooring data is that after the export to the bottom, oxygen concentrations increase, often exceeding 100% saturation for short period in summer. Decreasing light 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 increase in salinity. Increases in nitrate can occur together with intrusions of AtlW onto the shelf (Ladd et al., 2016). 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 inter-annual variability and changing conditions. Moore et al. (2018) developed the Arctic Marine Pulses conceptual model (from work that began in Moore and Stabeno (2015)) 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.

4. Recommendations

It is critical that we continue to moor physical and biological instrumentation in close proximity to better conduct interdisciplinary studies. 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 need to be addressed is the nutrient budget. Specifically, are the nutrients on the southern and middle shelf replenished primarily by advection or does local nitrification play a role? Observations show great horizontal variability in many lower trophic level parameters (e.g. temperature, salinity, nutrients, primary production, etc.). Another important question is what occurs under the ice and in the water column not just for the short time that ships are there to 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. Integrated ecosystem research needs to continue, but to understand mechanisms, regional scale modeling is a crucial partner with observations.

B. Shipboard Observations (lines: BS, DBO3, CL, LB, CkA, CkB, CkC, IC, WT, BX, BC, BfA)

1. Methods

Hydrography-- physical and chemical variables

Hydrographic data were collected during cruises in 2013, 2014 and 2015 (Table 45). 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 (Figure 117). 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.

Sampling was fully successful, with Sea-Bird SBE 911plus system with dual temperature and salinity sensors, oxygen (SBE-43) sensors, a 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 every 10 m and at the bottom of the cast.

Nutrient and chlorophyll samples were taken from each bottle, processed and frozen in the -80°C freezer for processing in the laboratories at the Pacific Marine Environmental Laboratory (PMEL) and the AFSC, respectively, in Seattle, Washington. Chlorophyll-a and phaeopigment concentrations were estimated after extracting the filters for 24 hr extraction in 90% acetone 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 (Oudot et al., 1988). The number of CTD stations and the number of nutrient and chlorophyll samples collected are shown in Table 45.

Table 45. The number of hydrographic stations occupied in the Chukchi Sea (including Bering Strait), together with number of nutrient samples and the number of chlorophyll samples collected and processed.

Cruise Dates	Vessel	CTDs	Nutrients	Chl.
2013: 13 AUG - 18 SEP	F/V *Aquila*	48	247	224
2014: 7 SEP - 20 OCT	F/V *Aquila*	86	444	425
2015: 6 AUG - 4 SEP	NOAAS Ronald H. Brown	127	693	465
2015: 8 SEP - 28 SEP	F/V *Aquila*	16	74	68
2016: 3 SEP - 29 SEP	F/V *Aquila*	71	369	423

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). 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.

Two 505 µm nets and a smaller 153 µm mesh net inside the second 505 µm were used along all transects except Barrow Canyon (Transect BC), the first 505 µm net was fished for 2 minutes along the bottom before being closed. At closure, the frame was retrieved at approximately 20 m min^{-1} so that the second 505 µm and the 153 µm nets 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.

Comparison of zooplankton estimates from the Tucker net and a TAPS-6

An older, 6-frequency TAPS-6 was used to estimate volume-scattering strength (Sv, dB re 1 m^{-1}) of zooplankton. The instrument and approach has been used in other subarctic and arctic ecosystems to examine patterns in the temporal and spatial distribution of zooplankton (Holliday et al., 2009). The six frequencies were: 265, 420, 700, 1100, 1850, and 3000 kHz. Note that the frequencies and instrument design are fundamentally different from the TAPS6-NG instruments designed and moored for this study and described in the previous section. The TAPS-6 was attached to the top of the epibenthic Tucker Sled, with the transducers angled towards the center of the net opening (Figure 145).

The instrument was used in a small volume (ca. 2.5 liters) measurement mode which collects Sv data at a range of 1.5-m from the transducer face. The TAPS-6 averages multiple ping cycles prior to storing the data. The number of ping cycles per average used during these deployments was 6, which gives a new data ensemble every 2.6 seconds. Since each ping averages 5 independent samples, each data set results in 30 degrees of freedom. TAPS-6 calibration was accomplished by determining the source and receiver levels for each frequency, before and after each field season, using a standard calibrated transducer.

Figure 145. 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.

For abundance comparisons of zooplankton between the nets and the TAPS-6, species abundance from the water column and bottom net samples were separated and then summed into copepod-shaped and elongate/euphausiid-shaped categories. For displacement volume comparisons, the water column Tucker large-mesh and 25-cm small-mesh net sample displacement volumes were summed for all species.

Matlab™ (R2012b) was used to process the TAPS-6 acoustic data. Raw data from each frequency of the TAPS-6 was recorded as Sv. Background noise was defined as the minimum intensities (W/m^2) for the entire cast for each frequency. Noise was then removed by subtracting it from each measurement. Signal-to-noise ratios of <10 dB were used as a threshold to reject Sv values that were not acceptable for further analysis.

Inverse methods were used to estimate the abundance of plankton scatterers in 1-m depth bins as a function of size (Holliday, 1977; Greenlaw, 1979; Greenlaw and Johnson, 1983). The TFS, DWBA, and hard elastic scattering models were used in the inverse calculation to estimate scattering from small, spherical organisms (e.g., copepods, eggs, nauplii), elongate organisms (e.g., euphausiids, mysids), and planktonic shelled molluscs, respectively (Holliday, 1992; Stanton, 1994; Holliday et al., 2003). Assumed values for the material properties and the assumed orientation of these scatterers are provided in Table 43. In this application, however, the Levenberg-Marquardt factors for the nonlinear regression was 1.0 x 10^{-3} as opposed to 1.0 x 10^{-4} that was used to process the moored acoustics data (Table 43). Euclidian norms were computed as a goodness-of-fit statistic between Sv and the inverse model, fit to verify that the inversion could adequately explain the measured Sv values.

Matlab™ (R2012b) was used for linear regression analysis. The TAPS-6 inverse-estimated abundance of copepods, pteropods, and euphausiids was compared to net sample estimates for those 3 taxonomic categories (copepods, euphausiids, and shelled molluscs) at all available stations. Finally, mean volume backscatter in the water column for each of the 6 frequencies measured along the Icy Cape line was compared to zooplankton displacement volume from the water column net from the same tows.

Contour section plots of zooplankton Sv at 420 kHz along the Icy Cape line were created using Surfer Plot (Version 10.7.972) and compared to temperature and salinity data collected during the CTD casts at the same station.

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 (NMDS) plot.

A 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.

2. Results

The Chukchi Sea consists of a broad shallow shelf (Figure 146), 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 the bathymetry (Figure 146). Three types of water enter onto the shelf from Bering Strait: ACC, BSW, and Anadyr Water (AW). In addition, intrusions of water from the Bering Sea basin onto the shelf can occur either through Bering Canyon or over the shelf break to the west of Bering Canyon. Water properties are modified by local processes such as ice formation, brine rejection 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 46. Summary of the range of properties expected for each water type, from Danielson et al., 2017. Data collected through this program provide insight into the magnitude of transport and flow pathways, and associated fluxes.

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

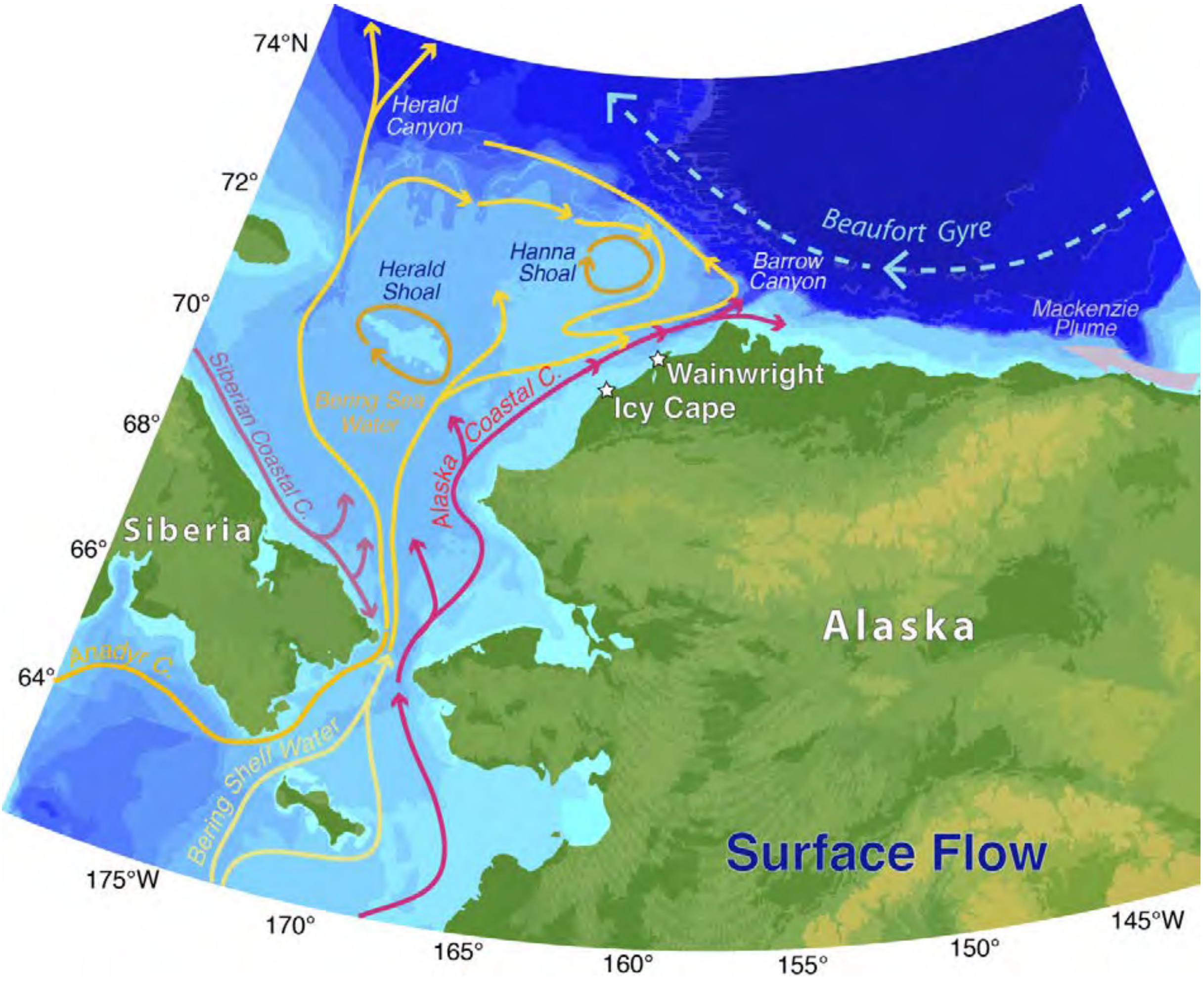


Figure 146. Map of currents over the Chukchi Shelf (modified from Wood et al., 2015).

Five hydrographic lines were occupied (Point Hope, Ledyard Bay, Icy Cape, Wainwright, and Barrow Canyon), but not all lines were occupied each year (Table 47). The BX and Hanna Shoal lines were part of the CHAOX-X program, but are included in this report to provide additional context for Wainwright and Barrow Canyon 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.

With a few exceptions (e.g., Point Hope) 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 47. Seven primary hydrographic lines (including the BX and Hanna Shoal lines that were part of the CHAOZ-X program). Additional transects were done just to the north of the Ledyard Bay transect in 2014 and 2015; data from these lines are not shown. 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
Point Hope	X		X
Ledyard Bay		X	X
Icy Cape	P	X	X
Wainwright	X	P	X
Barrow Canyon	X	X	X
BX	X	P	X
Hanna Shoal	X	X	

Point Hope (Figures 147-148)

This section was occupied in 2013 and 2015. In those years, the warmer, fresher water of the ACC was confined to the upper water column along the innermost portions of the line. Nutrients tended to be low near the coast in both years. In the offshore portion of this transect, the bottom layer was saltier and rich in nutrients (including ammonium), conditions that typify AW. Bottom temperatures were < 3°C in 2013, and > 3°C in 2015. In 2013, the center of the section was defined by: a strong two-layer system with a sharp pycnocline at ~15 m; a strong sub-surface chlorophyll maximum (SCM) between 15 and 30 m; and low oxygen saturation in the bottom water, likely due to respiration. Further offshore, the thermocline deepened and there was a near-surface chlorophyll maximum. In 2015, the water column was weakly stratified with a weak near-surface chlorophyll maximum, and higher (but still undersaturated) oxygen content in the bottom water.

Ledyard Bay (Figures 149-150)

This section was occupied in 2014 and 2015. Surface temperatures were warmer in 2015. In both years, warmer, fresher water of the ACC was still observed along the inner portions of the hydrographic line, and saltier nutrient rich water was evident in the middle of the section. In these mid-section bottom waters, nutrient concentrations were higher in 2014, and may have their origin from the Point Hope line. In 2015, the there was a sharp pycnocline at the offshore stations with cold and saltier bottom water. Cooler bottom water was also observed at the offshore stations in 2014, but the pycnocline was deeper and weaker. In 2014, there was a weak SCM above bottom waters that had reduced oxygen saturation. These features were absent in 2015.

Icy Cape (Figures 151-153)

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. But temperatures at Icy Cape were cooler than farther south (Point Hope and Ledyard Bay). 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, bottom waters that were cold, salty, and nutrient-rich, and a subsurface layer with a thin chlorophyll maximum and supersaturated oxygen content. In 2014, stratification was relatively weak, especially nearshore, and there was a strong SCM to the northwest. In 2014 and 2015, nutrient concentrations were relatively low, and nitrate was generally depleted.

Wainwright (Figures 154-156)

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 undersaturated 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 of < 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 157-159)

In 2013, a fresh surface layer extended over most of the transect. 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. Highest chlorophyll concentrations and oxygen supersaturation were observed northwest of the canyon in 2015.

BX Line (Figures 160-162)

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 northwest end of the Barrow Canyon Line were very similar to the northeast 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 WW 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 163-164)

The Hanna Shoal Line was occupied in 2013 and 2014. This 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 undersaturated waters below the SCM, and nitrate concentrations were especially low in 2014.

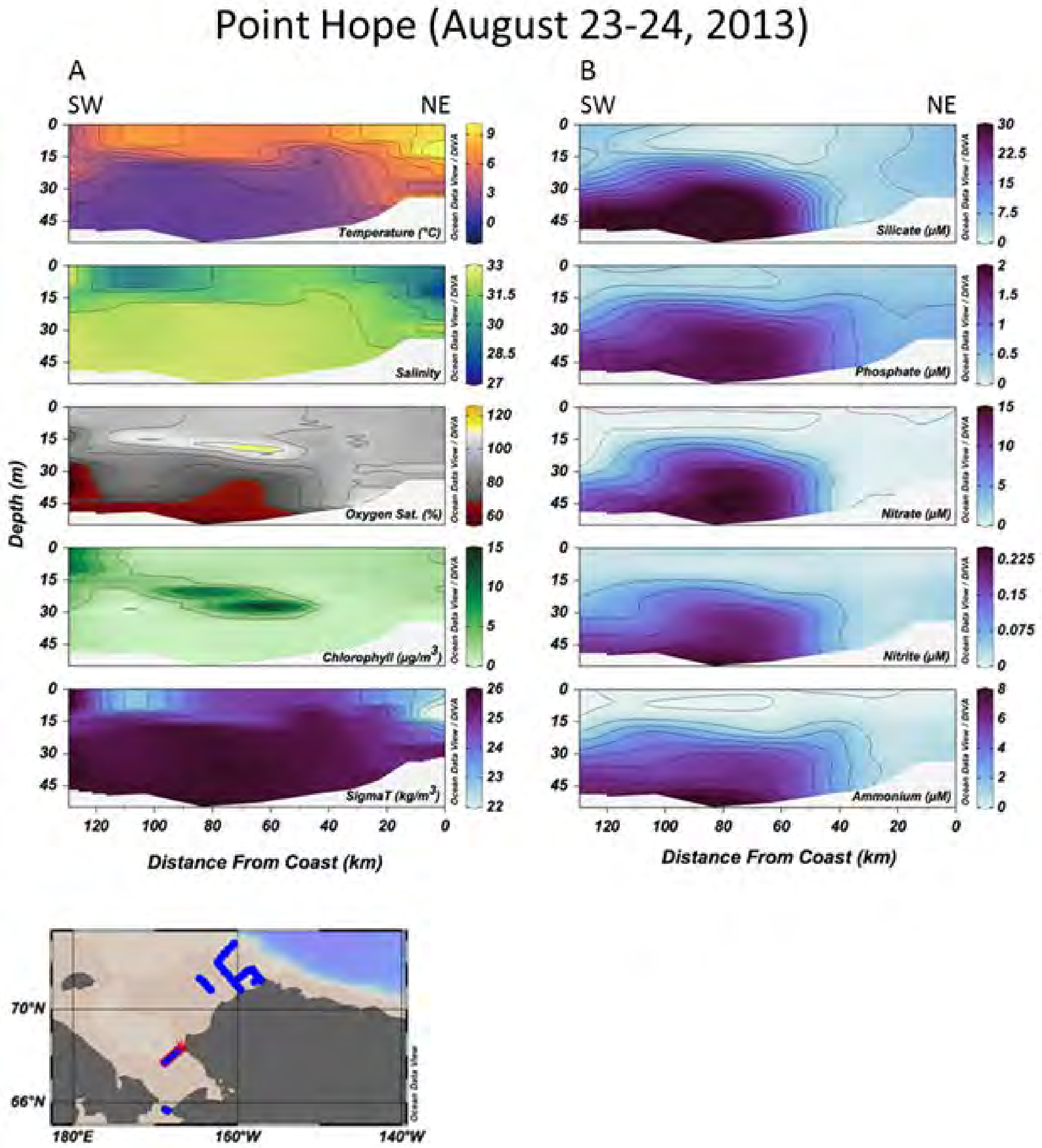


Figure 147. Hydrographic measurements at Point Hope in August 2013. (A) Top to bottom: temperature, salinity, oxygen (percent saturation), chlorophyll fluorescence and SIGMA-T. (B) Top to bottom: the five nutrients (silicate, phosphate, nitrate, nitrite and ammonium). The coastline is on the right side of each plot. The line occupied is indicated in red in the bottom left panel.

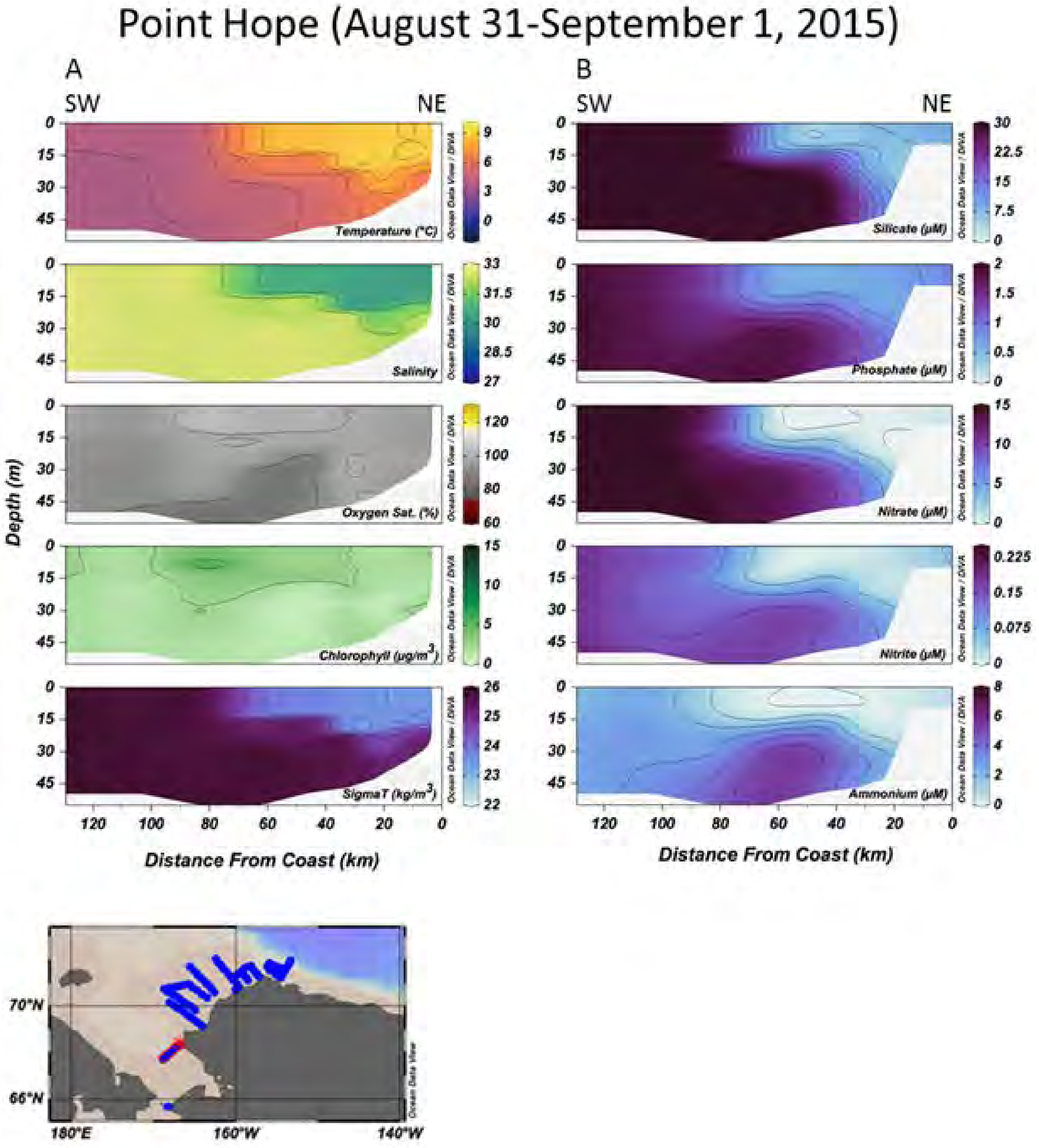


Figure 148. Hydrographic measurements at Point Hope in August and September 2015. (A) Top to bottom: temperature, salinity, oxygen (percent saturation), chlorophyll fluorescence and SIGMA-T. (B) Top to bottom: the five nutrients (silicate, phosphate, nitrate, nitrite and ammonium). The coastline is on the right side of each plot. The line occupied is indicated in red in the bottom left panel.

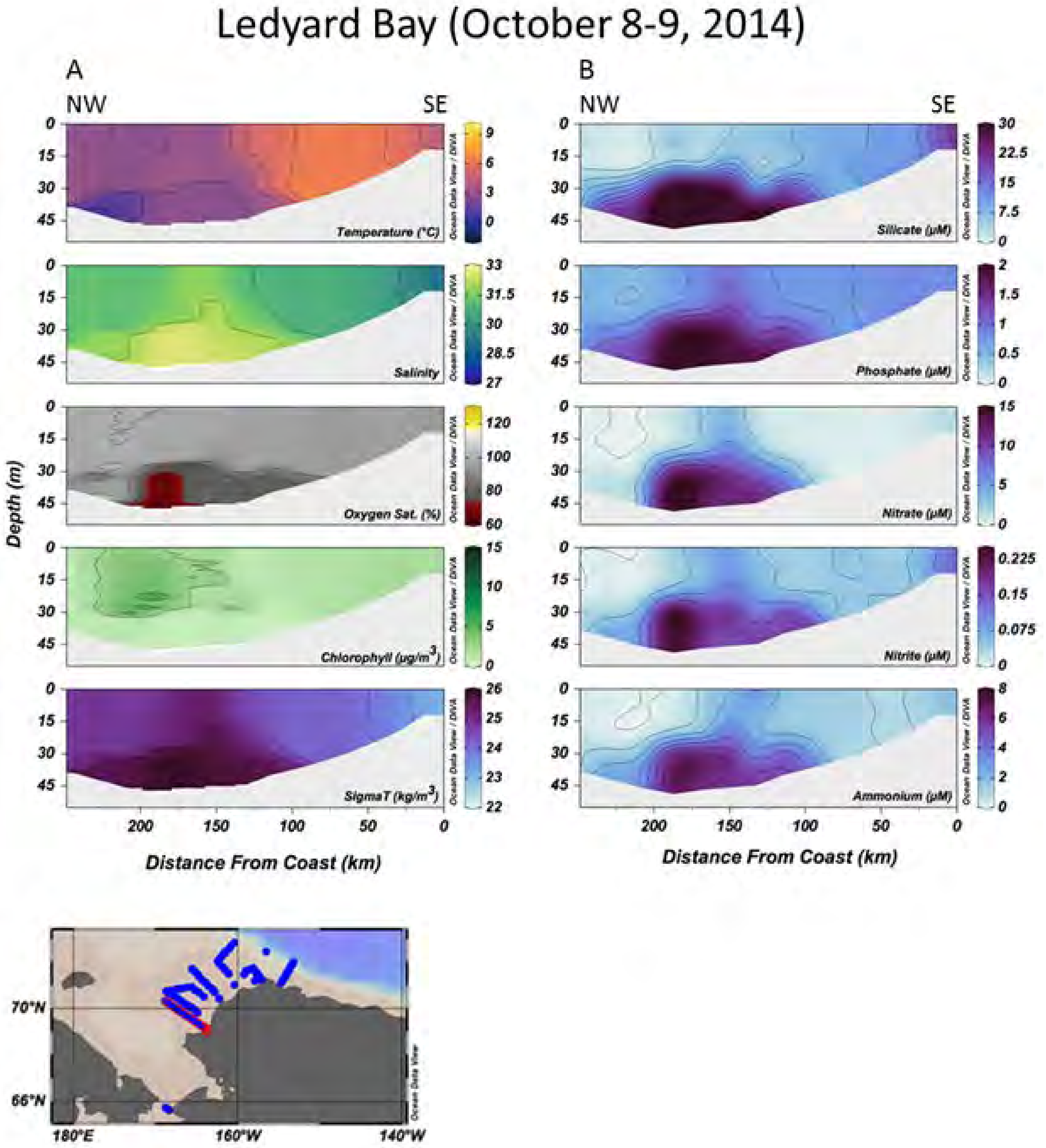


Figure 149. Hydrographic measurements at Ledyard Bay in October 2014. (A) Top to bottom: temperature, salinity, oxygen (percent saturation), chlorophyll fluorescence and SIGMA-T. (B) Top to bottom: the five nutrients (silicate, phosphate, nitrate, nitrite and ammonium). The coastline is on the right side of each plot. The line occupied is indicated in red in the bottom left panel.

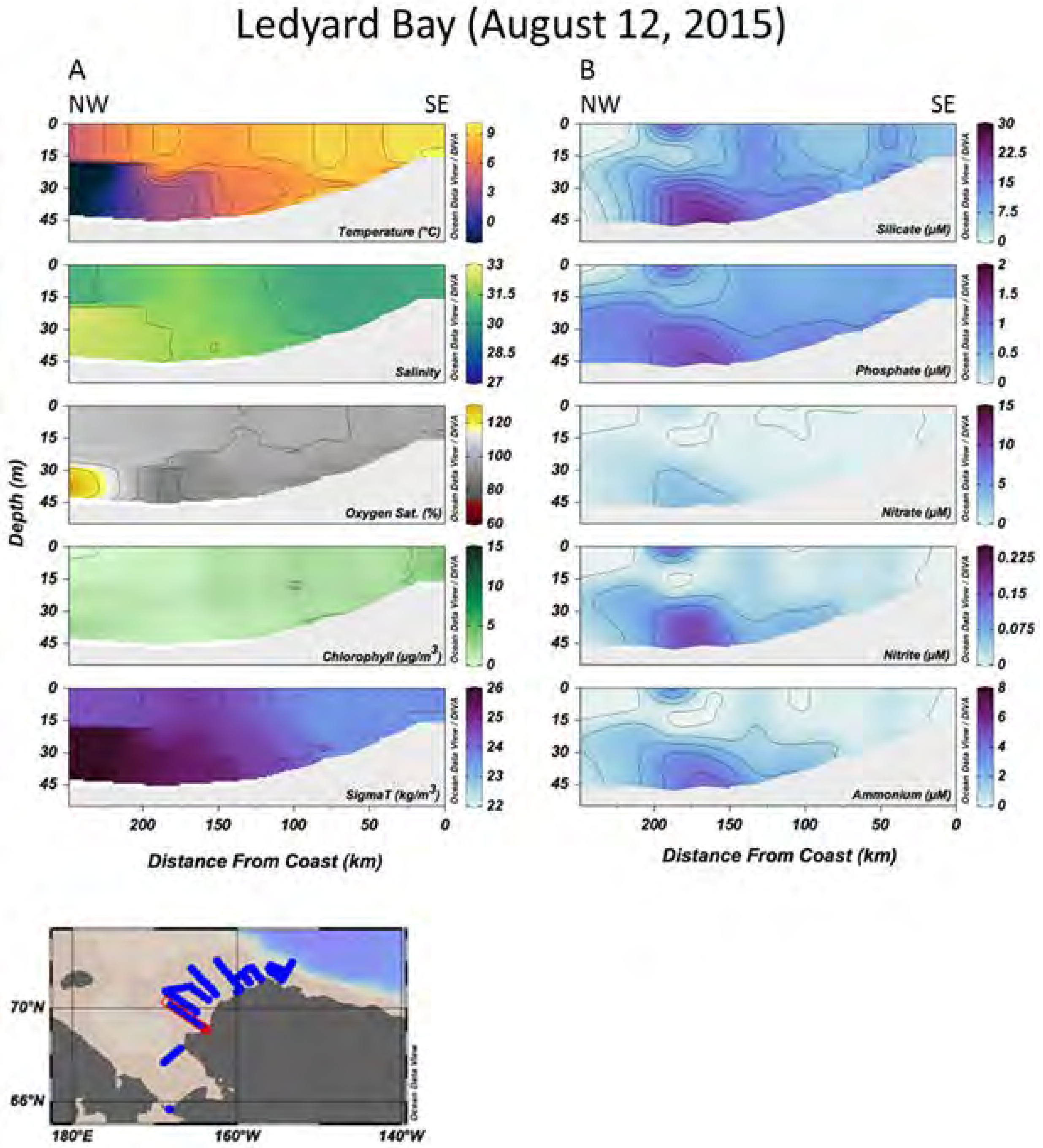


Figure 150. Hydrographic measurements at Ledyard Bay in August 2015. (A) Top to bottom: temperature, salinity, oxygen (percent saturation), chlorophyll fluorescence and SIGMA-T. (B) Top to bottom: the five nutrients (silicate, phosphate, nitrate, nitrite and ammonium). The coastline is on the right side of each plot. The line occupied is indicated in red in the bottom left panel.

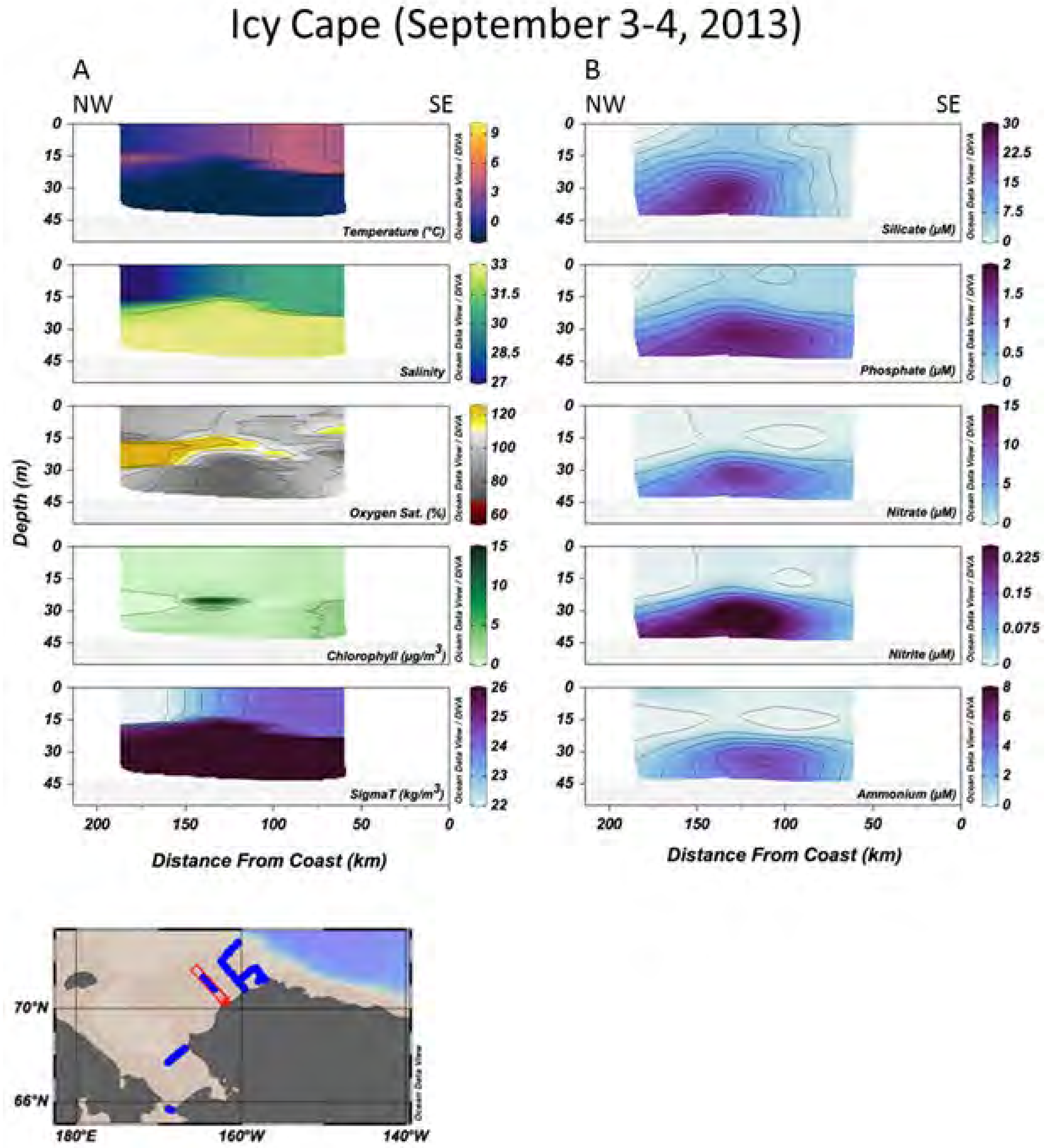


Figure 151. Hydrographic measurements at Icy Cape in September 2013. (A) Top to bottom: temperature, salinity, oxygen (percent saturation), chlorophyll fluorescence and SIGMA-T. (B) Top to bottom: the five nutrients (silicate, phosphate, nitrate, nitrite and ammonium). The coastline is on the right side of each plot. The line occupied is indicated in red in the bottom left panel.

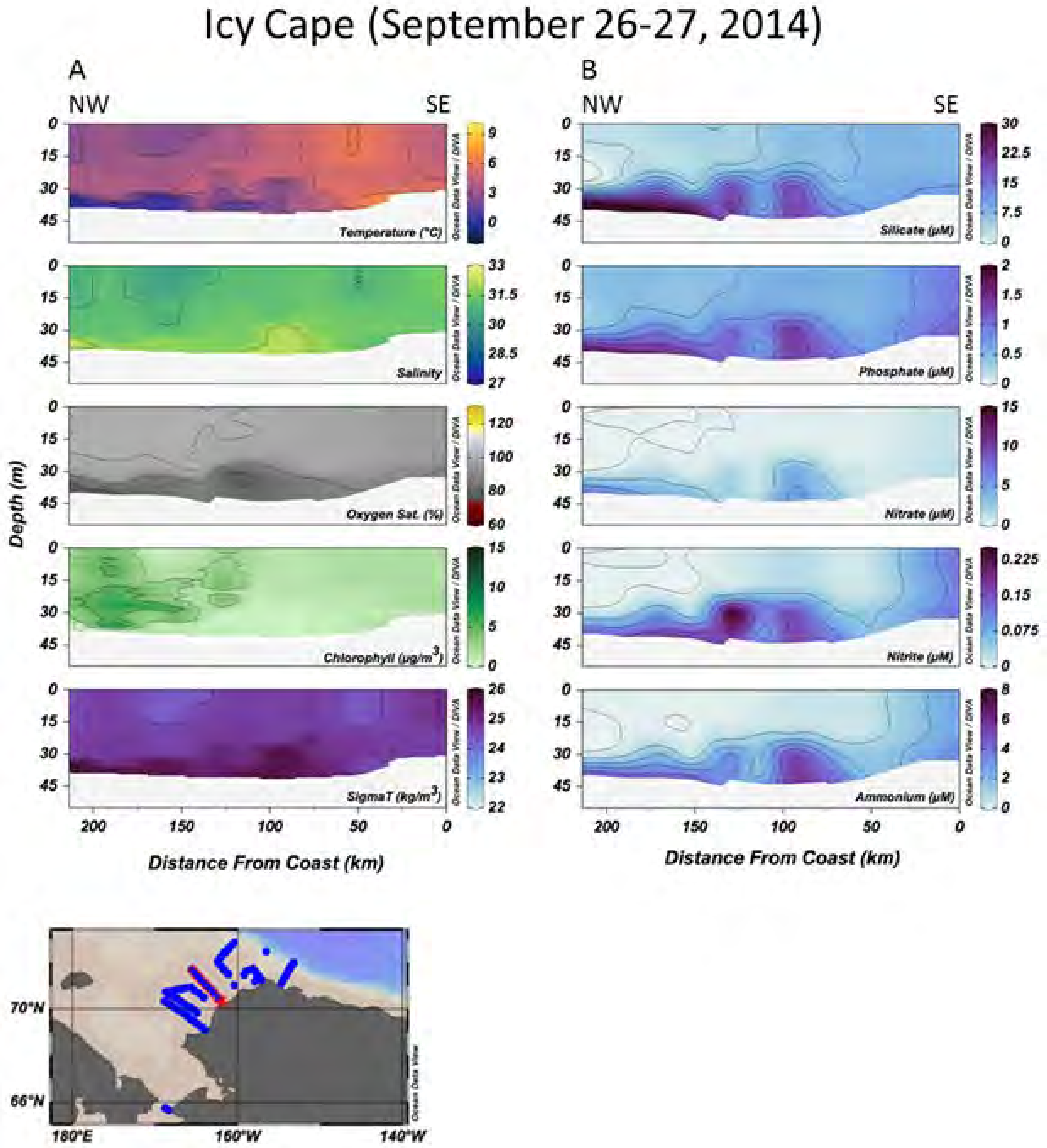


Figure 152. Hydrographic measurements at Icy Cape in September 2014. (A) Top to bottom: temperature, salinity, oxygen (percent saturation), chlorophyll fluorescence and SIGMA-T. (B) Top to bottom: the five nutrients (silicate, phosphate, nitrate, nitrite and ammonium). The coastline is on the right side of each plot. The line occupied is indicated in red in the bottom left panel.

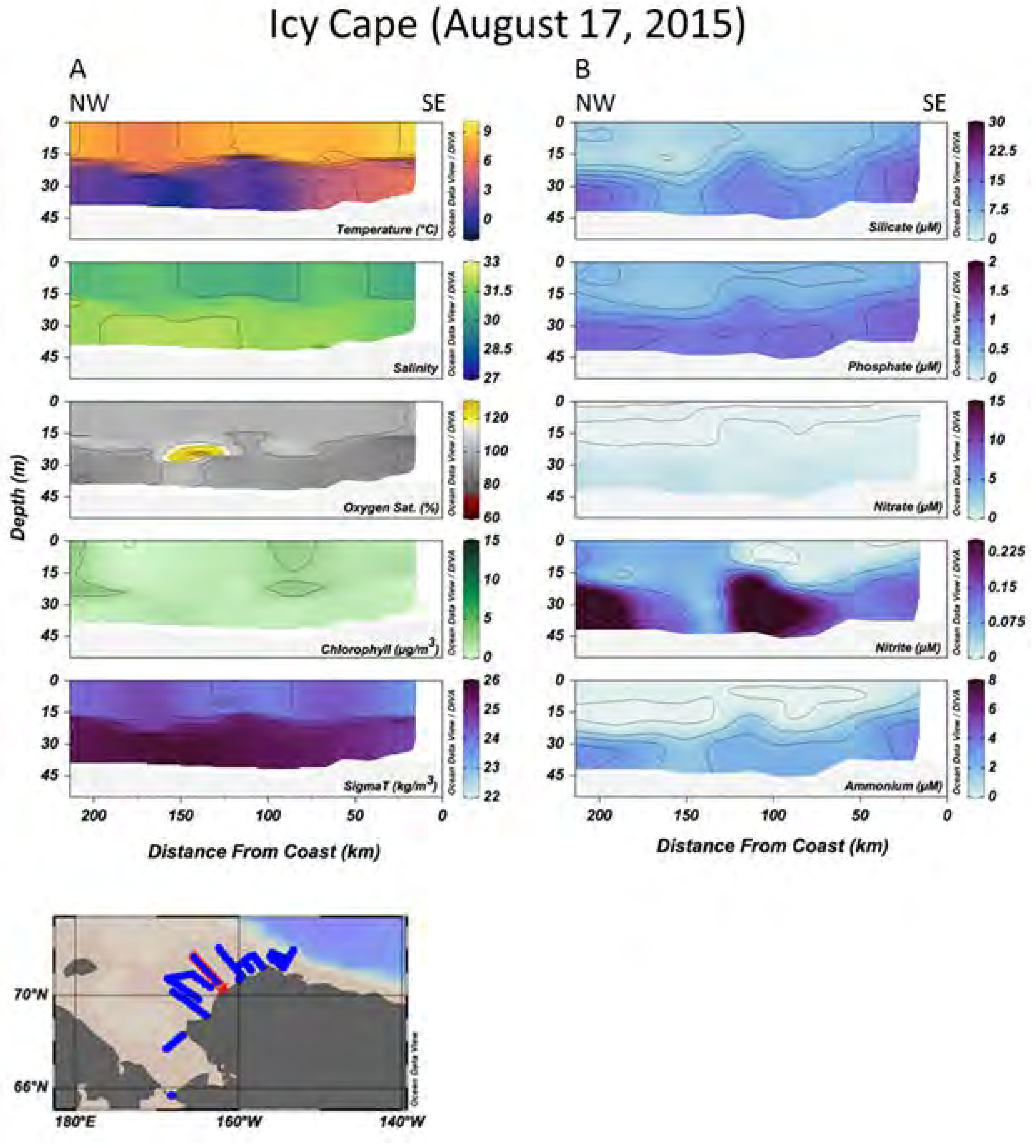


Figure 153. Hydrographic measurements at Icy Cape in August 2015. (A) Top to bottom: temperature, salinity, oxygen (percent saturation), chlorophyll fluorescence and SIGMA-T. (B) Top to bottom: the five nutrients (silicate, phosphate, nitrate, nitrite and ammonium). The coastline is on the right side of each plot. The line occupied is indicated in red in the bottom left panel.

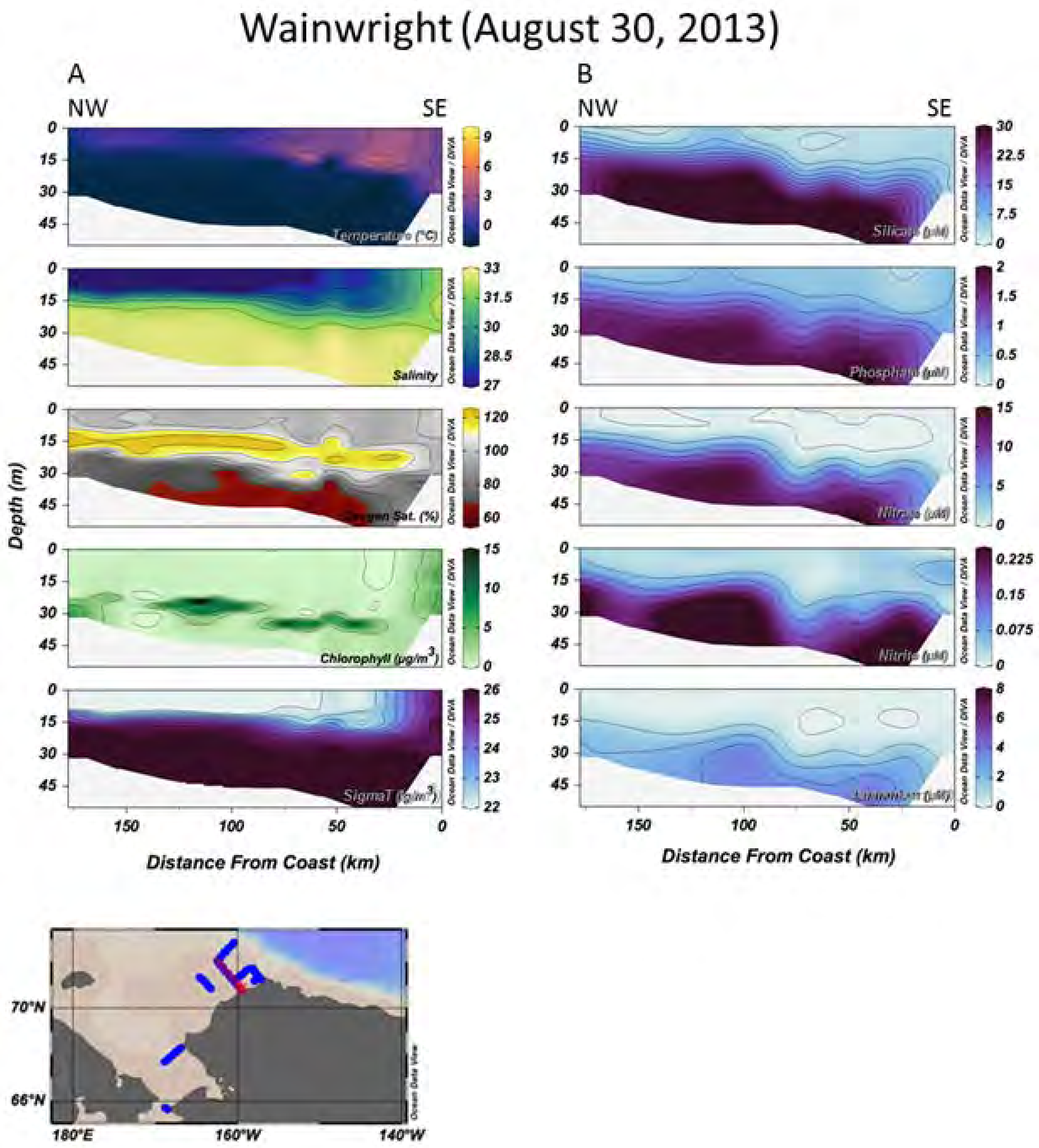


Figure 154. Hydrographic measurements at Wainwright in August 2013(A) Top to bottom: temperature, salinity, oxygen (percent saturation), chlorophyll fluorescence and SIGMA-T. (B) Top to bottom: the five nutrients (silicate, phosphate, nitrate, nitrite and ammonium). The coastline is on the right side of each plot. The line occupied is indicated in red in the bottom left panel.

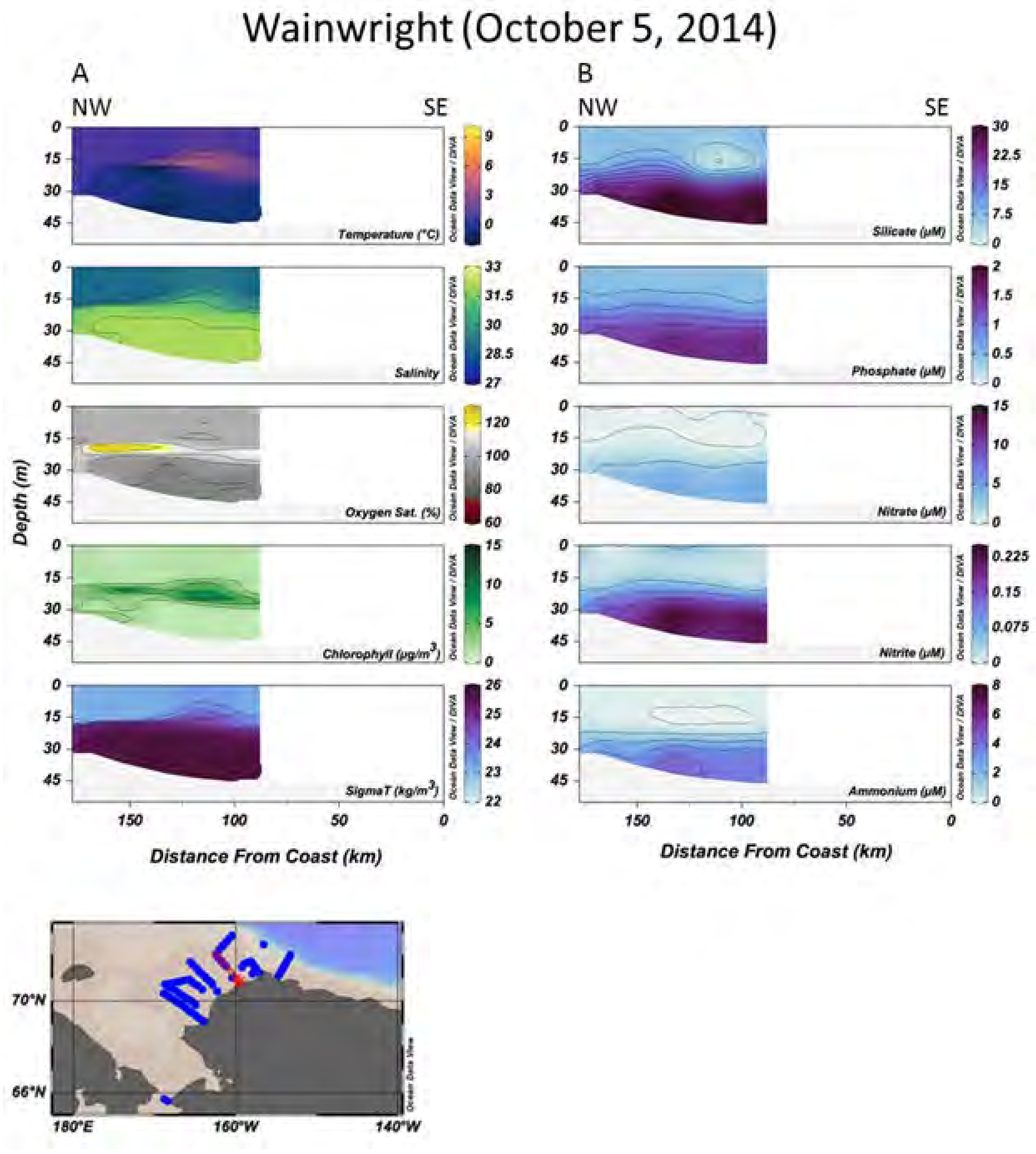


Figure 155. Hydrographic measurements at Wainwright in October 2014. (A) Top to bottom: temperature, salinity, oxygen (percent saturation), chlorophyll fluorescence and SIGMA-T. (B) Top to bottom: the five nutrients (silicate, phosphate, nitrate, nitrite and ammonium). The coastline is on the right side of each plot. The line occupied is indicated in red in the bottom left panel.

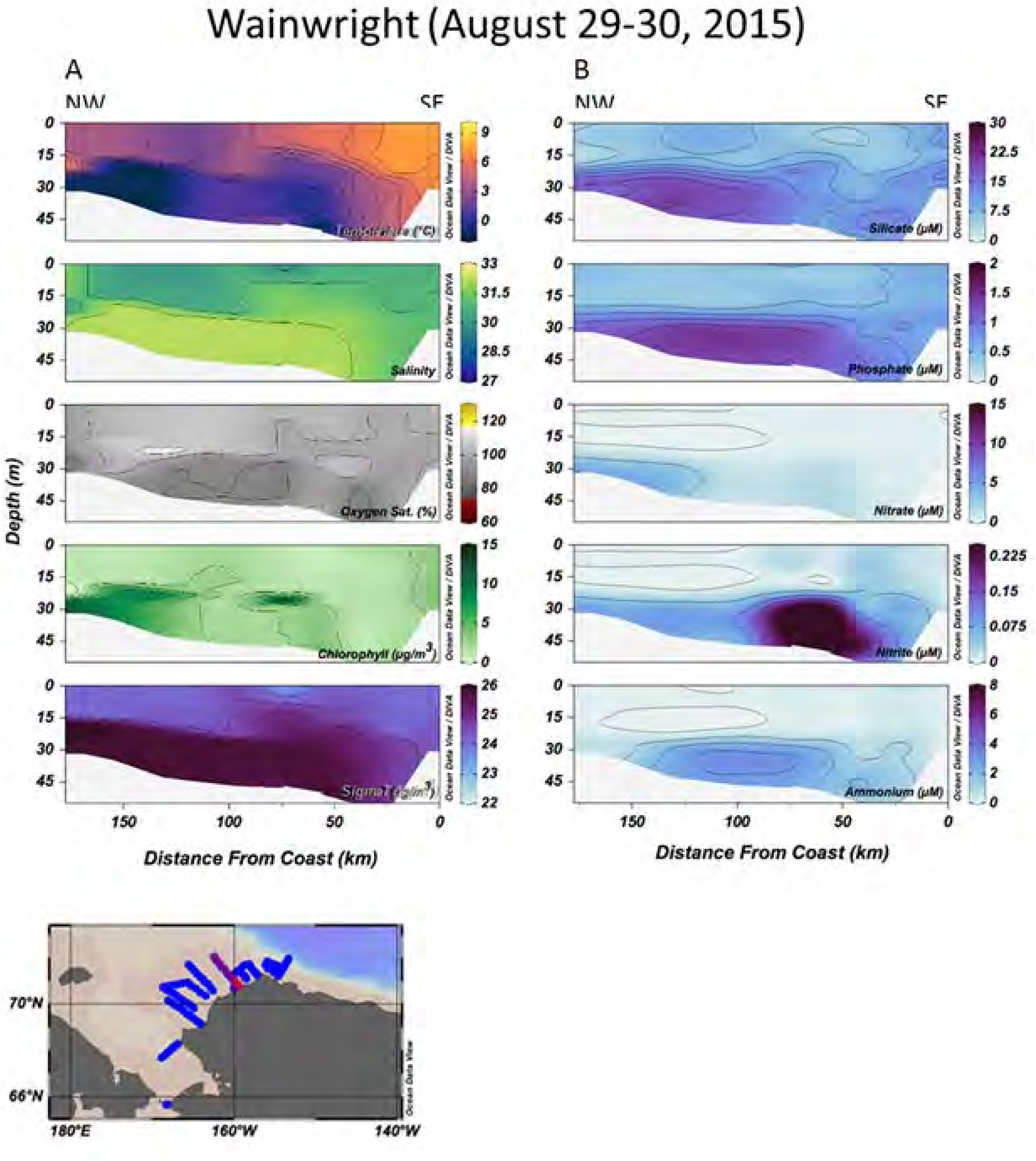


Figure 156. Hydrographic measurements at Wainwright in August 2015. (A) Top to bottom: temperature, salinity, oxygen (percent saturation), chlorophyll fluorescence and SIGMA-T. (B) Top to bottom: the five nutrients (silicate, phosphate, nitrate, nitrite and ammonium). The coastline is on the right side of each plot. The line occupied is indicated in red in the bottom left panel.

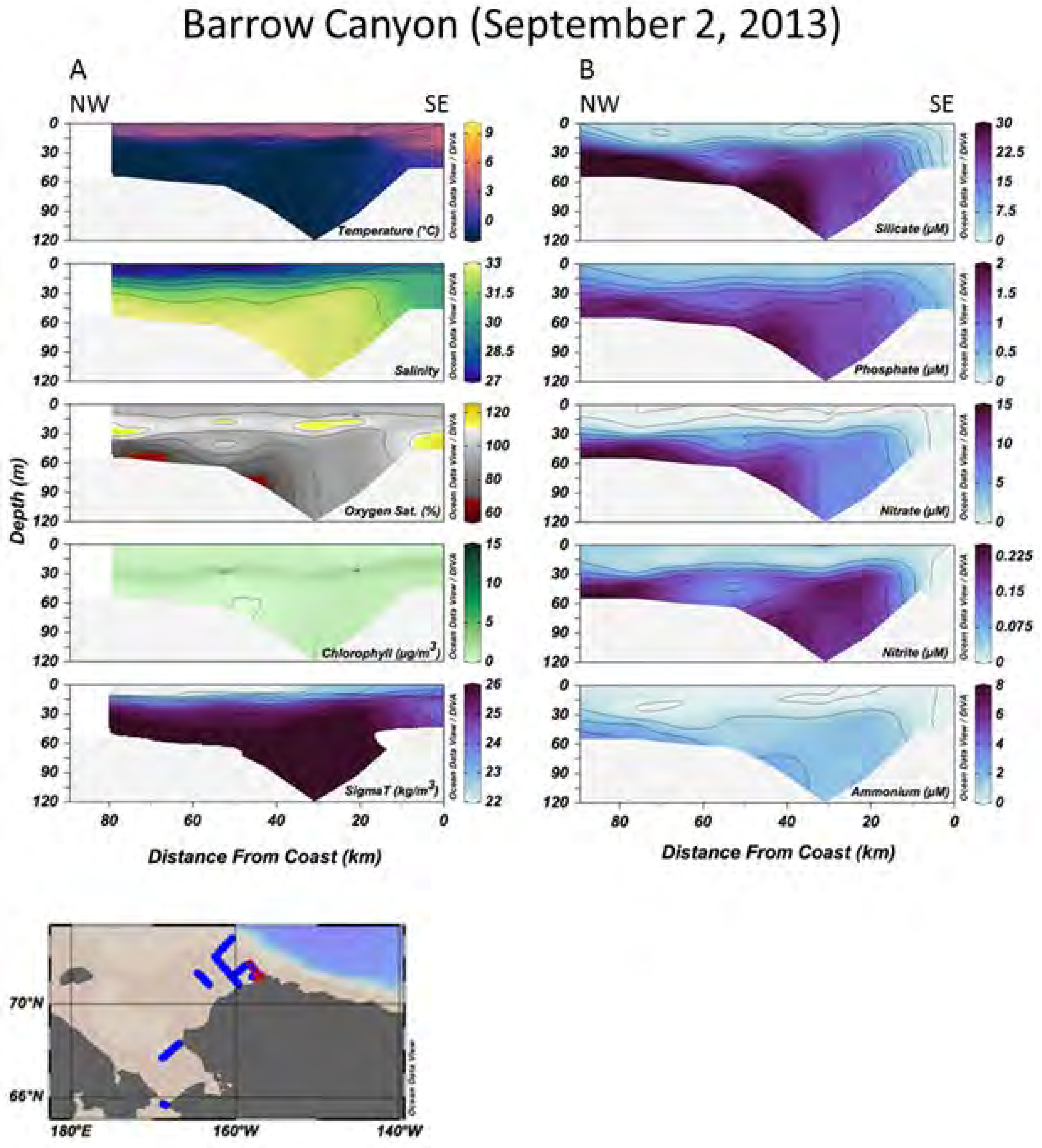


Figure 157. Hydrographic measurements at Barrow Canyon in August 2013. (A) Top to bottom: temperature, salinity, oxygen (percent saturation), chlorophyll fluorescence and SIGMA-T. (B) Top to bottom: the five nutrients (silicate, phosphate, nitrate, nitrite and ammonium). The coastline is on the right side of each plot. The line occupied is indicated in red in the bottom left panel.

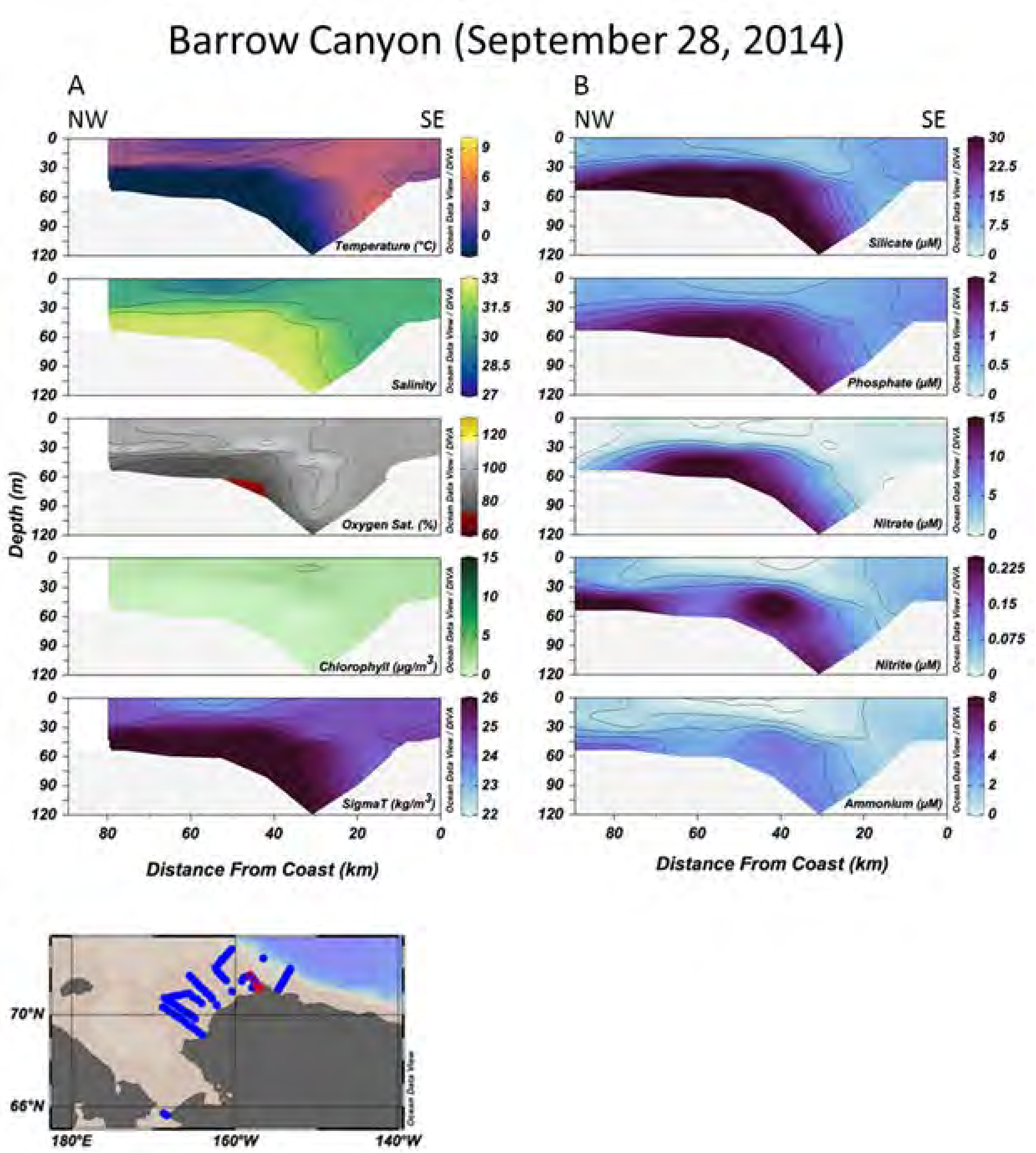


Figure 158. Hydrographic measurements at Barrow Canyon in September 2014. (A) Top to bottom: temperature, salinity, oxygen (percent saturation), chlorophyll fluorescence and SIGMA-T. (B) Top to bottom: the five nutrients (silicate, phosphate, nitrate, nitrite and ammonium). The coastline is on the right side of each plot. The line occupied is indicated in red in the bottom left panel.

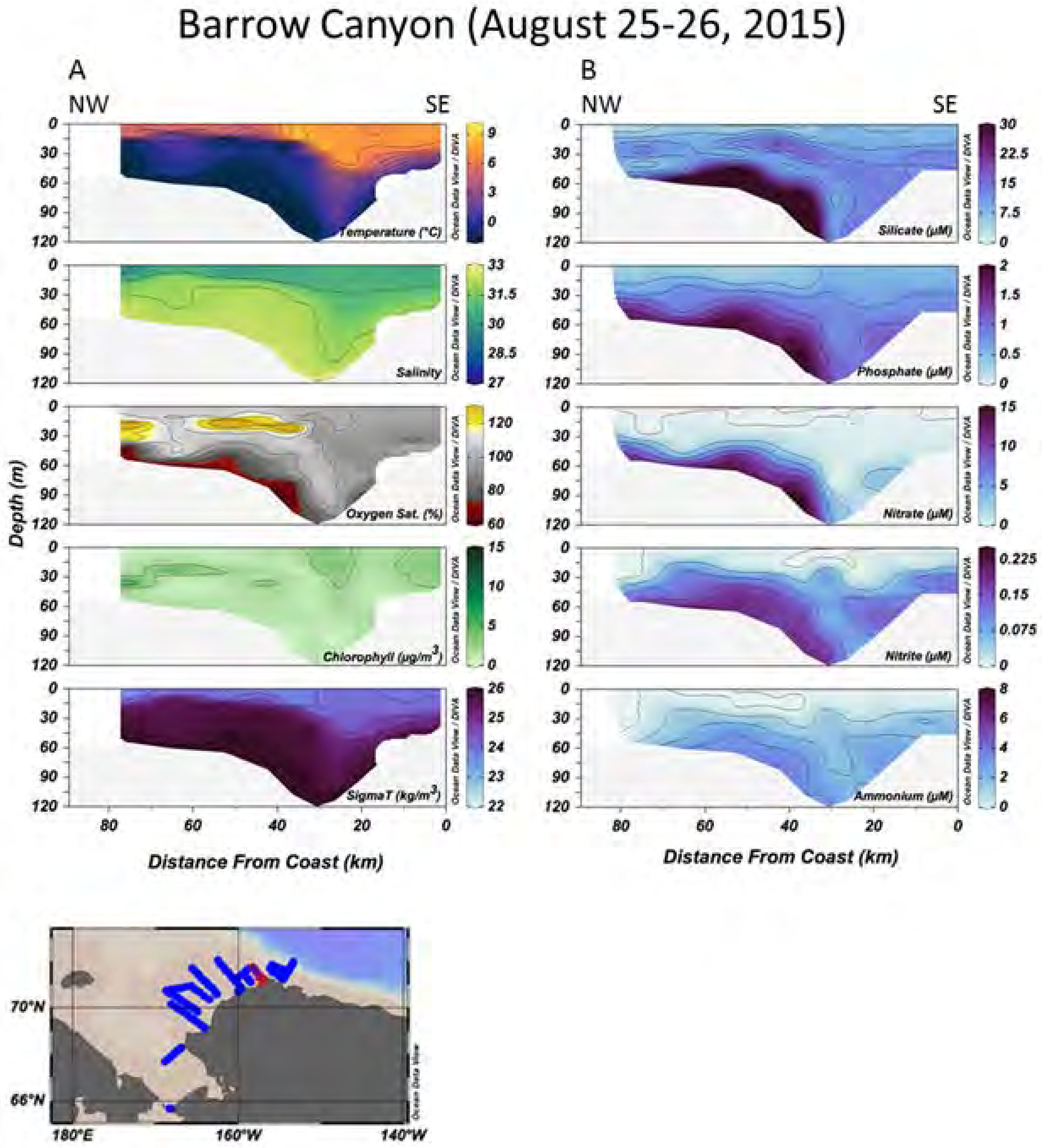


Figure 159. Hydrographic measurements at Barrow Canyon in August 2015. (A) Top to bottom: temperature, salinity, oxygen (percent saturation), chlorophyll fluorescence and SIGMA-T. (B) Top to bottom: the five nutrients (silicate, phosphate, nitrate, nitrite and ammonium). The coastline is on the right side of each plot. The line occupied is indicated in red in the bottom left panel.

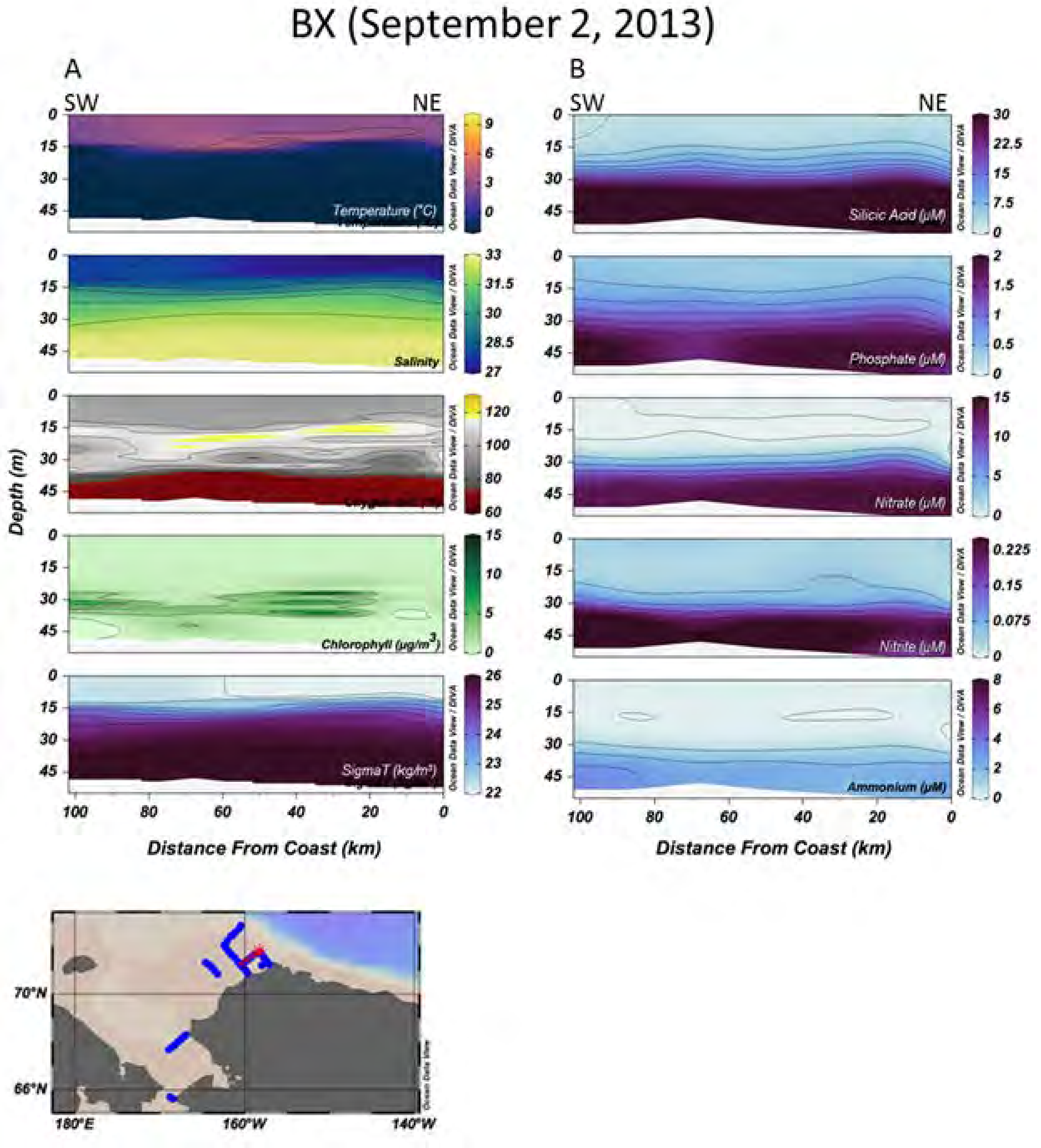


Figure 160. Hydrographic measurements along the BX line in September 2013. (A) Top to bottom: temperature, salinity, oxygen (percent saturation), chlorophyll fluorescence and SIGMA-T. (B) Top to bottom: the five nutrients (silicate, phosphate, nitrate, nitrite and ammonium). The northeastern point of the transect is on the right side of each plot. The line occupied is indicated in red in the bottom left panel.

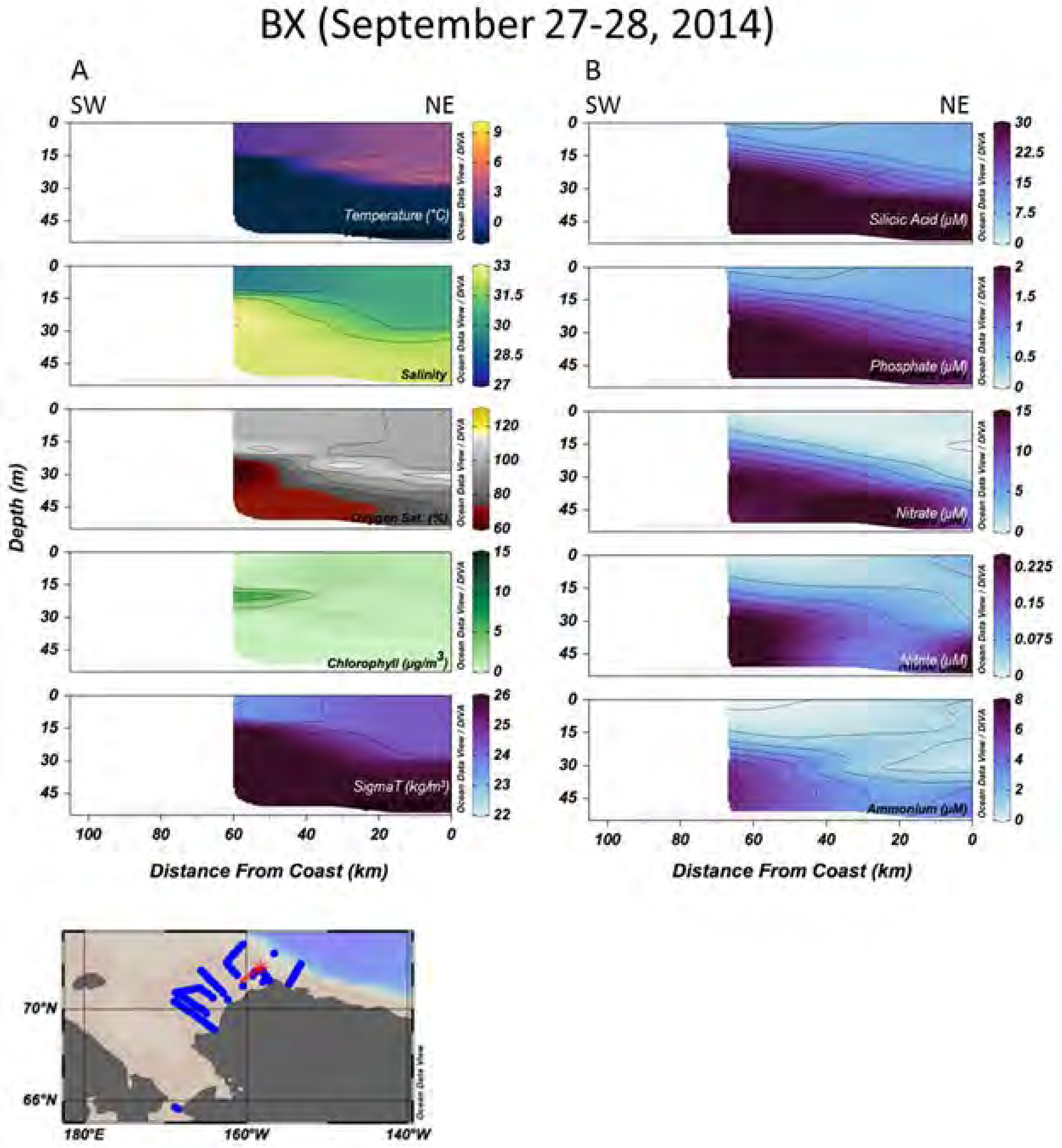


Figure 161. Hydrographic measurements along the BX line in September 2014. (A) Top to bottom: temperature, salinity, oxygen (percent saturation), chlorophyll fluorescence and SIGMA-T. (B) Top to bottom: the five nutrients (silicate, phosphate, nitrate, nitrite and ammonium). The northeastern point of the transect is on the right side of each plot. The line occupied is indicated in red in the bottom left panel.

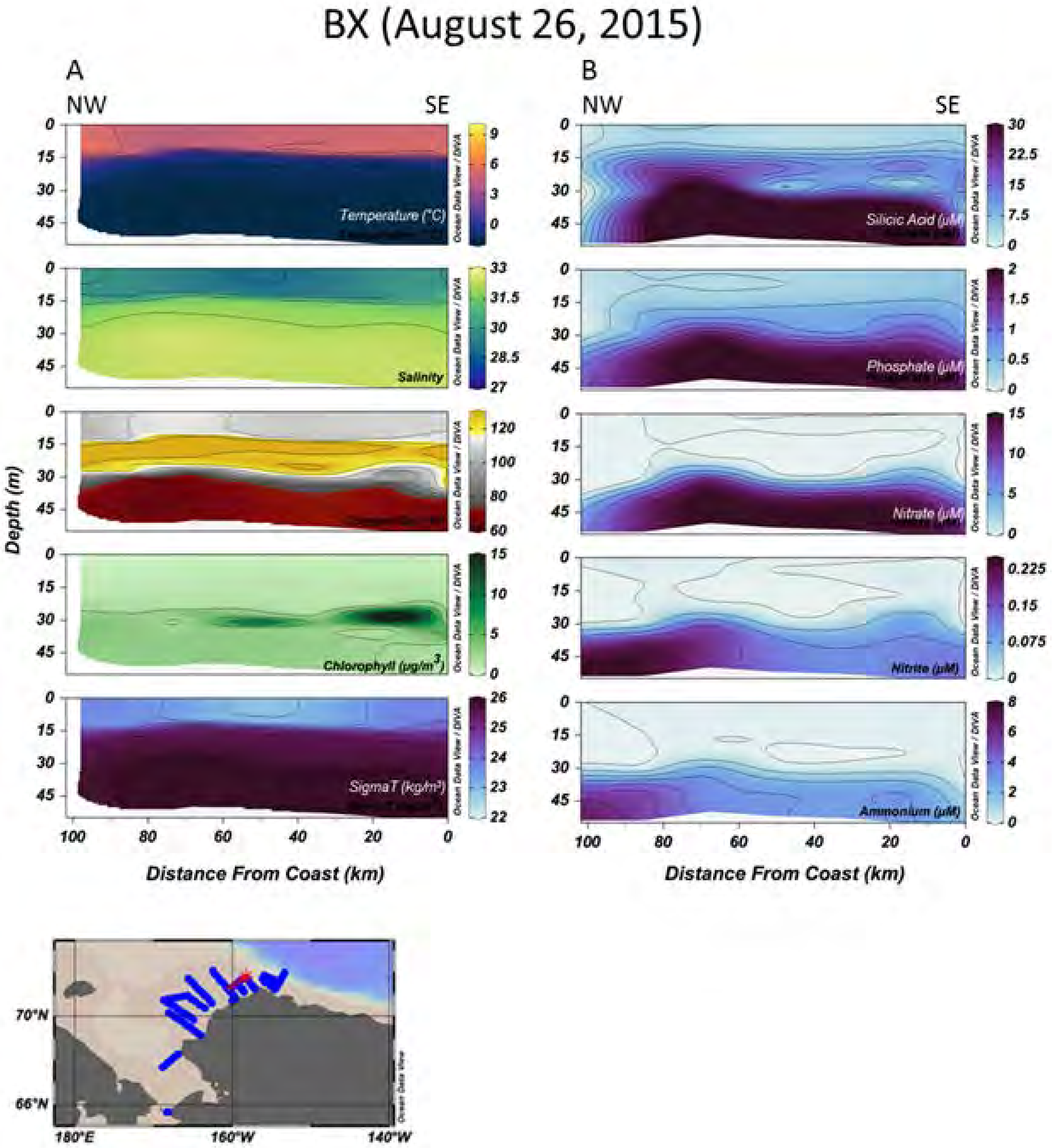


Figure 162. Hydrographic measurements along the BX line in August 2015. (A) Top to bottom: temperature, salinity, oxygen (percent saturation), chlorophyll fluorescence and SIGMA-T. (B) Top to bottom: the five nutrients (silicate, phosphate, nitrate, nitrite and ammonium). The northeastern point of the transect is on the right side of each plot. The line occupied is indicated in red in the bottom left panel.

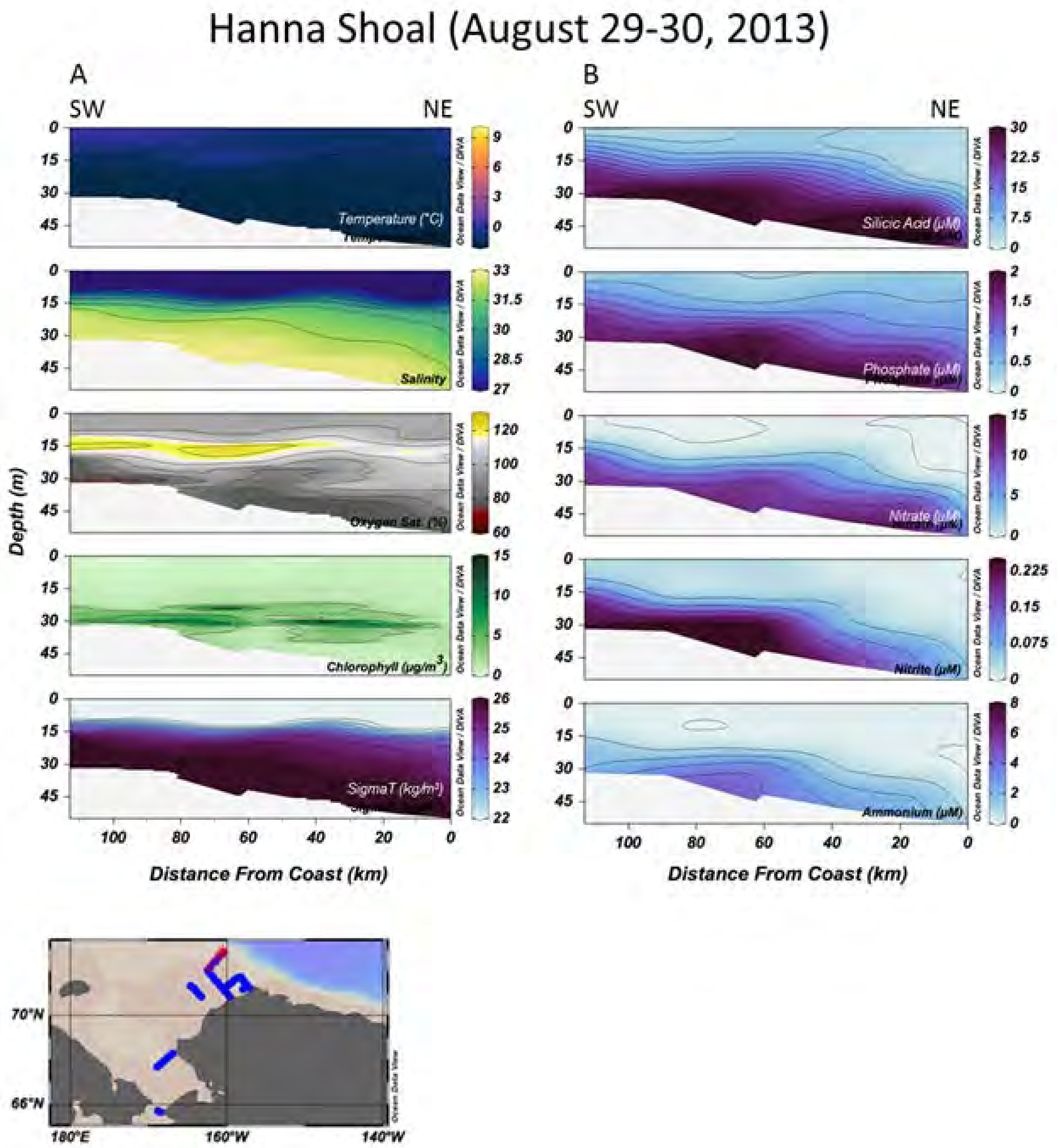


Figure 163. Hydrographic measurements along the Hanna Shoal line in September 2013. (A) Top to bottom: temperature, salinity, oxygen (percent saturation), chlorophyll fluorescence and SIGMA-T. (B) Top to bottom: the five nutrients (silicate, phosphate, nitrate, nitrite and ammonium). The northeastern point of the transect is on the right side of each plot. The line occupied is indicated in red in the bottom left panel.

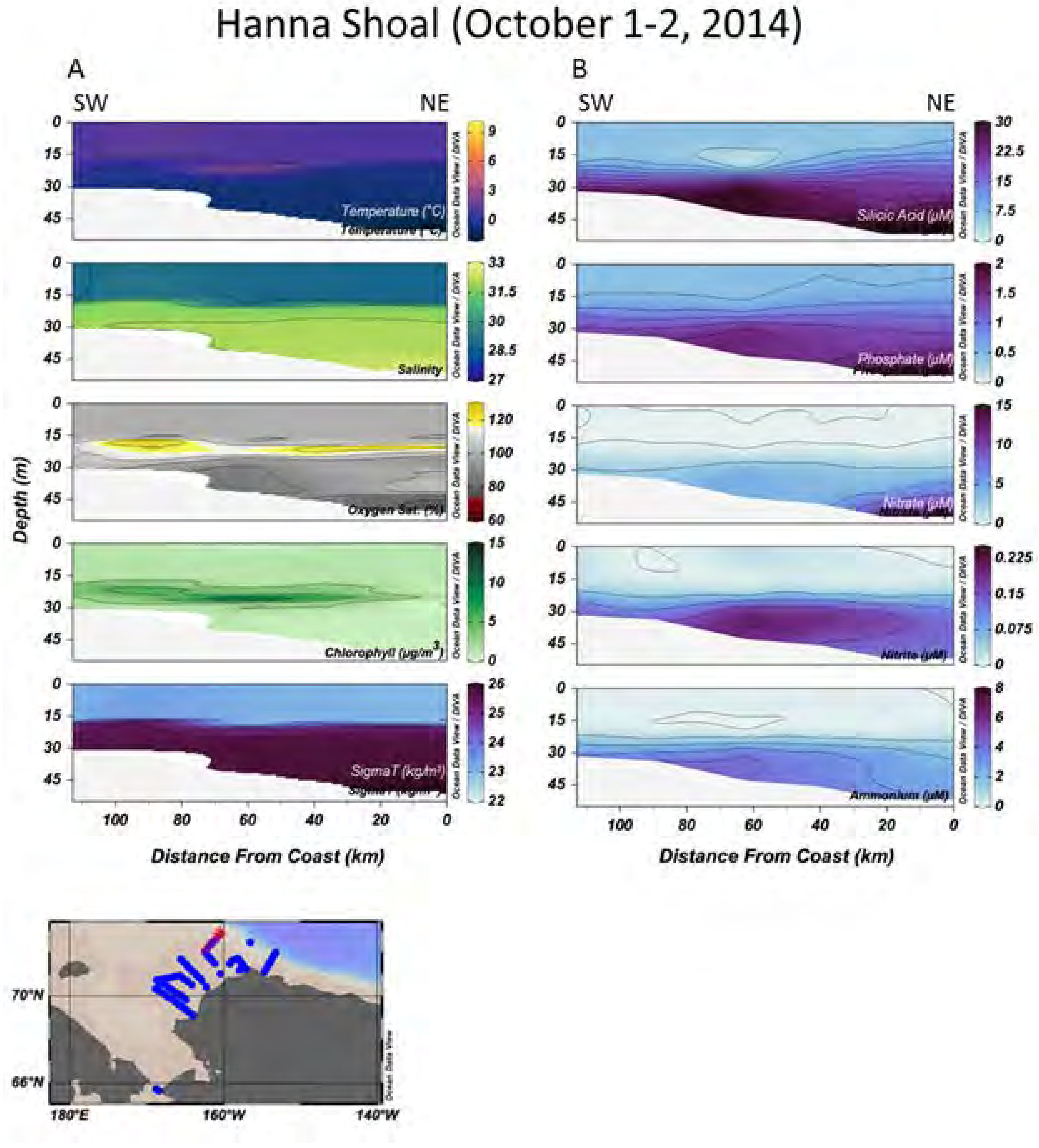


Figure 164. Hydrographic measurements along the Hanna Shoal line in October 2014. (A) Top to bottom: temperature, salinity, oxygen (percent saturation), chlorophyll fluorescence and SIGMA-T. (B) Top to bottom: the five nutrients (silicate, phosphate, nitrate, nitrite and ammonium). The northeastern point of the transect is on 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 ship time, and ice distribution (Figure 165). 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 (± 0.06) mg m^{-3} in 2014 (Table 48). Annual means were significantly different from each other ($p < 0.001$; Analysis of Variance (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 the depth distribution 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 CkA-C transects (Figure 165). 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.

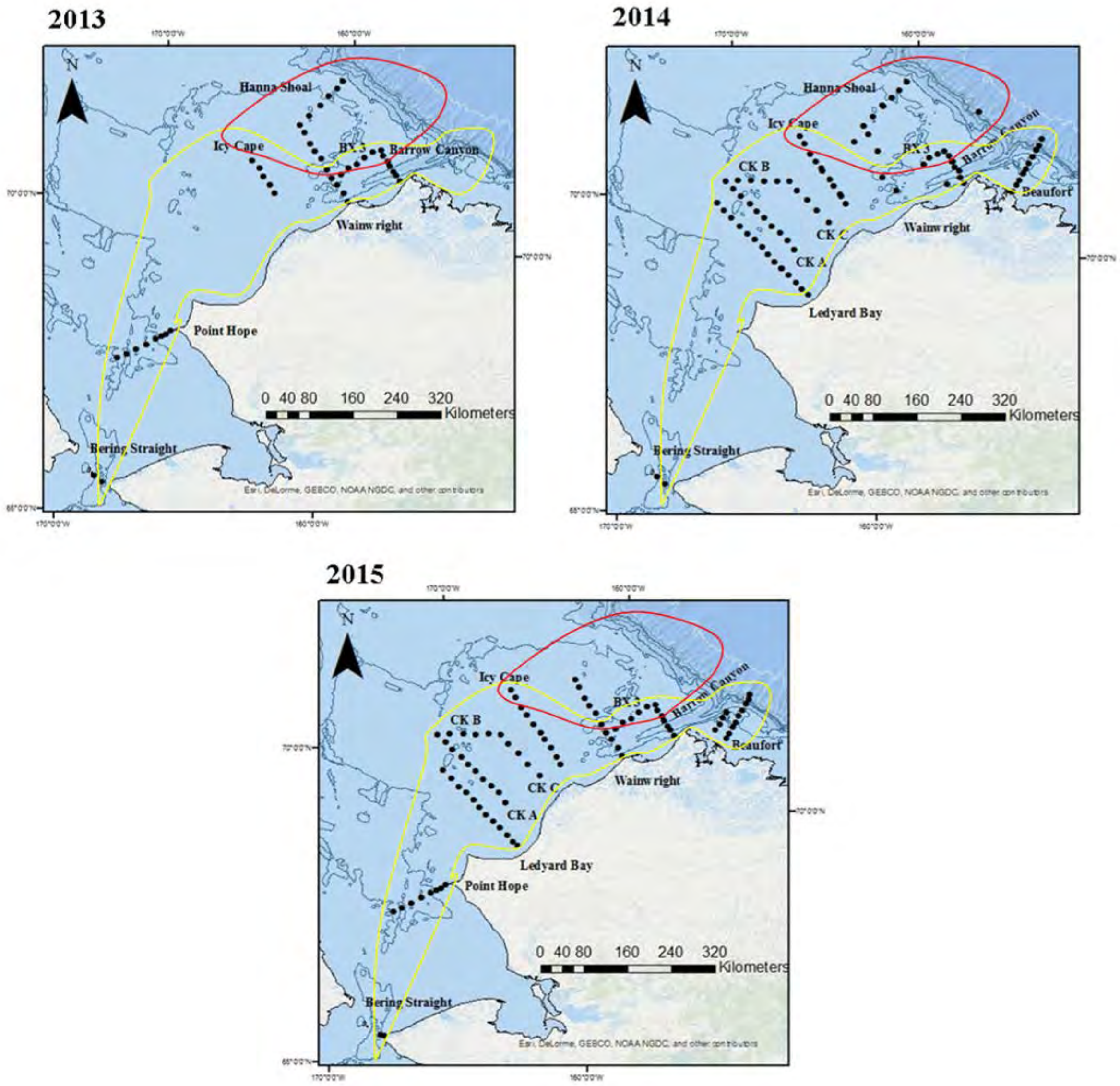


Figure 165. Transects where discrete depth chlorophyll samples were taken during the ARCWEST and CHAOZ-X field surveys (2013-2015).

Table 48. 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 49). 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 had its highest mean in 2013.

Table 49. 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 166-168). Each plot starts near shore (right margin) and continues to the end of transects (up to700 km offshore, left margin). Transects which run parallel to shore are oriented southwest (right side) to northeast (left side; BX, CkB, HS).

The 2013 transect maps (Figure 166) reflect large subsurface patches of higher than average chlorophyll (mg m^{-3}) approximately 50-100 km long. The subsurface patches are consistently centered near 30 m 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 167) except Hanna Shoal (HS) and BX, do not show large subsurface chlorophyll maxima, instead show chlorophyll maxima near surface and patch length extending across more stations than 2013. 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 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 168). At this location the shelf is shoaling as it approaches Hanna Shoal.

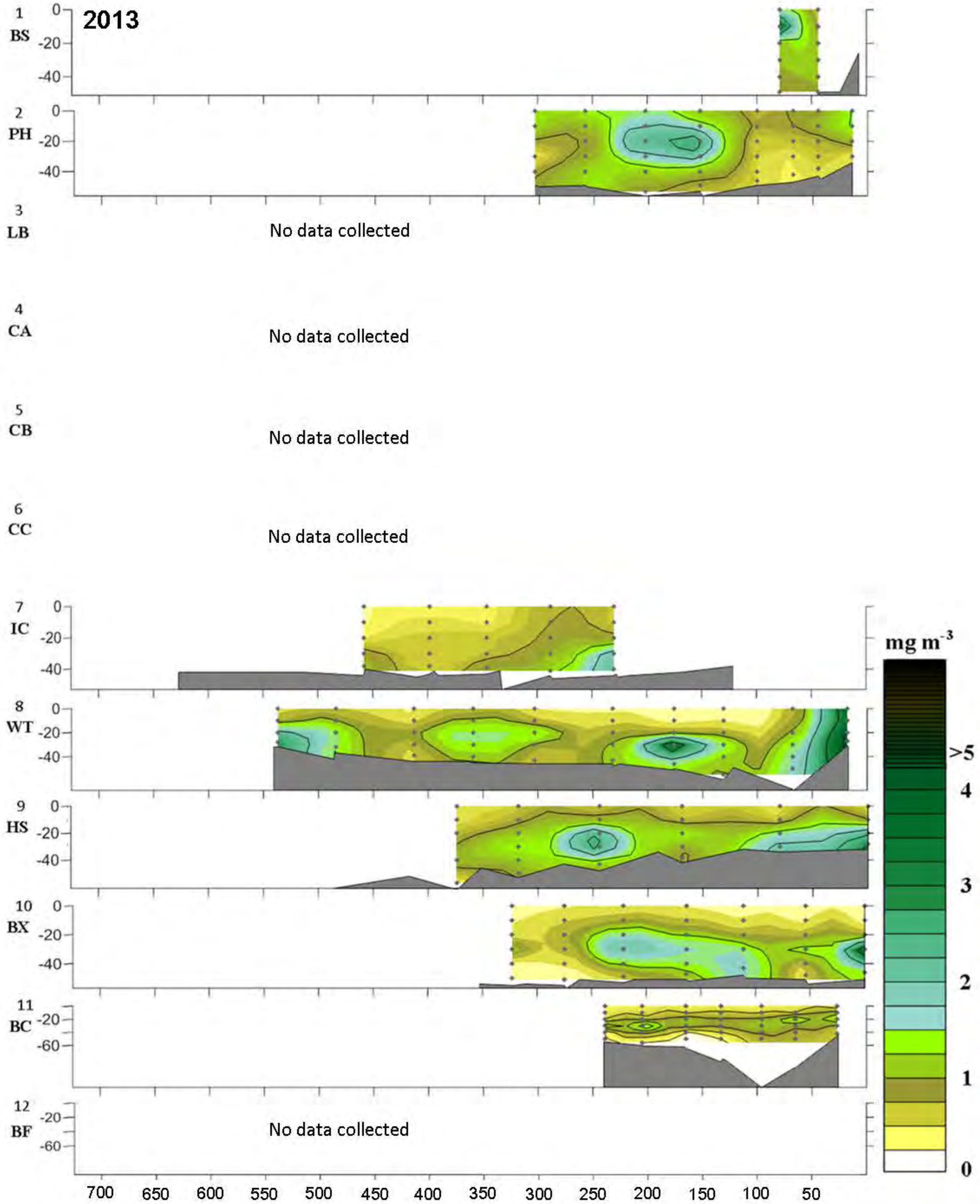


Figure 166. Section plots of chlorophyll-a concentration (mg m^{-3}) along transects sampled in 2013. Twelve unique transects were surveyed, but transects sampled among years varied. Dark diamonds (⬩) denote collection depths.

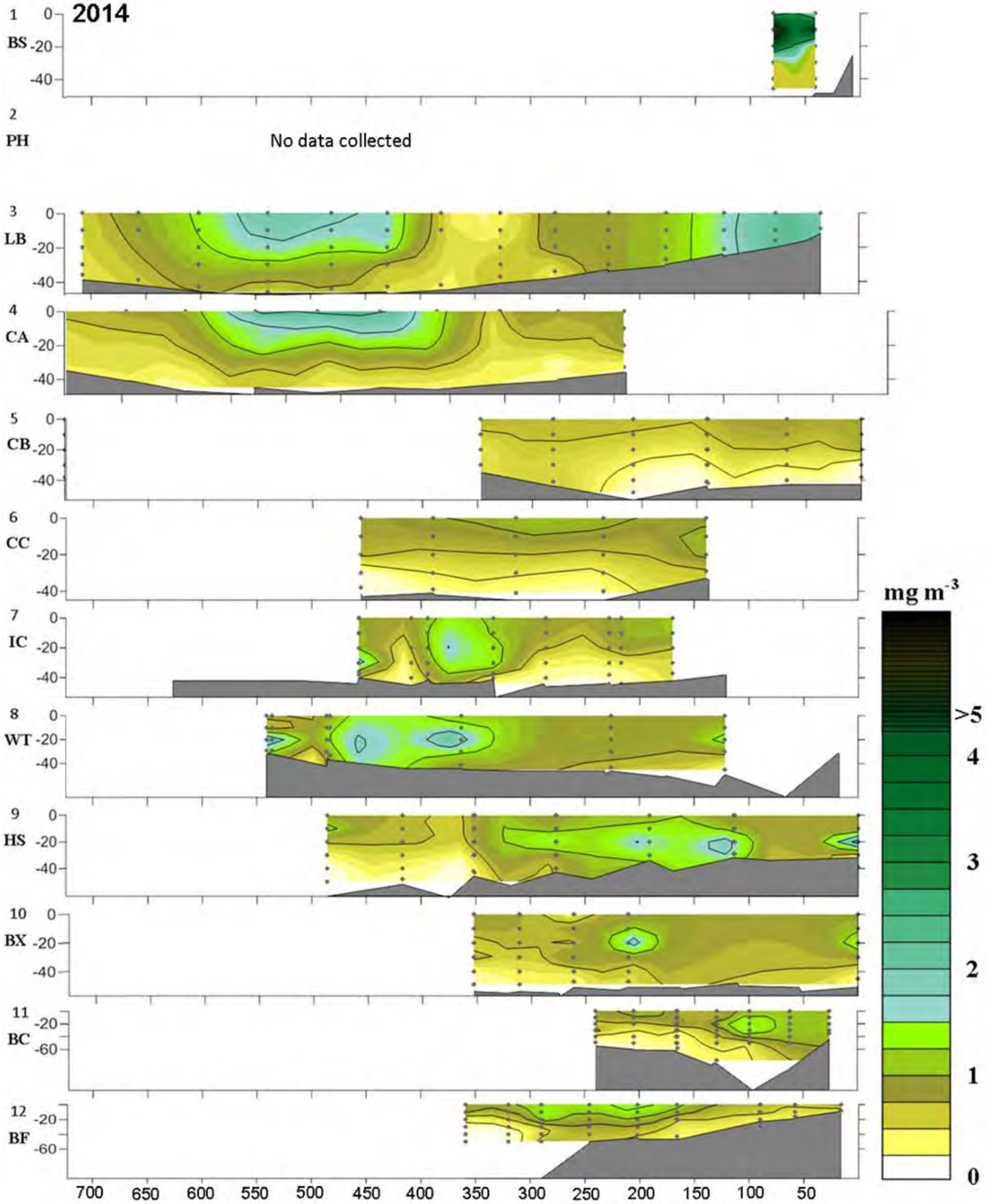


Figure 167. Section plots of chlorophyll-a concentration (mg m^{-3}) along transects sampled in 2014. Twelve unique transects were surveyed, but transects sampled among years varied. Dark diamonds (♦) denote collection depths.

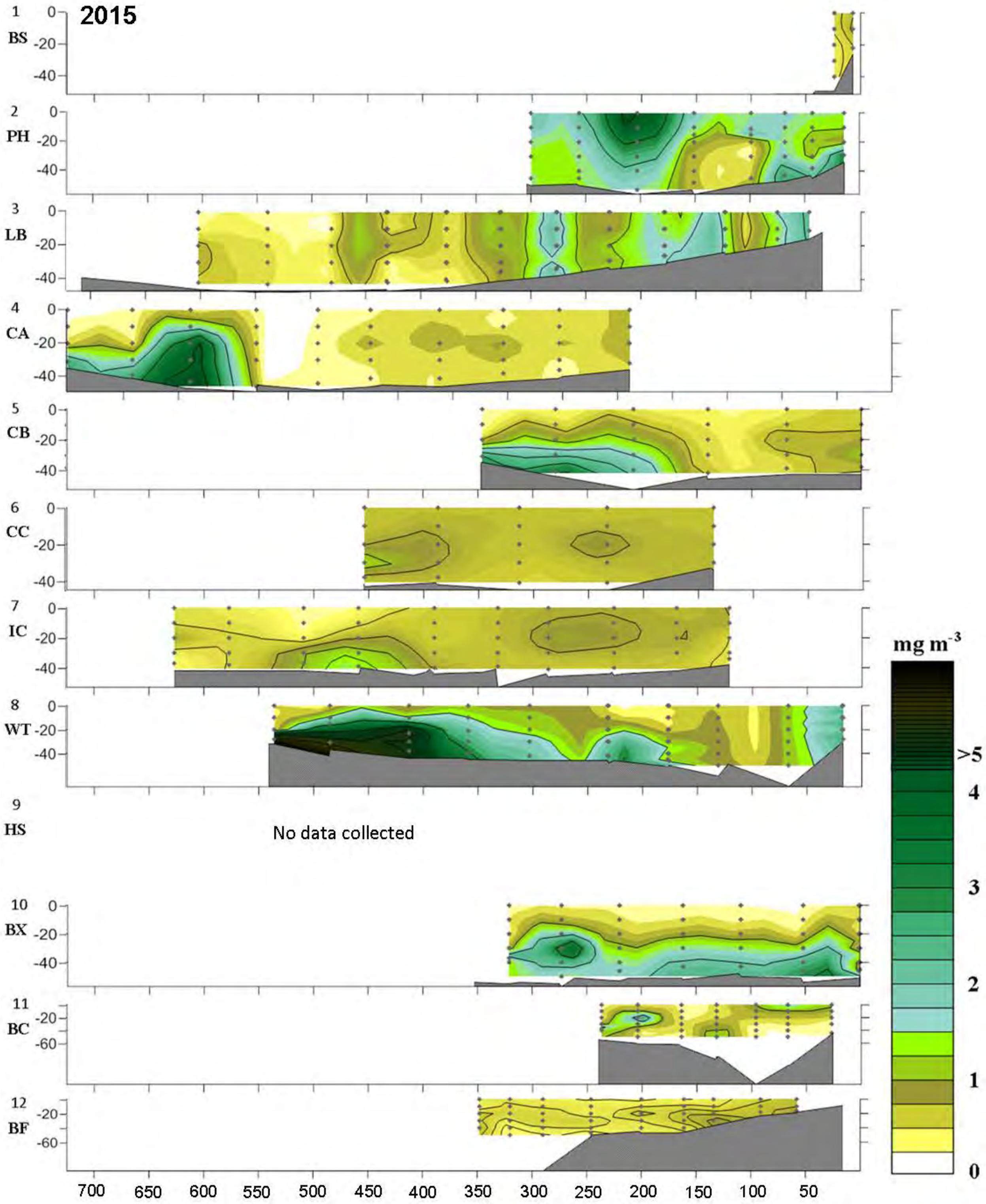


Figure 168. Section plots of chlorophyll-a concentration (mg m^{-3}) along transects sampled in 2015. Twelve unique transects were surveyed, but transects sampled among years varied. Dark diamonds (⬩) denote collection depths.

SCMs were identified for each year following methods of Martini (2016). The SCM threshold (i.e., the chlorophyll concentration that must be equaled or exceeded for a station/depth to be considered part of the SCM) was highest in 2014 (1.62 mg m^{-3}) and lowest in 2013 (1.03 mg m^{-3}; Table 41). Values under the determined SCM threshold were not displayed nor were the near-shore (<50 km) stations, where the SCM breaks down due to mixing. The percentage of stations with a SCM were highest in 2013 (Figure 166), 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 showed SCM emerged at 10-20 m depth and extended to near bottom. The Barrow Canyon transect SCM resided in the same depth strata as the other transects but did not extend to the near bottom where average bottom depth was 75.7 m. In 2014, the SCM nearly disappeared from all stations, where only 18% of the stations met or exceeded the threshold (Figure 167). When chlorophyll maxima were present they occurred at the surface or at 20 m depth. It's possible that the 2014 data were showing that stable SCM patches were starting to degrade by October through seasonal oceanographic processes. The SCM in 2015 exhibited patterns observed in both 2013 and 2014 (Figure 168). In 2015, the highest chlorophyll concentration values of all three years were recorded, but met the threshold for SCM's at only 39% of the stations. The Ledyard Bay (LB) 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 (IC), and Beaufort (BX, BC, BfA) 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 three differing collection categories. The three categories were: small zooplankton and large zooplankton from the oblique portion of the tow; and large benthic organisms from the portion of the tow when the sled was on the seafloor. Small zooplankton taxa/stages were those enumerated from the 153 µm mesh; 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 2mm 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%. Benthic organisms, collected using a 505 µm mesh, were numerically dominated by organisms similar to the large zooplankton category. 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 x 106 m^{-2}), and highest in 2014 (1.95 x 107 m^{-2}) for a range of about 5x among the 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. *Thysanoessa raschii* percent of the total integrated abundance was highest in 2014 at 11.6%, but comprised less than half a 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 comprising 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 stations where the abundance was well above average, however stations along the Ledyard Bay and Hanna Shoal transects had above average abundances. In 2015 there were several stations where the abundance was greater than average; two on the Ledyard Bay transect and several on the Barrow Canyon transect (BC, Figure 169). 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 transect. Abundances of appendicularians over Hanna Shoal were generally below the mean in 2013 and above in 2014; while abundances in the Beaufort Sea were generally higher in both years. Bivalve larvae had their highest integrated abundances in 2014 and relatively low abundances in 2013 and 2015 across all stations where zooplankton were collected.

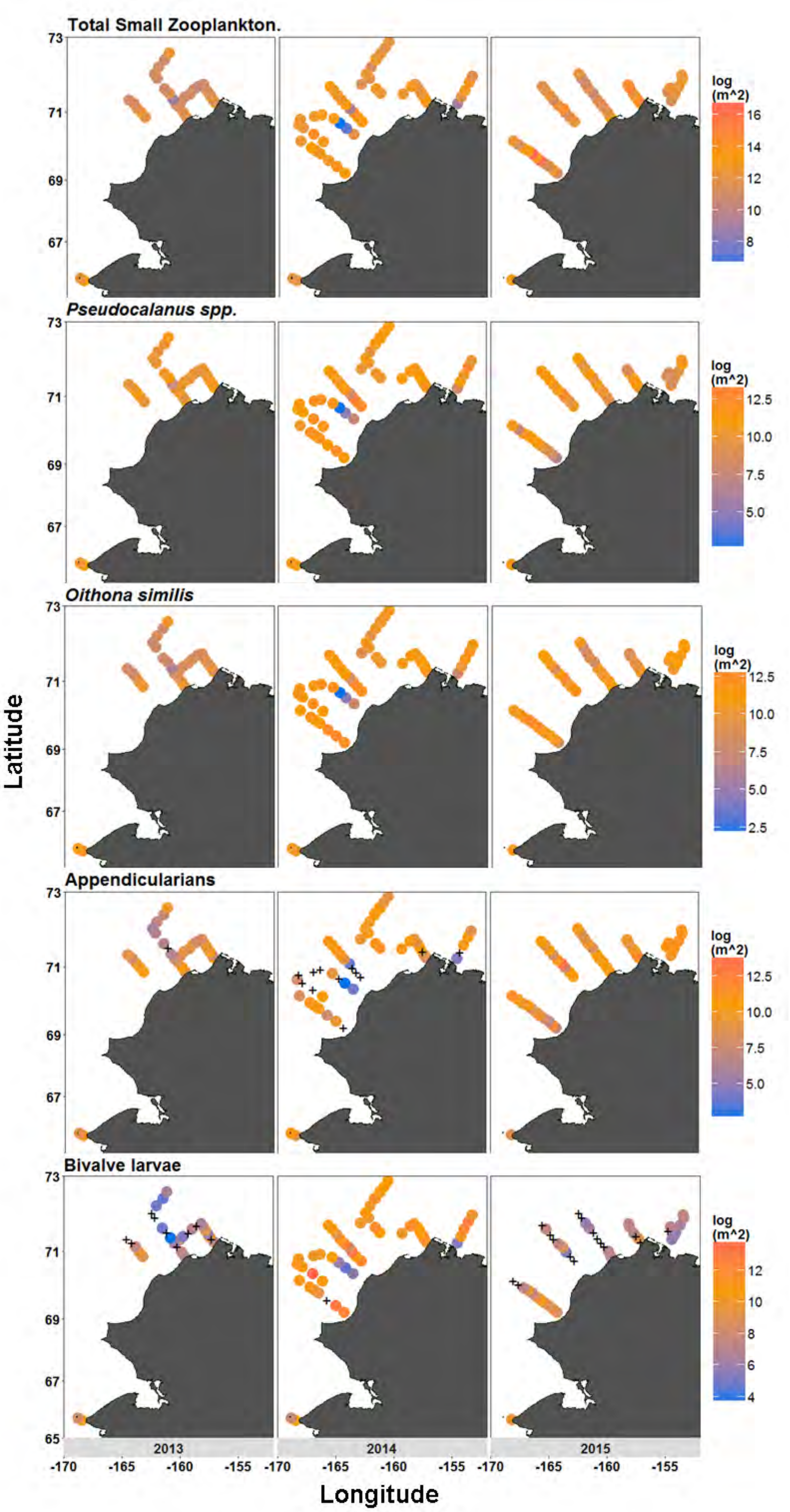


Figure 169. Integrated abundance (log no. m^{-2}) of selected small zooplankton taxa along ARCWEST and CHAOZ-X transects (2013 – 2015). First column is 2013; middle column 2014; and third column is 2015. Color scale indicates absolute values (log no. m^{-2}) and yellow is the average abundance for that taxon over the three years. The "+" symbol denotes tows were 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 170). *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 Ledyard Bay, Icy Cape, and Beaufort Sea lines. The highest integrated abundances were found in the middle 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 2015 high average abundances were found at the center of the Ledyard Bay transect.

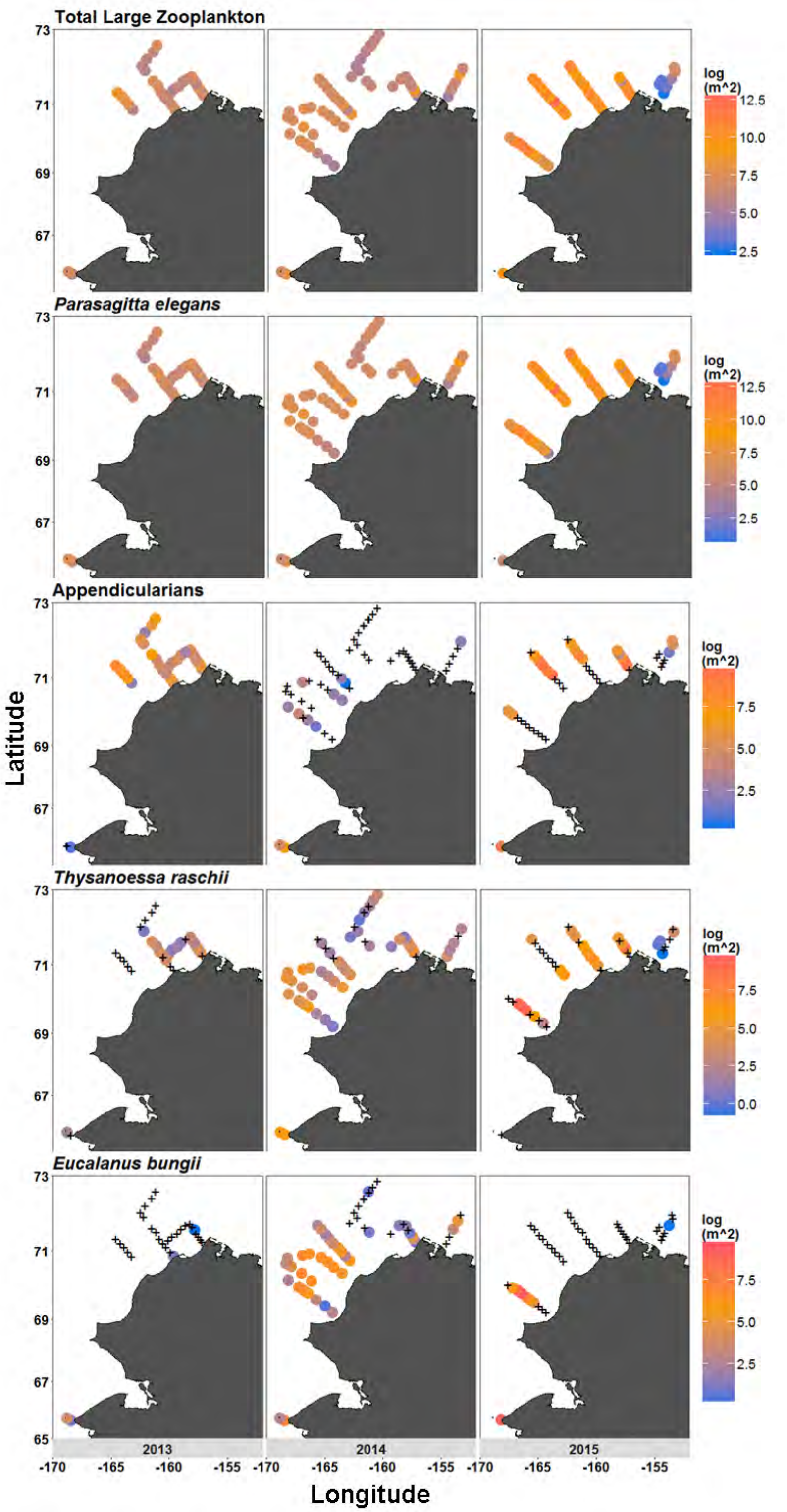


Figure 170. Integrated abundance (log no. m^{-2}) of selected large zooplankton taxa along ARCWEST and CHAOZ-X transects (2013 – 2015). First column is 2013; middle column 2014; and third column is 2015. Color scale indicates absolute values (log no. m^{-2}) and yellow is the average abundance for that taxon over the three years. The "+" symbol denotes tows were 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 different abundance patterns than their water column counterparts (Figure 171). 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 taxonomic 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. The area of highest above average abundance was near the middle of the Icy Cape line.

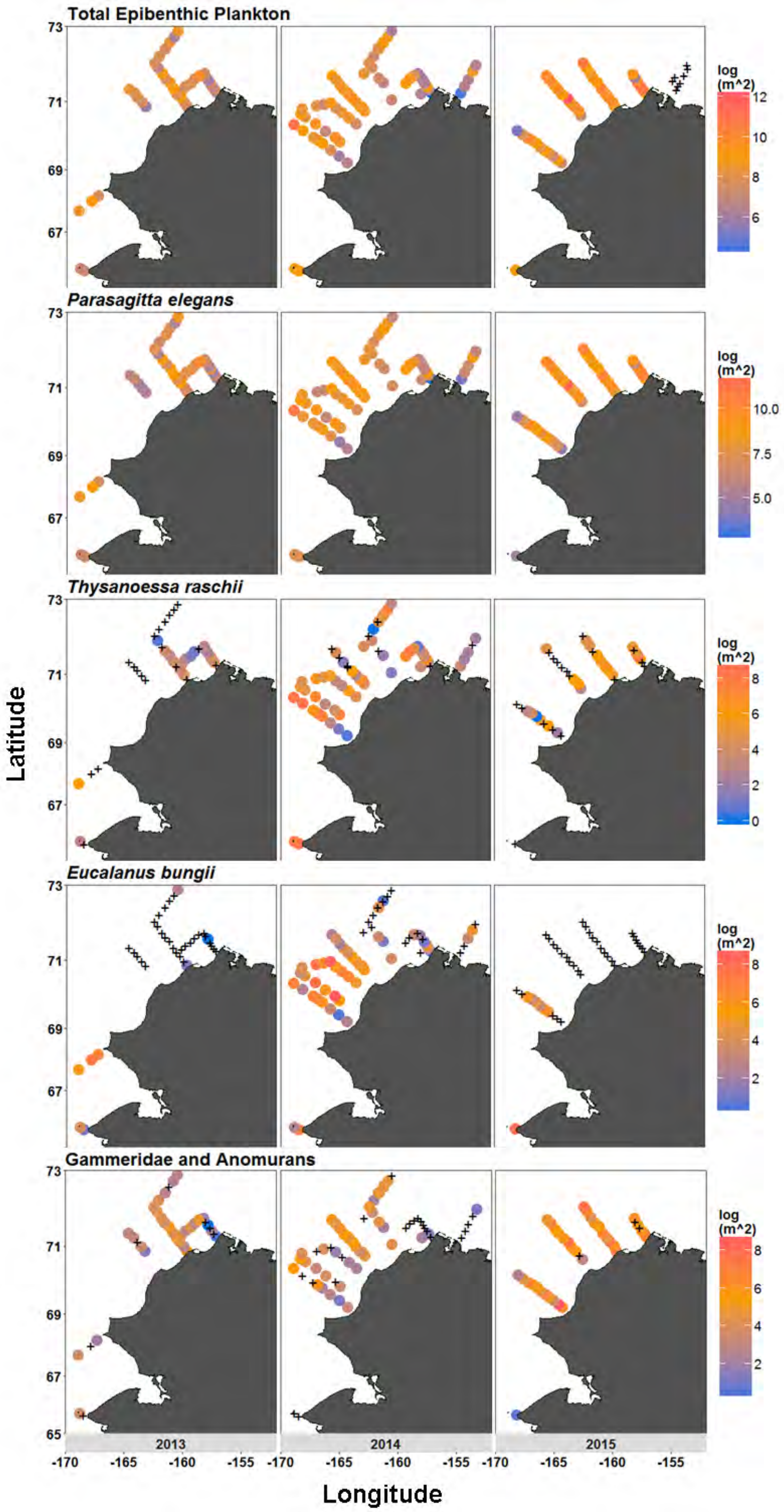


Figure 171. Integrated abundance (log no. m^{-2}) of selected epibenthic zooplankton taxa along ARCWEST and CHAOZ-X transects (2013 – 2015). First column is 2013; middle column 2014; and third column is 2015. Color scale indicates absolute values (log no. m^{-2}) and yellow is the average abundance over the three years. The "+" symbol denotes tows were 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*, *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 plus 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 172). 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 (0.63). *Calanus* and *Neocalanus* were also positively correlated with each other (0.57). Lastly, *Pseudocalanus* and appendicularians were positively correlated (0.36).

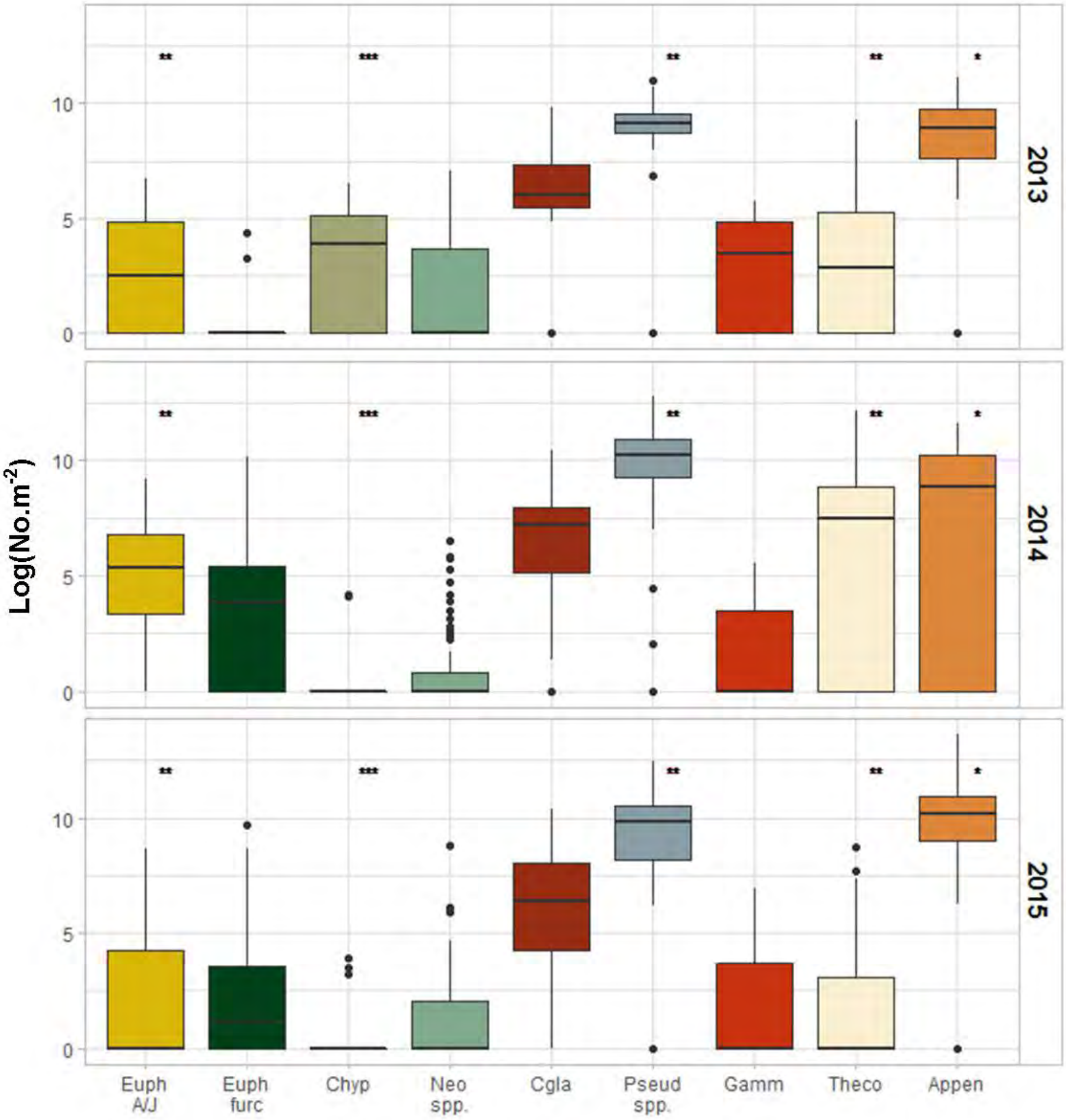


Figure 172. Box plots of the Log integrated abundances for selected zooplankton and epibenthic species by year. Abbreviations for taxa groups are: Euph A/J = Euphausiid Adults and juveniles, Euph furc = Euphausiid furcilia, Chyp = *Calanus hyperboreus*, Neo spp. = *Neocalanus flemingeri* and *N.plumchrus*, 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 GAM was used to determine spatial patterns and associations with environmental variables to the abundance anomalies of *Calanus glacialis*, CV. 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 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 at the offshore ends of the Pt. Hope, CkA and Icy Cape lines, the middle of the Icy Cape line and the inner portion of the Wainwright line (Figure 173). Low abundances were predicted for the inner portions of the Cape Lisburne, Pt. Hope, and Ledyard Bay transects (ACC water), Hanna Shoal, and the BX transect.

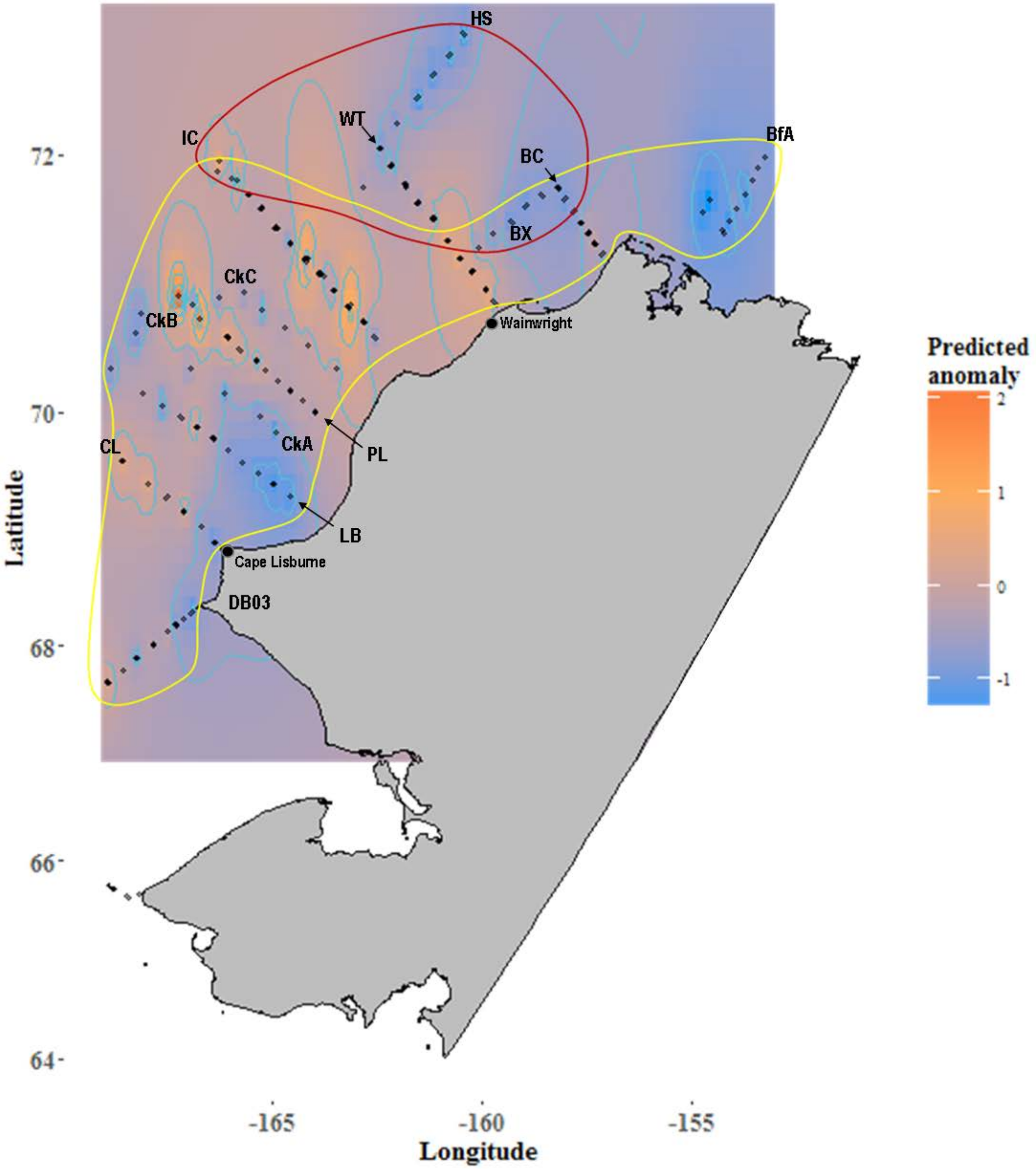


Figure 173. Modeled spatial distribution anomaly of *Calanus glacialis* CV, 2010 - 2015.

Zooplankton community analysis

Cluster analysis and NMDS 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 174). Cluster Groups 3 was observed in all three years, but only at a few stations each year (Figure 175). Cluster Group 4 dominated the survey area in 2014 and was prominent along the Ledyard Bay transect in 2015. The lack of any inter-annual similarity among cluster groups, shows that inter-annual 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 available data were scarce, Hanna Shoal did not appear to support a distinct zooplankton assemblage.

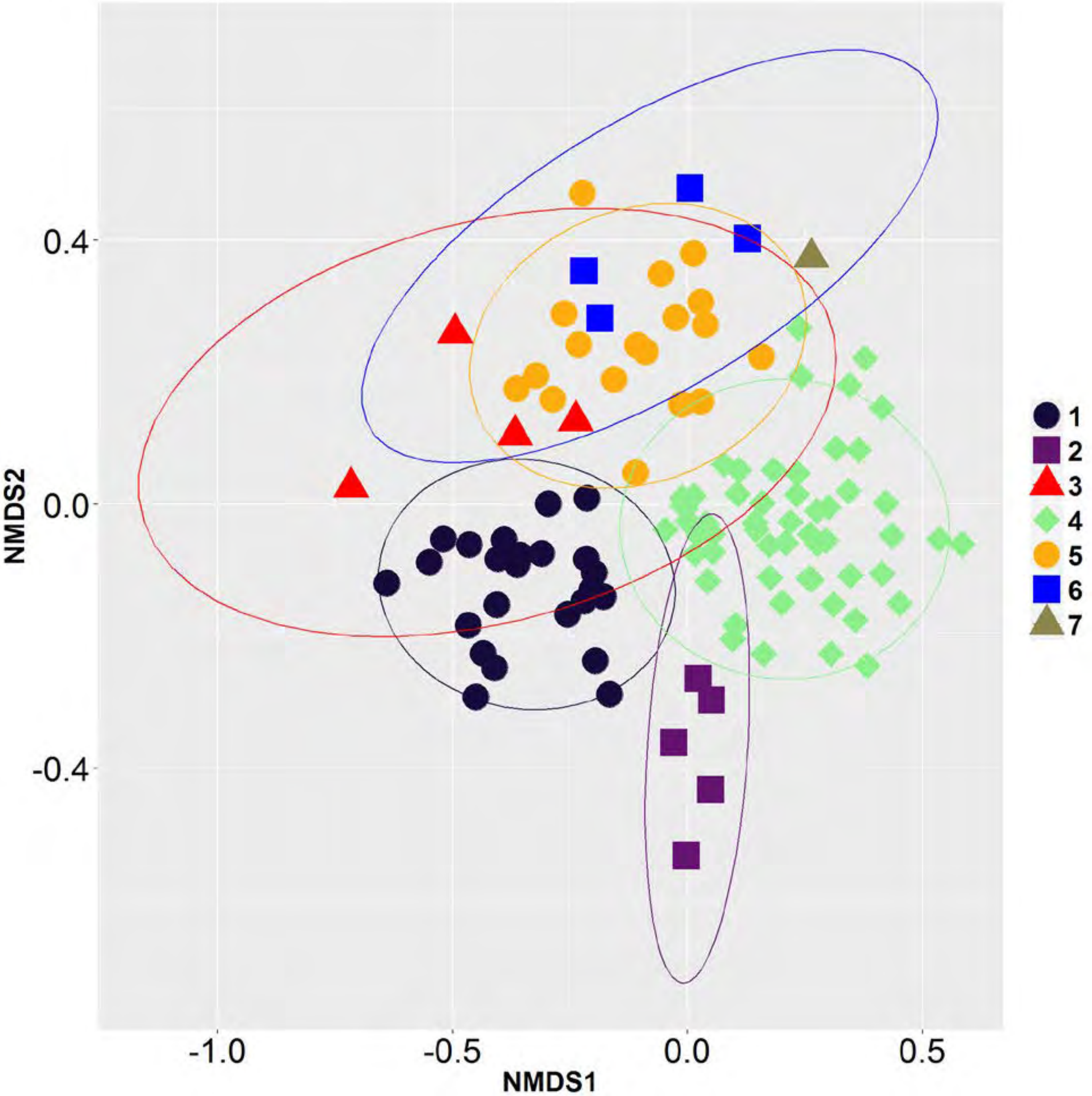


Figure 174. NMDS plot of zooplankton abundance (2013-2015). The analysis identified 7 zooplankton assemblages or clusters.

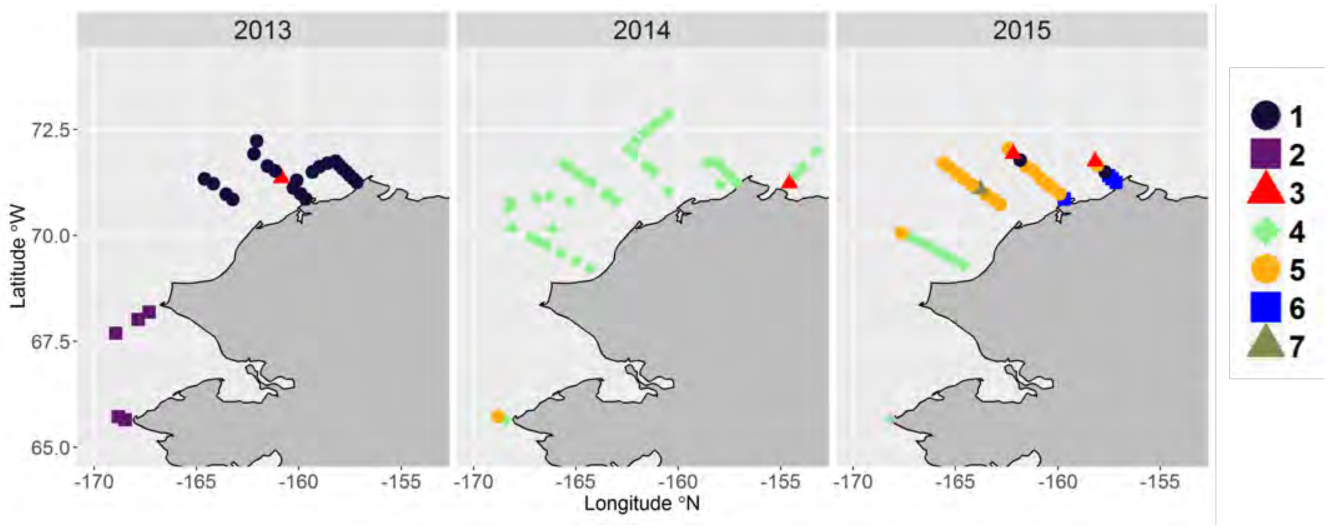


Figure 175. Distribution of the seven zooplankton assemblages by year.

It is instructive to examine the composition of each zooplankton assemblage to better understand how the assemblages vary across the region. For this we separated the analysis of each cluster group or assemblage by taxon size (represented by either the large or small mesh nets, Figures 176-177). Cluster Group 1 was distinguished from other assemblages by the high relative proportion of *C. glacialis*, *Pseudocalanus spp*., and polychaete larvae from the small mesh nets (Figure 176). Cluster Group 2 was distinguished from other assemblages by the high proportion of *Metridia pacifica/lucens* and *Oithona* spp. (small fraction) and *Themisto libellula* (large fraction; Figure 177). Cluster Group 3 was distinguished from the over groups by the large contribution of *Fritillaria* spp., Cirripedia (barnacle) larvae and the low proportion of *Oithona* spp. The euphausiid, *Thysanoessa raschii* was also important contributor to the assemblage (large fraction). Cluster Group 4 had a high relative contribution by 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 and 6, respectively. Anomuran larvae (Family Paguridae) were relatively more abundant in Group 6 than the other groups (large fraction).

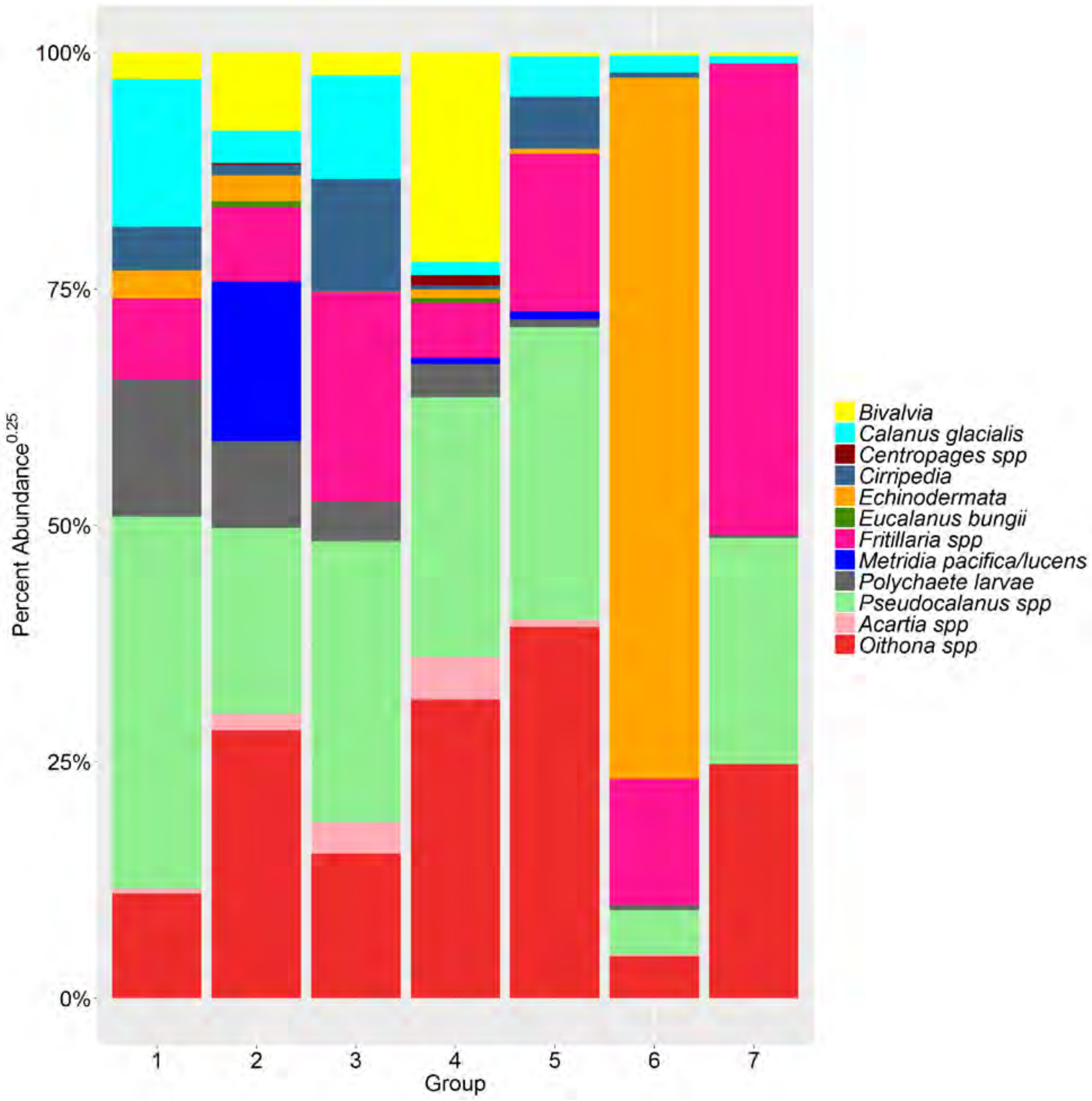


Figure 176. Percent composition of small mesh taxa from the 7 major zooplankton assemblages identified by cluster analysis (2013-2015).

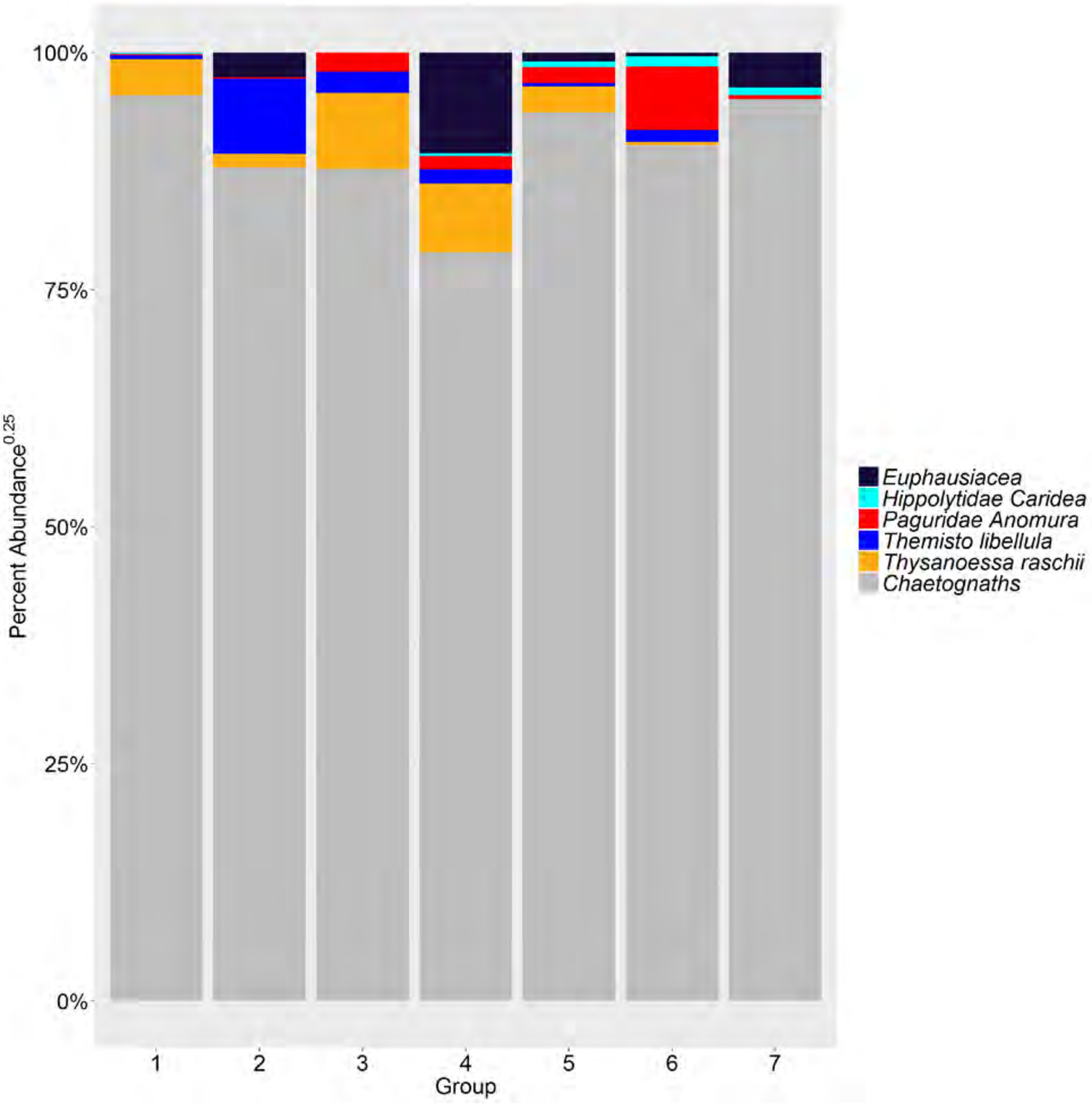


Figure 177. Percent composition abundance of (2013-2015) large mesh taxa from the 7 major zooplankton assemblages identified by cluster analysis.

We also identified zooplankton assemblages for each individual year by constructing similarity matrices and applying NMDS analysis to the annual data. In each year there were two or more major groupings or clusters identified (2013- two major and three minor assemblages at 71% similarity; 2014 -two major and three minor assemblages at 75% similarity; 2015 – four major clusters at 67% similarity; Figure 178). In 2013, the major clusters (assemblages) exhibited 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 179). In 2014, the two main cluster groups were split into southwest stations (Group 1) and northeast stations (Group 2). 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 180). Note the large temperature and small salinity range in 2015.

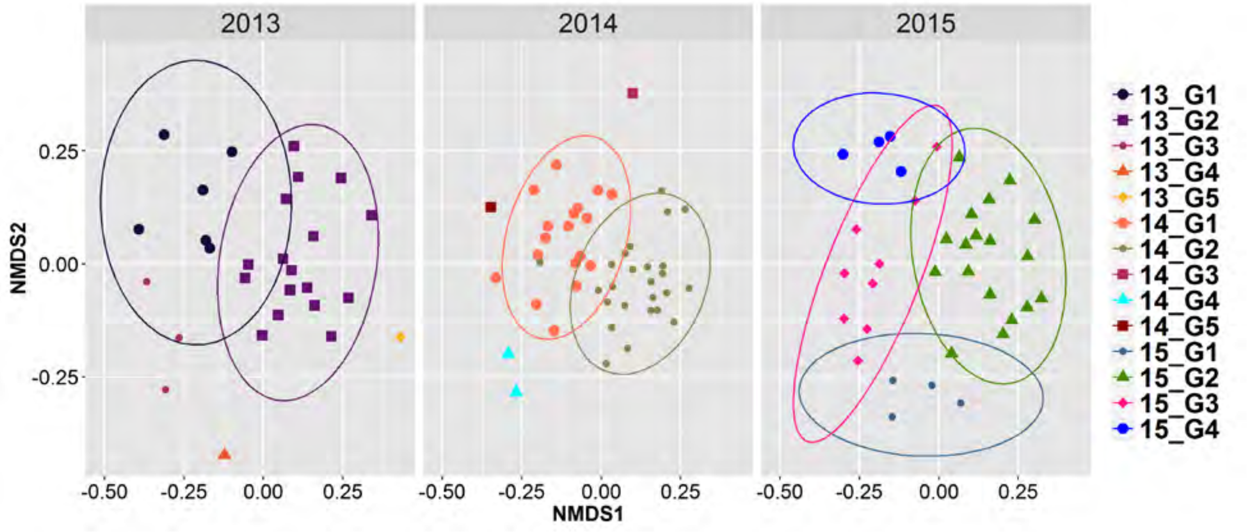


Figure 178. NMDS plots of zooplankton abundance during each individual year (2013-2015).

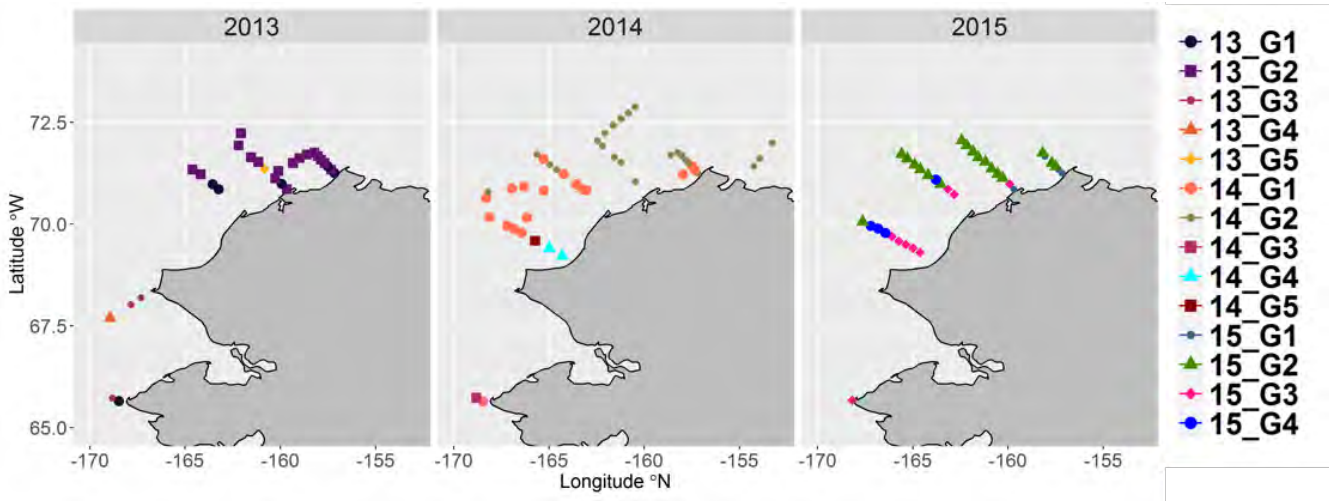


Figure 179. Distribution of the species assemblages within each year that were characteristic of that year

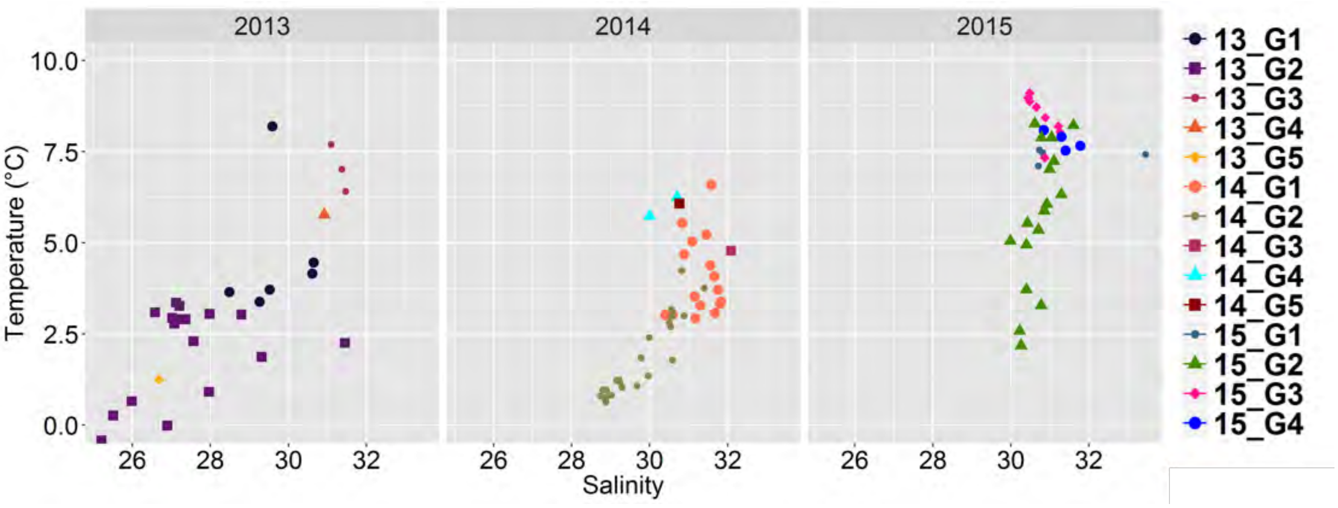


Figure 180. Relationship between the temperature and salinity of a particular station and the zooplankton assemblage found at the station.

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 181). 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 copepodite stages CI and CII 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 and/or groups suggesting that local production and advection were important processes for those stations.

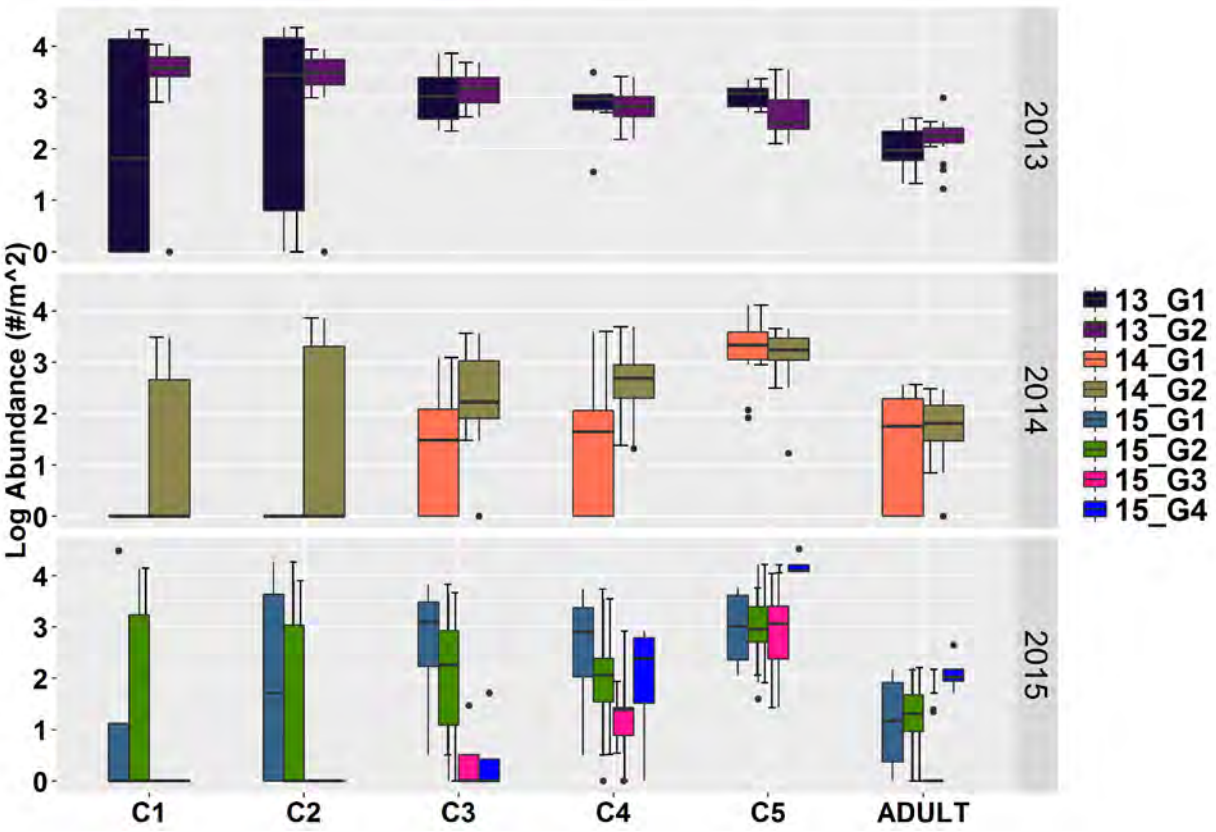


Figure 181. Box plots of the abundance of *C. glacialis* in each of the annual assemblages by developmental stage and year.

3. *Discussion*

Hydrography-- physical and chemical variables

Dissecting our data to examine causal factors was made difficult by differences in sampling time 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 precludes two or more years with similar conditions, and therefore there is no replication of like conditions against which one can test their mechanistic hypotheses. In the end, the Icy Cape, Barrow Canyon, BX, and offshore portion of the Wainwright transect lines were the only stations sampled all three years.

Environmental characteristics during the surveys for the three years were very different. Overall, there has been decline of average April sea ice extent across the entire Arctic from 1979 – 2019 (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). Using CTD data collected at the zooplankton stations we also observed an increase in the minimum temperature during the three years 2013 – 2015 (-0.25 to

2.0 °C) and a narrowing of the range of observed salinities (<26 – 31.5 to 30 – 32.5). Recent transport data through Bering Strait shows an increase in transport of Bering Sea waters from 2009 to 2012, however during our study, summer transport during 2014 (June - August; Stabeno et al., 2018) was lower than other years.

Chlorophyll-a and phaeopigments – concentration and distribution

Mean chlorophyll-a concentrations were significantly ($p < 0.001$) different among the years with values from 2014 being the lowest. This might be expected if the later sampling in 2014 occurred after nutrients were depleted, and grazing by microzooplankton and zooplankton remained constant over the summer. Similarly, day length rapidly decreases during August, and day length on the first day of the 2014 survey was 7-8 hr less than in 2013 and 2015. Thus, we can expect phytoplankton production in September-October 2014 to have been less than in August-September 2013 and 2015, even in the presence of sufficient nutrients.

The offshore distribution of chlorophyll-a with depth across the study region was characterized by large subsurface patches – products of very stable water column conditions and the settling of phytoplankton cells along the pycnocline. The patches often extended to the shallow seafloor implying that these patches may be the product of two separate processes - the sinking of cells from the spring ice-edge phytoplankton bloom and the summer pelagic production. Examination of the species composition and isotopic ratios of cells inside the patches may provide more information into how they were formed and whether or not the deep cells continue to photosynthesize during the summer while at depth. Chlorophyll vertical distribution appeared much less stratified in 2015 at some locations than it was in either 2013 or 2014. In this year there was at least one station along each of the following transects where the profile of chlorophyll was uniform with depth: Bering Strait, Point Hope, Ledyard Bay, CK, Icy Cape and Wainwright lines.

Our calculated threshold values for the subsurface chlorophyll maximum in 2013 (1.03 mg m^{-3}) was about 25% lower than the value reported by Martini et al. (2016) for the same year (1.39 mg m^{-3}). We attribute this to the inclusion of the Point Hope and Bering Strait stations in our calculation, as well as the means of data collection. Our value was calculated from discrete, extracted chlorophyll-a samples obtained by water bottles, and the Martini et al. (2016) value was derived from continuous measurements of chlorophyll fluorescence with depth from an EcoPuck optical sensor. The continuous measurements with depth were most likely able to identify and measure depths with peak pigment concentrations.

Note that the stratification also appeared to have very large scales, extending far offshore in many instances, however there did not appear to be much coherence among years for the locations of those high concentration patches, although it is particularly hard to examine this with only 3 years of data. There are several exceptions to this. The inshore area of the Wainwright transect (0 – 150 km) tended to have a well-mixed water column (2013 and 2015; no sampling in 2014) and chlorophyll concentration tended to increase, particularly at depth, as depth decreased towards Hanna Shoal. There was an area of high concentration between 150 – 250 km offshore of Pt Hope over the deepest water of that transect. Inside Ledyard Bay, chlorophyll tended to be uniform from the surface to the bottom out to at least 400 km offshore (2014 and 2015). Chlorophyll concentrations along transect CkC, between Ledyard Bay and Icy Cape were low in both years sampled (2014, 2015).

Zooplankton – abundance and distribution

The biomass and community composition of zooplankton over the east Chukchi Sea shelf results from the dynamic combination of advective and *in situ* processes (Ershova et al., 2015; Spear et al., 2019). In general, the presence of ice and cold dense water over the shelf and northerly winds impedes or slows transport of water through the Bering Strait (e.g., Stabeno et al., 2018). As ice recedes earlier and earlier from the Chukchi Shelf, the expectation is that lower trophic level structure and function over the shelf will look more and more like the eastern Bering Sea.

Transport from the eastern Bering Sea through Bering Strait and across the shelf to Barrow Canyon is on average about 100 days (Stabeno et al., 2018) and is a function of the winds. That means that zooplankters that spawn around the time of the spring bloom in the northern Bering Sea (say after DOY 200) would not be able to transit the entire shelf before it became ice covered. The fastest transport is in the Alaska Coastal Current waters (relatively warm and fresh) which also has somewhat lower zooplankton biomass. Much of the waters over the Chukchi shelf move relatively slowly during the summer (< 10 cm s^{-1}) particularly around Hanna Shoal and offshore of the Icy Cape Line. There are also episodic events that bring Atlantic Water onto the shelf through Herald, Central, and Barrow Canyons (Ladd et al., 2016). Northeastward transport in winter may reverse when winds are strongly from the north. All of these observations lead to the conclusion that plankton residence times may be quite long and *in situ* production is important in this system, particularly for species that have the ability to overwinter in a quiescent, active, or semi-active state. Should long-term wind patterns change in direction or magnitude, then they may also affect residence time.

Patterns in the distributions of particular species and assemblages also spoke to the importance of transport and the origin of the waters. Spear et al. (2019) showed inter-annual patterns in assemblages across the shelf using our earlier data from the CHAOZ project with 2010 and 2011 being very similar with a single assemblage dominating the shelf and 2012 having four different assemblages: one that dominated the eastern end of the shelf and 3 others in the western portion. In the ARCWEST/CHAOZ X time frame, the assemblage patterns were also very clear, but distinct among all three years. A reanalysis of flow patterns over the Chukchi Shelf from 1979 – 2014 showed that the flow patterns in any two sequential months (June – October) were rarely repeated (27 of 180 times) implying the dominance of month-to-month variation in a particular flow pattern (Bond et al., 2018). Thus, even without inter-annual variability, it is not likely that our sampling, which occurred at different times within three different years would show a similar pattern. Rarely was it a single taxon that distinguished one assemblage from another; rather it was the overall proportional contribution of several taxa that defined these assemblages. In two of the three years, similar to the case during CHAOZ, there was a strong connection between the salinity at a particular station and the zooplankton assemblage at that station. The exception to this was in 2015 where there was very little variation in salinity, but about a 6 °C variation in temperature that somewhat distinguished the different groups.

Zooplankton net data

The Tucker Sled data of zooplankton abundance and distribution showed great inter-annual and spatial variability. The hydrography (temperature, salinity, and location of different water masses) varied among years and the zooplankton distributions reflected this to a large degree. Our shipboard data also provided insight into "event-scale" phenomena. For example, the warmest year, 2010, had low, but detectable concentrations of an early developmental stage of euphausiids, indicating reproduction over the Chukchi Sea shelf. Previous work hypothesized that euphausiids in the Chukchi are expatriate populations that do not reproduce. Similarly, the presence of low, but detectable concentrations of *C. hyperboreus*, an Arctic basin species, was indicative of a major advective event that delivered water and organisms onto the Chukchi shelf. The documented variability in zooplankton community indicates that the arctic strongly responds to those forces that drive the summer physics, chemistry, and biology of this region.

The absence of high abundances of juvenile and adult euphausiids away from Barrow canyon concentration area is puzzling. Bowhead and other baleen whales transit through this region in spring and fall, and our expectation was that we would find high concentrations of euphausiids over the continental shelf. While the concentrating mechanism around Barrow Canyon is now well described (Ashjian et al., 2010), previous authors hypothesized that there was a "conveyor belt" of euphausiids that originated in the Bering Sea and were transported into the Chukchi Sea (Berline et al., 2008). Net-based estimates are known to underestimate actual euphausiid abundance due to avoidance of the sampler (e.g., Clutter and Anraku, 1968; Sameoto et al., 1993). Although we did not include a light to "blind" the targets, we did tow our nets on the bottom in anticipation that euphausiids would be hard on bottom as observed in the eastern Bering Sea (Napp, unpublished data). While many of the taxa we captured had abundances on bottom that were greater than or equal to water column abundance, there was no clear evidence of a euphausiid conveyor belt from samples collected during CHAOZ, ARCWEST, or CHAOZ-X.

Comparison of zooplankton estimates from the Tucker net and a TAPS-6

This exercise was a valuable test to see what, if any, information the older TAPS-6 units could provide on plankton abundance, biovolume, and size distribution in an Arctic environment. The older TAPS-6 instruments were designed with relatively high acoustic frequencies and low sample volume for vertical casts or moored deployment in regions where scattering was dominated by relatively small (down to 1 mm ESR), highly abundant, taxa like copepods. In our use of the instrument, the inverse-modeling analytical approach using two or three, simple scattering models (copepod, euphausiid, and pteropod) did not provide estimates of taxon-specific plankton abundance that closely approximated plankton abundance obtained with the Tucker sled. We attribute this to multiple factors: 1. the complexity of the zooplankton community that includes high abundances of organisms such as shelled molluscs, appendicularia, and chaetognaths that are difficult to model; 2. the potential contribution of marine snow; 3. the instrument configuration which averages multiple pings and saves the average value rather than the raw pings; 4. lack of true noise measurements. Comparison of the TAPS-estimated biovolume with net-captured biomass was not possible because we lacked wet weight information on the species retained by the net.

There was, however, good agreement between the number of organisms captured by the net and the S_v at 420 kHz ($R^2 = 0.68$). Although the water column is shallow throughout most of the Chukchi shelf (30-40 m) there is physical structure to the water column with the interleaving of different water masses. The structure was different among years with 2012 showing the highest degree of stratification. Zooplankton can recognize the differing temperatures and salinities of these water masses and may align themselves according to their preferences. Thus, in the absence of other information, using the S_v at 420 kHz may provide insight into the fine-scale vertical distribution of the zooplankton community, in general, in ways that could not be observed with the Tucker sled where a single sample is collected over the entire water column.

4. Conclusions

ARCWEST provided an excellent data set to examine large-scale variability in plankton over the Chukchi Shelf. The data collected help to solidify the idea that spatial patterns of biological and chemical properties are very responsive to hydrography. There was no evidence of BSW or AW along the Cape Lisburne line (CL), but there was some evidence of it at the seaward edge of Point Lay and Icy Cape lines (PL and IC). The greatest inter-annual variability in plankton was along the Wainwright line (WT). Subsurface (sub-pycnocline) blooms of phytoplankton were common, but not all areas of high subsurface chlorophyll concentration also had supersaturated oxygen concentrations. Oxygen saturation is likely confounded by rates of primary production, respiration, vertical mixing, and warming of the water column. During the time of our surveys, the surface was largely depleted of nutrients along all lines. Ammonium concentrations along the bottom were often >2 µM. Ammonium is the result of decomposition of organic matter, and is the preferred nitrogen source (over nitrate) for some phytoplankton. It can also be converted into nitrate through nitrification (ammonium nitrite). Nitrite as an intermediary product is usually found at low concentrations, as is observed in this data set.

At the Point Hope transect line (PH/DBO Line 3) the high concentrations of ammonium could be regionally formed or advected from the Bering Sea where high (>6 µM) concentrations are observed during summer and fall. Further investigation is necessary to examine timing of the bloom, rates of ammonification and regional advection to quantify the sources of ammonium. Vertical stratification along this line was strongest in 2010, primarily due to lower surface salinities in 2010. Farther north on the Chukchi plateau at lines PL and IC, the ACC appeared to be more confined in a narrow band along the coast. The biggest difference between the years was at Lines WT and BC. In 2012, intrusions of high silicate and nitrate were observed on the western Barrow Canyon and the shelf west of the canyon. We hypothesize that this is slope water intruding up the canyon and onto the shelf, perhaps a result of upwelling; perhaps affecting the ACC as well.

Zooplankton community composition showed great variability among years, as well as evidence for physical events such as advection, which introduced Arctic basin species to the shelf. Net-based estimates of juvenile and adult euphausiid concentrations were low and did not yield evidence for the conveyor belt hypothesis. Concentrations of the furcilia stage were much higher, and in 2010 and 2011 were present at all stations across the shelf. Therefore, it appears that in warm years with low summer areal ice extent, euphausiids may reproduce. However, the fate of those progeny is not known, and the question of endemic versus expatriate populations still exists. Finally, both net and acoustic estimates indicated that zooplankton concentrations are often as high or higher near the bottom than they are in the rest of the water column on the Chukchi shelf in summer.

5. Recommendations

It is important to utilize new and varied technologies to better sample this remote and difficult region. These include towed vehicles, and autonomous and semi-autonomous vehicles such as wave gliders and profiling gliders. The use of multiple-frequency, hull mounted acoustic transducers during spring and summer would help us to better map distribution and biomass of euphausiids (e.g., DeRobertis et al., 2010; Ressler et al., 2012). The combined data from CHAOZ, ARCWEST, and CHAOZ-X enabled us to better characterize inter-annual variability in the area patterns of the zooplankton community, and to test the strength of linkages between physics and biology. Further investigation is necessary to examine timing of the phytoplankton blooms, rates of ammonification, and regional advection to quantify the sources of ammonium.

C. Other Observations (Satellite-tracked drifters, Prawler)

1. Methods

Satellite-tracked drifters

In 2013 and 2015, 12 satellite-tracked drifters were deployed in the Chukchi Sea (Table 50). 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 usually below the mixed layer depth. Each drifter was instrumented with a temperature sensor at the bottom of float (e.g., 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 at 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 50. Deployment information for all drifters deployed during ARCWEST, including 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

In 2015, a Prawler mooring was deployed in the Chukchi Sea ~75 nm northwest of Icy Cape, AK at mooring site C2, 71 14.459' N, 164 18.067' W, as part of PMEL's Innovative Technology for Arctic Exploration (ITAE) program. 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 182). 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 ~75 nm northwest of Icy Cape, AK at 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 m 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 182). The submarine portion converts wave energy into forward motion of ~ 1 kt. Solar panels provide power for the sensors. Temperature was measured at 1 m intervals from surface to a depth of 6 m, and conductivity (salinity) was measured at the surface and at 6 m.

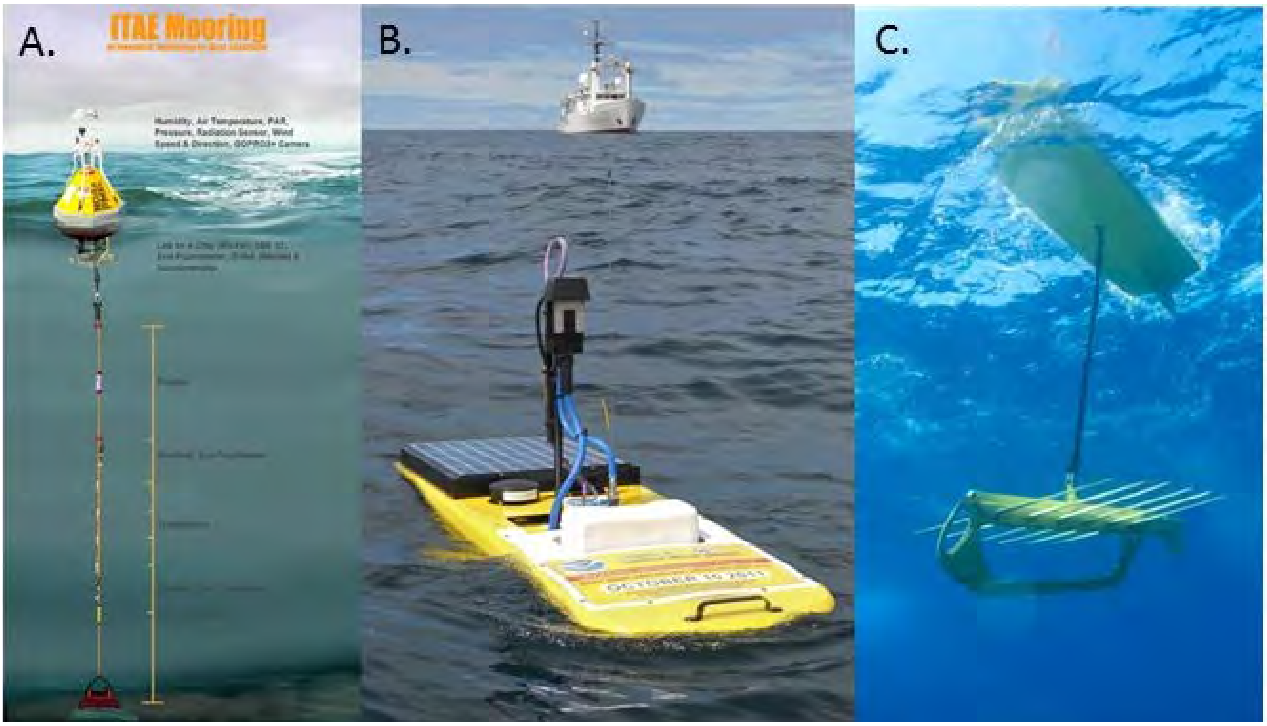


Figure 182. Schematic of the ITAE Mooring with Prawler (A); Wave Glider above (B) and below (C) the water's surface.

Other Satellite Derived Data

Daily ice coverage was estimated for each mooring location from ice concentration data from the National Snow and Ice Data Center (NSIDC; http://nsidc.org/data/collections.html; Nov. 2015) using the bootstrap ice concentrations from Special Sensor Microwave Imager (SSMI; 15 nm resolution, daily record; Comiso and Hall, 2014). Ice was calculated as the daily average of all points within a 25 km radius around each mooring location per day.

2. Results

Satellite-tracked drifters

Mean flow patterns: Satellite-tracked drifter trajectories and mean currents measurements

The Chukchi Sea consists of a broad shallow shelf, 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 183). 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. These 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 120; Section VIII.A.2). 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 is evident at C9 (Corlett and Pickart, 2017). The weakest flow, largely eastward, is evident north of Hanna Shoal (C7 and C8) and southeast of Hanna Shoal (C6).

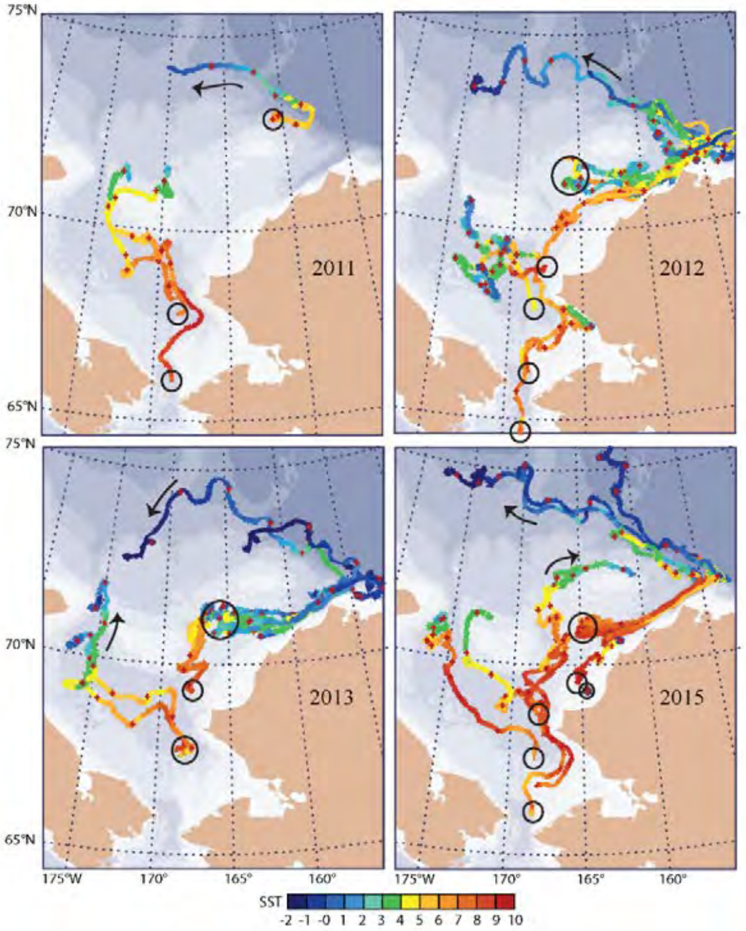


Figure 183. Drifter trajectories (drogue depth ~30 m) for four years. The drifters are color coded by sea surface temperature (scale [°C] is at the bottom). The length of time between red crosses on trajectories is five days. For 2011, 2012, and 2013 drifters were deployed in August, while in 2015 drifters were deployed primarily in July (see Table 50). The circles indicate deployment location and the arrows the direction of movement.

Prawler and Wave Glider

While the main moorings provide a time series of temperature in the near bottom, time series of temperature in upper water column are lacking. The ITAE mooring which contained a number of instruments, including the Prawler provides time series of temperature in the upper 25 m of the water column (Figure 184). Unfortunately, there are 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 is not steady, but varies by approximately 5 m on a time scale 3-5 days. This fluctuation does not appear to be related to wind mixing. Second, the near surface temperature changes rapidly, likely as a result of advection of different water masses past the mooring site. There are periods of rapid warming and of rapid cooling. Finally, a strong mixing event is evident in late August, when winds exceed 10 m s^{-1} for several days (Figure 184, top panel). The vertical mixing of the water column is evident in the water column (bottom panel). Warm water (>5 °C) is introduced to near bottom, but this warmer water is eventually replaced by cold (<2 °C) water.

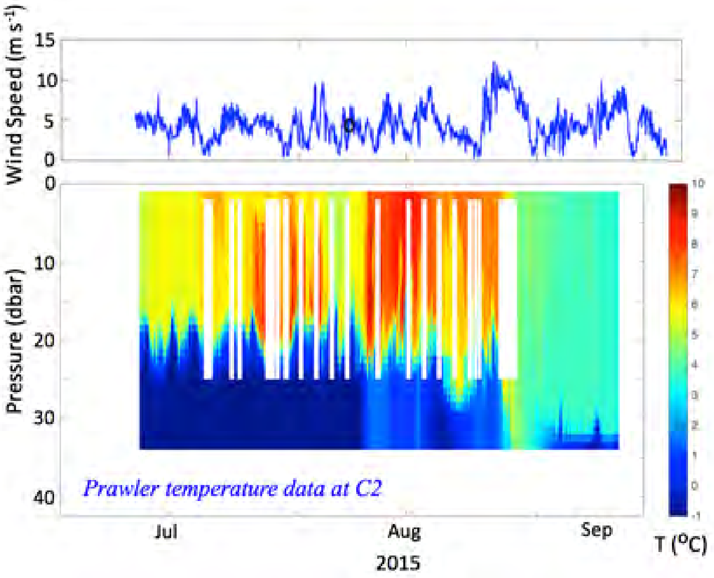


Figure 184. Measurements of (top) wind speed and (bottom) temperature at mooring site C2, collected on the ITAE Prawler mooring. The gaps in temperature resulted from technical problems with the Prawler.

In addition to the Prawler, 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 185 (upper panels) along a ~2 week trajectory (bottom panel). The transit began south of Hanna Shoal on 17 August and moved northwestward toward the shoals. On 21 August 2015 it 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 184) 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 melts it would continue to cool and freshen the surface (e.g., Martini et al., 2016). However, even areas away from the shoal show a patchwork of surface temperature and salinity.

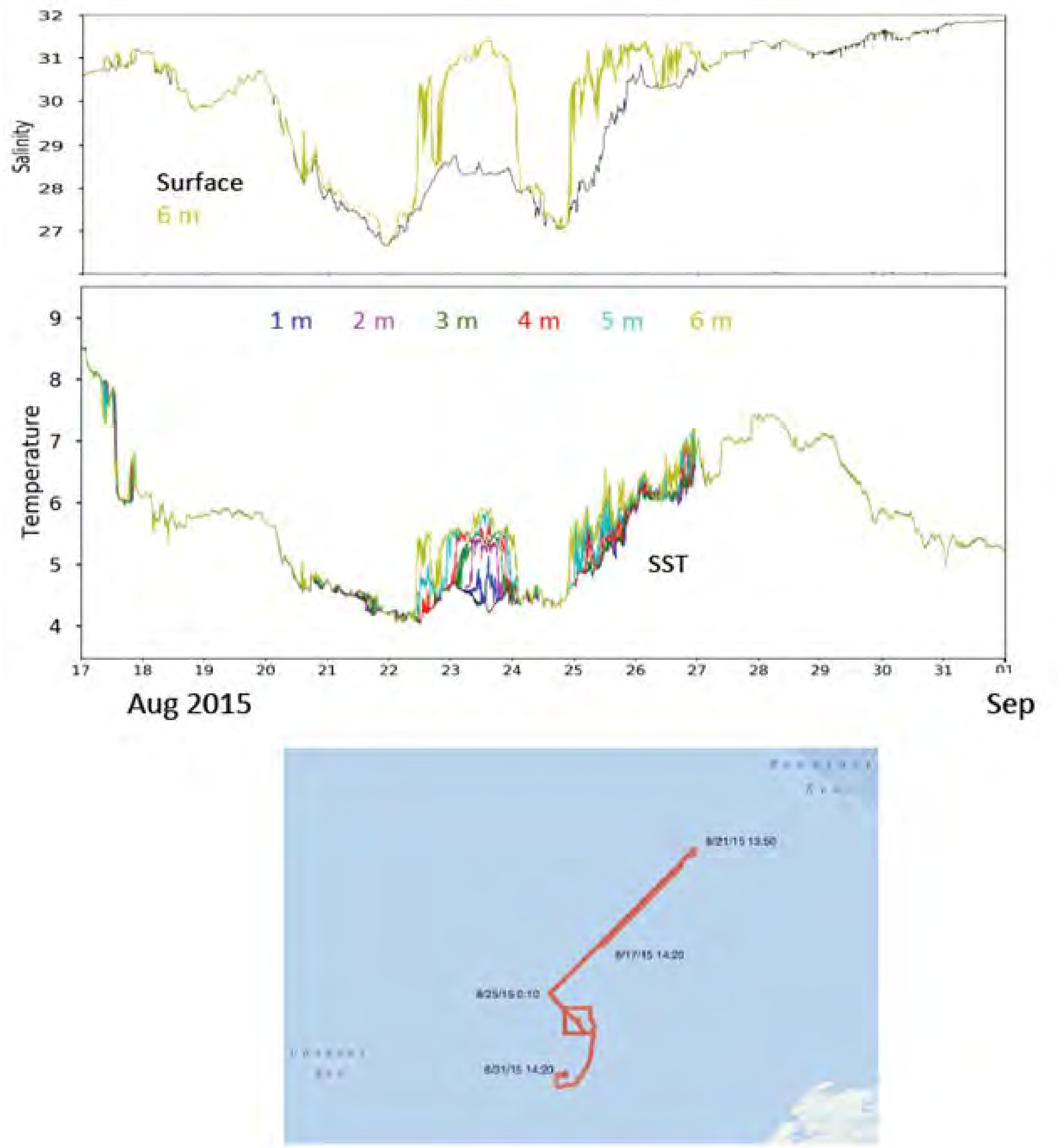


Figure 185. Time series of salinity (top panel) and temperature (middle panel) collected during the transit of the Wave Glider in the Chukchi Sea (bottom panel). Salinity was measured at the surface and at a depth of 6 m while temperature was collected at 1-m intervals from the surface to a depth of 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.

IX. AMBIENT NOISE CONTRIBUTORS AND ACOUSTIC ENVIRONMENT ANALYSIS

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

1. Methods

Equipment

Two 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 51). 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.1 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, because of the considerable amount 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 was not considered in this analysis.

Data analysis

The acoustic analysis was conducted for data from each mooring location (Table 51) for two different categories of ice concentration: open-water and ice. See section VIII.C for how ice concentrations were derived. This decision to categorize our data base 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 by 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 51. List of deployment information for MML moored passive acoustic recorders selected for ambient noise 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

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 186).

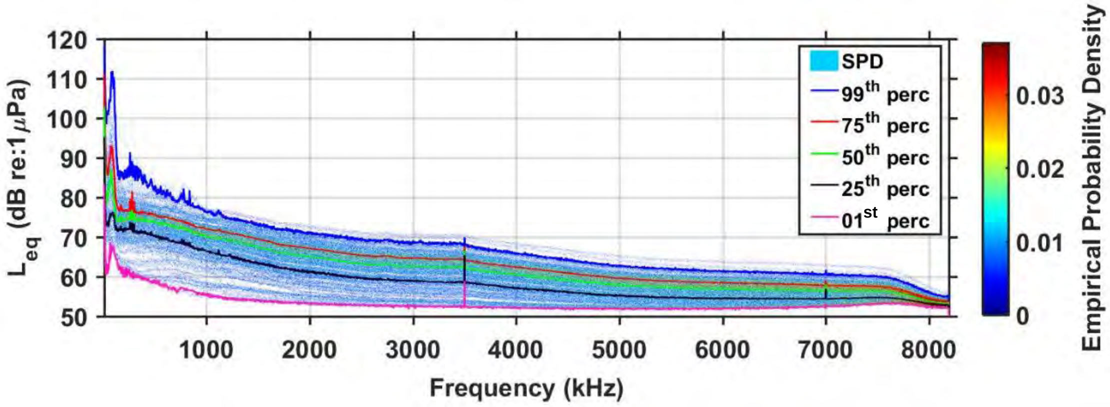


Figure 186. Spectral probability density and power spectral density percentiles for bowhead whale files during the 2012 ice season at WT1.

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.1. 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 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.

2. Results

Data were 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 in Section VII.A.1; Figure 2).

Mooring WT1

Results from the seasonal occurrence of marine mammals for this mooring location and period are presented in Figure 187 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 52.

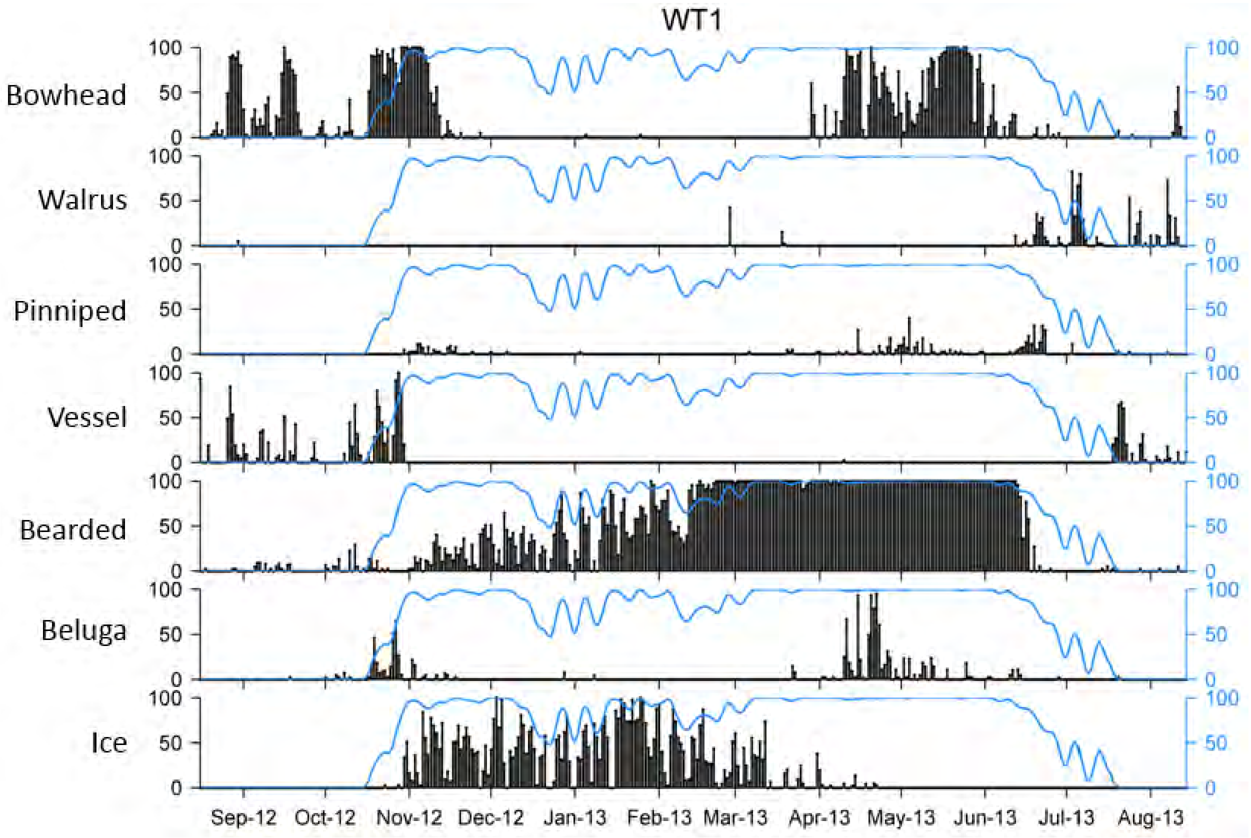


Figure 187. Seasonal occurrence (percent of time per day) at mooring WT1 during the period August 2012 to October 2013 for each of the seven acoustic contributors (black histogram) and for ice concentration (blue).

Table 52. 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 188. 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 189. 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.

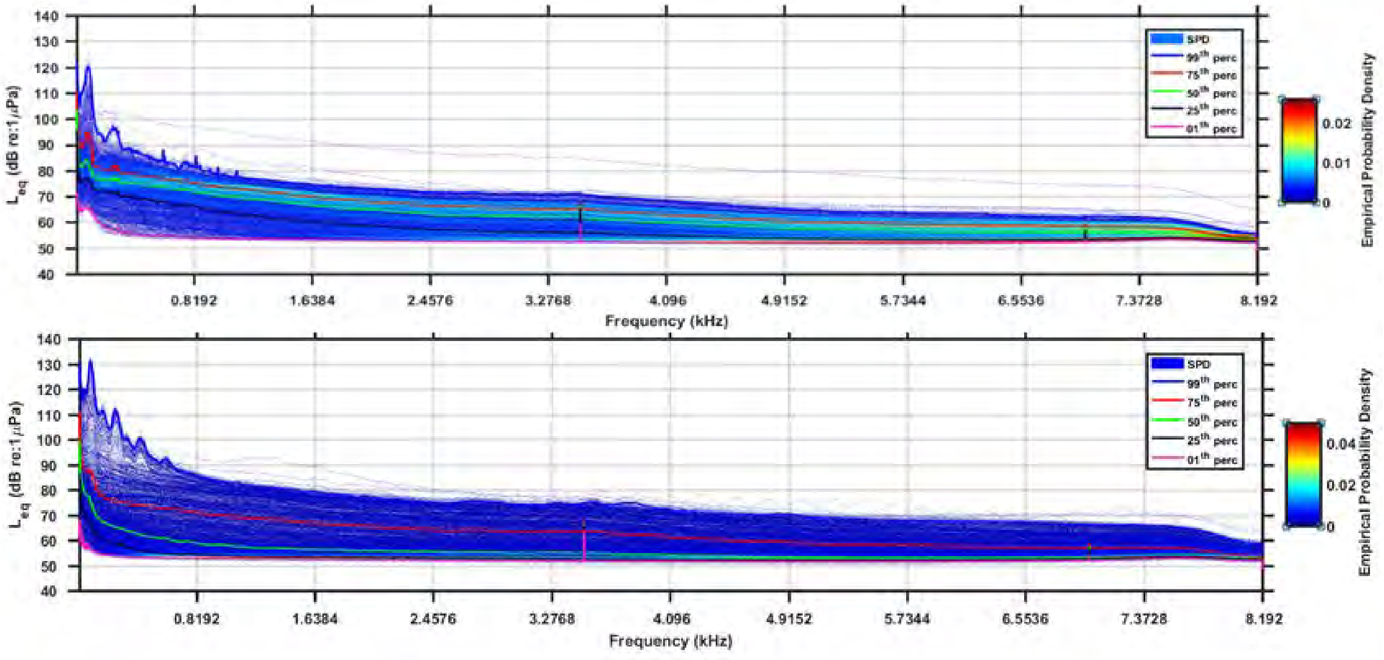


Figure 188. Spectral probability density plots and spectral percentiles for baseline ambient noise during the ice season (upper panel) and during the open water season (lower panel), for WT1 2012-2013.

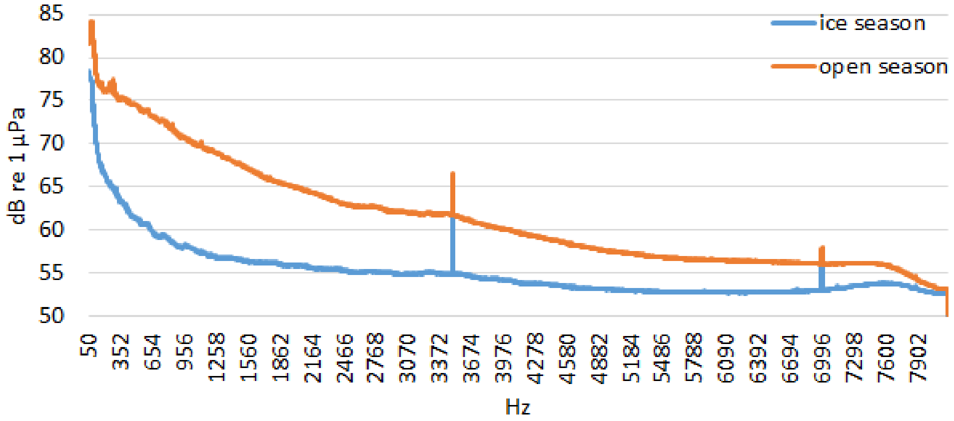


Figure 189. Spectral 50th percentile for ambient noise during the ice and open water seasons for WT1 2012-2013. Spikes at 3400 Hz and 7000 Hz are artifacts likely from electrical system noise.

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 190, 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 190, lower right panel, where its spectral curve exceeded 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.

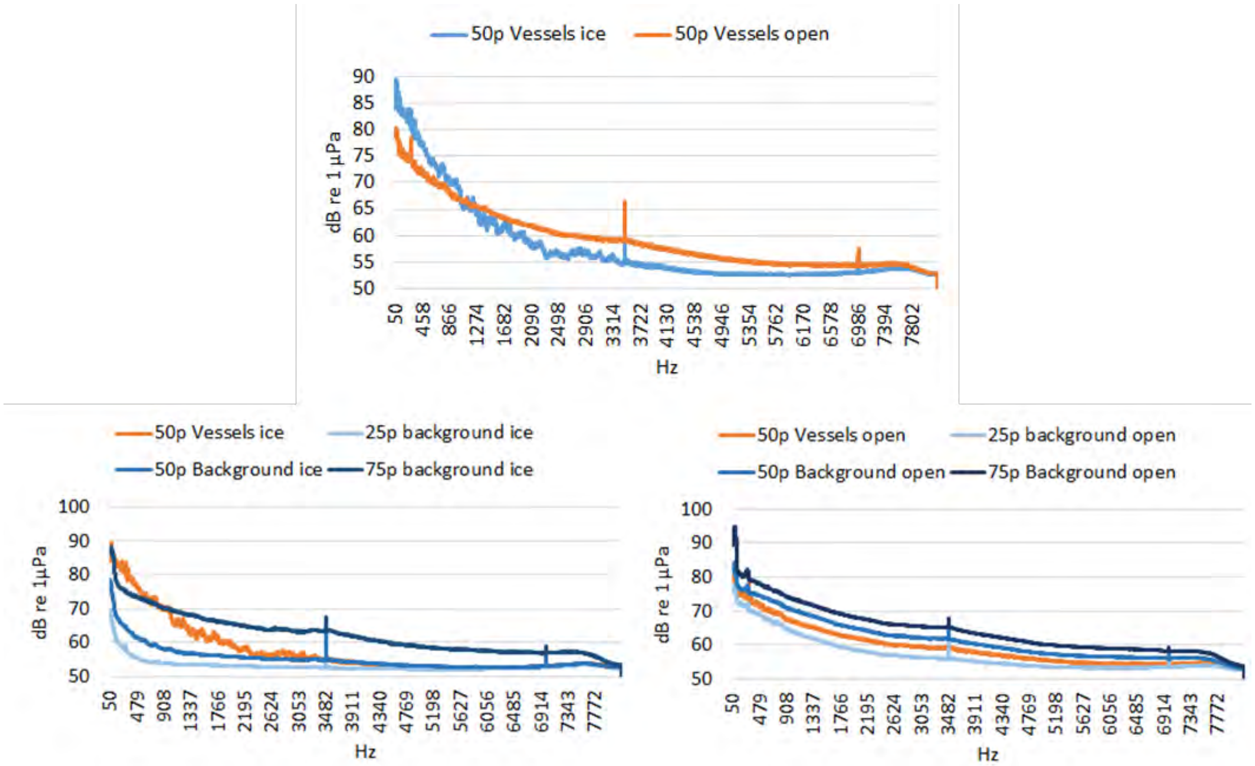


Figure 190. Upper panel: Spectral 50th percentile for vessel noise at WT1 2012-2013 during the open water (orange) and ice (blue) seasons. Lower left panel: Spectral 50th percentile for vessel noise at WT1 2012-2013 during the ice season and the 25th, 50th and 75 percentiles for ambient noise. Lower 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 191). 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.

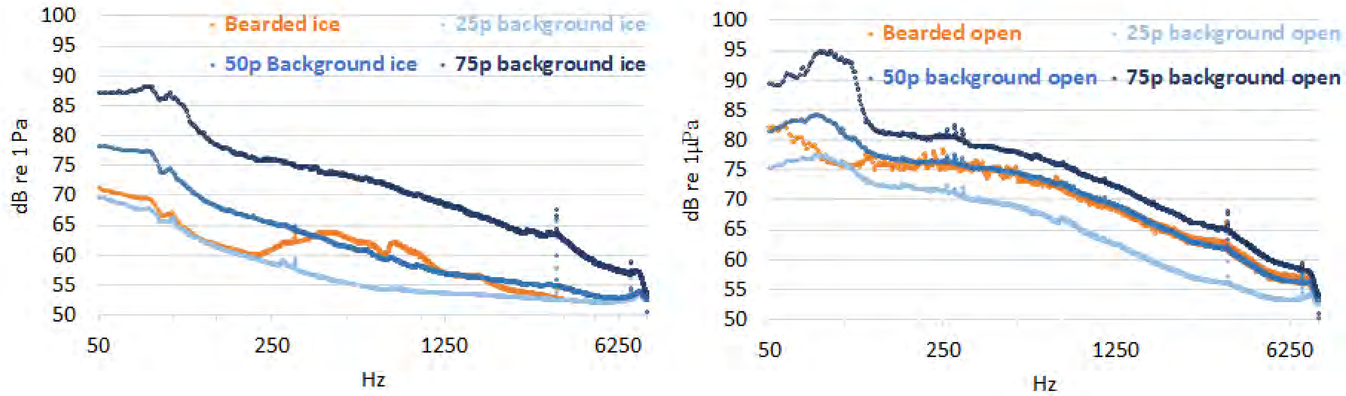


Figure 191. Left panel: Spectral 50th percentile for bearded seal signals at WT1 2012-2013 during the ice season and the 25th, 50th and 75th percentiles for ambient noise. Right panel: Spectral 50th percentile for bearded seal signals at WT1 2012-2013 during the open water season and the 25th, 50th and 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 192). 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 192). Bowhead singing behavior clearly marked these differences in acoustic contribution.

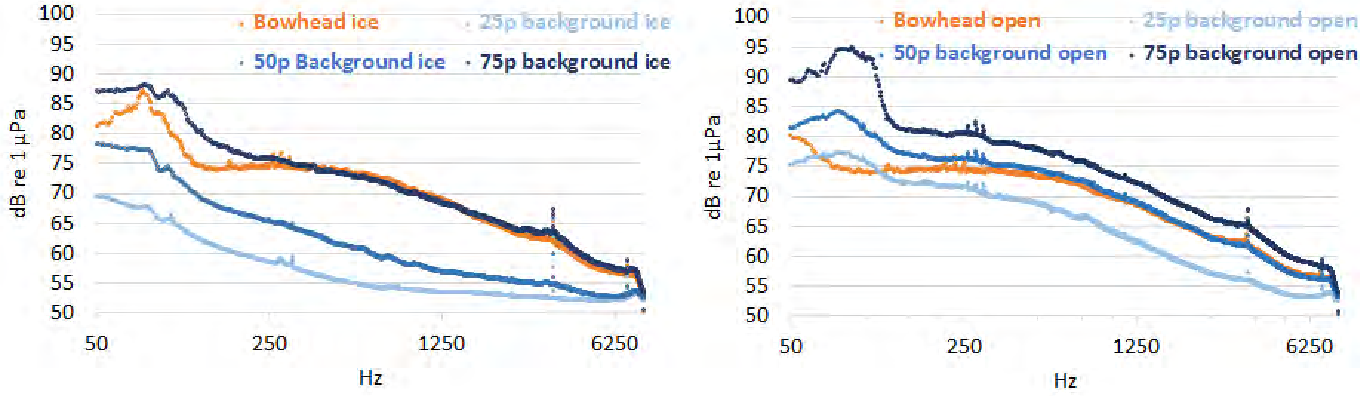


Figure 192. Left panel: Spectral 50th percentile for bowhead whale signals at WT1 2012-2013 during the ice season and the 25th, 50th and 75th percentiles for ambient noise. Right panel: Spectral 50th percentile for bowhead whale signals at WT1 2012-2013 during the open water season and the 25th, 50th 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 fell 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 more faint, below the ambient noise spectral 25th percentile, particularly in the lower frequency range, but louder than ice season signals above 200 Hz (Figure 193).

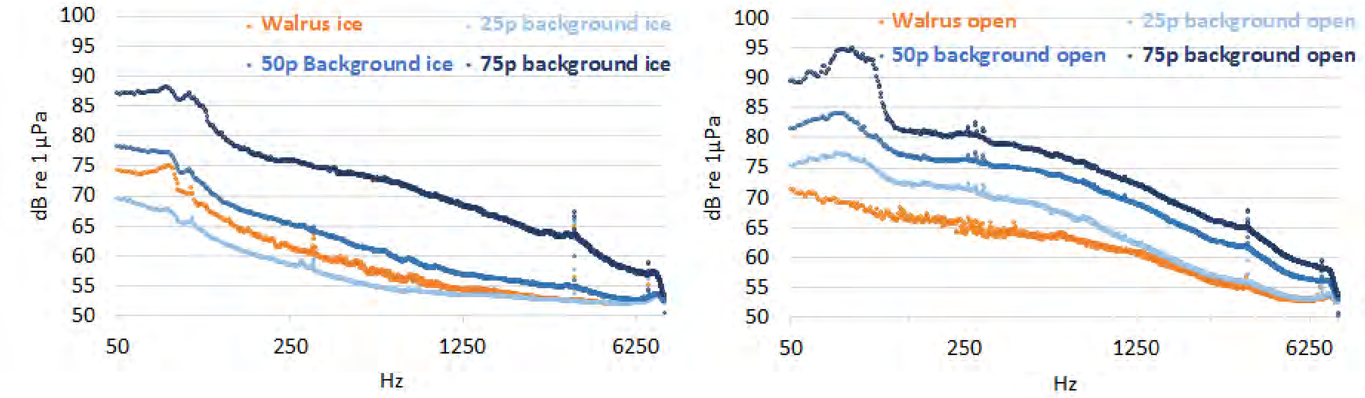


Figure 193. Left panel: Spectral 50th percentile for walrus signals at WT1 2012-2013 during the ice season and the 25th, 50th and 75th percentiles for ambient noise. Right panel: Spectral 50th percentile for walrus signals at WT1 2012-2013 during the open water season and the 25th, 50th and 75th percentiles 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 were compared by season, the higher acoustic contribution by bowhead whales was evident, however, for frequencies above 100 Hz during the open water season, the bearded seal contribution matched the curve of bowhead whales (Figure 194). When vessel noise contribution was considered, this anthropogenic disturbance clearly altered the acoustic environment at WT1. During the ice season, the median spectral curve for vessel noise exceeded all marine mammal curves up to 1000 Hz. During the open water season, vessel noise only exceeded the spectral curve of walrus signals, and partially overlapped the bearded seal and bowhead whale curves in the range 120-230 Hz.

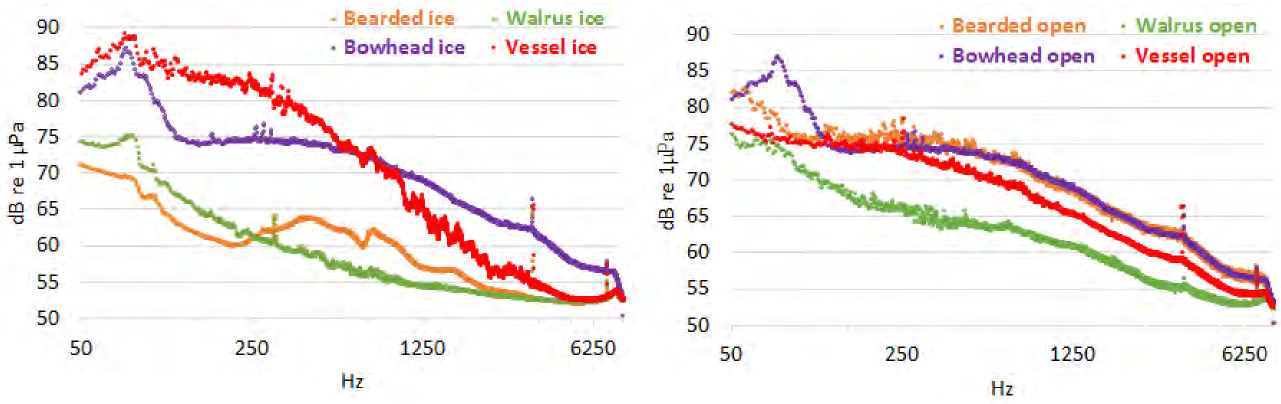


Figure 194. Spectral 50th percentile for bearded seal, bowhead whale, and walrus sounds, and vessel noise at WT1 2012-2013 during the ice season (left panel) and during the open water season (right panel). Spikes at 3400 Hz and 7000 Hz are artifacts likely from electrical system noise. Note, the x-axis 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 195 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 53.

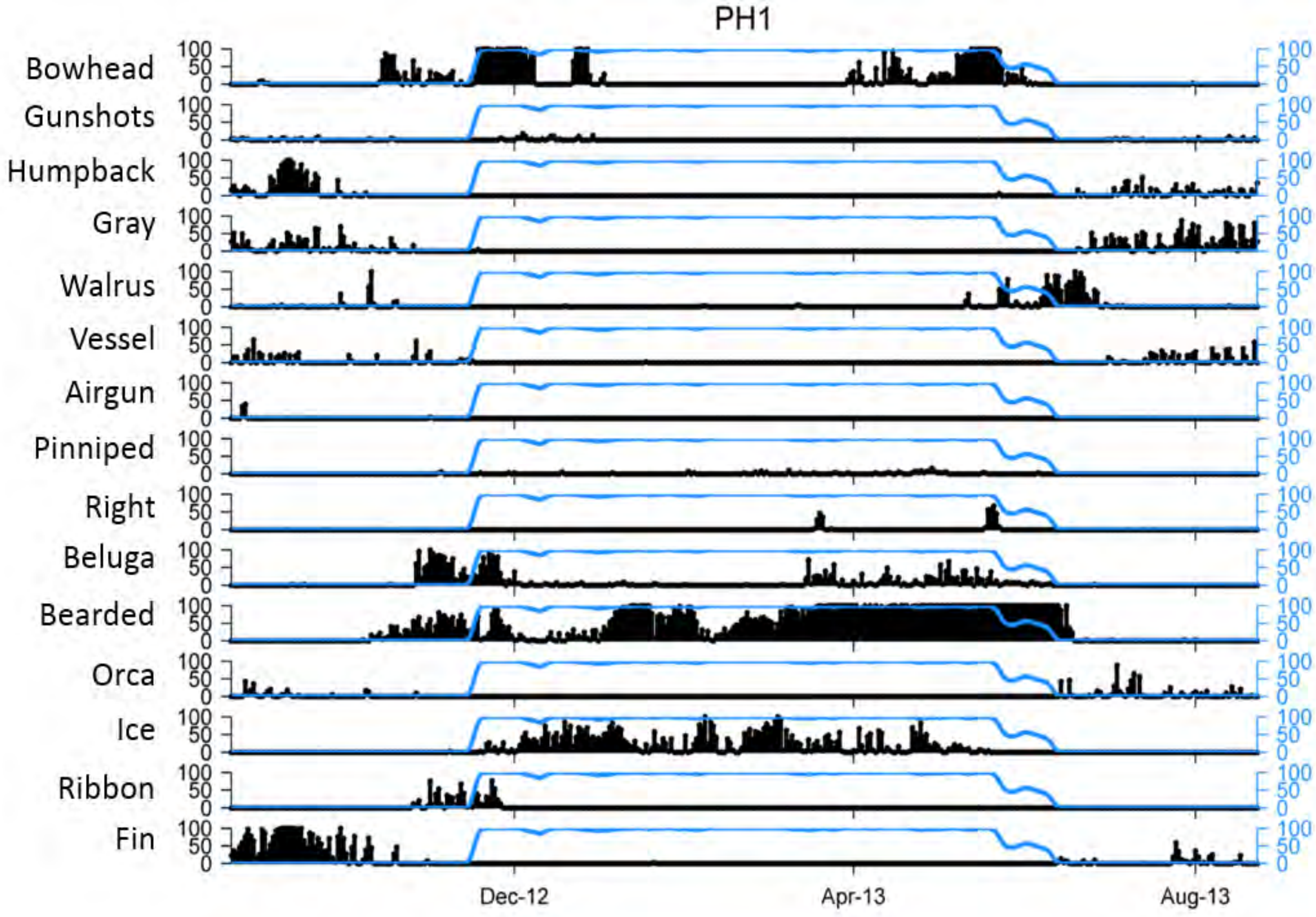


Figure 195. Seasonal occurrence (percent of time per day) at mooring PH1 during the period August 2012 to August 2013 for each of the seven acoustic contributors (black histogram) and for ice concentration (blue).

Table 53. 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 196. As opposed to WT1, the ambient noise in PH1 did not differ as much between seasons. This can be seen in the comparison of their 50th percentiles in 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.

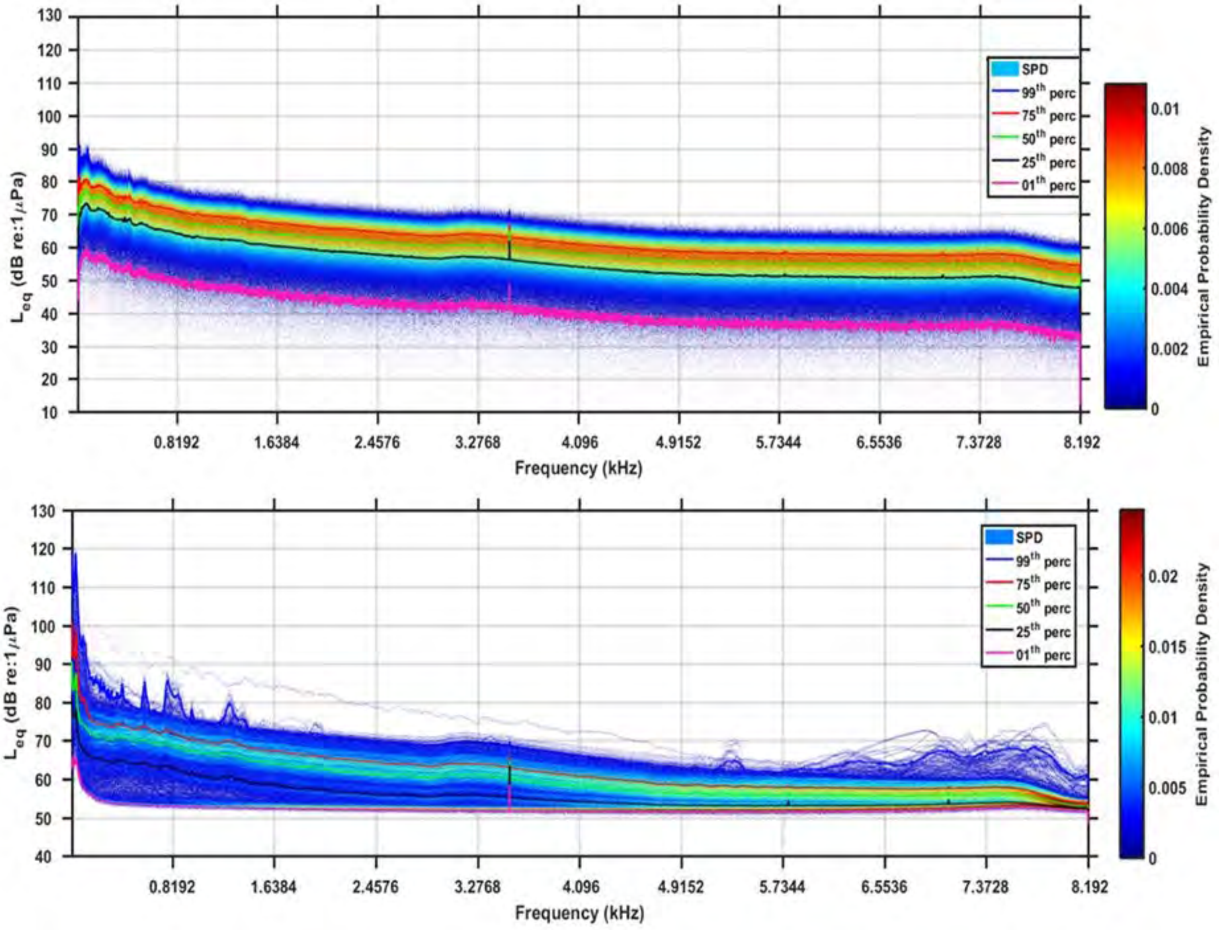


Figure 196. Spectral probability density plots and spectral percentiles for baseline ambient noise during the ice season (upper panel) and during the open water season (lower panel), for PH1 2012-2013.

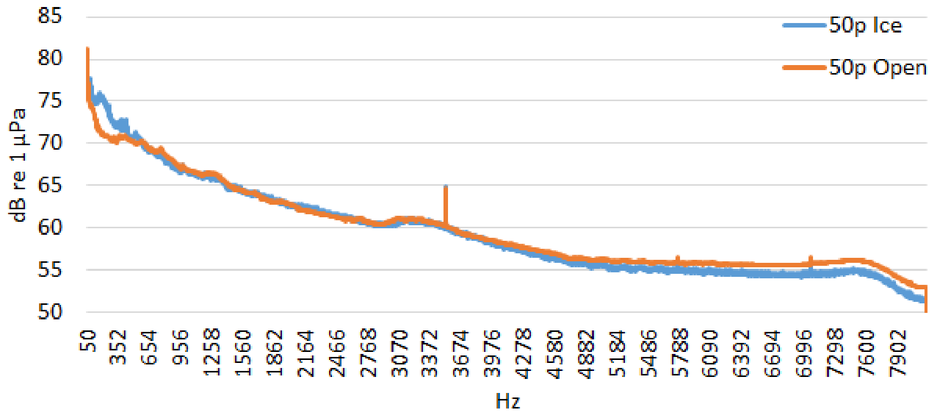


Figure 197. Spectral 50th percentile for ambient noise during the ice and open water seasons for PH1 2012-2013. The spike at 3400 Hz is an artifact likely from electrical system noise.

When PH1 ambient noise was compared to WT1 for the same time period and seasons, differences were observed for both seasons. PH1 location was louder during the ice season but quieter during the open season (Figure 198).

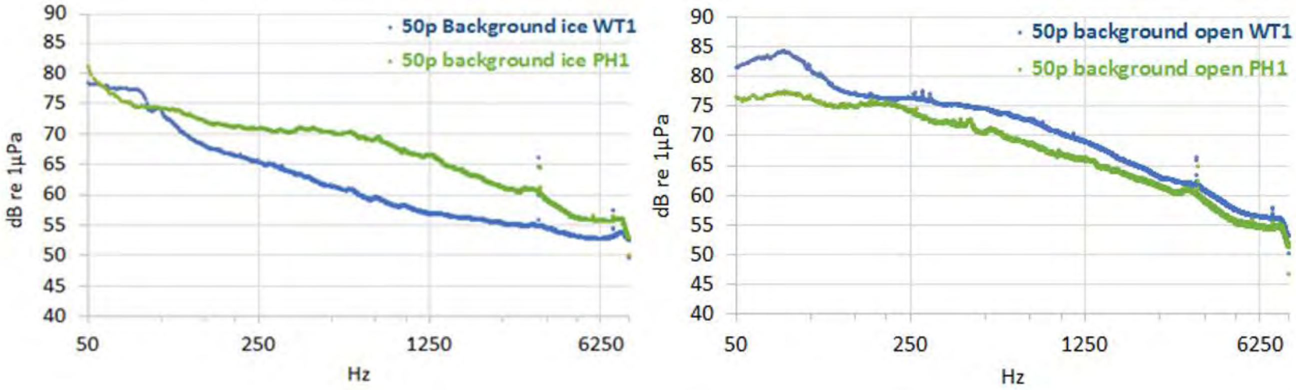


Figure 198. Spectral 50th percentile for ambient noise during the ice (left panel) and open water (right panel) seasons for PH1 (green) and WT1 (blue) for the period 2012-2013. The spikes at 3400 Hz and 7000 Hz are an artifact likely from electrical system noise.

As with 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 199). In general, vessel noise at PH1 was more faint than the levels reported at WT1 (Figure 200).

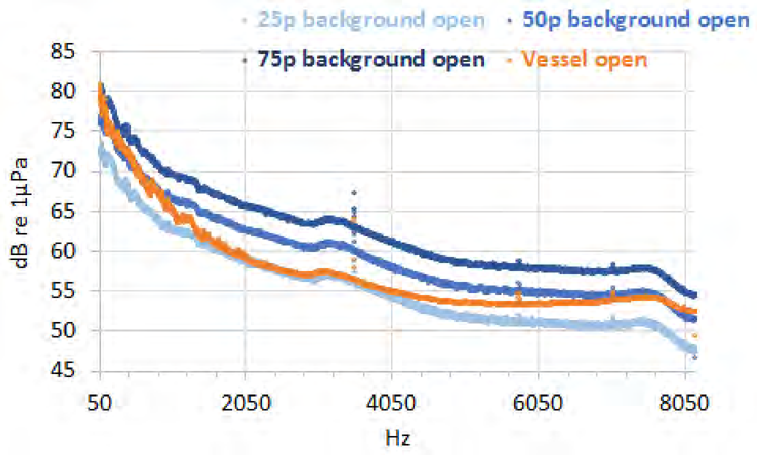


Figure 199. Spectral 50th percentile for vessel noise at PH1 2012-2013 during the open water season and the 25th, 50th and 75th percentiles for background noise. Spikes at 3400 Hz, 5500 Hz, and 7000 Hz are artifacts likely from electrical system noise

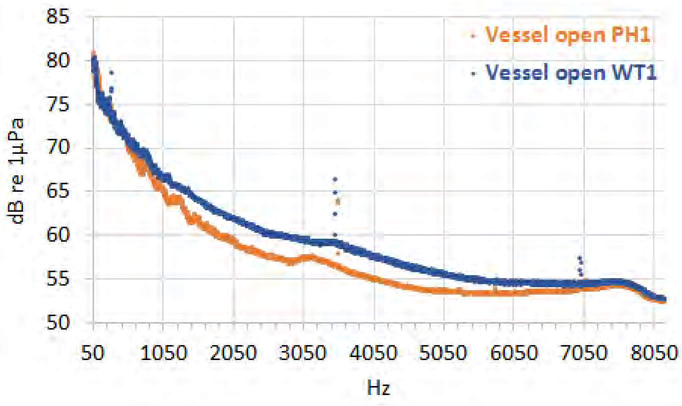


Figure 200. Spectral 50th percentile for vessel noise at PH1 and WT1 in 2012-2013 during the open water season. Spikes at 3400 Hz and 7000 Hz are artifacts likely from electrical system noise.

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 201). 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 201). This was an opposite pattern to the one found in WT1, where bowhead whale contribution was stronger during the ice season.

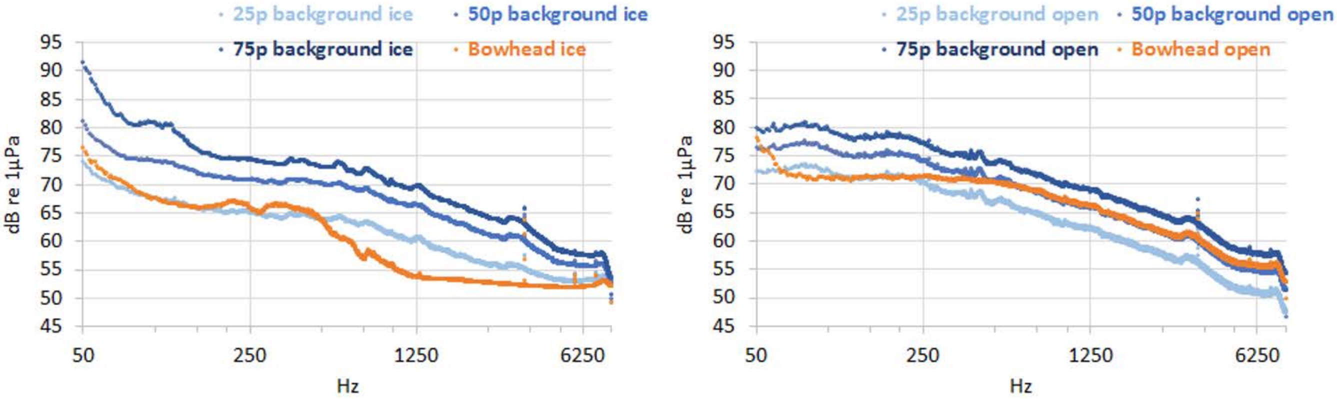


Figure 201. Left panel: Spectral 50th percentile for bowhead whale signals at PH1 2012-2013 during the ice season and the 25th, 50th and 75th percentiles for ambient noise. Right panel: Spectral 50th percentile for bowhead whale signals at PH1 2012-2013 during the open water season and the 25th, 50th 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 202).

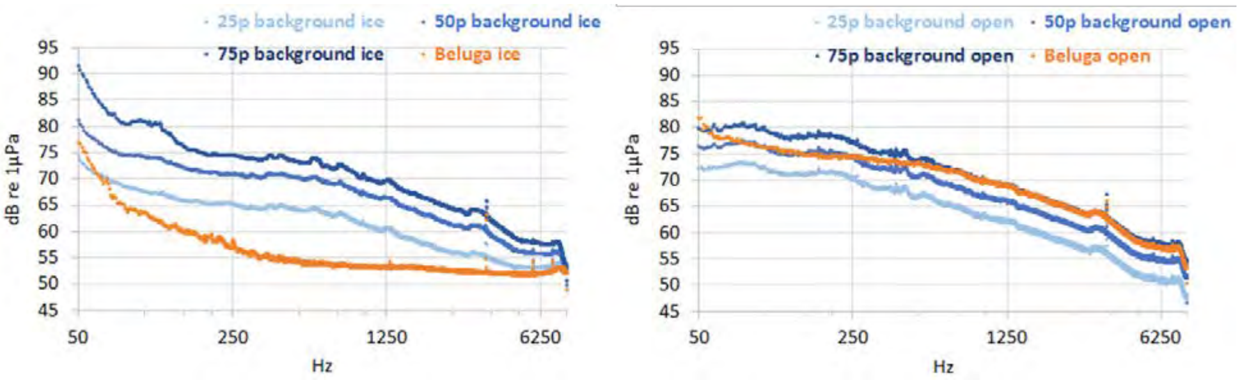


Figure 202. Left panel: Spectral 50th percentile for beluga signals at PH1 2012-2013 during the ice season and the 25th, 50th and 75th percentiles for ambient noise. Right panel: Spectral 50th percentile for beluga signals at PH1 2012-2013 during the open water season and the 25th, 50th and 75th percentiles 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 203). 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 203).

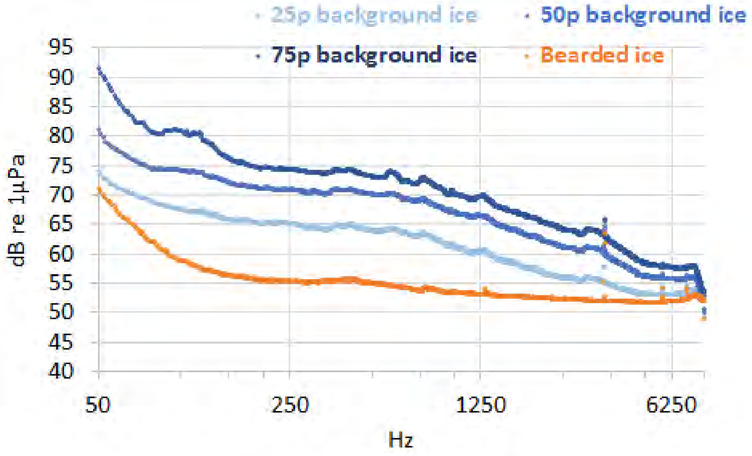


Figure 203. Spectral 50th percentile for bearded seal signals at PH1 2012-2013 during the open water season and the 25th, 50th and 75th percentiles for ambient noise. Spikes at 3400 Hz, 5500 Hz, and 7000 Hz are artifacts likely from electrical system noise. Note, the x-axis is presented in a base 5 logarithmic 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 204).

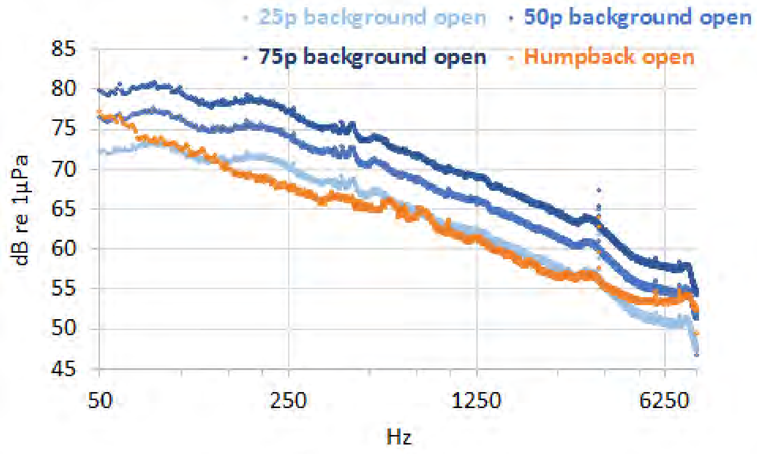


Figure 204. Spectral 50th percentile for humpback whale signals at PH1 2012-2013 during the open water season and the 25th, 50th and 75th percentiles for ambient noise. Spikes at 3400 Hz, 5500 Hz, and 7000 Hz are artifacts likely from electrical system noise. Note the x-axis is presented in a base 5 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 205).

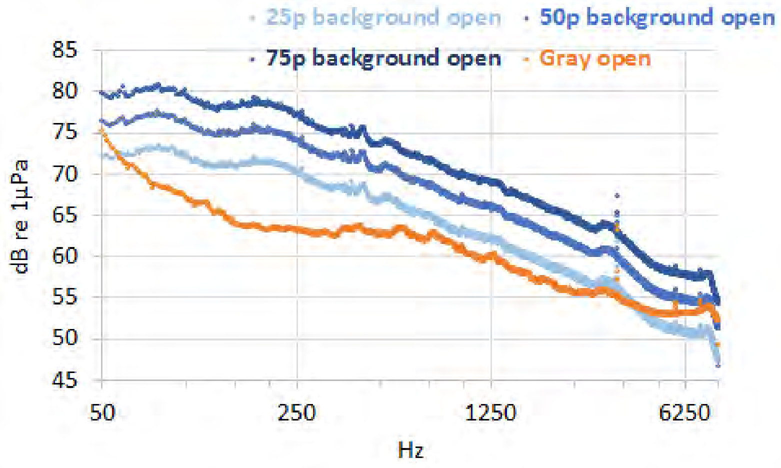


Figure 205. Spectral 50th percentile for gray whale signals at PH1 2012-2013 during the open water season and the 25th, 50th and 75th percentiles for ambient noise. Spikes at 3400 Hz, 5500 Hz, and 7000 Hz are artifacts likely from electrical system noise. Note, the x-axis is presented in a base 5 logarithmic 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 206).

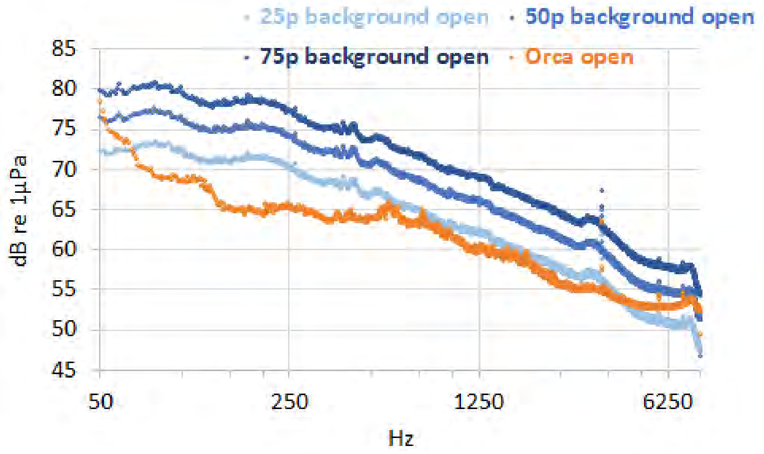


Figure 206. Spectral 50th percentile for killer whale signals at PH1 2012-2013 during the open water season and the 25th, 50th and 75th percentiles for ambient noise. Spikes at 3400 Hz, 5500 Hz, and 7000 Hz are artifacts likely from electrical system noise. Note, the x-axis is presented in a base 5 logarithmic scale to highlight the lower frequencies.

For the ice season, walrus were also 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 207).

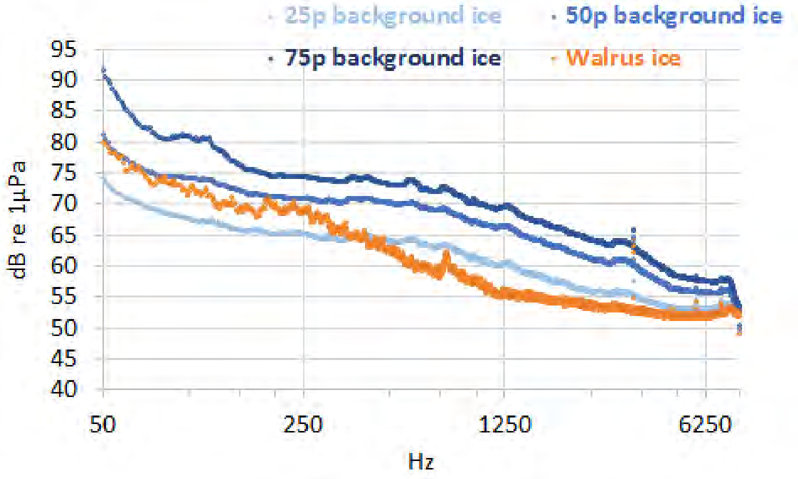


Figure 207.Spectral 50th percentile for walrus signals at PH1 2012-2013 during the open water season and the 25th, 50th and 75th percentiles for ambient noise. Spikes at 3400 Hz, 5500 Hz, and 7000 Hz are artifacts likely from electrical system noise. Note, the x-axis is presented in a base 5 logarithmic scale to highlight the lower frequencies.

When the three predominant species and vessel noise were compared by season, the higher acoustic contribution by bowhead whales was evident for the ice season (Figure 208). When vessel noise contribution was considered for the open water season, this anthropogenic disturbance exceeded the full spectral curve of humpback whale signals, and the lower frequencies of beluga and bowhead whale curves.

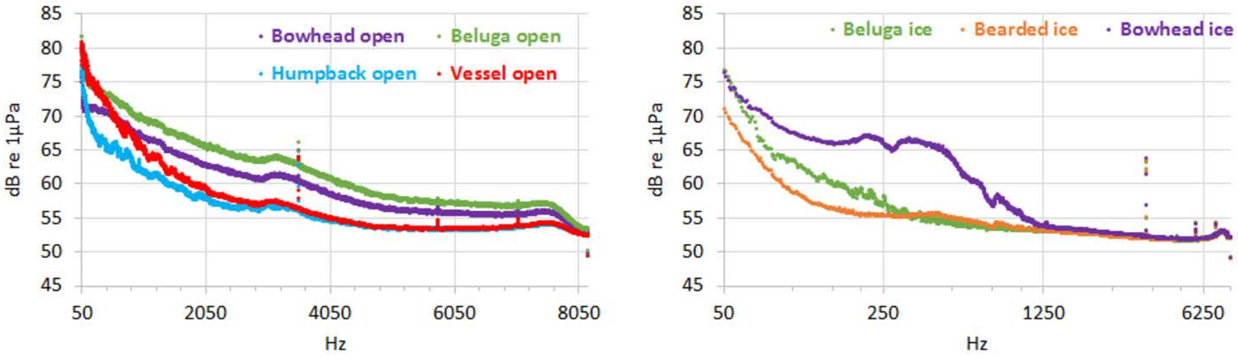


Figure 208. Spectral 50th percentile for bearded seal, bowhead whale, beluga sounds, and vessel noise at PH1 2012-2013 during the open water season (left panel) and during the ice season (right panel). Spikes at 3400 Hz, 5500 Hz, and 7000 Hz are artifacts likely from electrical system noise. Note, the 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 were limited to just the beginning and ending of the season when ice concentration was not high. 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 when ice concentration was not high. 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 these unexpected results. Source levels of ice breaking vessels have been documented to be higher than non-ice breaking vessels (Roth et al., 2012), 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 of 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. PH1 mooring is closer to the Bering Strait and acoustic data from this site was 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 leases during this time because Wainwright was a main logistics hub for those areas.

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). Like results in 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 orca and gray whales, which were absent in WT1, but their contribution was modest 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. Both acoustic environments were clearly dominated by three marine mammals: bowhead whales, bearded seals and walruses, except for the open water season in PH1, and both the open water and freezing period in October and November in WT1, when vessel noise 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 the ones for ambient noise, 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 the one of the ambient noise curves. It just indicates that the species presence occurs when ambient noise was high. But if the species spectral curve departs from the shape of the ambient noise curves, it highlights the frequencies of influence by the 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 instruments 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 U. 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. SYNTHESIS

A tremendous amount of data were collected during the ARCWEST and CHAOZ-X studies. We are only beginning to skim the surface of the power possible from this integrated time series. For this synthesis chapter/section we will explore four main topics: Correlation of marine mammal distribution with biophysical parameters; the Chukchi Sea polynya; Biological hotspots; and long-range predictive capabilities.

A. Correlation of marine mammal distribution to biophysical parameters

1. Introduction

The Chukchi Sea ecosystem is complicated: landscape ecology, and regional and local forcing all combine to determine whether or not there will be favorable conditions for both the permanent and transitory residents. The residents of interest in this study, marine mammals, belong to several different feeding guilds, further complicating our goal of understanding how climate change and other anthropogenic forcing will affect them.

Bottom currents were generally northeastward following bathymetry, and variability in currents was primarily wind-driven. Monthly mean transports were strongest in the summer months and the total transport across the Icy Cape line accounted for ~40% of the flow through Bering Strait. Around the C2 and C3 mooring sites, most of the northward flow up Central Channel turned eastward to join the coastal flow which exited through Barrow Canyon. The strongest flow occured along the coast from Icy Cape (C1) to the slope (C4 and C5). The remainder of the northward flow in Central Channel appeared to parallel the bathymetry on the northern and western side of Hanna shoal. This flow was much weaker than the flow on the Icy Cape line and along the coast. Reversals of flow up Barrow Canyon occured and were linked to oceanographic conditions over the shelf, and have facilitated the physical transport of Arctic basin zooplankton species; for example “high” concentrations of *C. hyperboreus* were observed around the outer shelf in 2011. In addition, five instances of polynyas were detected throughout the study period.

Summer phytoplankton biomass was higher on the flanks and over the top of Hanna Shoal than other offshore shelf areas. Additionally, the nutrient-rich subsurface layer was likely an area of active photosynthesis over much of the shelf (at least in water depths of <45 m). Zooplankton community structure showed a great deal of inter-annual variability with some tendency for an east-west pattern in some years. Particular zooplankton assemblages within a year were often associated or distinguished by different temperature and salinity waters. Evidence for euphausiid transport from the Bering Sea (conveyor belt hypothesis) was not present during the summer season, and in one or more years, the presence of early life history stages of euphausiids suggested that some euphausiid reproduction occurred in the Chukchi. Unlike the Beaufort, we did not find evidence for a euphausiid trap in the Chukchi; there were no hotspots with high aggregations of euphausiid or other invertebrate prey. There was also weak evidence to support the hypothesis that diel vertical migration was important over this shallow shelf.

In this section we examine how these unique qualities affect the presence of marine mammals on the shoal. We present general findings, then highlight a few key results.

2. *Methods*

An iterative approach using regression tree analysis and 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[26] 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, 2015). Regression tree models were fitted using the rpart and prune functions from the rpart package (Therneau et al., 2017). Default settings were used including allowing rpart to use surrogate variables or the majority direction to split observations with missing data 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 10 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 identified as important.

There were 36 different biophysical measurements available to include for each regression tree for individual mooring data (Table 54), and an additional 4 location variables for the analyses which included multiple moorings. Because of differences in instrument deployment between years and moorings and instrument failure, all biophysical variables were not always available for days when there was acoustic data. To minimize misleading results, analyses were limited to ARCWEST moorings C2, C3, and C4 and to biophysical variables which had 36% or fewer missing data points. Sufficient acoustic data existed for the analysis of bowhead, gray, and beluga whales, bowhead whale gunshot calls, bearded seals, and walrus. Regression trees were constructed for C2, C4, and C5 individually with the biophysical measurements. These three mooring sites were combined as an ARCWEST set of moorings. Regression trees were then run on the ARCWEST set for two scenarios: 1) with the biophysical measurements and location variables; and 2) with only the biophysical measurements. Adding the location variables did not change the top five primary variables for the first split, and will not be considered further here. For gray whales, sufficient data only existed for the ARCWEST mooring C5 and for the combined analysis. Before these results are published, the individual moorings will be examined by deployment year to see if additional data can be included without increasing the percentage of missing explanatory data.

GAMs were fitted for the presence/absence of bowhead, gray, and beluga whales, gunshot calls, bearded seals, and walrus. As a first run, explanatory variables were the five

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

primary variables identified for the first node in the regression analysis using all three moorings (C2, C4, and C5) combined and only biophysical measurements (i.e., location variables were not included). This was chosen to give spatial coverage along the ACC 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 ($p < 0.05$). 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 primary variables. For all species except gray whales, all five primary variables were significant. For gray whales, month was dropped because it was not significant ($p = 0.98 - 1.00$ depending on month). Note that the y-scale on the GAM plots was often reduced to show the pattern in the explanatory variable; therefore, the plots often under-represent the variation in the results.

We included all available data from 2010 through 2015 for this statistical analyses. However, because our dataset was 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 recorder locations was used in the marine mammal distribution section above (Section VII), only those that were deployed in clusters with the biophysical moorings were included in the regression tree and GAM analyses. An additional caveat of our analysis is that although the datasets were collected over a similar time and spatial scales, the overlap between the passive acoustic results and the oceanographic measurements was sometimes patchy[27]; 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 were the best models for these data at this time. All variables were included regardless of possible correlations between variables.

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[27] 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. For GAMs, days with missing explanatory variables used in the model were removed.

Table 54. Variables used in the regression tree models. Listed are the variable codes, descriptions, the percentage of missing data on all ARCWEST and CHAOZ-X moorings combined, and the percentage of missing data on C2, C4 and C5 combined. Only variables with 36% or fewer missing data points were included in the regression tree models.

Variable	Description	All	C2, C4, & C5
Ice.Conc	Ice Concentration (%)	0	0
Winds.u	Zonal Wind (Component of Horizontal Wind towards East)	0	0
Winds.v	Meridional Wind (Component of Horizontal Wind towards North)	0	0
Winds.spd	Wind Speed (m s^{-1})	0	0
Month	Month data were collected	0	0
Year	Year data were 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 (Sverdrup)	0	0
Temp	Temperature (°C)	24	0
Salinity	Salinity (psu)	26	1
PAR	Photosynthetic Active Radiation (mEin cm^{-2} s^{-1})	40	16
Currents.U.bottom	Bottom Zonal Velocity (Current toward East, cm s^{-1})	43	14
Currents.V.bottom	Bottom Meridional Velocity (Current toward North, cm s^{-1})	43	14
Chlorophyll	Chlorophyll concentration derived from fluorescence (µg L^{-1})	45	11
O2.bottom	Bottom O_2 (mMol kg^{-1})	56	26
O2.bottomSat	Bottom O_2 Saturation (%)	56	26
Ice.Thick.Ave	Average Ice Thickness (m)	58	36
Ice.Thick.Med	Median Ice Thickness (m)	58	36
Ice.Thick.SD	Standard Deviance in Ice Thickness (m)	58	36
ADCP.300.Bottom.Sv	Acoustic Doppler Current Profiler at 300 kHz, Bottom Layer Only Volume Backscattering (dB re 1 m^{-1})	72	57
ADCP.300.Column.Sa	Acoustic Doppler Current Profiler at 300 kHz, Entire Water Column, Area Backscattering (dB re 1(m^2 m^{-2}))	72	57

Variable cont.	**Description**	**All**	**C2, C4, & C5**
ADCP.600.Bottom.Sv	Acoustic Doppler Current Profiler 600 kHz, Bottom Layer Only, Volume Backscattering (dB re 1 m^{-1})	72	73
ADCP.600.Column.Sa	Acoustic Doppler Current Profiler 600 kHz, Entire Water Column, Area Backscattering (dB re 1(m^2 m^{-2}))	72	73
Currents.U.surface	Surface Zonal Velocity (Current toward East, cm s^{-1})	85	84
Currents.V.surface	Surface Meridional Velocity (Current toward North, cm s^{-1})	85	84
Turbidity	Turbidity (FNU)	88	84
Nitrate	Bottom Nitrate (µM)	89	86
TAPS.BioVol.Full.col	Tracor Acoustic Profiling System, Total BioVolume (mm^3/m^3) of the Water Column	100	99
TAPS.BioVol.Bottom	Tracor Acoustic Profiling System, Total BioVolume (mm^3/m^3) at the Bottom	100	99
TAPS.Euphausiid.Full.col	Tracor Acoustic Profiling System, Euphausiid Abundance ($/m^3$) of the Water Column	100	99
TAPS.Euphausiid.Bottom	Tracor Acoustic Profiling System, Euphausiid Abundance ($/m^3$) at the Bottom	100	99
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	99
TAPS.420.Bottom	Tracor Acoustic Profiling System, 420 kHz Volume Backscatter (Sv) at the Bottom (dB re 1 m^{-1})	100	99
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	99
TAPS.50.Bottom	Tracor Acoustic Profiling System, 50 kHz Volume Backscatter (Sv) at the Bottom (dB re 1 m^{-1})	100	99
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 ARCWEST C2, C4, and C5 moorings and on the ARCWEST set of these moorings, the GAMs analysis focused on the combined ARCWEST set of moorings and on the primary variables identified for the first node of the combined regression tree analysis. In addition, the acoustic data was reduced to presence/absence for the GAMs analysis for ease of analysis as the modeling of acoustics data is still being developed by the statistical community at large. This reduction lost the detail of the level of calling activity present on each day and made 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, we presented the pruned regression tree, the primary variables for the first node of the tree, and the GAM results.

Bowhead whale

The regression tree indicated month, PAR, salinity, temperature, bottom oxygen, meridional currents, and wind speed were important variables for bowhead whales (Figure 209). Three of the first twelve splits were determined by month, three were salinity, and two were bottom oxygen. Month could have been a proxy for temporal oceanographic conditions which were not measured or might represent endogenous cycles driving bowhead migration and distribution.

Only month and temperature were both in the first twelve splits of the regression tree and in the group of five primary variables for moorings C2, C4, and C5 combined (Figure 209; Table 55). Average ice thickness was important for all three individual moorings but not for the combined set. Examining the individual mooring results, there was individual variation between mooring locations except for month which was important for all moorings. This individual variation may be due to different environmental drivers at different locations.

The GAM results indicate that the relationships between bowhead calls and temperature, chlorophyll, and ice concentration were non-linear. Calling was fairly consistent until about 2 °C, after which there was a slight increase then a decline; however, uncertainty increased at higher temperatures. Calling increased at chlorophyll concentrations of about 0.5 and 5 $\mu g\ L^{-1}$; there were too few samples at very high chlorophyll levels to interpret the patterns. Calling activity peaked at ice concentrations of about 30% and 65%. Calling activity peaked in April/May and October/November, and seemed to be increasing since 2010 (Figure 210).

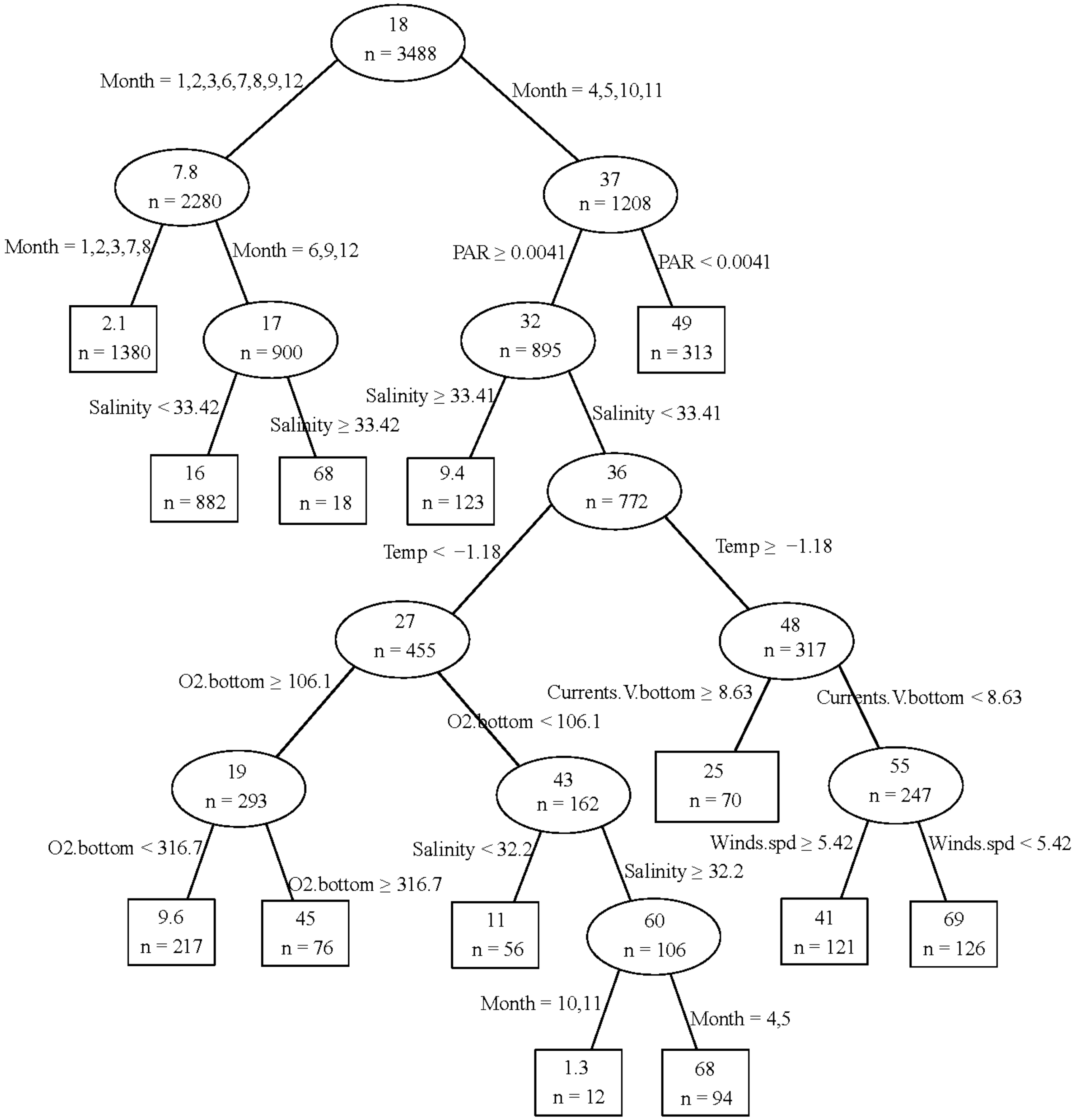
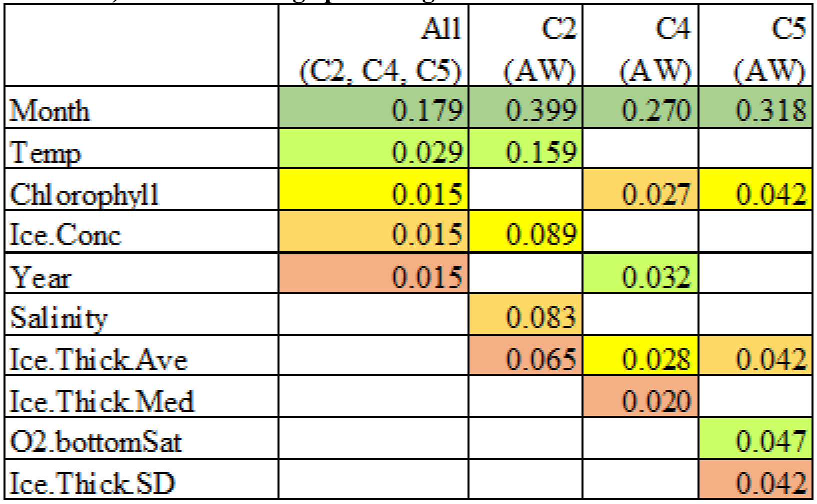


Figure 209. Pruned regression tree for bowhead whale calls including ARCWEST moorings C2, C4, and C5. The original pruned tree accounting for relative error (xerror) versus the complexity parameter (cp) was still very complex; additional pruning reduced this tree to 13 terminal nodes (12 splits). The 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 55. The primary variables for the first node of the regression trees for bowhead whales using ARCWEST moorings C2, C4, and C5 combined and each alone. Variables are color coded by the level of improvement in the model with dark green providing the most improvement (and is the variable defining the first node) and dark orange providing the least.



	All (C2, C4, C5)	C2 (AW)	C4 (AW)	C5 (AW)
Month	0.179	0.399	0.270	0.318
Temp	0.029	0.159		
Chlorophyll	0.015		0.027	0.042
Ice.Conc	0.015	0.089		
Year	0.015		0.032	
Salinity		0.083		
Ice.Thick.Ave		0.065	0.028	0.042
Ice.Thick.Med			0.020	
O2.bottomSat				0.047
Ice.Thick.SD				0.042

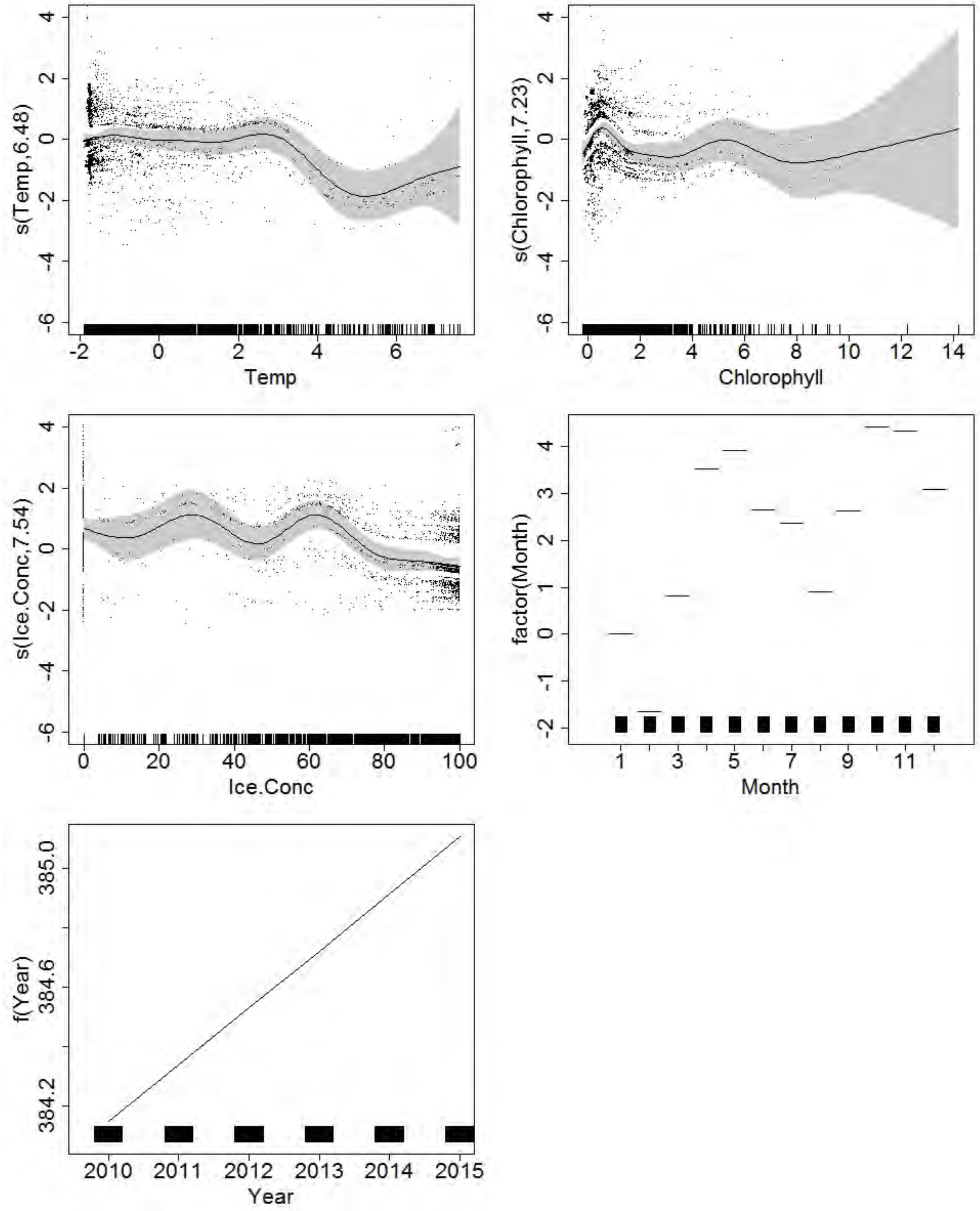


Figure 210. GAM results for bowhead whale call presence/absence using the primary variables for node one from the combined C2, C4, and C5 regression tree as explanatory variables. Temperature, chlorophyll, and ice concentration were included as smoothed variables, month as a factor, and year as linear. For smooth functions, partial residuals were plotted, and the gray shaded regions indicate the confidence bands. All plots include a rug plot of the marginal distribution of each variable along x axis.

Gunshot calls (Bowheads)

The regression tree including ARCWEST C2, C4, and C5 moorings indicated month, chlorophyll, ice concentration, PAR, bottom oxygen, salinity, bottom currents, and variability in the ice thickness were important variables for gunshot calls (Figure 211). Highest gunshot call rates seemed to occur in November and December with low chlorophyll levels, bottom currents toward the east at less than 8.5 cm s^{-1}, and low variability and high ice concentrations.

Four of the variables (month, chlorophyll, bottom oxygen, and ice concentration) in the regression tree combining moorings C2, C4, and C5 (Figure 211) were identified as possibilities for defining the first split for that regression tree (Table 56); month and bottom oxygen were included for the regression trees for the individual ARCWEST moorings along with bottom oxygen saturation, chlorophyll for C2 and C5. The primary variables for the individual moorings were similar to the combined mooring results with three to four variables in common.

The GAM results indicate that gunshot calls increase with increased bottom oxygen levels but decrease with increased bottom oxygen saturation (Figure 212). However, bottom oxygen level was not significant ($p = 0.33$) in the full GAM even though it was significant ($p < 0.05$) in the single variable model. Gunshot calls increase with increased ice concentration. Days with gunshot calls were more prevalent in the later half of the year, and were lowest in March. It was difficult to interpret the chlorophyll pattern; gunshot calls decreased at high chlorophyll levels (8 µg L^{-1} and above) but model uncertainty was very high at these chlorophyll levels because of low sample sizes.

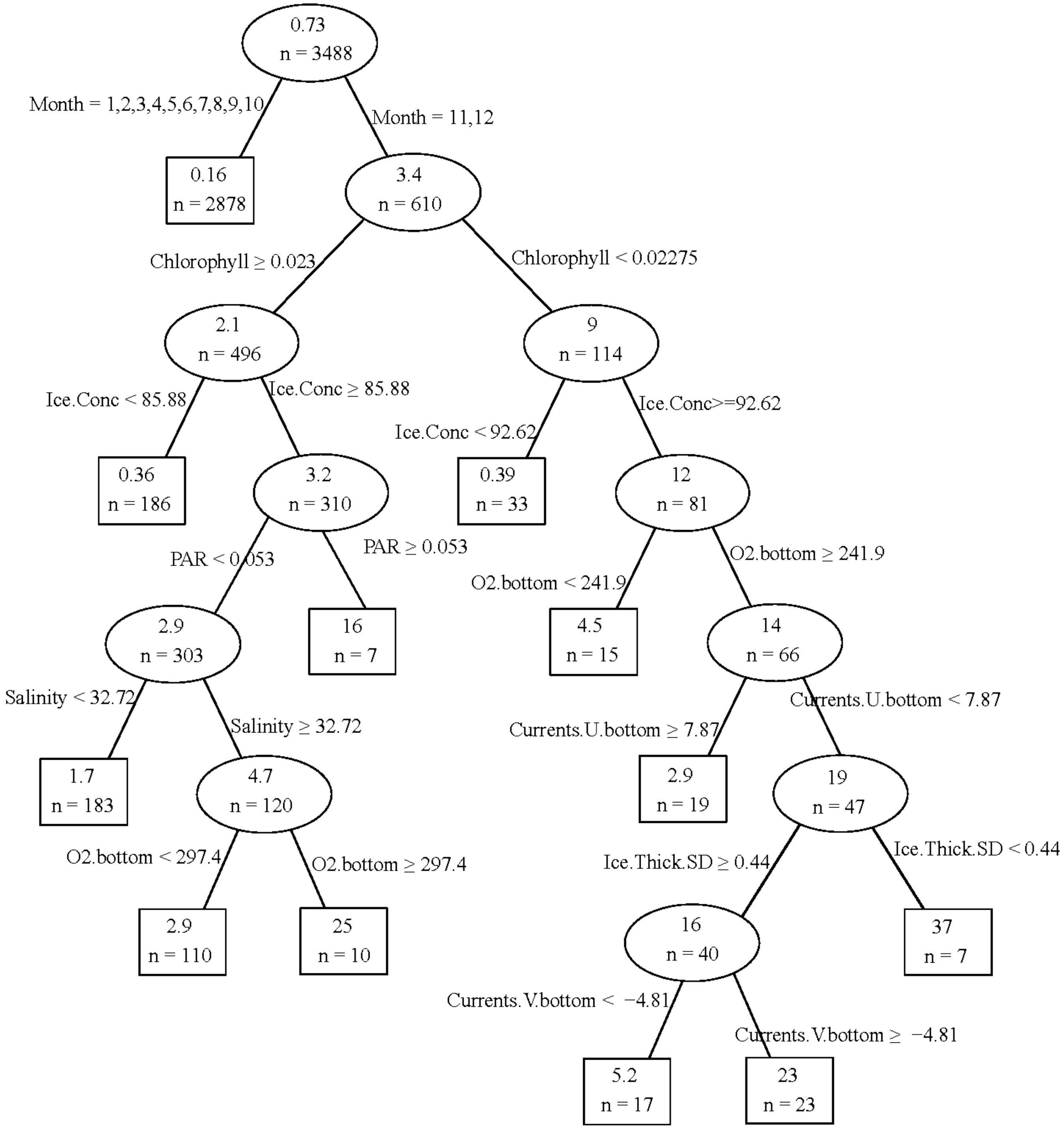
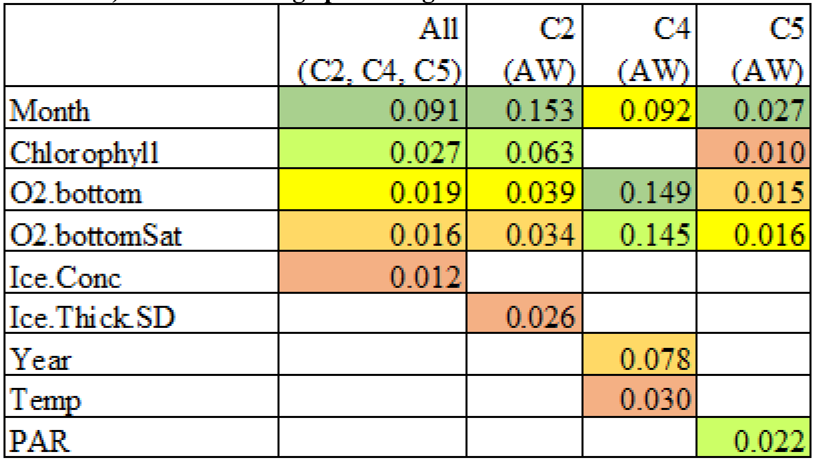


Figure 211. Pruned regression tree for gunshot calls including ARCWEST moorings C2, C4, and C5. The pruned tree accounts for relative error (xerror) versus the complexity parameter (cp). The values in each node are the predicted daily calling activity (%) for the node and the number of cases (i.e., number of days) reaching the node.

Table 56. The primary variables for the first node of the regression trees for gunshot calling using ARCWEST moorings C2, C4, and C5 combined and each alone. Variables are color coded by the level of improvement in the model with dark green providing the most improvement (and is the variable defining the first node) and dark orange providing the least.



	All (C2, C4, C5)	C2 (AW)	C4 (AW)	C5 (AW)
Month	0.091	0.153	0.092	0.027
Chlorophyll	0.027	0.063		0.010
O2.bottom	0.019	0.039	0.149	0.015
O2.bottomSat	0.016	0.034	0.145	0.016
Ice.Conc	0.012			
Ice.Thick.SD		0.026		
Year			0.078	
Temp			0.030	
PAR				0.022

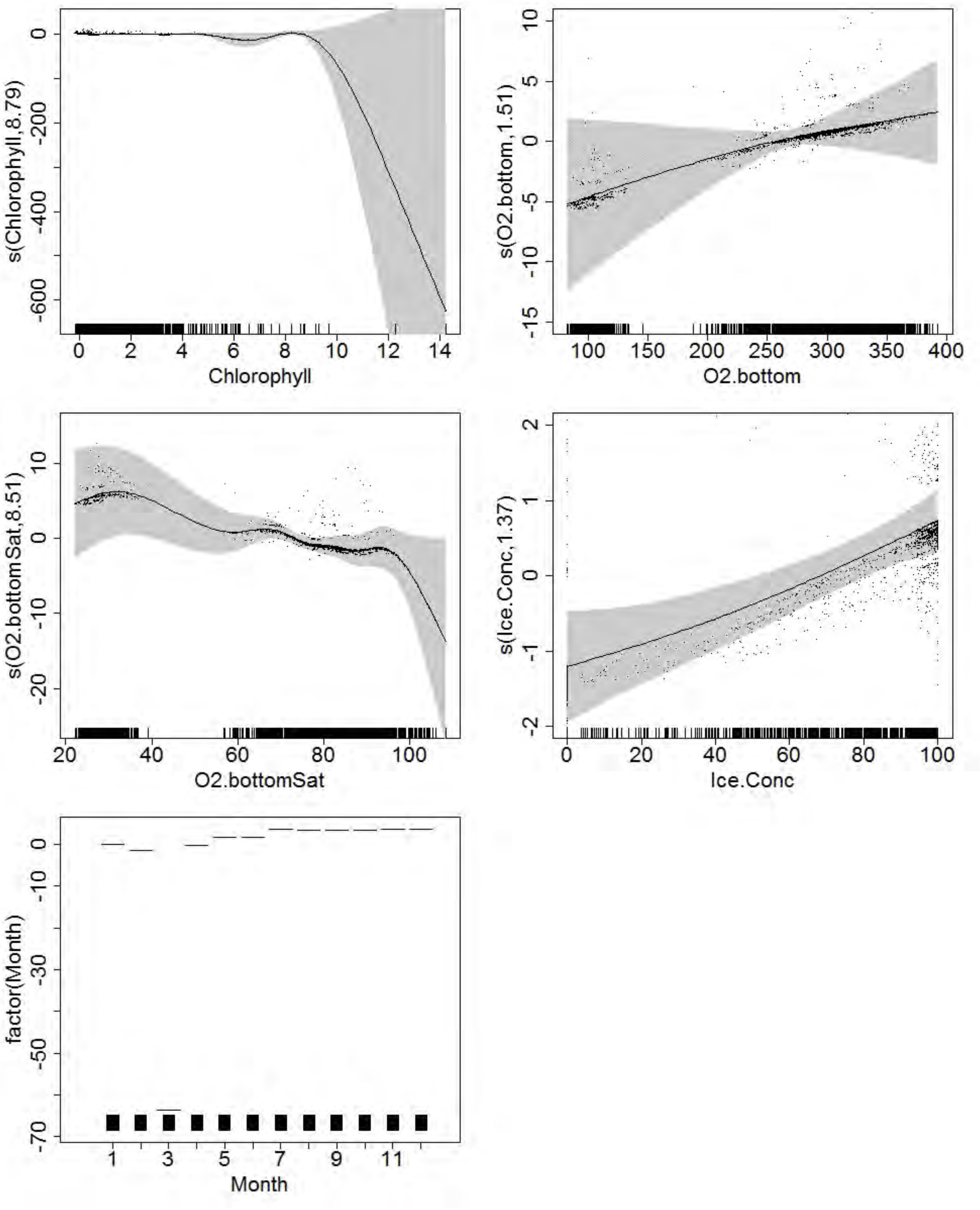


Figure 212. GAM results for gunshot call presence/absence using the primary variables for node one from the combined C2, C4, and C5 regression tree as explanatory variables. The chlorophyll, bottom oxygen level and saturation, and ice concentration were included as smoothed variables and month as a factor. For smooth functions, partial residuals were plotted, and the gray shaded regions indicate the confidence. All plots include a rug plot of the marginal distribution of each variable along x axis.

Beluga whale

The regression tree indicated month, average ice thickness, and chlorophyll were important variables for beluga whales. Samples in April and May with low average ice thickness were categorized as having the highest calling rate (Figure 213). However, these results should be taken with caution. Examining the call data, 3429 sample days (98%) have zero calling activity.

The primary variables for node one of the combined C2, C4, and C5 mooring tree were month, wind speed, ice concentration, median ice thickness, and meridional winds (Table 57). Examining the individual mooring results, there was large individual variation between mooring locations. Month was the only variable that was consistent across all three individual moorings and the only variable shared by more than one mooring. Mooring C4 was the most similar to the combined mooring results.

The GAM results indicate that beluga calls increased at moderate ice concentrations, low median ice thickness, high meridional winds, and low wind speeds. Calling activity peaked in April and May but were still high from June through November (Figure 214). However, median ice thickness and meridional winds were not significant (ice thickness $p = 0.19$, meridional winds $p = 0.13$) in the full GAM even though they were significant in the single variable models (both $p < 0.05$).

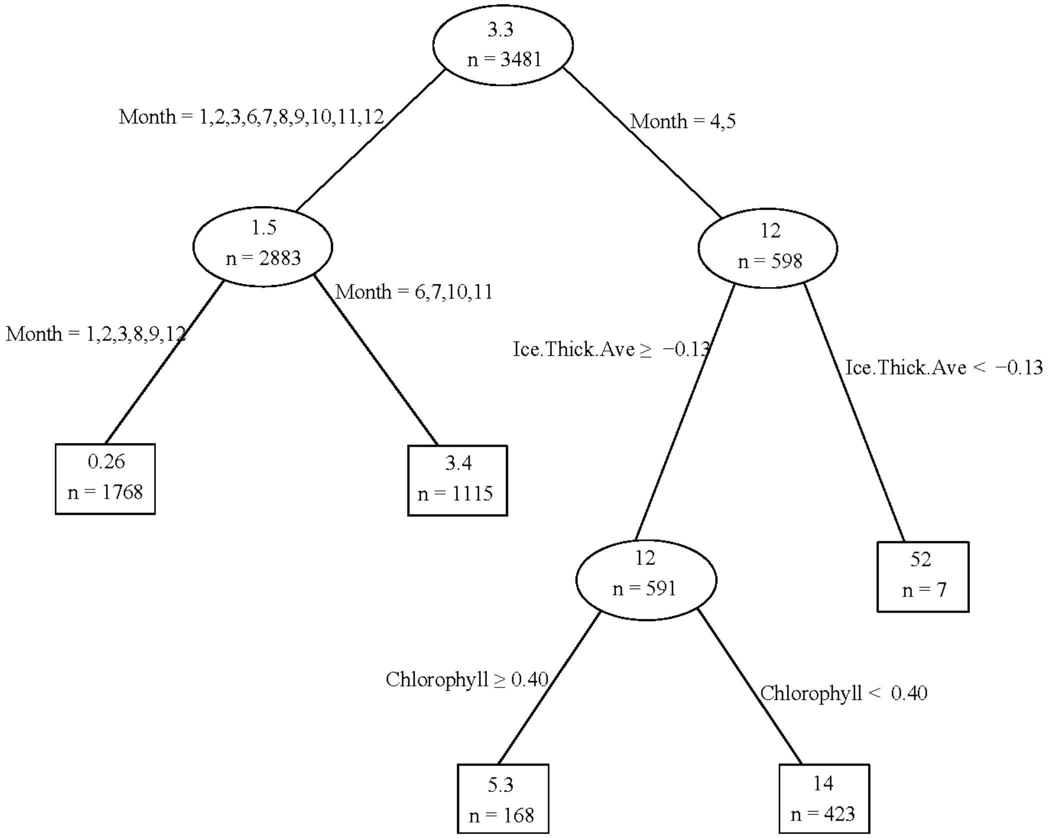


Figure 213. Pruned regression tree for beluga whale calls including ARCWEST moorings C2, C4, and C5. The original pruned tree accounts for relative error (xerror) versus the complexity parameter (cp). The values in each node are the predicted daily calling activity (%) for the node and the number of cases (i.e., number of days) reaching the node.

Table 57. The primary variables for the first node of the regression trees for beluga whales using ARCWEST moorings C2, C4, and C5 combined and each alone. Variables are color coded by the level of improvement in the model with dark green providing the most improvement (and is the variable defining the first node) and dark orange providing the least.

	All (C2, C4, C5)	C2 (AW)	C4 (AW)	C5 (AW)
Month	0.147	0.140	0.203	0.143
Winds.spd	0.017			0.034
Ice.Conc	0.017		0.026	
Ice.Thick.Med	0.014		0.024	
Winds.v	0.013			
Temp		0.081	0.027	
Salinity		0.072		
Ice.Thick.SD		0.031		0.033
Ice.Thick.Ave		0.027		
Chlorophyll			0.028	
O2.bottom				0.039
Winds.u				0.024

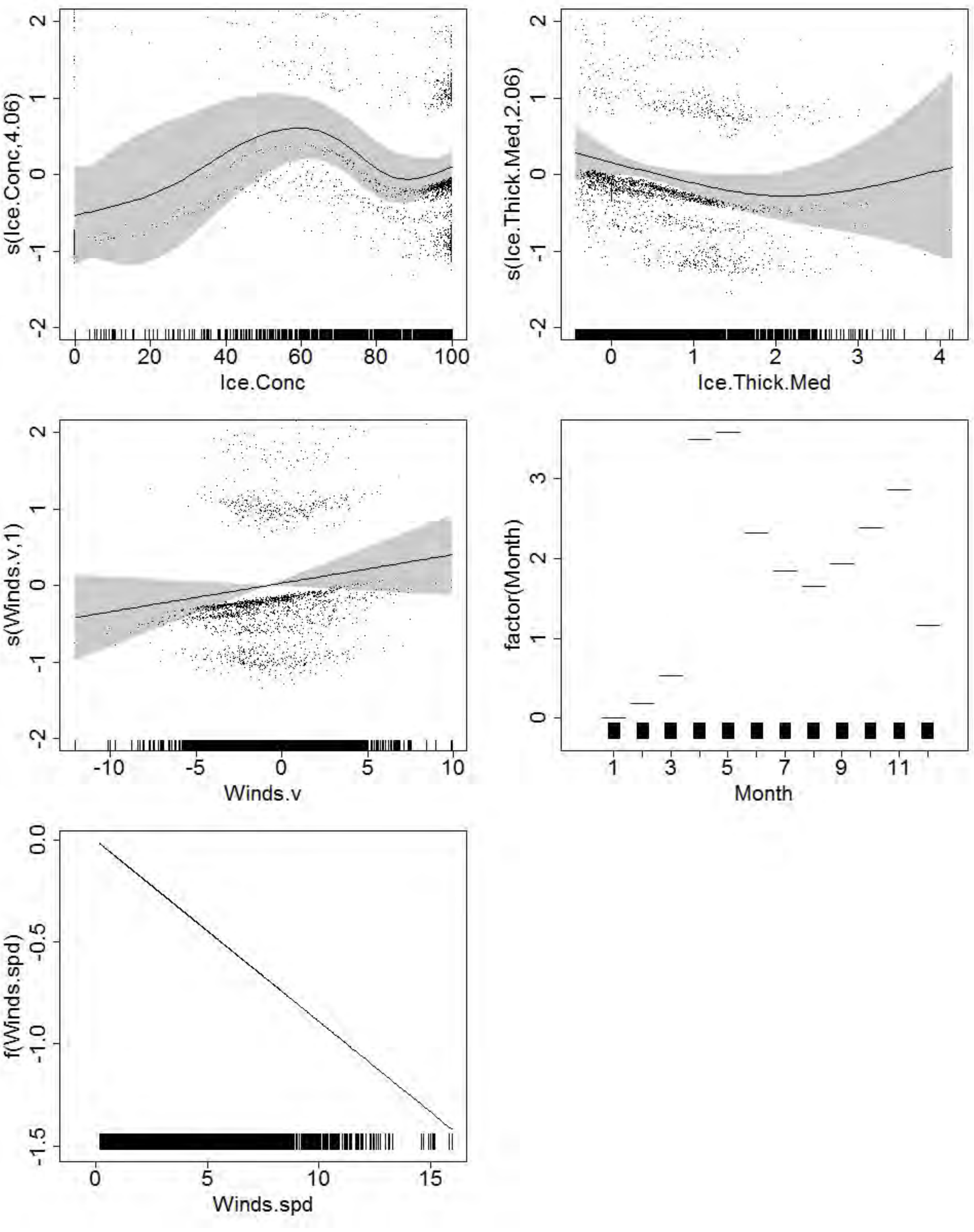


Figure 214. GAM results for beluga whale calls presence/absence using the primary variables for node one from the combined C2, C4, and C5 regression tree as explanatory variables. Ice concentration, median ice thickness, and meridional winds were included as smoothed variables, month as a factor, and wind speed as linear. For smooth functions, partial residuals were plotted, and the gray shaded regions indicate the confidence bands. All plots include a rug plot of the marginal distribution of each variable along x axis.

Gray whale

The regression tree indicated the bottom oxygen saturation, PAR, and bottom currents were important variable for gray whales (Figure 215). The grouping with the highest average gray whale call rate had bottom O_2 saturation levels lower than 34.45% and PAR level higher than 0.54 mEin cm^{-2} s^{-1}. Accuracy of model results were tenuous since only 1% (99) of the samples contained gray whale calls.

The primary variables for the first split of the all mooring regression tree were bottom oxygen saturation and levels, temperature, PAR, and month (Table 58). First split primary variables that were in common with the splits in the pruned tree were bottom oxygen saturation and PAR (Figure 215). The C5 mooring was the only individual mooring with enough non-zero samples to run the regression tree analysis and the only primary variables in common with the all mooring results were PAR and month. When location variables were included in the regression tree analysis, distance to shore replaced month as an important variable.

The GAM results indicated that gray whale calls increased at higher PAR, low oxygen bottom saturation, low to moderate bottom oxygen levels, and higher temperatures (Figure 216). Oxygen variables were driven by temperature: lower temperatures resulted in higher oxygen saturations and also in lower bottom oxygen levels.

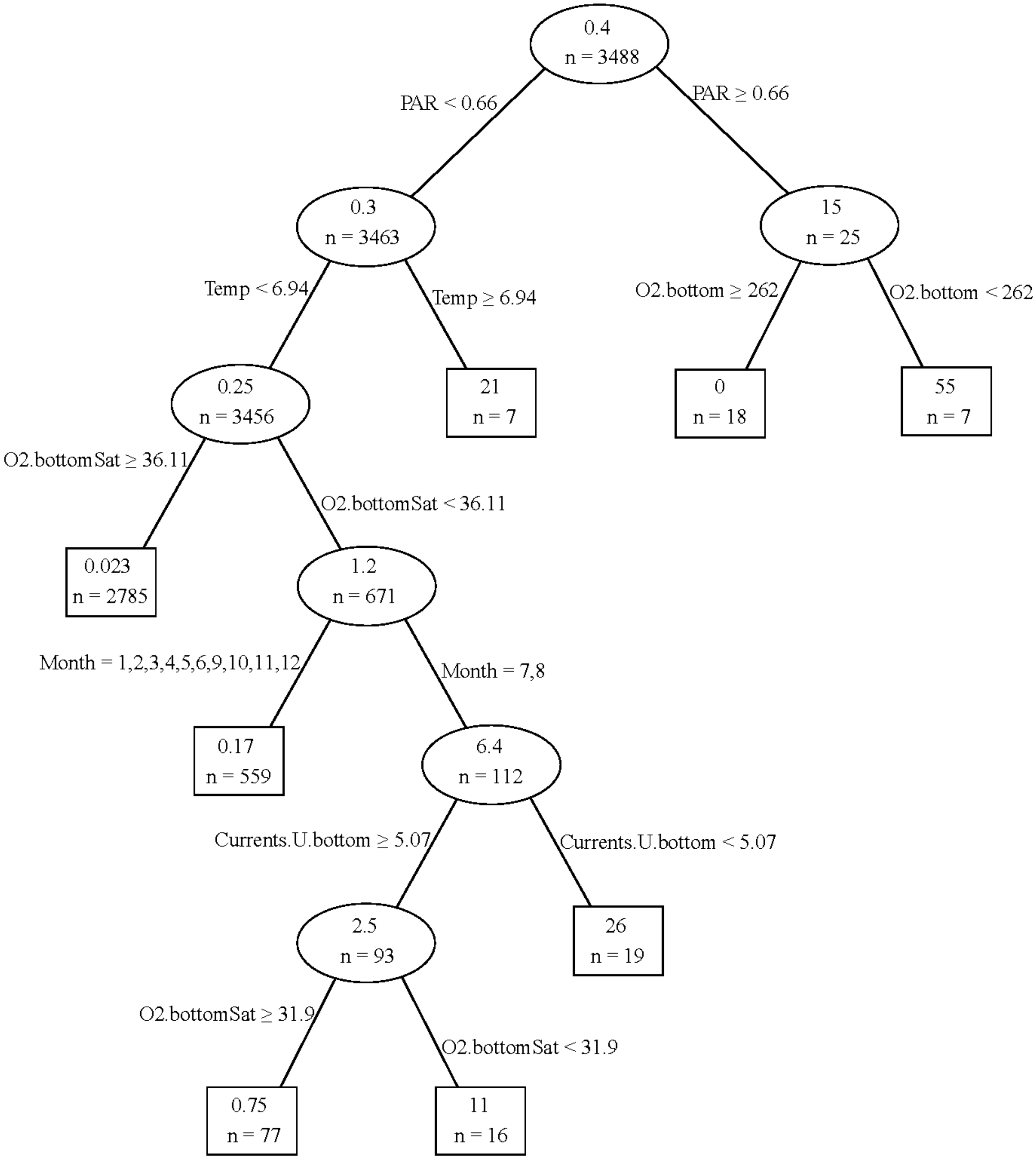


Figure 215. Pruned regression tree for gray whale calls including ARCWEST moorings C2, C4, and C5. The original pruned tree accounts for relative error (xerror) versus the complexity parameter (cp). The values in each node are the predicted daily calling activity (%) for the node and the number of cases (i.e., number of days) reaching the node.

Table 58. The primary variables for the first node of the regression trees for gray whales using ARCWEST moorings C2, C4, and C5 combined and each alone. Variables are color coded by the level of improvement in the model with dark green providing the most improvement (and is the variable defining the first node) and dark orange providing the least.

	All (C2, C4, C5)	C5 (AW)
PAR	0.088	0.320
O2.bottomSat	0.069	
O2.bottom	0.068	
Temp	0.044	
Month	0.043	0.163
Ice.Conc		0.099
Salinity		0.074
Year		0.071

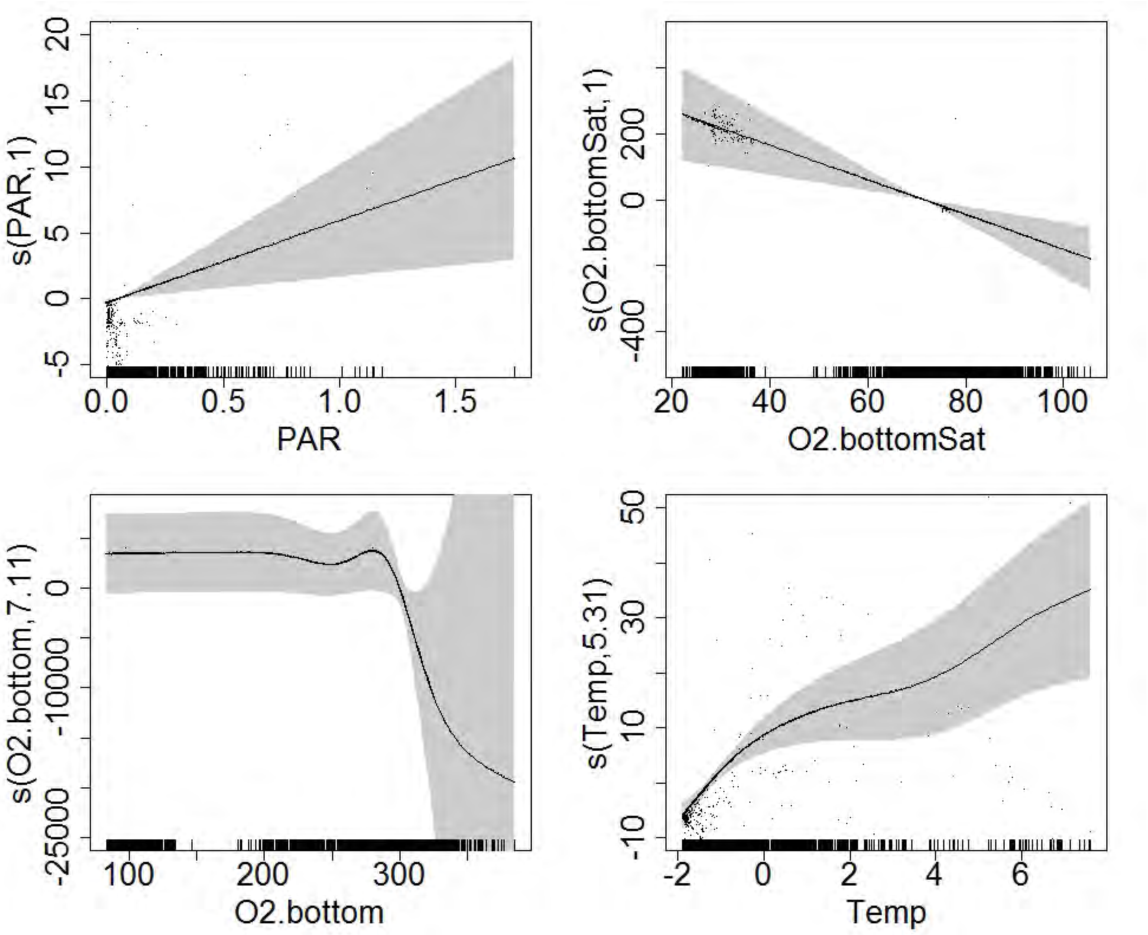


Figure 216. GAM results for gray whale call presence/absence using the primary variables for node one from the combined C2, C4, and C5 regression tree as explanatory variables. Photosynthetic active radiation (PAR), percent bottom O_2 saturation, bottom O_2 level, and temperature were all included as smoothed variables. For smooth functions, partial residuals were plotted, and the gray shaded regions indicate the confidence bands. All plots include a rug plot of the marginal distribution of each variable along x axis.

Walrus

The C2, C4, and C5 combined mooring regression tree for walrus calls indicated month, ice thickness (average and standard deviation), temperature, PAR, winds (meridional and speed), and oxygen bottom levels were important variables for walrus (Figure 217). As seen in the regression tree, highest average daily calling activity levels (73; n=37) occured in June and July with higher temperatures and higher meridional winds. Moderate calling activity levels (45; n=93) occured in June and July with lower temperatures, PAR, average ice thickness, wind speed, and oxygen bottom levels.

The primary variables for the first split of the C2, C4, and C5 combined mooring regression tree were month, chlorophyll, ice concentration, standard deviation of ice thickness, and temperature (Table 59). Of these possible first split variables, only month, ice temperature, and standard deviation of ice thickness were included in the pruned regression tree (Figure 217). Examining the individual mooring results, C2 was almost identical to the results for the combined moorings, C4 had three variables on common, and C5 had two (Table 59).

The relationship between walrus calls and ice modeled by the all moorings GAM was higher calling activity at high ice concentration (Figure 218). Calling activity declined at the lowest chlorophyll rates. Calling activity peaked in June and July and remained high through November. The relationships with the standard deviation of ice thickness and temperature were more complex, with three small peaks across the range of the variation in ice thickness and a single peak at ~4 °C across the range of temperatures. Temperature and ice concentration were not significant (temperature $p = 0.68$, ice concentration $p = 0.05$) in the final GAM even though they were significant in the single variable models (both $p < 0.05$).

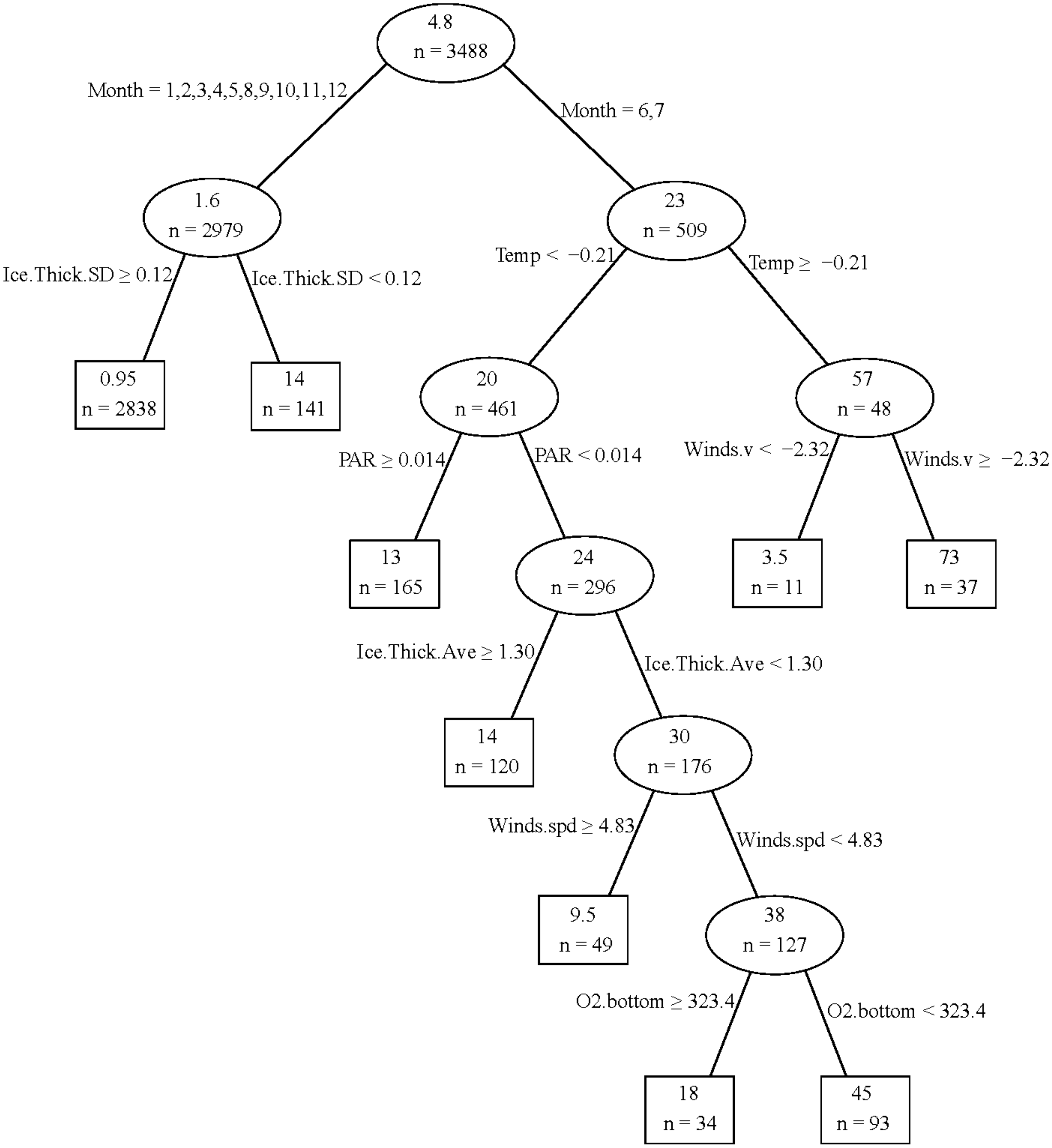
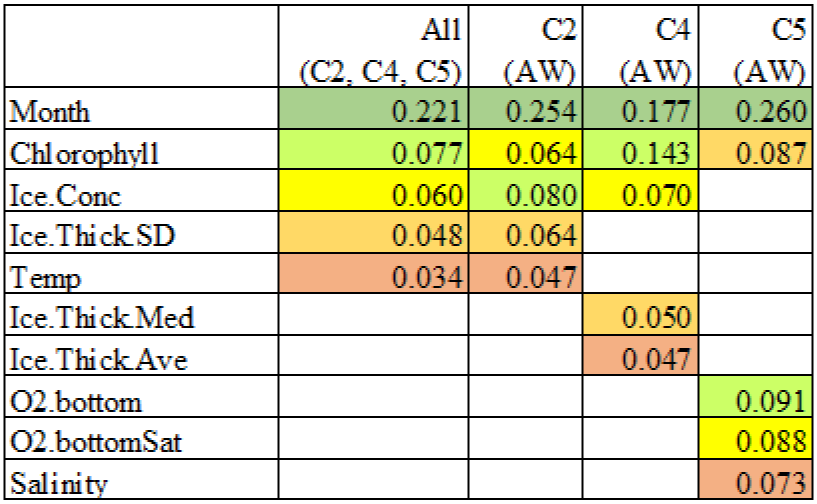


Figure 217. Pruned regression tree for walrus calls including ARCWEST moorings C2, C4, and C5. The original pruned tree accounts for relative error (xerror) versus the complexity parameter (cp). The values in each node are the predicted daily calling activity (%) for the node and the number of cases (i.e., number of days) reaching the node.

Table 59. The primary variables for the first node of the regression trees for walrus using ARCWEST moorings C2, C4, and C5 combined and each alone. Variables are color coded by the level of improvement in the model with dark green providing the most improvement (and is the variable defining the first node) and dark orange providing the least.



	All (C2, C4, C5)	C2 (AW)	C4 (AW)	C5 (AW)
Month	0.221	0.254	0.177	0.260
Chlorophyll	0.077	0.064	0.143	0.087
Ice.Conc	0.060	0.080	0.070	
Ice.Thick.SD	0.048	0.064		
Temp	0.034	0.047		
Ice.Thick.Med			0.050	
Ice.Thick.Ave			0.047	
O2.bottom				0.091
O2.bottomSat				0.088
Salinity				0.073

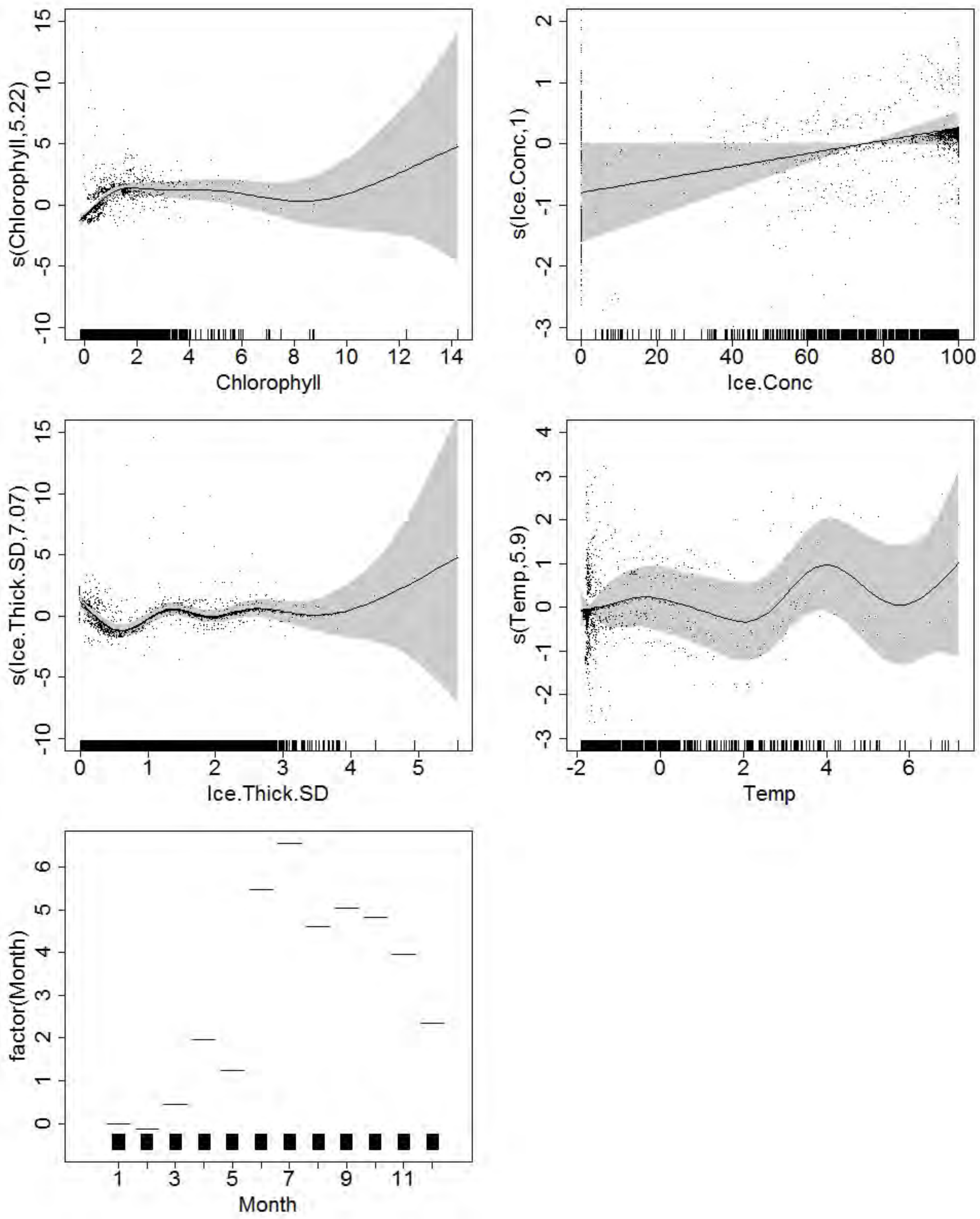


Figure 218. GAM results for walrus calls presence/absence using the primary variables for node one from the combined C2, C4, and C5 regression tree as explanatory variables. Chlorophyll, Ice concentration, standard deviation of ice thickness, and temperature were included as smoothed variables and month as a factor. For smooth functions, partial residuals were plotted, and the gray shaded regions indicate the confidence bands. All plots include a rug plot of the marginal distribution of each variable along x axis.

Bearded seal

The C2, C4, and C5 mooring regression tree indicated month, ice concentration, wind speed, temperature, chlorophyll, and transport were the driving factors for bearded seal calls. Highest calling rates occured between January and June under various conditions off the other important variables (Figure 219). Lowest call rates occured between July and December.

The primary variables for node one of the C2, C4, and C5 moorings combined regression tree were month, ice concentration, temperature, and average and median ice thickness (Table 60). This was not surprising given the results of the full regression tree (with month, ice concentration, and temperature in common; Figure 219), and the fact that bearded seals are ice associated (three ice related variables). Examining the individual mooring results, there was little individual variation between mooring locations; C2 is almost identical, C4 shared four variables, and C5 shared three variables. Month, ice concentration, and temperature were consistent across all four moorings, and average ice thickness was consistent across two moorings.

The C2, C4, and C5 combined mooring GAM results were complex for temperature with a peak in calling activity just below 4°C (Figure 220). In addition, bearded seal calling activity increased at high ice concentration and peaked in March, April, May and June. Calling activity increased with high average ice thickness but low median ice thickness; however, average and median ice thickness were not significant (average $p = 0.40$, median $p = 0.82$) in the five variable model even though they were significant in single variable models (both $p < 0.05$).

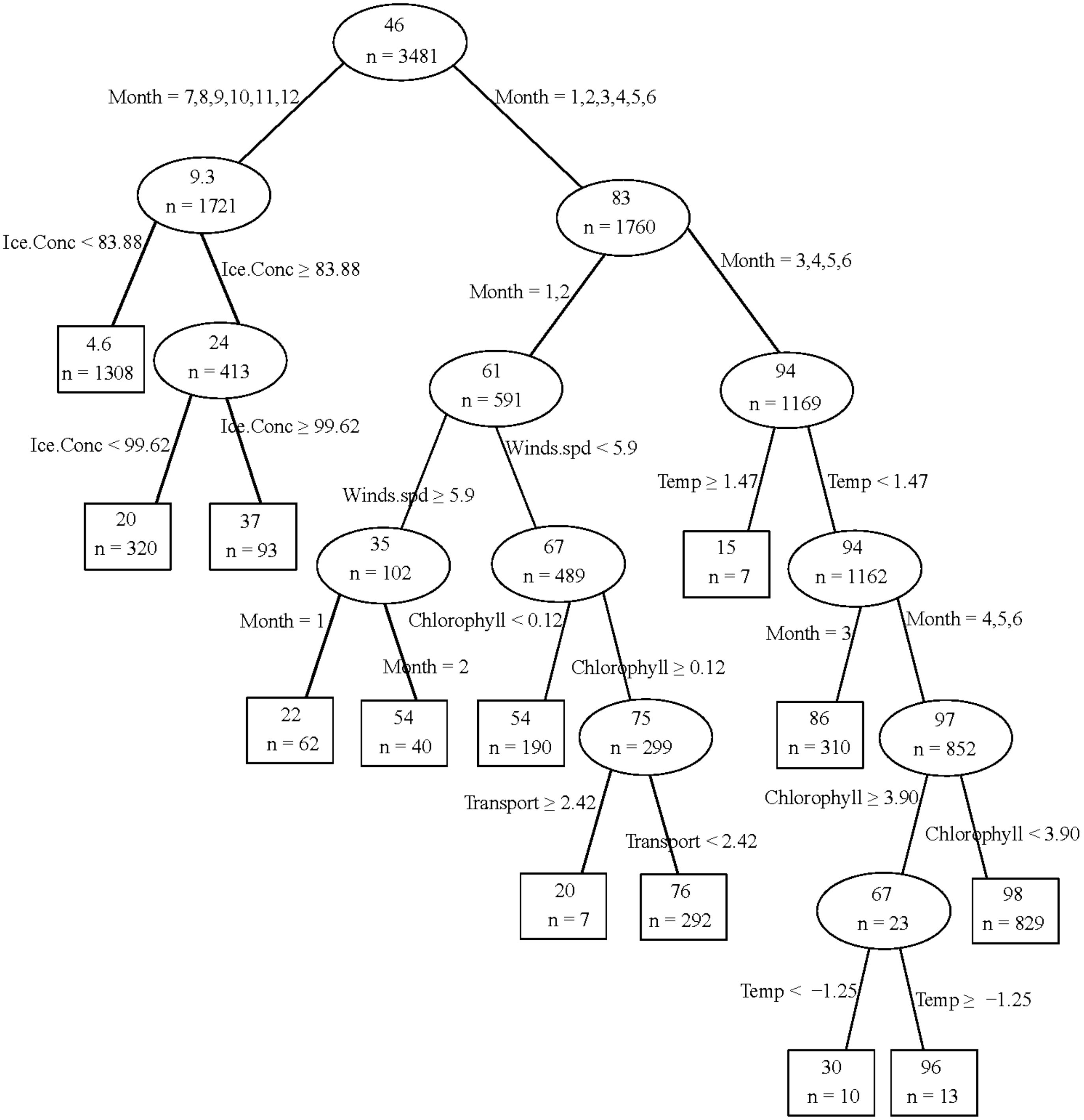
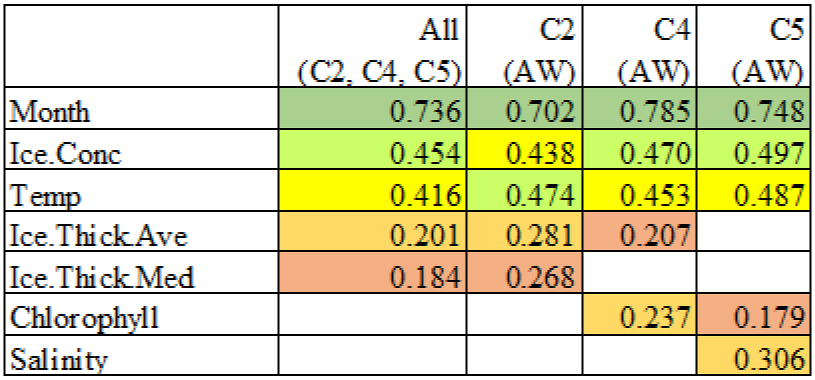


Figure 219. Pruned regression tree for bearded seal calls including ARCWEST moorings C2, C4, and C5. The original pruned tree accounting for relative error (xerror) versus the complexity parameter (cp) was still very complex; additional pruning reduced this tree to 13 terminal nodes (12 splits). The values in each node are the predicted daily calling activity (%) for the node and number of cases (i.e., number of days) reaching the node.

Table 60. The primary variables for the first node the regression trees for bearded seals using all of ARCWEST moorings C2, C4, and C5 combined and each alone. Variables are color coded by the level of improvement in the model with dark green providing the most improvement (and is the variable defining the first node) and dark orange providing the least.



	All (C2, C4, C5)	C2 (AW)	C4 (AW)	C5 (AW)
Month	0.736	0.702	0.785	0.748
Ice.Conc	0.454	0.438	0.470	0.497
Temp	0.416	0.474	0.453	0.487
Ice.Thick.Ave	0.201	0.281	0.207	
Ice.Thick.Med	0.184	0.268		
Chlorophyll			0.237	0.179
Salinity				0.306

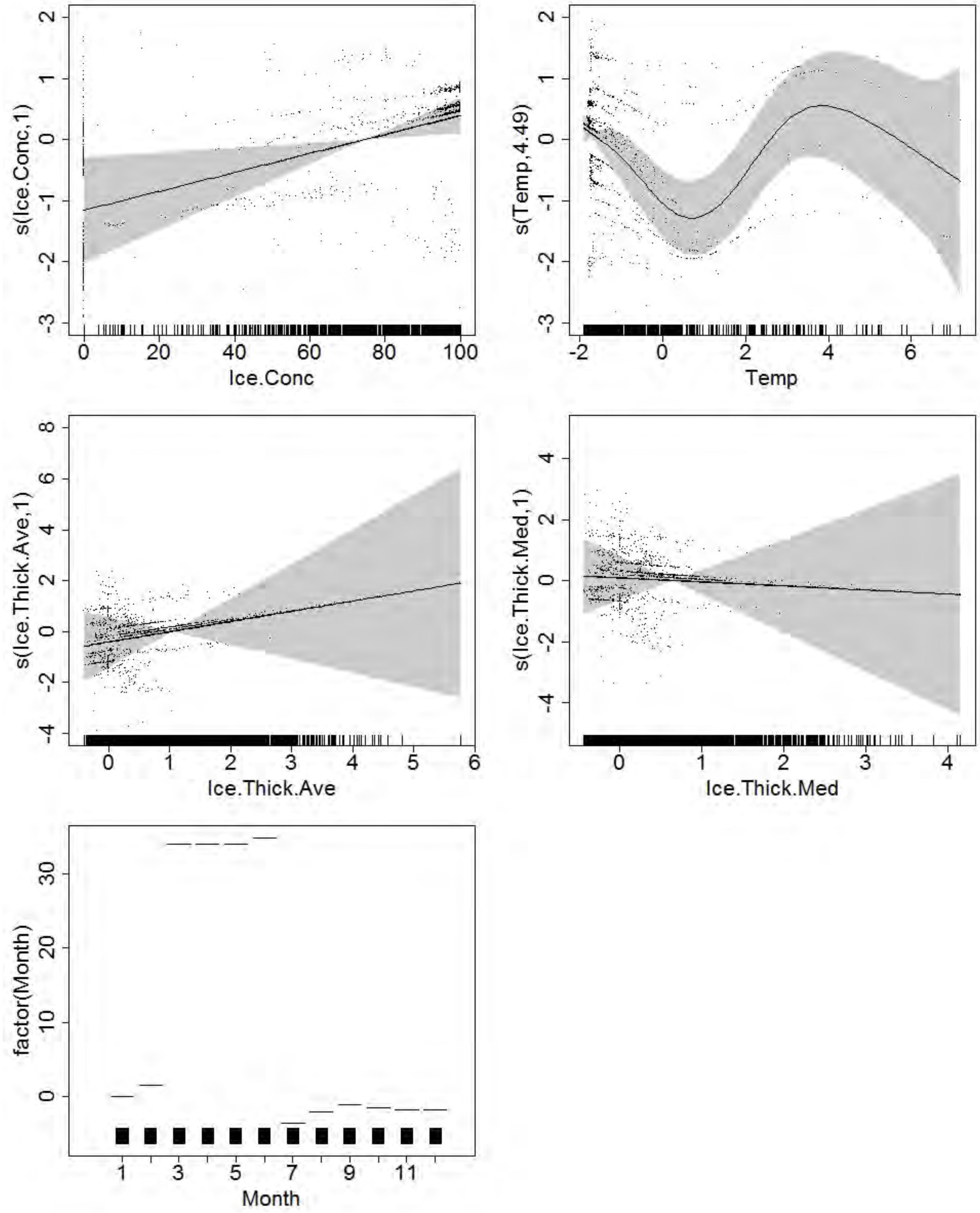


Figure 220. GAM results for bearded seal call presence/absence using the primary variables for node one from the combined C2, C4, and C5 regression tree as explanatory variables. Ice concentration, temperature, and the average and median of ice thickness were included as smoothed variables and month as a factor. For smooth functions, partial residuals were plotted, and the gray shaded regions indicate the confidence bands. All plots include a rug plot of the marginal distribution of each variable along x axis.

4. Discussion

As passive acoustic data sets on marine mammal species continue to grow, there is an ongoing effort to expand their usefulness beyond seasonal distribution of acoustic presence. One area of expansion is in evaluation of the extent to which variability in environmental conditions, such as ice concentration or sea surface temperature, affects the distribution of marine mammals. Relationships between these factors are rarely straightforward (i.e., linear), and marine mammal distribution is rarely controlled by a single factor, which is especially apparent for projects such as ARCWEST, CHAOZ-X, and CHAOZ, where acoustic recorders have been deployed in close proximity to a full suite of oceanographic and zooplankton instrumentation. Because of these reasons, GAMs seem the most appropriate mechanism for approaching this problem in a meaningful way. Application of GAM methods to acoustic data is an emerging area of research, and as such, is subject to many new quirks which warrant further consideration. The most critical of these, especially valid for the binned PAM analyses conducted under the ARCWEST project, is the treatment of the PAM results. The daily calling activity used in this study is a binomial (i.e., presence/absence) percentage value using the binned PAM results. However, current methods make it difficult to accurately model the binomial daily percentage data, resulting in nonsensical models. For future analyses for publication, we hope to be able to use the daily percentage data in generalized additive mixed models that account for temporal autocorrelation in addition to increased flexibility in model parameters in an attempt to appropriately model the call data.

A publication including these GAM results is planned for the near future. Prior to submission, additional analyses will be conducted, including the following: 1) Individual moorings will be examined by deployment year to see if data from additional moorings could be included without increasing the percentage of missing explanatory data; and 2) A more thorough examination of which explanatory variables to include in the GAM for each species will be conducted This will involve consultation with species experts, further examination of the regression trees, an analysis of which variables are correlated to avoid the inclusion of correlated variables (e.g., the mean and median of ice thickness), and the possible use of satellite derived oceanographic data. Depending on which variables are determined to be important for a species' distribution, the inclusion of AURALs which were not collocated with oceanographic data will be included if supplemental data are available as a substitute (e.g., the AURAL temperature data). Including these additional moorings will expand the geographic range over which distribution is modeled. Finally, additional data collected since the ARCWEST project will be included in this analysis and publication.

With these caveats in mind, however, our first attempt at evaluating environmental effects on marine mammal distributions does contain some interesting correlations. There are some minor improvements that can be made to the current analyses, and these will be pursued in more depth for upcoming peer-reviewed publications. In the future, these analyses will be rerun as additional techniques are developed by the statistical community for dealing with PAM data.

Bowhead whale

At first glance the lack of ice factors in the splits among the first few nodes of the bowhead whale regression tree (Figure 209) seem counterintuitive. Bowheads are a migratory species that are ice associative - moving into and out of the Arctic with the advance and retreat of ice. However, as shown in Figure 6, the presence/absence of bowhead calling did not have a binary dependence on ice. In the fall, the migratory pulse in calling activity started prior to ice formation; however, it did not end until well after ice concentration levels have reached 100%. The spring migration showed even less of an association with ice, with the pulse in calling activity beginning weeks before ice retreat; it is well established that bowheads use leads[28] to migrate east in spring (Moore and Reeves, 1993).

The first two major nodes in the regression tree were based on month. The first node split off April/May and October/November, the months with the highest monthly calling activity for the northeastern Chukchi Sea. The next two splits on that branch of the tree were PAR and salinity; both are factors that can be proxies indicating open water areas such as leads. Higher PAR levels suggest a reduction in ice, allowing sunlight to penetrate into the water column. When these higher PAR levels are accompanied by lower salinity values, recent ice melt and vertical mixing is suspected; higher PAR levels without the accompanying lower salinity suggests lead formation with little melting of ice or no mixing. In the first case, melting ice can result in export and mixing of ice-associated algae through the water column, whereas less vertical mixing is expected from the latter case. However, there is generally a time delay between primary productivity and food availability for upper trophic level species. It is most likely, therefore, that the presence of bowhead whales was primarily due to the availability of open water for migration and the increased productivity of these waters was coincidental.

The second branch off the main node was split again using month, with the overwinter season split from those months more closely associated with the fall/spring migrations. Salinity was again a determining factor in further splits. Because these statistical analyses are preliminary, this discussion will not include details of the lower-level splits other than to say that some, like temperature, bottom oxygen levels, and salinity may indicate productivity, while others like bottom currents and wind speed may indicate upwellings, ice movement (Weingartner et al., 2013), or potentially higher noise levels that would reduce acoustic detection range of the calling bowhead whales.

Comparison with the other bowhead whale regression tree runs (Table 55) showed that although a variety of other parameters were possible for the first node split, they all would have provided less improvement (i.e., most were on the order of a tenth that of month). An interesting side note from this table is that improvement (in describing calling rates) with the split by month was doubled when the moorings were run individually than when combined. The most plausible explanation for this is that these mooring are located along the main bowhead migratory corridor, and as such, the migratory pulse timing should progress along the moorings and not appear at exactly the same time on each.

The GAM results (Figure 210) showed lowest calling presence on days where temperatures were greater than 4 °C (the uptick in the curve at higher temperatures may be an artifact of low n). Since bowhead whales are an ice associative species, this makes sense; bowheads are present when ice is around and temperatures are low. The slight peak of calling activity with a temperature of ~3 °C, however is an interesting feature that should be explored in greater detail in the future. Likewise, the two peaks in calling presence with chlorophyll levels of ~1 mg l^{-1} and ~5.5 mg l^{-1} warrant further investigation. The double peak of calling presence

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[28] However, note that satellite tag (Quakenbush et al., 2013) and other passive acoustic data (Clark et al., 1986) have shown that not all whales are confined to the lead system in the spring, and are capable of migrating through heavy ice cover (see Moore and Laidre, 2006 and references therein).

with ~30% and ~70% may be the byproduct of migrations that straddle ice formation and retreat every year. As seen from the regression tree analysis, and as expected, the peak bowhead migration months April/May and October/November came out on top in the GAM results, while January through March were at the bottom. One final interesting GAM result is that calling presence increased over the six year study. After the 2018 bowhead abundance survey, the calling activity will be examined in relation to the population growth rate to see if any correlation exists. Recent data suggest changes in overwinter distribution. To examine this further, the spatial distribution of calling activity will be examined over time and in relation to oceanographic varibles.

Gunshot calls (bowheads)

Although qualitatively (Figure 13) the largest peaks in gunshot call activity were strongly correlated to both bowhead whale calling activity and ice conditions, the three moorings used here for the regression tree and GAM analyses (C2, C4, and C5, which are IC2, WT1, and PB1 in Figure 13, respectively) did not all share this same pattern. From Figure 13 it appeared that the peak in gunshot calling activity was broader and higher in level as the fall migration moved westward, ranging from non-existent on BF2 to very extensive on CL1. For the most part, however, gunshot calling was more common during the end of the fall versus the spring migration. This was seen for the first node of the regression tree (Figure 211) where November/December were split from the rest of the months. No further splits were made with the latter; which had an average calling activity level of <1%. For gunshot calls that occurred at the end of the fall migration, however, chlorophyll controlled the next node. Since bowhead whales do not eat chlorophyll directly, further investigation is needed to determine whether any lags between this primary productivity and gunshot calling exist. No matter what the chlorophyll levels, however, ice concentration controlled the next set of splits, with higher calling levels associated with ice concentrations greater than ~90%. The same factors (bottom oxygen, salinity, PAR, and bottom currents) seen for regular bowhead calling were present here for gunshot calling. Some, like PAR and salinity, go hand-in-hand with increasing ice concentrations. Others, like currents, may again indicate upwellings or simply quieter periods with higher detection probabilities.

One interesting component of the regression tree was the node that split on the variability in ice thickness. Similar to what was found for the CHAOZ study (i.e., calling ceased when ice thickness exceeded 0.5 m; Berchok et al., 2015), more calling activity was detected when ice thickness variability was <0.44 m. Combined with the fact that ice thickness was less variable during the beginning of the ice season (i.e., during ice formation), this might just be coincidental. However, observations do show that bowheads are able to break through ice of at least 18 cm (George et al., 1989). 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 utilized 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. The threshold of <0.44 m variability may relate to their ability to get a clear picture of ice thickness, with greater variability possibly creating uncertainty in the received echoes through increased scattering. However, it may also be a coincidence of lower variability occurring during ice formation when the whales are migrating out of the Arctic.

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. If so, 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. 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. Why either of these functions would be less critical in the western Beaufort versus the Cape Lisburne area, however, is interesting. The gunshot call is 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 56) showed that month, again, was the top variable in describing gunshot calling rates by a factor of over 3x that of the other variables. The results for the regression trees run on each individual mooring, however, showed some different variables for the C4 mooring site, where bottom oxygen levels surpassed month in describing the calling rates. This result cannot be explained currently, and further investigation will be pursued in the future.

The GAM results (Figure 212), showed similar patterns to those from the regular bowhead calling analysis; with higher gunshot calling presence seen with both higher ice concentration and bottom oxygen concentrations levels. Typically increasing oxygen saturation can happen when temperatures increase and oxygen concentrations remain level. Oxygen levels can also increase if nutrients are being exported to the bottom and consumed by phytoplankton, giving off oxygen. This latter case seems more likely since ice concentration levels are increasing, indicating cooling temperatures. In order to investigate whether bowheads are attracted to these areas because of the potential increase in bottom-layer primary productivity, however, more analyses are needed to determine the relationship between bowhead calling presence and these oceanographic factors. The association between month and gunshot calling was different than that seen for the regression trees; November and December still showed high calling activity levels, but July through October did as well. It seems likely that this was an artifact of the binary (yes/no) nature of calling activity in the GAM analysis, as it ignored the detail of the percent daily calling activity and the shape of the seasonal timing, which started with low daily percentage and then peaked, and was flattened.

Beluga Whale

The regression tree analysis for beluga whales (Figure 213), as for both types of bowhead calling, had month being the factor influencing the first node of the tree. This node split off April and May, the two months with the highest monthly averages of calling activity (Table 7). The rest of the months split one more time into two sets: the higher average calling activity level group including the fall migration months of October and November, and the tail end of the spring migration (June and July). For the main spring migration branch of the tree, average ice thickness was the next split, with higher calling activity levels present when average ice thickness was <13 cm. However, the ice thickness of 13 cm might not be the specific biological threshold. Beluga whales have been observed breaking through ice up to 20 cm thick (Fraker, 1979), and can simply push 7-8 cm ice up without breaking it to create an air pocket to breathe (McVay, 1973). Furthermore, the ability to break through the ice will likely be related to individual attributes such as age, size, health, etc.

For those days with lower levels of calling activity, chlorophyll was the final split, with higher average calling activity levels with lower chlorophyll concentrations. It is unclear whether these lower levels are a byproduct of ice cover limiting productivity in the water column, or whether there was a sufficient delay along the food chain from primary productivity to presence of fish aggregations to suggest the beluga were feeding during this time. Further study is needed with more robust measures of zooplankton and fish abundance (such as the work conducted under the Arctic Integrated Ecosystem Research Program (IERP) study) to answer this question.

Again, the lack of ice concentration not being a factor in the best regression tree was expected as the spring beluga migration commenced far before the ice concentration levels began to decline (Figure 14). This fit with visual observations which showed belugas swimming within areas with high ice concentrations, and transiting between open areas up to 3 km apart (Fraker, 1979), as well as satellite tag results (Suydam et al., 2001) and other passive acoustic studies (Delarue et al., 2011; Moore et al., 2012; Hannay et al., 2013).

Similar to what was seen for bowhead whales, the possible variables for the first split in the regression tree for beluga whales (Table 57) showed a much lower (10x less) improvement than month. Interestingly, though, the trees run for the individual moorings did not show a larger improvement with month than the trees run on the moorings combined. With the two separate beluga whale stocks moving through this area at different times, the migration signal implied in individual mooring results for bowhead whales would not be expected to be as strong. See the discussion in the long term mooring section for more details (Section VII.A.3).

The GAM results for beluga calling presence/absence (Figure 214) showed that the highest calling presence occurred during April/May. They also showed a peak with ice concentrations of around 60%. Looking at Figure 14, it seems this result is influenced the most by the C4 and C5 (WT1 and PB1 respectively) mooring sites, where the spring calling peak continued during the ice breakup period. The other ice factor, median ice thickness, showed calling presence was negatively correlated with thickness, although the lower number of samples with ice thickness greater than 2.5 m (and subsequent increases in the uncertainty) makes interpretation of the trend difficult. However, it is expected that beluga have a limit with regards to ice thickness. The last factors considered for the GAMs involved winds: speed and north-south direction. Combined, they suggest lower beluga whale calling presence with higher winds toward the north. It is difficult to determine whether this indicates an increased presence of beluga whales, or whether the higher winds are just creating higher ambient noise levels that are decreasing the detection radius of the calling animals. The connection with wind direction may indicate that the higher winds were coming from the south.

Gray whales

The regression tree for gray whales (Figure 215) distinguished this species from the migratory bowhead and beluga whales. Month was not a top factor in the first couple of nodes in the tree. Light levels (PAR) influenced the first split, with low PAR levels associated with lowest average gray whale calling activity levels for the majority of the days. Higher (50x) average calling activity levels were seen on fewer days (two orders of magnitude fewer) when PAR values were higher. At first glance, higher PAR levels would indicate the presence of benthic productivity in that area. Connecting this to gray whale calling activity, however, was more nebulous and relied on knowledge of calling rates during feeding. It could be that when animals have enough prey available they have more time to socialize, as has been seen in other baleen whale species (Berchok, 2004), and therefore more calling is present. More data on actual benthic productivity or visual confirmation of gray whale feeding behavior are needed before more than an educated guess can be made. The other parameters included in the lower nodes of the tree were equally as difficult to explain definitively. It appeared the conditions with the highest calling rate were when PAR was high and bottom oxygen was low (47% or greater calling activity).

Comparison among gray whale regression trees (Table 58) showed PAR to have the largest influence, but the difference between that and the other factors was not as pronounced as for the bowhead and beluga regression trees. The C5 mooring (PB1) was the only mooring with enough available days with calling present to run separately, but showed a much greater dependence on PAR (5x greater than year which was the factor with the lowest improvement). The Peard Bay area, near the head of Barrow Canyon, is a known gray whale hotspot and feeding there was expected, so this results was unsurprising. Month had a larger influence on calling presence at the Peard Bay location than for the three moorings combined, reflecting the seasonal presence of gray whales in that area.

GAM results (Figure 216) showed a positive correlation of calling presence with PAR and temperature and a negative correlation with bottom oxygen saturation. There was a potential peak in calling presence with bottom oxygen concentrations of around 275 mMol kg^{-1}, followed by a decline at higher levels although the uncertainty in the model results at higher oxygen levels made interpretation difficult. As with the results from the regression trees, it is difficult at this point to provide scientifically backed interpretation of the GAM results since only 59 days (1.7%) contained gray whale calls. It may be necessary to limit the gray whale analysis to the C5 mooring since 56 of the 59 days with calling occurred at C5.

Walrus

As mentioned previously, walrus calling activity is a good metric for presence of this species. The first node in the regression tree for walrus (Figure 217) split off June and July from the rest of the year as having a much higher (more than 10x) average daily calling activity level than the other months, which is consistent with their arrival at the summering grounds in the Arctic, and the long-term seasonal distribution results for the moorings included (i.e., IC2, WT1, and PB1; Figure 28). Even though this summer pulse in calling activity straddled the ice breakup period, the next set of factors affecting the subsequent splits were not ice-dependent. The highest average calling rates occurred with both higher temperatures and winds to the south. The branch following lower temperatures contained many additional nodes with high average monthly calling levels splitting off at lower PAR, ice thickness, wind, and bottom oxygen levels. Although some of the factors, and their values, seemed to tie into each other (for example, lower PAR levels because of ice presence), there were many ways to speculate how, combined, they all affect walrus presence. One example could be that ice algae is being exported to the benthos with the melting ice, causing PAR levels to decrease and reducing oxygen levels on the bottom as this organic matter is consumed by zooplankton. The low wind speeds would mean that the ice is not blowing out rapidly, allowing benthic productivity to increase to a point where it is energetically cost efficient for walrus to feed in that area. However, if this would be the case, why are salinity values not decreasing, and why is chlorophyll not included at any node. It is also uncertain whether the values at which the nodes were splitting are physically relevant. For this reason, it is premature to attempt interpretation of these results without further data available from the benthic and zooplankton communities.

For the non-summering months, the only factor included in the tree is the standard deviation of ice thickness, with ~5% of the days having an average calling rate of 14% and less variability in ice thickness and the majority of days with a 0.95% calling rate and higher variability in ice thickness. However, the 14% average calling rate here was much lower that for most of the nodes under the summering month branch (Figure 217).

The results from the other walrus regression trees (Table 59) were similar to that of bowhead and beluga whales, with month surpassing the other variables by a factor of three, except for C4. There was also a large variation in the top variables selected for the individual moorings, with chlorophyll being almost tied with month at the C4 (WT1) site which is the closest location to the walrus aggregation on the southwest flank of Hanna Shoal.

The GAM results (Figure 218) showed some interesting trends. First, as expected, the number of days with walrus calling present was positively correlated with ice concentration. Although walrus can maintain ice holes with their tusks and break through up to 20 cm of ice with their heads, they typically need access to open water and are, therefore, not present in ice concentrations >80% (Fay, 1982). Although ice concentration was included in the models as a smooth function following the results of the single model test of linear versus smooth, the resulting relationship was highly linear. It is possible that further exploration and modeling will discover a decline in calling activity at extremely high ice concentrations following Fay’s (1982) results.

Ice thickness was also a prominent factor in walrus calling, although in relation to its variability (SD in m) and not its actual thickness, with increased calling at increased variability. This implies walrus presence was tied more closely the ice break-up period, when there has been time for thicker pieces of ice to form then break into smaller chunks. As this break up period creates open water areas, it is logical that walrus presence would increase during this time. However, low sample size in the high variability range, make this relationship tentative.

A peak in the number of days with walrus calling occurred around 4 °C, which is the temperature at which water is the most dense, possibly creating a turnover in the water column which will in turn bring nutrients to the benthos. It is interesting to see that although the main regression tree did not include chlorophyll concentrations as a factor, the GAM results did. A peak in walrus calling activity was seen at chlorophyll levels just under 2 $\mu g\ L^{-1}$, but it is unknown at this time what levels should be expected on the bottom. The months that rose to the top of the GAM analysis were again in agreement with those from the regression tree.

Bearded seal

The first node of the bearded seal regression tree (Figure 219) split an almost equal number of days into two branches. The January through June branch had an ~80% average calling activity level, which was almost ten times larger than that of the other branch (July through December). This does accurately capture the main calling period of this species at the mooring sites analyzed (Table 10) 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 March through June). For these months, the daily calling level was 94% and was increased to near 100% through a complicated branching pattern with temperature, chlorophyll, and removing March. Describing how these factors influence bearded seal presence is premature at this stage in the analysis of the acoustic data, but may be helpful in explaining why calling ceases within about a week across all locations in a year, and does not seem to be related to ice in any way (Figure 21).

The more interesting branches of the tree, to us, were the ones associated with the non-saturated months. That is, the ones associated with the ramp-up of calling (September through February), especially for those months closer to the start of the ramp-up than the end where calling activity is reaching saturation levels (January/February). For these initial ramp-up months, ice concentration appeared to have a very tight influence, with calling activity levels branching off into groups based on specific ranges of ice concentration. However, the ranges with higher calling rates were a bit on the higher side from their preferred 70-90% range (Cameron et al., 2010).

Again, when comparing the results of multiple regression tree runs (Table 60), month as a factor was almost double that of its nearest neighbor. For most of the single-mooring runs, and for the combined run, ice concentration was the second-best factor, although temperature was a close third. In addition, three ice factors (concentration and average and median thickness) were present in the combined regression tree case, showcasing its importance to bearded seals.

The GAM results (Figure 220) revealed a lot of reasonable trends. Bearded seal calling activity levels increased with increasing ice concentrations; as with walrus, further exploration might reveal a peak around 70-90% supporting Cameron et al.'s (2010) results. The decrease in sample size around 2.5-3 m average and median ice thickness and resulting increase in variability, make interpretation of these results difficult. The opposing trends for the average and median ice thickness indicated that correlated variables needed to be identified and only one was included, but could indicate a peak existed somewhere around 1 m of thickness. As with the GAM results for walrus, there appeared to be a peak in the number of days with bearded seal calling presence at a temperature of ~4 °C, again perhaps suggesting some sort of water column turnover. Lastly, it is curious that although the March through June months were shown to be associated with a high number of days with calling present, the pattern from September through February was less clear with an increase in the number of calling days from July to September, a higher increase from January to February, but a slight decrease from October through December. It is important to remember, however, that the GAM analysis was based on binary presence/absence information, so 10 days with 100% calling activity levels would look the same as 10 days with calling present in just one bin per day.

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.

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 codependency of correlated variables will produce much cleaner and more realistic results.

Also, 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. For example, techniques are being developed by a graduate student at Duke University (Dana Wright) to apply the GAMs to calling activity instead of daily presence/absence. Modeling the calling activities will incorporate more information in the models since high calling days were counted as equivalent to low calling days in the current analysis.

B. Polynyas

1. *Introduction*

The broad, shallow Chukchi Sea Shelf is covered in ice seasonally from approximately November to July. During the winter, a polynya often forms between Cape Lisburne and Point Barrow. A polynya is an area of reduced ice within a region of extensive ice cover. Typically, polynyas are defined as either “wind-driven” or “sensible heat” based on the mechanism of their formation. Wind-driven polynyas (sometimes referred to as “latent heat polynyas”) are mechanically driven, and are a result of winds or currents creating divergent ice motion. Wind-driven polynyas are characterized by an increase in salinity, but a decrease in temperature. Sensible heat polynyas are driven by ocean heat melting or preventing the formation of ice. This polynya-forming heat is usually a result of an intrusion of warmer water that increases the water temperature enough to cause ice melt. These events are characterized by an increase in both temperature and salinity. Ladd et al. (2016) recently reported evidence of warm, salty Atlantic Water being upwelled from the Barrow Canyon all the way to Icy Cape. This intrusion of nutrient-rich Atlantic Water leads to an increase in water temperature, often resulting in a polynya formation. Although previously assumed to be a wind-driven polynya, based on the frequent intrusion of Atlantic Water, Ladd et al. (2016) suggest that the Chukchi polynya is better classified as a hybrid sensible heat/wind-driven polynya.

Because light availability is the primary controller of phytoplankton growth, it is typically assumed that primary production increases within a polynya (due to the increase in light availability) relative to the ice-covered regions next to it during seasons when the sun rises well above the horizon (Tremblay and Smith, Jr., 2007). These localized increases in primary productivity often support benthic communities through vertical carbon flux, and may result in an increase in benthic biomass (Grebmeier and Barry, 2007). However, the amount of primary productivity that occurs in a polynya is dependent upon several factors, including the size and duration of the polynya event, water depth, the distribution of ice and snow, and circulation or residence time within the polynya, and the light history of the phytoplankton cells (Tremblay and Smith, Jr., 2007). When describing the coupling between phytoplankton blooms and ecosystem responses, the systems are often referred to as either "export" or "retentive" systems (Grebmeier and Barry, 2007). In a retentive system, the seasonal phytoplankton blooms happen gradually, such that the zooplankton population has enough time to increase in response, and prey on a significant portion of the production. This strong coupling reduces the export of carbon to the benthos, limiting the benthic population growth. However, in an export system, if the bloom happens so rapidly that the zooplankton cannot keep up with the amount of phytoplankton, the coupling is weak, and more of that primary productivity gets exported to the benthos, supporting a rich benthic environment. Grebmeier and Barry (2007) found that depth was the underlying factor driving the amount of carbon export to the benthos, where shallower environments yielded more benthic-rich systems.

Although a considerable amount of research has been done on several Arctic polynyas (namely the Northeast Water polynya off Greenland, the North Water polynya in Baffin Bay, and the St. Lawrence Island polynya (SLIP) in the northern Bering Sea), the Chukchi polynya has only recently become the subject of focused study. Ladd et al. (2016) characterized the Chukchi polynya as being a hybrid sensible heat/wind-driven polynya. Given the shallow nature of both the SLIP and the Chukchi Polynya, similar formation mechanisms, and similar oceanographic features driving nutrient advection to the area, the Chukchi polynya is assumed to be similar to the SLIP regarding its effect on primary productivity and, by extension, the benthos.

2. Results

Ladd et al. (2016) describe in great detail the mechanisms driving the Chukchi polynya. Although the size and breadth of the polynya may vary from year-to-year, the location remains consistent, centered around Icy Cape and Wainwright, and sometimes extending to Cape Lisburne to the west and south and Peard Bay in the northeast (Ladd et al., 2016). During the ARCWEST and CHAOZ study time frames, five major polynya events occurred during the ice-covered months. These events were compared with the long term moored passive acoustic recorder data to determine if there was a correlation between the presence of a polynya and an increase in marine mammal presence (inferred from an increase in calling activity; methods for which are described in Section VII.A.1). The major polynya events will be summarized below and in Table 61; for specific details, see Ladd et al. (2016).

In the winter of 2010-11, a major polynya formed and remained close to shore from 1 to 7 January 2011, centered around IC1/C1. This polynya was driven by an intrusion of AtlW; consequently, it was characterized as a "heat-driven" polynya. Beluga whale calling activity was detected at IC1/C1 on 12 Jan 2011, just a few days after this major polynya (Garland et al., 2015b). Walrus calling activity was detected sporadically in the three weeks following the polynya event. Bearded seal calling activity appeared to decrease during the first week of January when the polynya was present at IC1/C1. No bowhead whales or gray whales were detected during the polynya.

In the winter of 2012-13, the entire month of January also saw a substantial reduction in ice at the IC1/C1 location. This event was again driven by an intrusion of warm, salty AtlW. The only calling activity detected at IC1/C1 during January 2013 was bearded seal. Despite a lack of other species at IC1/C1, at a nearby mooring, WT1/C4, beluga calling activity was detected (albeit in low numbers) on two days in January: 11 and 22 January 2013. Bowhead whale calling activity was also detected on one day (19 January 2013), again in very low numbers. There was no walrus or gray whale calling activity detected at WT1/C4.

In the winter of 2013-14, two major polynya events occurred. December of 2013 saw a substantial reduction in ice at IC1/C1. However, unlike the previous polynya events, this one was not driven by an intrusion of AtlW. During this month of sea ice reduction, bowhead whale calling activity continued through 23 December 2013 as they completed their fall migration. Additionally, bearded seal calling activity was detected during the entire month, and beluga calling activity was detected on two days in late December and one day in early January (5, 28 December 2013; 3 January 2014). Following this month of ice reduction, in late January (23-29 January 2014), a polynya forms at WT1/C4, then spreads out to encompass IC1/C1, WT1/C4, and PB1/C5 (see Figure 221, Figure 11 in Ladd et al., 2016). This polynya event was driven by an intrusion of AtlW. Only bearded seal calling activity was detected during the polynya event at WT1/C4. However, in addition to bearded seals, beluga calling activity was detected in low numbers on one day on 31 January 2014 at PB1/C5. Bowhead calling activity was only detected one week after the polynya event, on one day (5 Feb 2014) at PB1/C5 at low levels. There was no walrus or gray whale calling activity detected at any site.

The final major polynya event that occurred during ice-covered months took place from 26 January to 26 February 2015. This event consisted of an extensive polynya that occurred from Cape Lisburne to Icy Cape, with the strongest effects seen at Cape Lisburne. During this polynya event, on 31 January 2015 a brine rejection event took place that resulted in the highest salinity levels ever recorded at IC1/C1. This led to a polynya that lasted for a month, from 26 January to 26 February 2015. Although the only species detected during the polynya event was bearded seals, interestingly there were seven days of bowhead calling, five of which were over 50%, in early January prior to the polynya forming. This calling activity took place almost a full month past the last date of calling during their fall migration. Additionally, beluga whales were detected on 28 February, only two days after the polynya event ended.

Table 61. Description of polynya events that occurred from 2010 to 2015, including species detected. AtlW = Atlantic Water.

Year	Date	Event and location	Mechanism	Species detected	Dates detected
2011	1-7 January	Major polynya centered around IC1	AtlW-driven	Beluga	12-Jan
				Walrus	15, 22, 23, 26, 31 January
				Bearded	Entire month
2013	January	Substantial ice cover reduction, entire month of January at IC1	AtlW-driven	Beluga (WT1)	11, 22 January
				Bowhead (WT1)	19-Jan
				Bearded	Entire month
2013	December	Substantial ice cover reduction, entire month of December near IC1	not AtlW-driven	Beluga	25, 28 December; 3 January
				Bowhead	1-23 December
				Bearded	Entire month
2014	23-29 January	Major polynya, starts at WT1, extends to IC1 and PB1.	AtlW-driven	Beluga (PB1)	31-Jan
				Bowhead (PB1)	5-Feb
				Bearded	Entire month
2015	31-Jan	Highest salinity levels ever recorded at IC1. Coincides with extensive polynya from Cape Lisburne to Icy Cape.	Brine rejection	Beluga	28-Feb
				Bowhead	1-7 January
				Bearded	Entire month

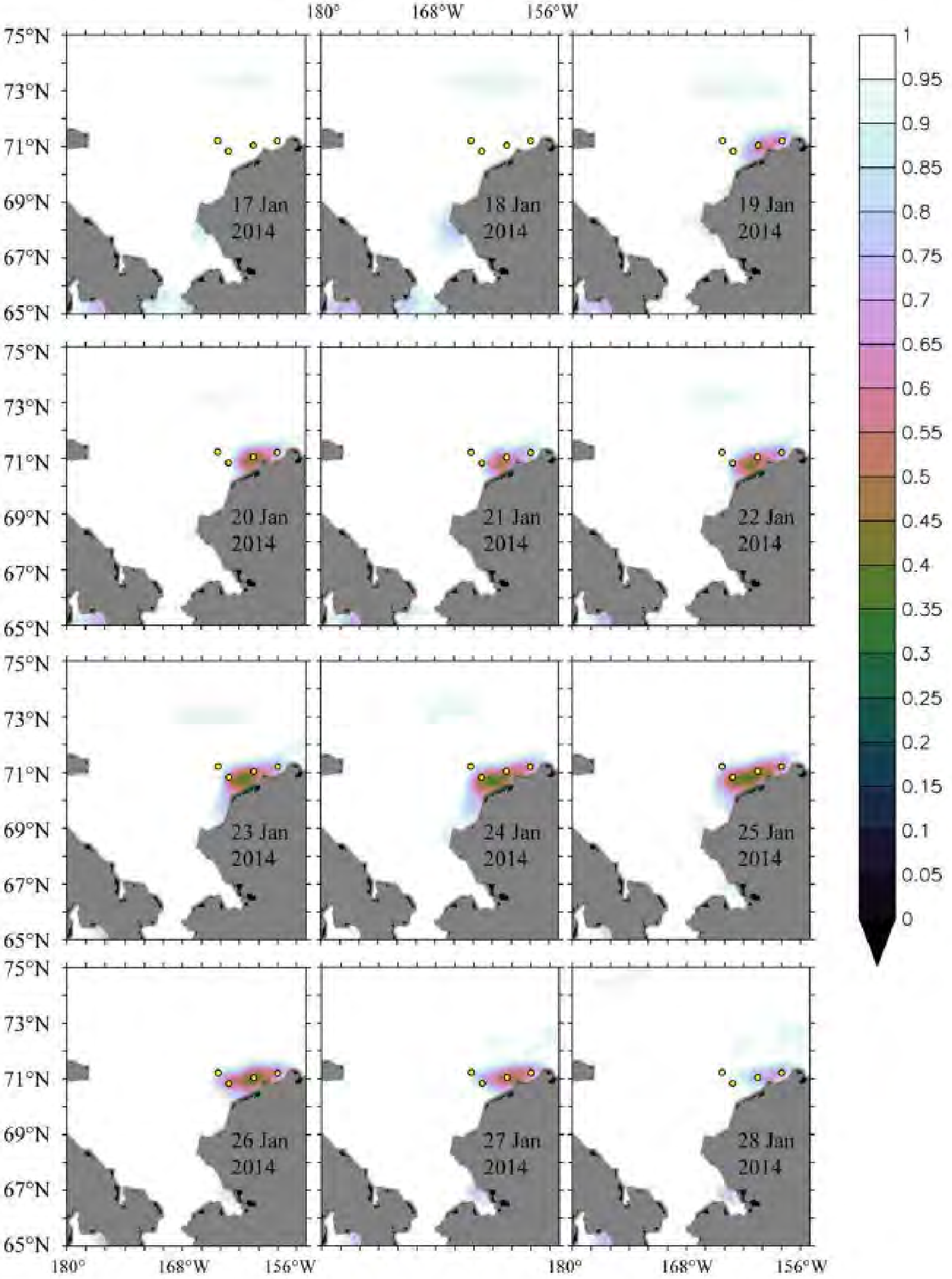

Figure 221. Percent daily sea ice concentration (denoted by color scale) from 17 January to 28 January 2014. From Ladd et al. 2016. Yellow circles denote long-term mooring locations.

3. *Discussion*

Given the lack of data, no inferences could be made regarding a numerical response by zooplankton to the primary production during the polynya events. However, given the similarities in bathymetry, depth, and oceanographic features, it is assumed that the Chukchi polynya is similar to the SLIP, and results in an increase in primary productivity. Oceanographic results from the long-term moorings do not show any clear indication of a change in primary productivity following the polynya events. This is in part due to the location of measurements - because of presence of sea ice, instrumentation of year-round moorings is limited to the within 10 m of the sea flow. This is a good location to measure the ice algae and phytoplankton that has been exported to the near bottom of water column, but not of the subsurface phytoplankton blooms that occur just below the surface mixed layer (Martini et al., 2016). Although no immediate changes were discernible, the effects of the polynya on primary productivity may not happen within the range of the polynya itself; for the SLIP, the effects occur to the southwest of the polynya, as the currents shift the nutrients away from the polynya itself.

If the noticeable effects of the polynya occur at a great enough distance, marine mammal vocalizations may be too far from the recorders to be detected. Overall, only a handful of marine mammal detections occurred; however, it is important to take into consideration the migration and distribution patterns as well as the behavior of the species. For example, bearded seals, which were detected during every polynya event, overwinter in the Chukchi Sea (Section VII.A.2). Even during the major polynya event in January 2014, percent ice cover never dropped below 30%, so it is not unexpected that bearded seals were detected during all polynya events. Beluga whales do migrate south to the Bering Sea in winter; however, beluga calling activity was detected overwinter in the Chukchi Sea (Garland et al., 2015b), suggesting that a portion of the population remains in the Chukchi Sea overwinter, and may be well suited to take advantage of polynyas. Although bowhead whales migrate south to the Bering Sea in winter, there were a few days of calling activity detected during the polynya events. This could be individuals that delayed migration south to the Bering, or it may be individuals that remained overwinter in the Chukchi Sea. Given the relatively brief duration of the polynyas (max 757 hours, 2015 winter polynya), it is unlikely that individuals in the Bering Sea would migrate north up to the polynya in time for the event; it is more likely that individuals were overwintering in the Chukchi Sea and were taking advantage of the polynya's open water. Additionally, although the location of the Chukchi polynya is consistent, the annual pattern of its formation is variable; as such, animals may not have any instinctual behavioral response to migrate to that location. Rather, their appearance during a polynya is more likely a result of an opening of a lead, or an increase in prey resources, or perhaps both.

Another reason for the seeming lack of marine mammal presence (aside from bearded seals) may be that they are not vocalizing. However, given the highly vocal nature of both beluga whales and bowhead whales, this is unlikely. It is possible that they are too far from the moored recorder to be detected. As seen in Figure 221, the center of the polynya is in between the WT1/C4 and IC1/C1 moorings. If the animals are in the center of the polynya, they may be too far from the recorders for their vocalizations to be detected, particularly for high frequency species like belugas.

Yet another explanation could be that perhaps there is no noticeable increase in primary productivity, but rather the individuals detected during the polynya events were simply taking advantage of the open water to utilize new resources. If polynyas do result in an increase in primary productivity, there would be a lag until that bloom in productivity had an effect on secondary productivity, and consequently any noticeable effect on the benthos or fish populations. However, confirmation of any correlations between the Chukchi polynya and marine mammal presence requires quantifiable data at every trophic level, something which has not yet been measured. More data are necessary to fully understand the effect the polynya has on primary productivity and the bottom up effects on the ecosystem.

4. *Conclusions*

Generally, polynyas in the spring result in an increase in primary productivity (i.e., the rate of primary production). An increase in light availability (brought about by a decrease in ice cover) causes an increase in primary productivity. If phytoplankton production and zooplankton grazing are not in balance, then that production accumulates (i.e., there is a bloom) and it eventually falls to the seafloor. For the Chukchi Sea, this predominantly “export” system leads to carbon being exported to the seafloor, which in turn causes an increase in benthic productivity. However, this polynya has not been the focused study of benthic or plankton studies. To test the above hypothesis, winter /spring *in situ* measurements of phytoplankton production, micro- and macrozooplankton standing stock, and sediment flux are necessary.

Marine mammals were only detected infrequently during the major polynya events; because of the migration and distribution patterns of each species and the size of the polynya relative to their winter distribution, it is likely that the sporadic detections were overwintering individuals taking advantage of an opening in sea ice. Given that these upper trophic level predators were detected only infrequently during polynya events, combined with the lack of specific data on the coupling in this region, we suggest three hypotheses: 1. The production pulse is too brief, or is not spatially constrained enough to create noticeable impacts within the polynya’s area; 2. The production pulse is not large enough (relative to the large amount of seasonal productivity) to be of great ecological importance; or 3. The lag between the phytoplankton bloom brought about by the polynya, its export to the benthos, and the subsequent increase in benthic biomass was too great a time span for any noticeable results to appear in the long-term moorings. While the results presented here were inconclusive, it highlights the needs for a dedicated study of the specific biophysical coupling surrounding the formation of polynyas and their general importance for the ecosystem.

5. *Recommendations*

Additional research on the Chukchi polynya and its link to the benthos/upper trophic levels is crucial to begin to understand this important relationship and the overarching effects on the ecosystem. We need to obtain measurements of not only the primary production and its export to the benthos, but also the resulting benthic biomass increase. Specifically, we need to measure primary production throughout the water column during the period of ice cover. Such technology is just now becoming available. Finally, not only is it critical that we continue to maintain the long-term moored array of collocated oceanographic/passive acoustic/zooplankton moorings, but ensure that they are located in positions that obtain complete coverage of the polynya formation area. Only with these data can we begin to understand the relationship between the Chukchi polynya and its effect on the local biota.

C. 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 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 throughout the ARCWEST 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 levels and biophysical properties along line transects sampled during the 2013-2015 field surveys for five transects (Point Hope/DBO3 (PH), Ledyard Bay (LB), Point Lay (CkA), Icy Cape (IC), Wainwright/DBO4 (WT[29]), Barrow Canyon/DBO5 (BC), Barrow Canyon to Wainwright Box (BX), and the western Beaufort (BfA)) which 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.

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[29] Note that this transect line is not the final DBO4 sampling line, but is in the general vicinity.

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 R/V *Aquila* on which the marine mammal sightings and detections were made. The results, therefore, had a seasonal or monthly component that made it difficult to clearly identify the inter-annual signal. This temporal mismatch may have decreased the overall strength of our conclusions. Nonetheless, there are still some interesting stories that emerged from these short-term efforts.

The Point Hope (PH) transect line (Figure 222), as was seen for the CHAOZ study (Berchok et al., 2015), showed the best correlation between the oceanographic parameters and marine mammal distribution. For the 2013 sampling (Figure 222, left panels**)**, high concentrations of both nitrate and ammonium were present over the outer two-thirds of the line, topped by a strong pycnocline. Sightings and acoustic detections of gray, humpback, and fin whales were present in this outer area. Little to no zooplankton sampling was done, however. Dangerous deck conditions in 2014 precluded sampling along the Point Hope line, even though two days were spent waiting for the seas to subside. Distributions in 2015 were different than those in 2013 (Figure 222, right panels**)**. In 2015, the outer half of the line showed relatively warm, salty, nitrate-rich water throughout a well-mixed water column. The inshore part of the line showed a surface layer of ACC water with low concentrations of nitrogen. No marine mammals were sighted or detected along this line in 2015, despite good visual effort. However, it is important to remember that the mammal effort occurred one month later than the oceanographic sampling, and changes to the ecosystem during that month may have altered marine mammal distributions as they relate to prey. There was no zooplankton sampling of this line on either cruise.

Results from the Wainwright (WT) line (Figure 223) varied inter-annually, although 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 nitrogen. High levels of walrus detections/sightings were observed in the regions during the ARCWEST field survey. No corresponding aggregations of zooplankton were seen. Concentrations of nitrogen along the WT line were much lower in 2014 and 2015. These concentrations, however, were still high enough to support primary production, if sufficient light was reaching the bottom. *C. glacialis* was moderately abundant along this 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 still aggregated in 2014, as were bearded seals and bowhead whales.

The Ledyard Bay (LB) and Point Lay (CkA) transect lines (Figures 224, 225) were very similar, and so we focused on the Ledyard Bay results here. Similar to PH, LB contained an area with high concentrations of ammonium in the bottom waters. This time it occurred during the 2014 field survey, which was sampled later in the season (i.e., late September/early October). Zooplankton concentrations tended to be highest in the middle, stratified portions of the transects each year. In 2014 there were moderate concentrations of *C. glacialis* over the middle transect and in 2015 we observed the highest concentrations of *C. glacialis*, *Neocalanus* spp., and euphausiid furcilia over the middle of the transect. Despite good visual survey and passive acoustic monitoring effort, only one detection (of a bearded seal) was made.

The Icy Cape (IC) transect line (Figure 226) showed similar patterns to that of Ledyard Bay: nitrate and ammonium concentrations were not as widespread as those at Wainwright or Point Hope. The 2013 transect data showed a much stronger presence of a potential hotspot compared with 2014 and 2015; and it had a much more defined pycnocline. 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.

Consistent in each of the years the Barrow Canyon line (Figure 227) was sampled, 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 appeared to be a slightly higher concentration of furcilia near the outer (western) edge of the canyon.

The western Beaufort (BfA) transect line (Figure 228), to the east of Barrow Canyon, revealed the presence of AtlW below 150 m. The extensive ice in August 2015 was reflected in the layer of fresh water at the surface. High nitrate was found below 45 m, while the highest concentration of ammonium was between 40 and 100 m. Zooplankton abundances were similar in both years, but Thecosomata abundances were highest on the outer shelf and slope. The only mammals present (bowhead whales and seal spp.) were on the shelf portion of the transect, although those detections/sightings were made one month after the biophysical sampling was conducted.

The Box (BX) line (Figure 229) paralleling the shore between the Barrow Canyon and Wainwright lines, showed the least variability in the physical and chemical variability. 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.

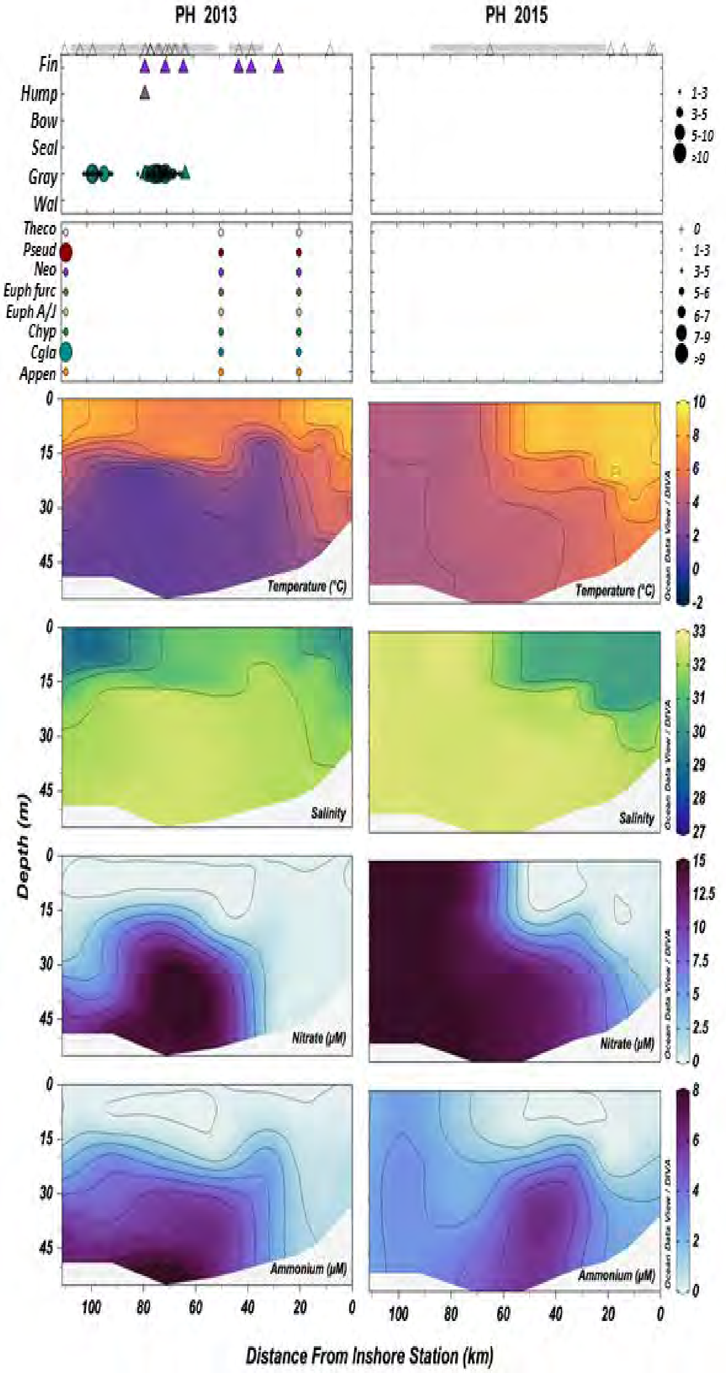

Figure 222. Point Hope transect line of oceanographic, zooplankton, and marine mammal survey results, 2013 and 2015. X-axis refers to distance along transect, where 0 km indicates the inshore station. Top row: sonobuoy effort (open triangles along top) and detections (filled triangles) as well as visual 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 (°C). Fourth row: Salinity. Fifth row: Nitrate (µM). Bottom row: Ammonium (µM). Note color scale for oceanographic variables is to the right.

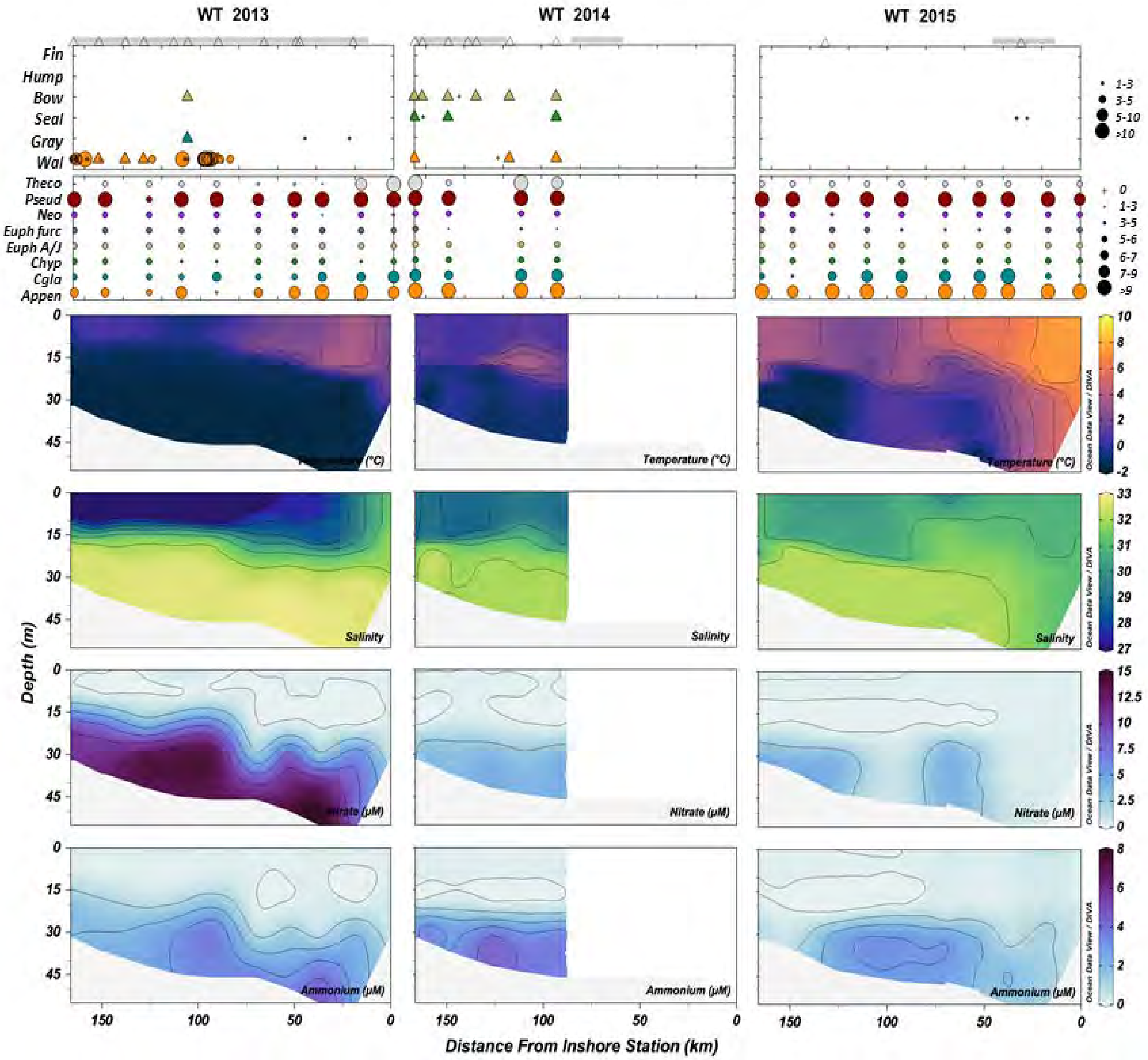

Figure 223. Wainwright transect line oceanographic, zooplankton, and marine mammal survey results, 2013-2015. X-axis refers to distance along transect, where 0 km = inshore station. Top row: sonobuoy effort (open triangles along top) and detections (filled triangles) as well as visual survey effort (gray 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.

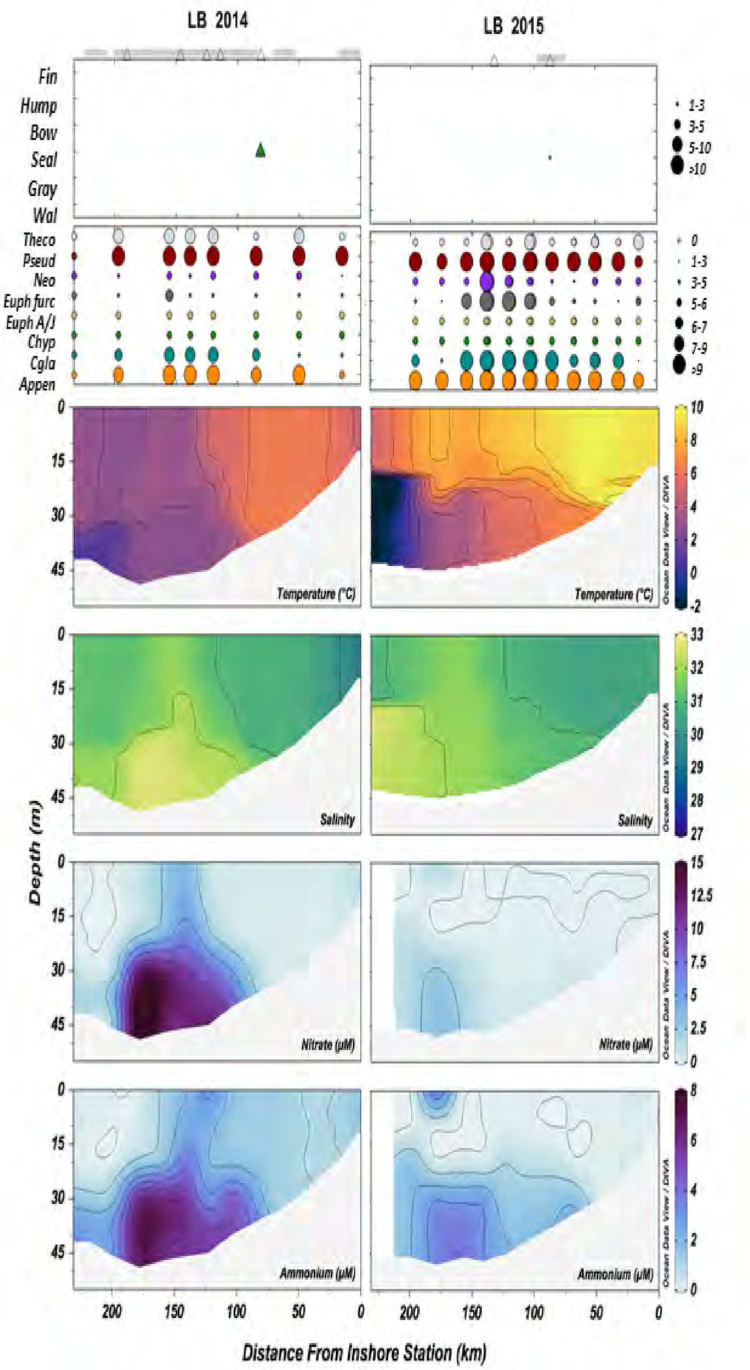

Figure 224. Ledyard Bay transect line oceanographic, zooplankton, and marine mammal survey results, 2014 & 2015. X-axis refers to distance along transect, where 0 km = inshore station. Top row: sonobuoy effort (open triangles along top) and detections (filled triangles) as well as visual survey effort (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 (°C). Fourth row: Salinity (PSU). Fifth row: Nitrate (µM). Bottom row: Ammonium (µM). Note color scale for oceanographic variables is to the right.

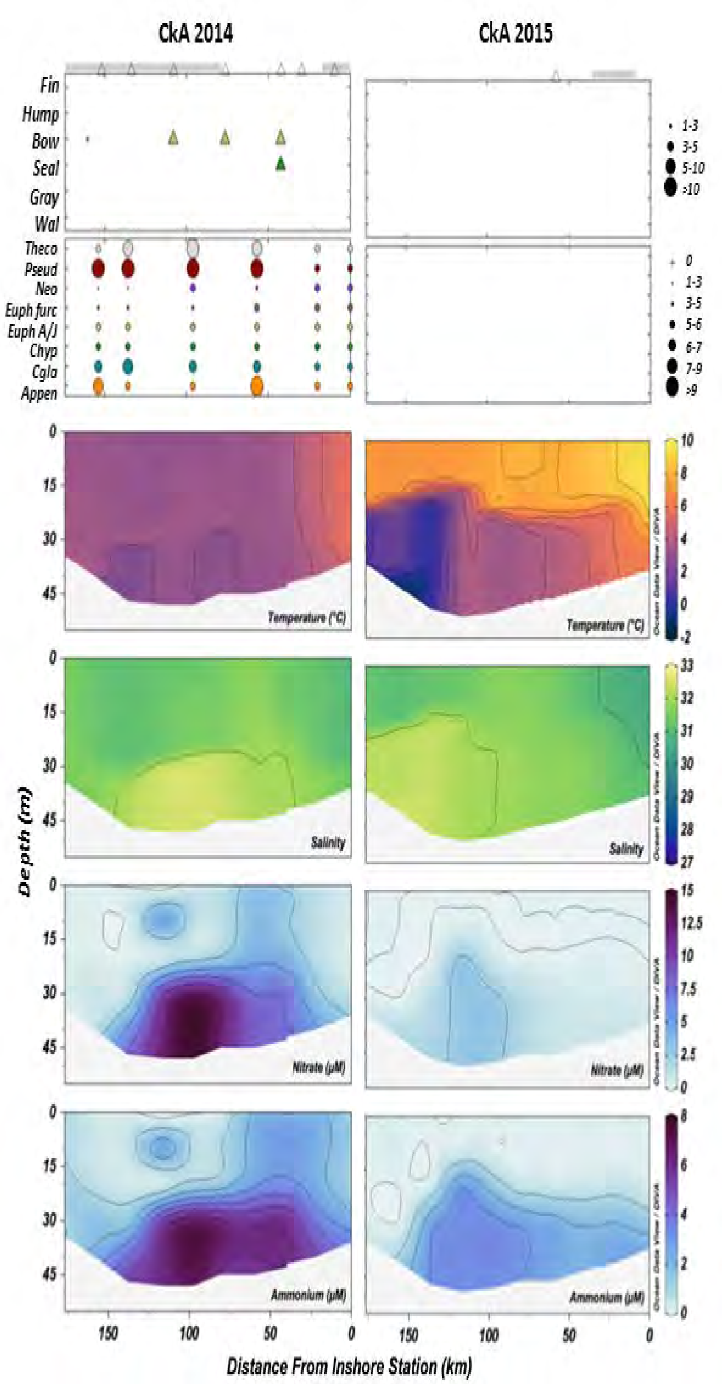

Figure 225. CkA (off Pt. Lay) transect line oceanographic, zooplankton, and marine mammal survey results, 2013-2015. X-axis refers to distance along transect, where 0 km = inshore station. Top row: sonobuoy effort (open triangles along top) and detections (filled triangles) as well as visual survey effort (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 (Furcillia); Euph A/J = Euphausiids (Adult + juvenile), Chyp = *Calanus hyperboreus*; Cgla = *Calanus glacialis*; Append = Appendicularia. Third row: Temperature (°C). Fourth row: Salinity (PSU). Fifth row: Nitrate (µM). Bottom row: Ammonium (µM). Note color scale for oceanographic variables is to the right.

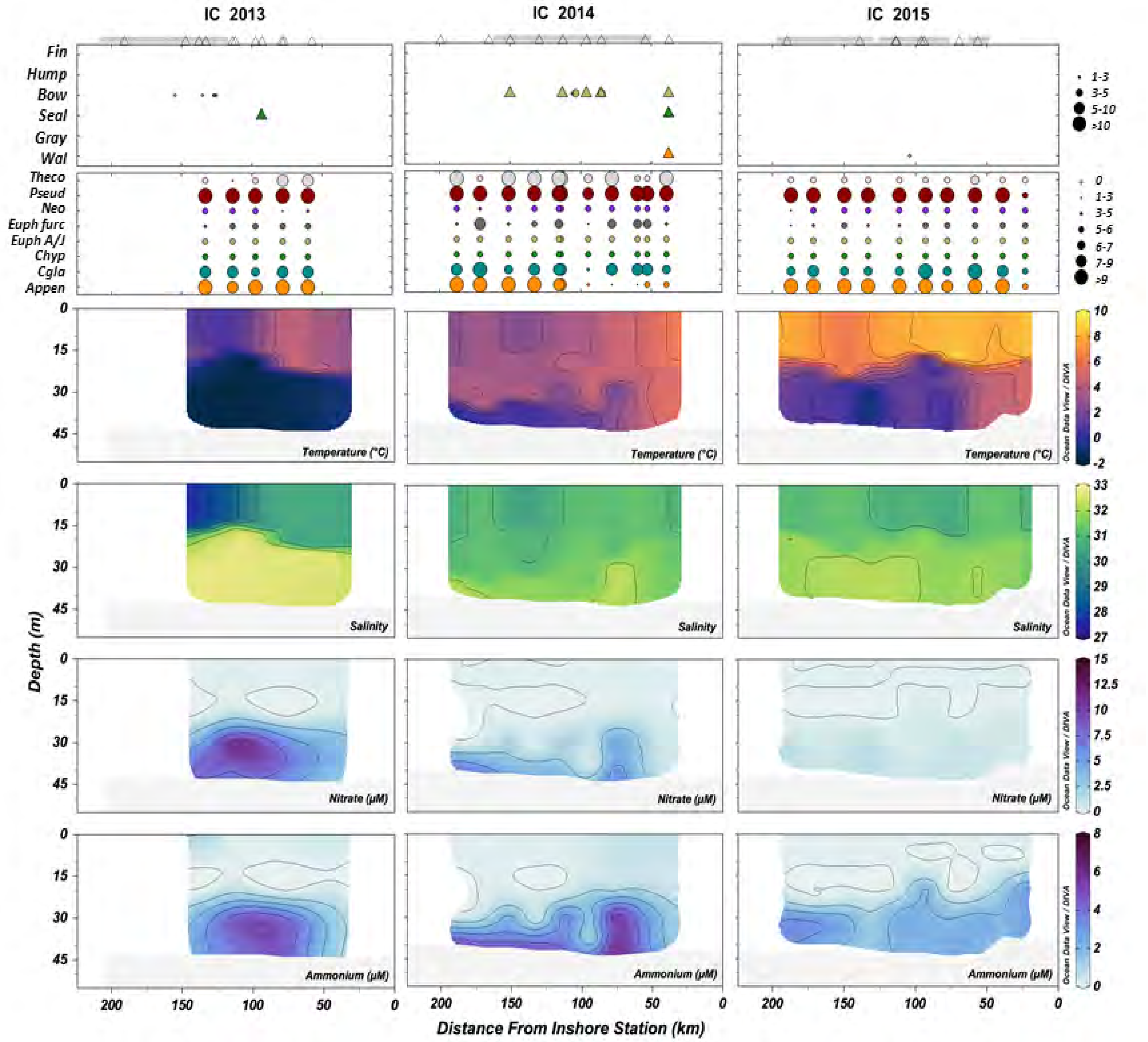

Figure 226. Icy Cape transect line oceanographic, zooplankton, and marine mammal survey results, 2013-2015. X-axis refers to distance along transect, where 0 km = inshore station. Top row: sonobuoy effort (open triangles along top) and detections (filled triangles) as well as visual survey effort (gray 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.

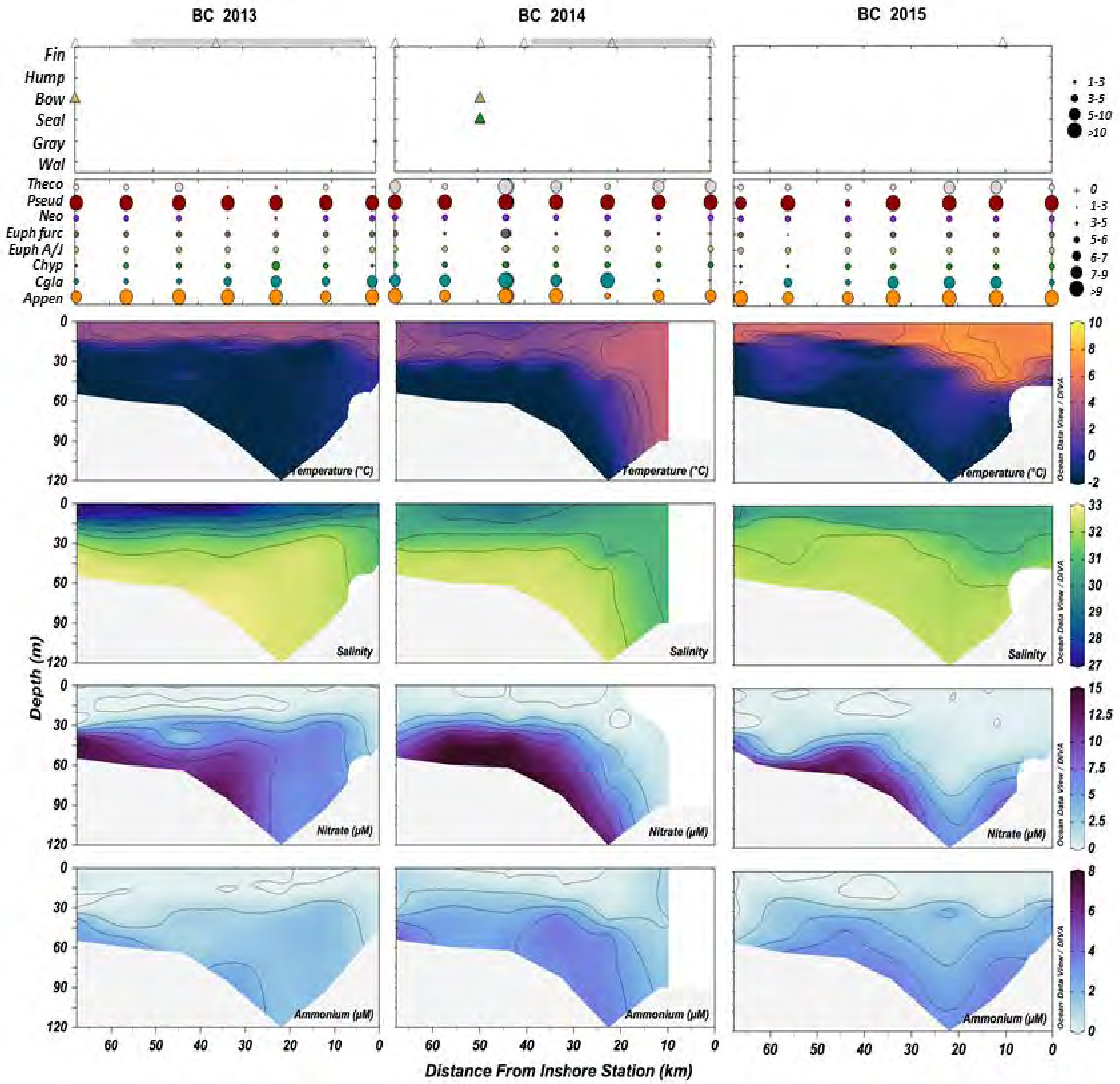

Figure 227. Barrow Canyon transect line oceanographic, zooplankton, and marine mammal survey results, 2013-2015. X-axis refers to distance along transect, where 0 km = inshore station. Top row: sonobuoy effort (open triangles along top) and detections (filled triangles) as well as visual survey effort (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.

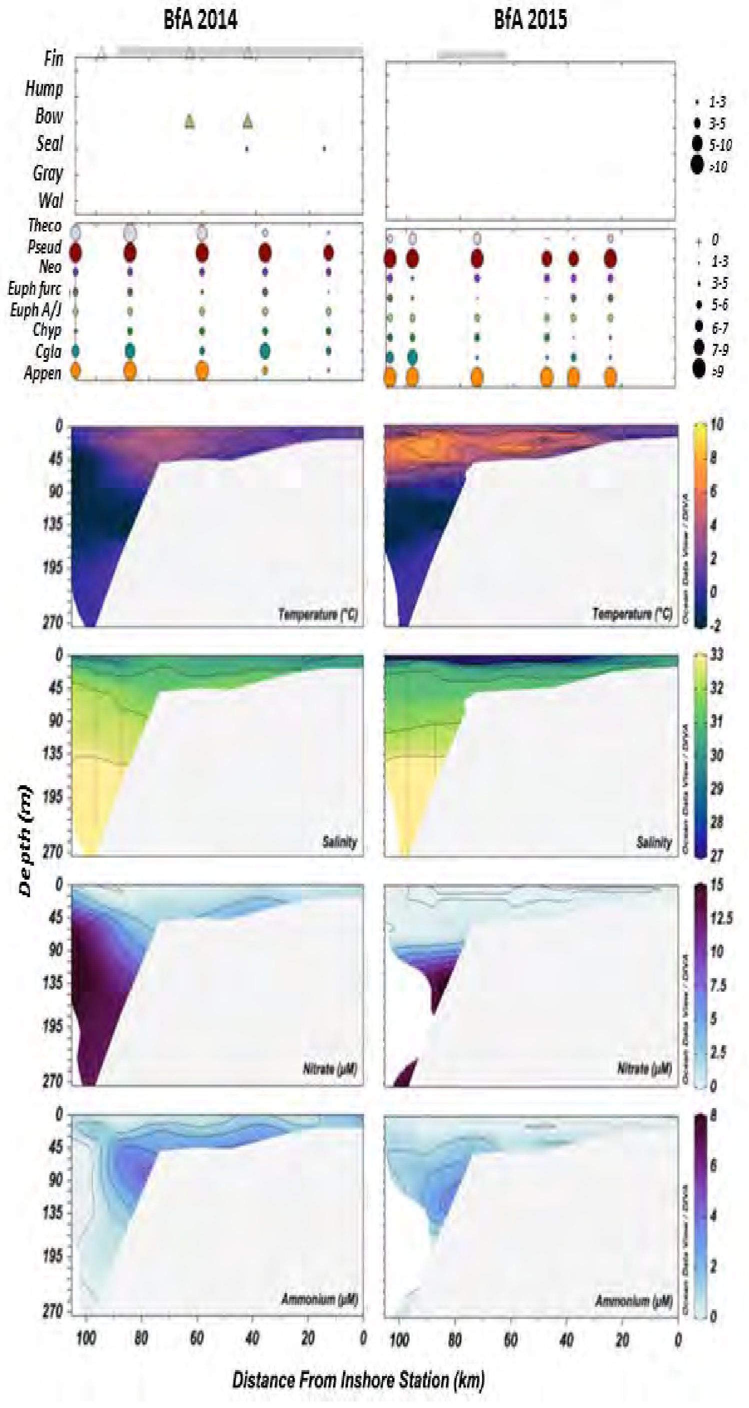

Figure 228. Beaufort transect line oceanographic, zooplankton, and marine mammal survey results, 2013-2015. X-axis refers to distance along transect, where 0 km = inshore station. Top row: sonobuoy effort (open triangles along top) and detections (filled triangles) as well as visual survey effort (gray 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.

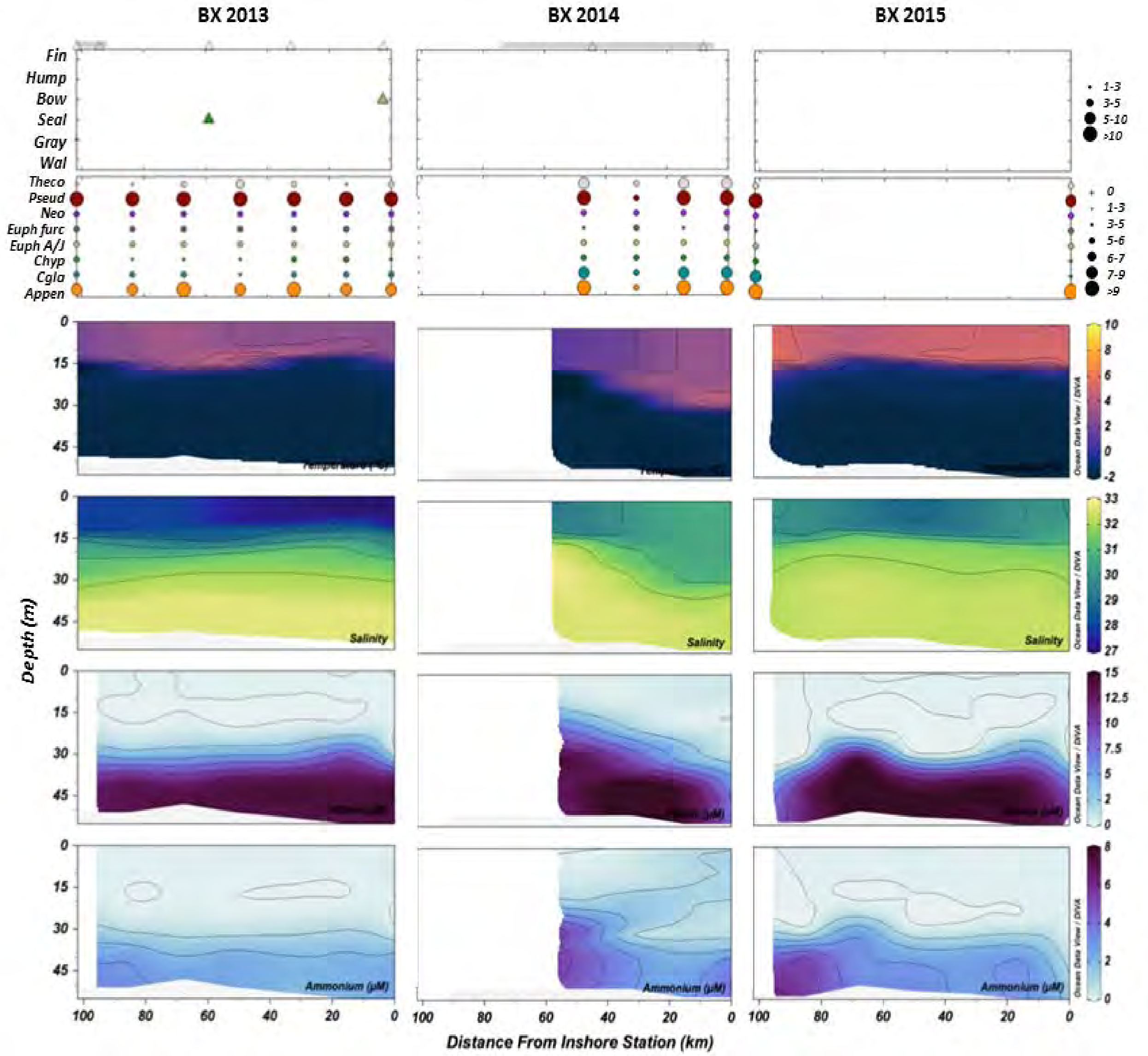

Figure 229. Box transect line oceanographic, zooplankton, and marine mammal survey results, 2013-2015. X-axis refers to distance along transect, where 0 km = northeastern station. Top row: sonobuoy effort figure (open triangles along top) and detections (filled triangles) as well as visual survey effort (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*

There were four types of transect lines through the ARCWEST study area: three that run perpendicular to the coast and include known benthic hotspots, potential benthic hotspots, pelagic hotpots, and one that runs parallel to the coast. The discussion below is grouped into these four categories.

Known benthic hotspots: Point Hope and Wainwright lines.

The oceanographic/nutrient conditions present over the outer part of the Point Hope line in 2013 (i.e., high concentrations of both nitrate and ammonium topped by a strong pycnocline) suggests 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., "SECS", Grebmeier et al., 2015). As expected, this strong hotspot region correlated well with the cluster of sightings/detections of gray whales, a benthic feeder. In addition, sightings of pelagic feeding humpback and fin whales suggest that there was also high plankton standing stock in and near this benthic hotspot region; however little to no zooplankton sampling was done, so it was difficult to verify this or to describe its community composition. In 2015, however, the lack of nutrient drawdown in the surface layer was indicative of recently mixed water that has not supported a phytoplankton bloom. Although the timing was off by one month for the marine mammal survey effort, the aerial survey data showed similar results. There were only four gray whale sightings in the southeastern Chukchi Sea, all of which occurred in late August (Clarke et al., 2017). Not only were all four sightings farther south than the PH transect line, but there also was no evidence of feeding. Similarly, there were no aerial sightings of walrus in the southeastern Chukchi Sea in all of August and September (Clarke et al., 2017). We speculate that this area did not contain high food concentrations during our 2015 surveys, however it is very difficult to test that hypothesis using our data. Tsujii et al. (2016) recorded fin whales calls in the southern Chukchi in 2012 and 2013 between August and October concomitant with the seasonal maximum in area backscattering strength (S_A) at 125 kHz. The observed scattering presumably represented potential zooplankton or fish prey items.

The same conditions seen in the 2013 Point Hope line, nitrogen-rich waters topped by a pycnocline, were seen at the 2013 Wainwright line. The aggregation of walrus and gray whale detections/sightings present in this region was expected as the offshore portion of this line crosses the southwest flank of Hanna Shoal, a known hotspot area for these species (Grebmeier et al., 2015). Although no corresponding aggregations 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 were 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 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 hindered further investigation of similar associations.

Potential hotspots: Ledyard Bay, Point Lay, and Icy Cape lines.

The next type of transect line were those that showed a more ephemeral character; they are not hotspots by the strict definition (i.e., that they are persistent), but they exhibit enough of the same oceanographic/nutrient characteristics that their potential as hotspots should be discussed.

The deeper part of both the Ledyard Bay (LB) and Point Lay (CkA) lines transects the Central Channel. Water from the Point Hope transect is advected into the channel on its way to Barrow Canyon. The high ammonium levels in the bottom layers of the LB and CkA lines suggested export to the benthos, although the signal was likely advected into the region. The concentration of zooplankton over the middle stratified portions of the transects each year could lead to a higher flux of particulate carbon and nitrogen to the bottom over that portion of the shelf. However, even with good survey effort, marine mammal detections/sightings were near absent. This suggests this potential hotspot was small in spatial and/or temporal scale. Although the long-term passive acoustic data showed that by the time this line was sampled in 2014, most of the gray whale population had migrated out of the northeastern Chukchi Sea (a finding that was consistent with years of shore-based and aerial surveys; Rugh et al., 2001; Clarke and Ferguson, 2010), lack of a similar potential hotspot in the 2015 data, though sampled much earlier in the season, provided support of the view that the highly productive area that develops here is tenuous rather than consistent throughout the season or inter-annually.

The Icy Cape line also showed evidence of small concentrations of nitrogen varying inter-annually. The low presence of marine mammals did 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 hotspots: Barrow Canyon and the western Beaufort lines.

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 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 was 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 showed the greatest number of sightings in August and October at the mouth of the Canyon, with none in the waters surrounding 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).

For the western Beaufort line (BfA), it was not surprising that the sightings/detections of bowhead whales, in particular, were made on the shelf. This species is known to migrate in the fall through the Beaufort Sea in waters 50 m or less, fanning out over the wider Chukchi shelf once past Point Barrow (Clarke et al., 2015a). The fact that bowheads were not seen/detected in large aggregations on the shelf, however, was also not surprising as there was no evidence of upwelling of this water onto the slope during that period of time.

Lines parallel to the coast: the Box.

Results for the box line (BX), which paralleled the shore between the Barrow Canyon and Wainwright lines, were expected. In general, most changes in oceanographic parameters occured cross-shelf and not along-shelf. The uniform nature of biophysical measurements, and low zooplankton abundances helped 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 BSW 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 Sea, 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 BSW. 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 Ledyard Bay, Point Lay, and Icy Cape Lines are all examples of these ephemeral hotspots.

More permanent hotpots are found along the Point Hope 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 occurred over much of the Chukchi shelf. This is likely a result of two processes - advection of high concentrations of ammonium 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 and western Beaufort lines are situated in areas 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 Chukchi Sea ecosystem is reflected in the upper trophic level data. For the benthic feeders (i.e., gray whales, bearded seals, and walrus), it was expected that they aggregate around prime benthic hotspots such as those found along the Point Hope 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 narrower 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 inter-annually. The degree to which migrating species take advantage of transient feeding opportunities, and for how long those ephemerally productive areas remain productive, are questions to be addressed with further intra- and inter-annual interdisciplinary sampling.

6. *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, Wainwright, and Ledyard Bay 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).

D. Long-range predictions

Current Situation

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, earlier retreat from and thus longer open-water seasons. Although changes before 2050 are limited in the ensemble mean predictions for spring, there are episodic early sea-ice retreat events predicted by the models beginning in 2020. While 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 the bottom for the region as a whole, with a potential decrease in the flux of phytoplankton carbon and nitrogen to the benthos.

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 a favorable condition for the production of epontic algae that are eventually delivered to the seafloor. Further, the *in situ* melting of sea ice helps to establish strong stratification (decrease in salinity) that vertically separates the water column. After the spring phytoplankton bloom, the subsurface layer often has the highest phytoplankton concentrations. This is because the shallow depths of the region enable sunlight to reach the subsurface layer where there are high concentrations of nutrients. In low light, high nutrient concentration environments, phytoplankton cells are able to photosynthesize, sustaining production throughout the summer until the nutrient reservoir at depth is depleted or, more commonly, when the combination of mixing due to late summer storms and reduction in light limit production.

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 substantial 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 230 is a schematic representing the current conditions in the Chukchi, as well as the two different scenarios.

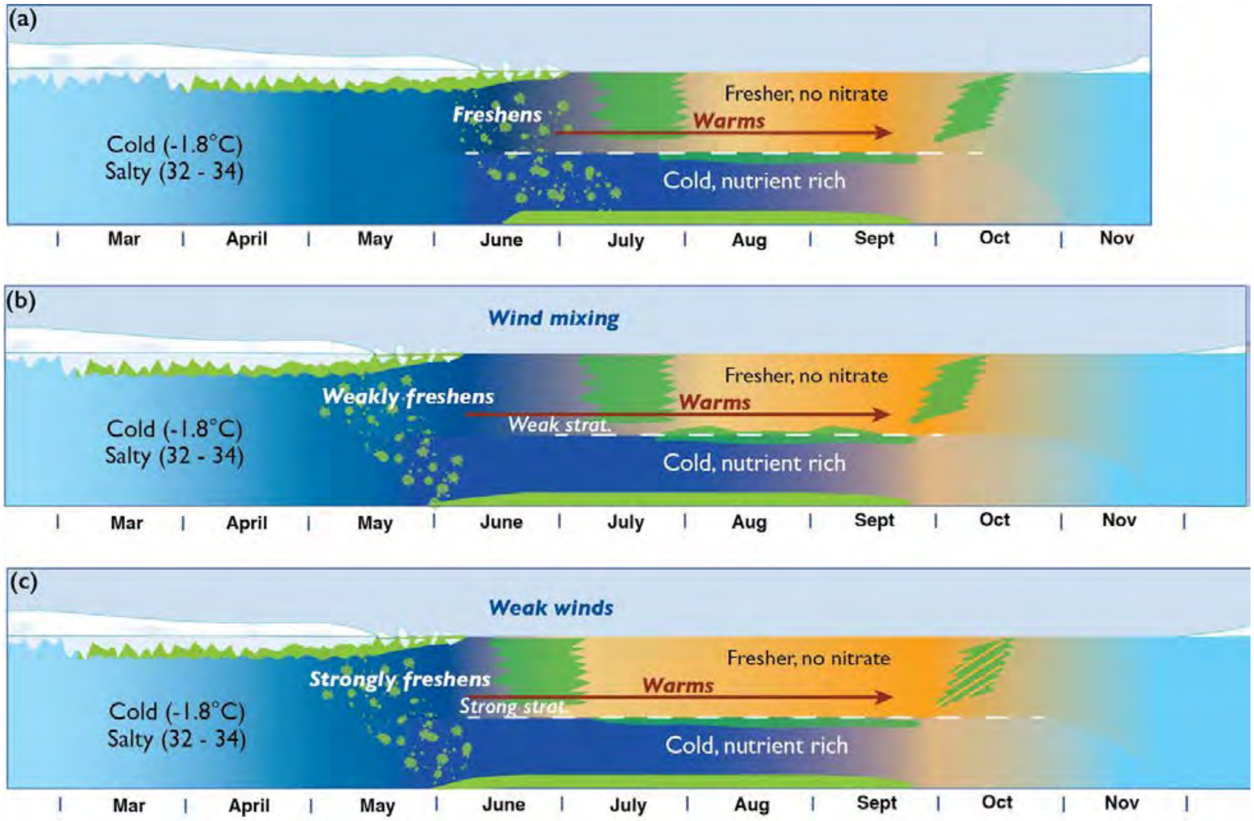

Figure 230. Schematic of ecosystems and possible future scenarios. A) Current conditions in the Chukchi Sea. B) Scenario 1. Ice retreat due to wind forcing. C) Scenario 2. Rapid ice melt and weaker winds (from Berchok et al., 2015).

Scenario 1: Early ice retreat with strong winds and less ice melt

In Scenario 1, strong winds from the southwest 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 that are initially transported to below the pycnocline during the summer. Phytoplankton blooms in the surface waters would occur earlier in the year with the consequence of early nutrient depletion (in the absence of wind mixing from spring and summer storms). Phytoplankton trapped below the pycnocline, either as a result of the early ice melt or sedimentation of the spring surface phytoplankton bloom 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 earlier than normal in the spring season and creates strong stratification. The early melt would again would shorten the period during which epontic algae rain down onto the seafloor, but with ice melting in place all the algae present in the ice would reach the seafloor. It is thus likely that the amount of phytoplankton biomass trapped below the pycnocline during summer would be greater than in Scenario 1, but less than under present conditions. 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.

The two scenarios above can be viewed as testable hypotheses. *In situ* studies using remote monitoring of bloom development by moored sensors and the flux of carbon to the seafloor is one means to better understand the coupling between ice and production. One dimensional modeling is also a tool that would help us to better understand how early loss of seasonal sea ice affects the balance of carbon export to the seafloor.

Conclusion

The ultimate goal is to better understand the connections between lower and upper trophic level processes in the Arctic and the impact of continued loss of sea ice. Established food web linkages between sea ice, plankton, Arctic cod, and upper trophic levels may be in jeopardy with declining seasonal sea ice. Will Arctic cod populations remain healthy without sea ice and if not, what will take their place? One hypothesis is that saffron cod, a congener, will take its place; however, saffron cod have lower lipid levels and thus are less desirable as prey for upper trophic levels. Previously it was hypothesized that even with the loss of seasonal sea ice, winter conditions would be too harsh to support populations of subarctic fish species from the south. More recently, we are learning that the eggs and larvae of subarctic species such as Walleye pollock (*Gadus chalcogrammus*) can develop and hatch at very low temperatures (Laurel et al., 2016). Recent surveys for midwater fishes found large numbers of pollock and Pacific cod in the northern Bering Sea and a large concentration of pollock along the continental shelf of the western Beaufort Sea (Arctic IERP survey). Both may be sources of immigrants and a signal that subarctic species are finding ways to colonize the Chukchi and survive the harsh winters. We need to rethink our ideas about the potential immigration of species into the Chukchi Sea, and to be able to better quantify how impacts of loss of sea ice at lower trophic levels will cascade to impact marine mammals and other high level Arctic predators.

Table 62. Summary of the effects of Scenarios 1 and 2 at Hanna Shoal on specific marine mammals.

Species	Impacts on marine mammals
Gray Whales	• Early decrease in ice over shoals and shallow areas 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 (i.e. prey types), 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 and other shallow areas across the Chukchi shelf.
Bearded Seal	• Decreased access to ice as a platform for pupping and feeding. • General decline in benthic prey availability over the region as a whole results in a shift in foraging strategies to take advantage of increased pelagic prey availability.

XI. SUMMARY

A. Overall summary

This integrative multi-year study was first able to document spatial patterns in the presence of marine mammals and the distributions of key physical, chemical, and biological oceanographic variables over the Chukchi Sea shelf. This enabled us to correlate marine mammal distributions with oceanographic parameters, and indices of potential prey availability. The technologies utilized in this study allowed us to assess complex trophic interactions, and illustrated the benefit of annual investigations. By including data from the BOEM-funded CHAOZ project, we now have a 7-year (2010-2016) dataset that will serve as a baseline for future studies of change in the Arctic.

Long-term passive acoustic data throughout the southern and northeastern Chukchi Sea as well as the western Beaufort allowed for year-round broad spatial monitoring of bowhead, beluga, gray, killer, minke, fin, and humpback whales, walrus, and bearded and ribbon seals, several noise sources (vessels, airguns, and ice), and potentially fish. Detections on the passive acoustic recordings have been able to monitor the spring and fall migrations of bowhead and beluga whales; some of which appear to be multimodal suggesting sex/age class or population timing differences, respectively. A possible small fall migratory pulse of ribbon and bearded seals was also detected. The spread of moorings throughout the southern and northeastern Chukchi as well as the western Beaufort Sea enabled monitoring of Arctic and subarctic species in both the open water and ice seasons. The western Beaufort was unique in its high levels of open water season bowhead whale and absence of gray whale calling. The southern Chukchi Sea not only has the expected high levels of humpback, fin, and gray whales during the open water season, but in addition high levels of bowheads, bearded seals, and walrus were also detected overwinter. Calling activity levels of both Arctic and subarctic species during the open water season in the northeastern Chukchi had no surprises; however, low levels of Arctic species (i.e., belugas, gray whales, and walrus) and subarctic species (killer whales and ribbon seals) were detected overwinter. These data form the foundation of monitoring whether a northward shift of subarctic marine mammal species into the Arctic is occurring and whether some Arctic species are altering their behavior to remain in the Chukchi during the winter; at this time, it is unknown whether these detections represent new trends in seasonal occurrence or an artifact of the increased monitoring effort made possible with passive acoustics. The passive acoustic data were also used to look at baseline ambient conditions in the study area. Concurrent with the passive acoustic monitoring, satellite tagging provided novel information on habitat use and revealed heterogeneous movement patterns and important foraging areas for gray whales in the Chukchi and the northern Bering Sea.

The use of drifters and biophysical moorings over the 7-year period enabled us to describe shelf flows, demonstrating the “strong” nature of flow along the coast with much weaker flow offshore and around Hanna Shoal. Monthly mean transports are strongest in the summer months and the total transport accounts for ~40% of the flow through Bering Strait. Reversals of flow up Barrow Canyon and winter polynyas were also described and linked to oceanographic conditions over the shelf. Temporal, vertical and horizontal patterns of nutrients, and phytoplankton pigments were described confirming that summer phytoplankton biomass was higher on the flanks and over the top of Hanna Shoal than other offshore shelf areas.

Additionally, these nutrient patterns and phytoplankton confirmed that the nutrient-rich subsurface layer was likely an area of active photosynthesis over much of the shelf (at least in water depths of <45 m). Zooplankton community structure showed a great deal of inter-annual variability with some tendency for an east-west pattern in some years. Particular zooplankton assemblages within a year were often associated or distinguished by different temperature and salinity waters. Evidence for euphausiid transport from the Bering Sea (conveyor belt hypothesis) was not present during the summer season, and in one or more years, the presence of early life history stages of euphausiids suggested that some euphausiid reproduction occurred in the Chukchi Sea. Unlike the Beaufort Sea, we did not find evidence for a euphausiid trap in the Chukchi; there were no locations with high aggregations of euphausiid or other invertebrate prey. There was also little evidence to support the hypothesis that diel vertical migration was important over this shallow shelf. Evidence for the physical transport of Arctic basin zooplankton species was observed in one year when "high" concentrations of *C. hyperboreus* were observed around the outer shelf.

Although statistical modeling using passive acoustic data is currently an emerging field, we conducted some analyses to determine how oceanographic factors influence calling rates of the five Arctic species. Month was found to be the most important, suggesting the influence of endogenous cycles. Ice factors, including possible proxies for leads, were next highest in their explanatory power. However, more long-term lower trophic level data are needed to determine whether any underlying influences, such as prey availability, exist.

B. Recommendations for future work

The data collected for the ARCWEST project demonstrate the utility and benefit of concurrent zooplankton, oceanography, and marine mammal monitoring. These data, combined with those from the BOEM-funded CHAOZ-X project and previously collected for the CHAOZ project, represent the only long-term integrated dataset of its kind from the Chukchi Sea and U.S. Arctic in general. A continuation of this monitoring dataset would will allow us to more fully assess year-round distributions as well as quantify inter-annual natural variation. It may also allow us to better document and better quantify present, and 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.

We therefore recommend continuation of the long-term integrated mooring deployments. In addition, new technology that measures nutrients, primary production, and water column structure are needed to better quantify change, and to help understand bottom-up mechanisms that influence this ecosystem. For instance, with new commercially available technology to replace the TAPS6-NG instruments (Simrad Wide Band Autonomous Scientific Echosounder), we believe we will be able to collect the plankton and fish data, concurrently with the marine mammal passive acoustics data, that we could not collect in this study. These data will allow for assessment of trophic interactions on an annual time scale. It will also be possible to continue monitoring for changes or shifts in multi-year patterns of marine mammal distributions as they relate to indices of zooplankton and oceanographic conditions. In addition, instruments that measure the recycling of the nutrients under the ice will provide information on the various sources of nutrients (e.g., Bering Sea, Beaufort slope, or recycling). Additional measurements are necessary to understand how primary production is changing (e.g., magnitude, rates, types of cells) with a reduction in ice duration.

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 mammals that feed on benthic epifauna and infauna.

In this study, deployment of satellite tags focused on gray whales and revealed novel information on movements and habitat use of a species commonly found in the Arctic. Increasing use of this region by other large whale species (e.g., humpback and fin whales) commonly found in the Bering Sea is expected due to loss of sea-ice. The potential ecosystem implications of increasing abundance of baleen whales could be better understood if the movements and behavior of these species are monitored. Considering recent advances in tagging technology, including more robust hardware and improved sensors, we recommend deployment of both short and long-term bio-logging instruments to better understand habitat preferences of large whale species in the Alaskan subarctic and Arctic. Tagging should be carried out in areas of known high density to maximize deployments and should include multi-sensor tags. We also recommend that sampling of the environment (e.g. prey fields, oceanography) and passive acoustic monitoring occur concurrently with tagging to better understand how whale behavior is coupled with the surrounding environment and identify context-specific calling behavior in the archived long-term time series.

To better predict what the future Arctic ecosystem will look like, we need to better understand the operative mechanisms that currently determine the structure and function of this ecosystem. CHAOZ, ARCWEST, and CHAOZ-X have given us good insight into how oceanographic conditions may change, and the variance in different spatial and temporal patterns. At this point we need to begin adding a new generation of mechanistic or process studies to our research portfolio. For example, studies at the southern edge of the Chukchi Sea Large Marine Ecosystem (i.e., the northern Bering Sea) that examine how early ice retreat impacted the flux of primary production to the seafloor and its subsequent impact on the production and benthic community composition would help us to better understand what may happen over the Chukchi shelf in the next couple of decades. Similarly, examining the overwinter strategy of subarctic organisms at the northern end of their population range may help to identify potential colonizers of the high Arctic. Laboratory studies of the early life history of residents and potential colonizers to describe their temperature-dependent hatching success, growth, and survival will help. These data can then be included in future studies to help better understand marine mammal distribution in this changing environment.

In summary, we recommend continuation of the long-term integrated mooring deployments and biophysical shipboard surveys, as well as initiating new process-oriented studies of operative mechanisms that couple lower and upper trophic levels and the plankton and benthos. To understand and predict how the ecosystem may change with loss of seasonal and permanent sea ice, we must understand the mechanisms.

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XIV. LIST OF PUBLICATIONS AND PRESENTATIONS

Publications

Ladd, C., C. Mordy, S.A. Salo, and P. Stabeno. 2016. Winter Water Properties and the Chukchi Polynya. Journal of Geophysical Research: Oceans 121: 5516-5534. doi: 10.1002/2016JC011918

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Oral Presentations

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Stabeno, P. 2014. US Arctic Present and Future. Oral presentation to the NOAA Senior Research Council. Pacific Marine Environmental Laboratory. 12 August 2014. Seattle, WA.

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Poster Presentations

Berchok, C., J. Crance, B. Rone, and S. Moore. 2015. Marine mammal occurrence in the Distributed Biological Observatory (DBO) from ship-based visual and passive acoustic surveys. Alaska Marine Science Symposium, Anchorage, AK.

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

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Crance, J.L., C.L. Berchok, P.J. Stabeno, J. Napp, B. Rone, A. Kennedy, and C. Clark. 2017. Seven years of integrative Arctic research. Alaska Marine Science Symposium, 23-27 January, Anchorage, AK (Poster).

Martini, K., Stabeno, P., Ladd, C., and Weingartner, T. 2015. Internal Wave Generation and Propagation in the Chukchi Sea. Alaska Marine Science Symposium, Anchorage, AK (Poster).

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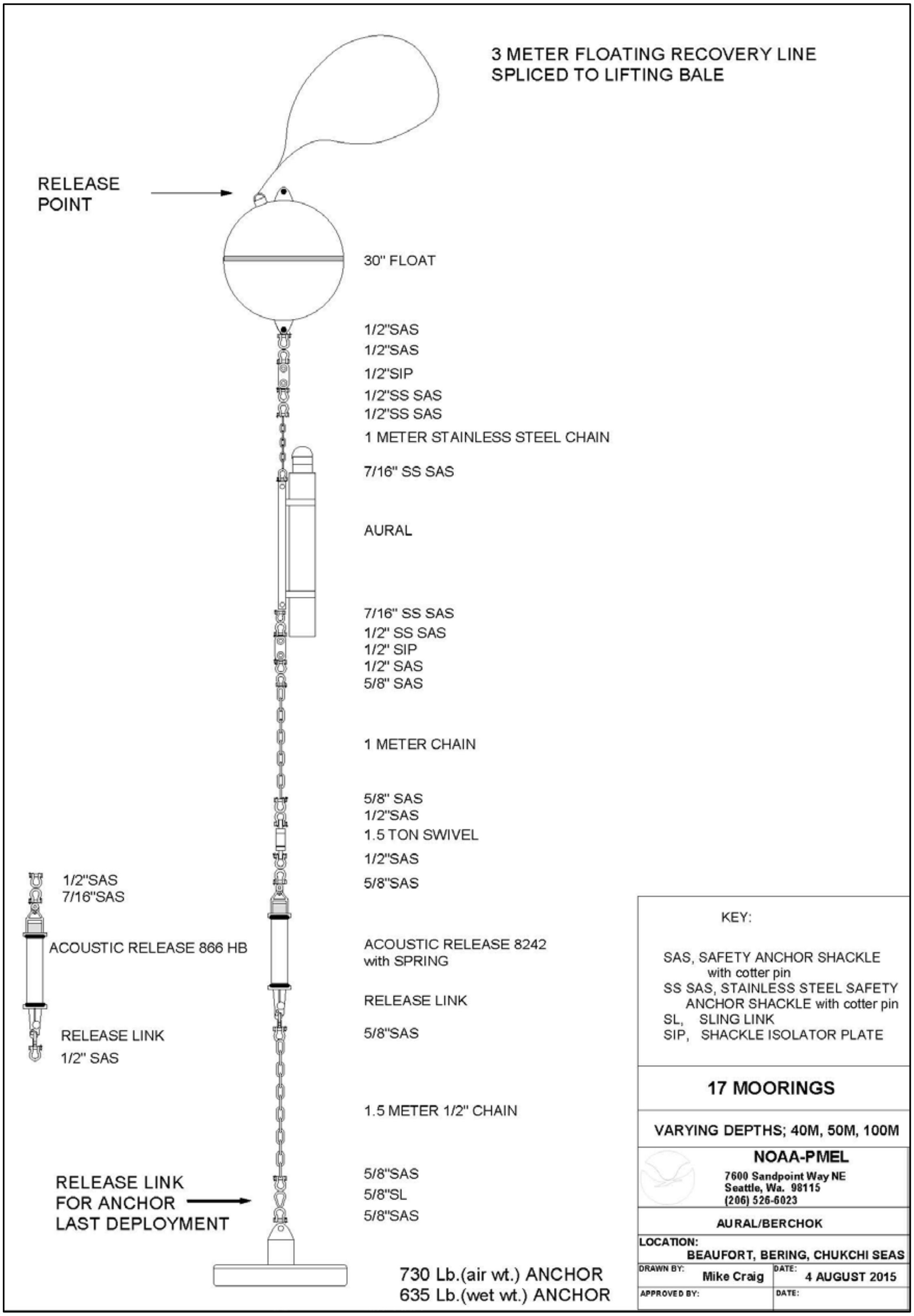
Spear, A.H., Napp, J.M., Duffy-Anderson, J.T., Salo, S., and Stabeno, P.J. 2016. Spatial and temporal variability in zooplankton. AGU Ocean Sciences Meeting, New Orleans, LA

XV. APPENDICES

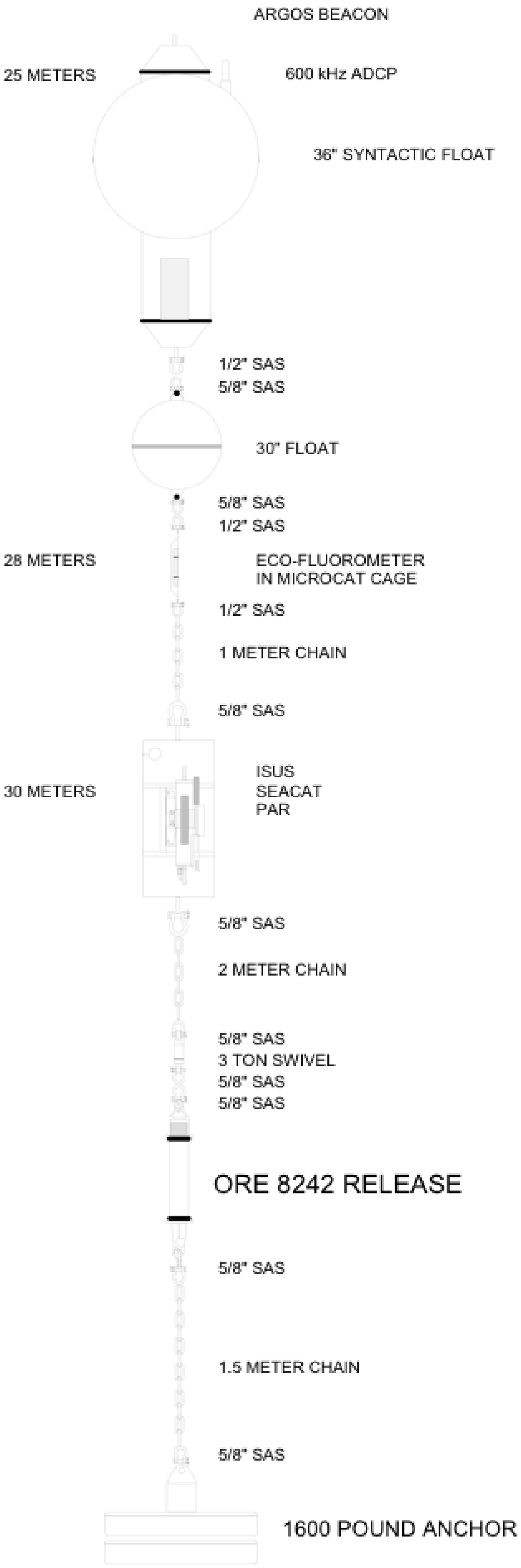
A. Field survey summary table

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

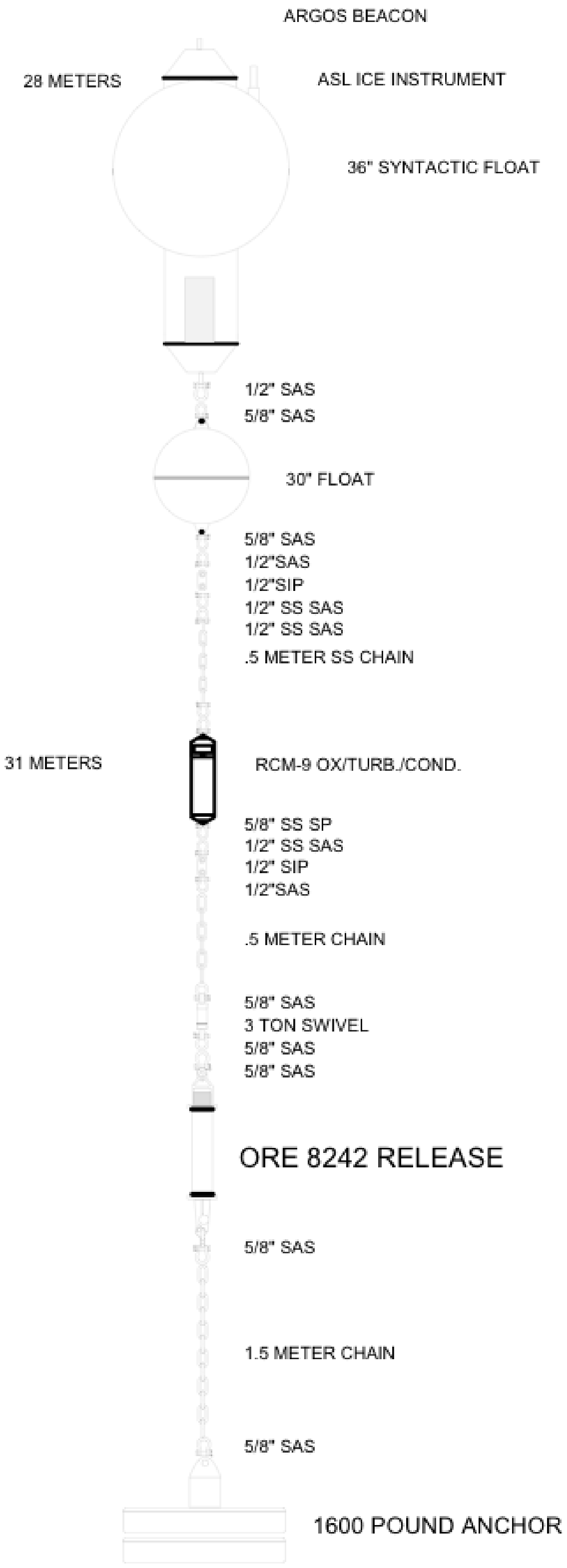
B. Mooring diagrams



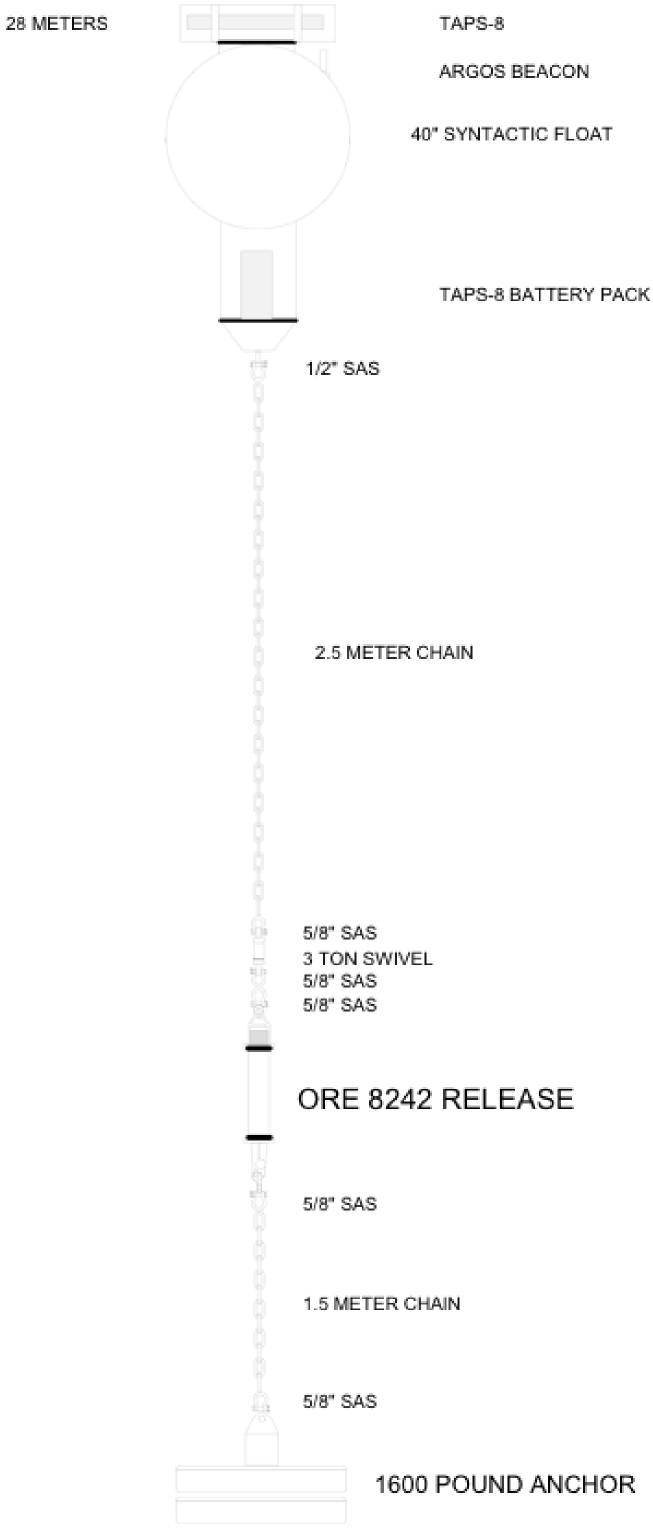
Appendix B. 1. Mooring diagram for passive acoustic recorders.



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. Table Appendix C. 2 contains the same results, but averaged over all years for each month. Tables Appendix C. 3 - 15 again contain the same results, but as monthly averages for each year for individual species. 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 Appendix C. 1. and Appendix 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 – 15: minke whale (non-boing), sperm whale, and right whale; the data were analyzed for these species, but no detections were made.

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	0	0	-	0	0	-	0	0	-	60	113	53	70	113	62	64	113	57	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	45	103	44
Bowhead	2011	0	0	-	0	0	-	0	0	-	40	284	14	75	297	25	120	298	40	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	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	0	0	-	0	0	-	0	0	-	75	124	60	0	0	-	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	0	0	-	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	0	0	-	96	256	38	103	257	40	130	257	51
Beluga	2010	0	0	-	0	0	-	0	0	-	8	113	7	23	113	20	26	113	23	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	35	103	34
Beluga	2011	0	0	-	0	0	-	0	0	-	19	284	7	32	297	11	71	298	24	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	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	0	0	-	0	0	-	0	0	-	27	124	22	0	0	-	166	334	50
Beluga	2013	63	364	17	135	365	37	42	365	12	57	364	16	67	338	20	86	365	24	36	317	11	4	124	3	0	0	-	12	64	19	74	365	20	32	121	26	174	363	48
Beluga	2014	85	365	23	118	364	32	51	364	14	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	60	264	23	53	263	20	31	254	12	21	260	8	30	256	12	73	261	28	35	260	13	15	259	6	19	259	7	0	0	-	56	250	22	55	257	21	125	257	49
Bearded	2010	0	0	-	0	0	-	0	0	-	26	113	23	52	113	46	64	113	57	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	68	103	66
Bearded	2011	0	0	-	0	0	-	0	0	-	224	284	79	252	297	85	258	298	87	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	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	0	0	-	0	0	-	0	0	-	74	124	60	0	0	-	287	334	86
Bearded	2013	221	364	61	265	365	73	223	365	61	223	364	61	261	338	77	188	365	52	228	317	72	65	124	52	0	0	-	5	64	8	253	365	69	96	121	79	277	363	76
Bearded	2014	227	365	62	250	364	69	226	364	62	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	151	254	59	177	260	68	180	256	70	176	261	67	189	260	73	193	259	75	181	259	70	0	0	-	177	250	71	213	257	83	215	257	84
Walrus	2010	0	0	-	0	0	-	0	0	-	38	113	34	20	113	18	35	113	31	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	2	103	2
Walrus	2011	0	0	-	0	0	-	0	0	-	106	284	37	76	297	26	110	298	37	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	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	0	0	-	0	0	-	0	0	-	1	124	1	0	0	-	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	0	-	0	64	0	50	365	14	4	121	3	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	59	364	16	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	0	0	-	43	256	17	29	257	11	10	257	4
Gray	2010	0	0	-	0	0	-	0	0	-	0	113	0	1	113	1	6	113	5	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	103	0
Gray	2011	0	0	-	0	0	-	0	0	-	0	284	0	0	297	0	5	298	2	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	363	0
Gray	2012	2	133	2	56	132	42	5	131	4	0	261	0	0	267	0	13	363	4	0	124	0	0	0	-	0	0	-	0	0	-	0	124	0	0	0	-	0	334	0
Gray	2013	17	364	5	127	365	35	1	365	<1	0	364	0	0	338	0	1	365	<1	0	317	0	0	124	0	0	0	-	0	64	0	0	365	0	2	121	2	0	363	0
Gray	2014	57	365	16	128	364	35	0	364	0	1	365	<1	0	365	0	0	365	0	0	87	0	1	364	<1	0	89	0	0	265	0	1	365	<1	5	364	1	0	364	0
Gray	2015	31	264	12	57	264	22	45	263	17	1	260	<1	0	256	0	0	261	0	0	260	0	0	259	0	0	259	0	0	0	-	1	256	<1	49	257	19	0	257	0
Humpback	2010	0	0	-	0	0	-	0	0	-	0	113	0	0	113	0	0	113	0	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	103	0
Humpback	2011	0	0	-	0	0	-	0	0	-	0	284	0	0	297	0	0	298	0	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	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	0	-	0	0	-	0	0	-	0	124	0	0	0	-	0	334	0
Humpback	2013	67	364	18	75	365	21	11	365	3	0	364	0	0	338	0	0	365	0	0	317	0	0	124	0	0	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	<1	0	365	0	0	365	0	0	87	0	0	364	0	0	89	0	0	265	0	1	365	<1	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	0	0	-	2	256	1	0	257	0	0	257	0
Gunshot	2010	0	0	-	0	0	-	0	0	-	38	113	34	13	113	12	13	113	12	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	103	0
Gunshot	2011	0	0	-	0	0	-	0	0	-	20	284	7	12	297	4	34	298	11	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	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	0	0	-	0	0	-	0	0	-	34	124	27	0	0	-	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	0	-	0	64	0	29	365	8	12	121	10	11	363	3
Gunshot	2014	1	365	<1	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	30	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	<1	5	259	2	0	0	-	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	0	-	0	0	-	0	0	-	0	113	**0**	0	113	**0**	0	113	**0**	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-
Fin	2011	0	0	-	0	0	-	0	0	-	0	284	**0**	0	297	**0**	0	298	**0**	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-
Fin	2012	0	0	-	51	132	**39**	27	131	**21**	0	135	**0**	0	140	**0**	0	235	**0**	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-
Fin	2013	0	0	-	78	365	**21**	51	365	**14**	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-
Fin	2014	0	0	-	34	258	**13**	29	267	**11**	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-
Fin	2015	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-
Ribbon	2010	0	0	-	0	0	-	0	0	-	0	113	**0**	0	113	**0**	0	113	**0**	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	10	103	**10**
Ribbon	2011	0	0	-	0	0	-	0	0	-	0	284	**0**	0	297	**0**	1	298	**<1**	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	25	363	**7**
Ribbon	2012	3	133	**2**	29	132	**22**	20	131	**15**	4	261	**2**	3	267	**1**	1	363	**<1**	1	124	**1**	0	0	-	0	0	-	0	0	-	3	124	**2**	0	0	-	22	334	**7**
Ribbon	2013	0	364	**0**	10	365	**3**	15	365	**4**	2	364	**1**	8	338	**2**	4	365	**1**	5	317	**2**	2	124	**2**	0	0	-	4	64	**6**	3	365	**1**	1	121	**1**	48	363	**13**
Ribbon	2014	0	365	**0**	0	364	**0**	1	364	**<1**	4	365	**1**	3	365	**1**	5	365	**1**	0	87	**0**	0	364	**0**	0	89	**0**	13	263	**5**	1	364	**<1**	0	364	**0**	13	364	**4**
Ribbon	2015	7	264	**3**	2	263	**1**	0	254	**0**	0	260	**0**	0	256	**0**	0	261	**0**	0	260	**0**	0	259	**0**	0	259	**0**	0	0	-	0	250	**0**	1	257	**<1**	0	257	**0**
Killer	2010	0	0	-	0	0	-	0	0	-	0	113	**0**	0	113	**0**	0	113	**0**	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	103	**0**
Killer	2011	0	0	-	0	0	-	0	0	-	0	284	**0**	0	297	**0**	4	298	**1**	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	363	**0**
Killer	2012	1	133	**1**	17	132	**13**	0	131	**0**	1	261	**<1**	1	267	**<1**	2	363	**1**	0	124	**0**	0	0	-	0	0	-	0	0	-	1	124	**1**	0	0	-	4	334	**1**
Killer	2013	29	364	**8**	39	365	**11**	2	365	**1**	0	364	**0**	0	338	**0**	2	365	**1**	2	317	**1**	0	124	**0**	0	0	-	0	64	**0**	0	365	**0**	7	121	**6**	2	363	**1**
Killer	2014	46	365	**13**	34	364	**9**	3	364	**1**	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	21	264	**8**	20	263	**8**	1	254	**<1**	0	260	**0**	0	256	**0**	0	261	**0**	1	260	**<1**	1	259	**<1**	0	259	**0**	0	0	-	0	250	**0**	0	257	**0**	1	257	**<1**
Boing	2010	0	0	-	0	0	-	0	0	-	0	113	**0**	0	113	**0**	0	113	**0**	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	103	**0**
Boing	2011	0	0	-	0	0	-	0	0	-	0	284	**0**	0	297	**0**	2	298	**1**	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	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	0	-	0	0	-	0	0	-	0	124	**0**	0	0	-	0	334	**0**
Boing	2013	2	364	**1**	1	365	**<1**	10	365	**3**	0	364	**0**	0	338	**0**	0	365	**0**	0	317	**0**	0	124	**0**	0	0	-	0	64	**0**	0	365	**0**	0	121	**0**	0	363	**0**
Boing	2014	1	365	**<1**	1	364	**<1**	5	364	**1**	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	254	**0**	0	260	**0**	0	256	**0**	0	261	**0**	0	260	**0**	0	259	**0**	0	259	**0**	0	0	-	0	250	**0**	0	257	**0**	0	257	**0**
UnidPin	2010	0	0	-	0	0	-	0	0	-	0	113	**0**	3	113	**3**	10	113	**9**	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	13	103	**13**
UnidPin	2011	0	0	-	0	0	-	0	0	-	2	284	**1**	25	297	**8**	45	298	**15**	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	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**	0	0	-	0	0	-	0	0	-	18	124	**15**	0	0	-	18	334	**5**
UnidPin	2013	1	364	**<1**	35	365	**10**	32	365	**9**	7	364	**2**	24	338	**7**	66	365	**18**	16	317	**5**	7	124	**6**	0	0	-	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**	43	364	**12**	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**	0	0	-	27	256	**11**	12	257	**5**	12	257	**5**
DblKnck	2010	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	3	103	**3**
DblKnck	2011	0	0	-	0	0	-	0	0	-	0	4	**0**	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	1	363	**<1**
DblKnck	2012	0	0	-	0	0	-	12	39	**31**	0	3	**0**	0	0	-	2	129	**2**	2	124	**2**	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	3	207	**1**
DblKnck	2013	0	0	-	0	1	**<1**	79	365	**22**	0	0	-	0	0	-	61	365	**17**	51	240	**21**	0	47	**0**	0	0	-	0	0	-	0	0	-	0	84	**0**	0	0	-
DblKnck	2014	0	0	-	0	33	**0**	106	364	**29**	0	62	**0**	0	0	-	125	365	**34**	0	59	**0**	0	140	**0**	0	89	**0**	0	0	-	0	31	**0**	46	289	**16**	0	0	-
DblKnck	2015	0	0	-	0	245	**0**	89	263	**34**	0	260	**0**	0	0	-	47	261	**18**	45	196	**23**	35	259	**14**	38	259	**15**	0	0	-	0	226	**0**	34	257	**13**	0	0	-

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	0	0	-	0	0	-	0	0	-	20	113	**18**	21	113	**19**	21	113	**19**	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	6	103	**6**
Airgun	2011	0	0	-	0	0	-	0	0	-	21	284	**7**	22	297	**7**	14	298	**5**	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	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**	0	0	-	0	0	-	0	0	-	2	124	**2**	0	0	-	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**	0	0	-	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	0	-	0	256	**0**	2	257	**1**	0	257	**0**
Vessel	2010	0	0	-	0	0	-	0	0	-	0	113	**0**	2	113	**2**	11	113	**10**	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	14	103	**14**
Vessel	2011	0	0	-	0	0	-	0	0	-	6	284	**2**	15	297	**5**	5	298	**2**	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	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**	0	0	-	0	0	-	0	0	-	42	124	**34**	0	0	-	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**	0	0	-	7	64	**11**	45	365	**12**	17	121	**14**	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**	42	364	**12**	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**	0	0	-	58	256	**23**	53	257	**21**	8	257	**3**
Ice	2010	0	0	-	0	0	-	0	0	-	25	113	**22**	34	113	**30**	29	113	**26**	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	60	103	**58**
Ice	2011	0	0	-	0	0	-	0	0	-	88	284	**31**	57	297	**19**	109	298	**37**	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	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**	0	0	-	0	0	-	0	0	-	49	124	**40**	0	0	-	238	334	**71**
Ice	2013	121	364	**33**	130	365	**36**	143	365	**39**	254	364	**70**	238	338	**70**	131	365	**36**	215	317	**68**	64	124	**52**	0	0	-	43	64	**67**	129	365	**35**	40	121	**33**	268	363	**74**
Ice	2014	125	365	**34**	149	364	**41**	165	364	**45**	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	107	264	**41**	127	263	**48**	123	254	**48**	170	260	**65**	177	256	**69**	102	261	**39**	169	260	**65**	141	259	**54**	105	259	**41**	0	0	-	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	14	93	15	20	93	22	0	93	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	13	84	15	4	84	5	0	84	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	38	93	41	41	93	44	6	93	6	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	66	90	73	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	37	93	40	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	3	90	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	93	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	102	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	0	111	0	2	109	2	0	100	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	93	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	44	90	49	85	90	94	30	90	33	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	28	93	30	46	93	49	2	93	2	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	71	93	76	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	84	84	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	92	93	99	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	90	90	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	93	93	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	60	90	67	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	1	93	1	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	102	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	9	100	9	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	55	93	59	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	71	90	79	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	41	93	44	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	0	62	0	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	0	56	0	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	0	62	0	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	0	60	0	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	0	62	0	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	25	60	42	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	1	62	2	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	7	60	12	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**	0	62	**0**	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**	0	60	**0**	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**	0	62	**0**	0	155	**0**
Gray	Jun	34	90	**38**	35	90	**39**	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**	1	60	**2**	0	150	**0**
Gray	Jul	28	93	**30**	85	93	**91**	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**	90	110	**82**	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**	66	93	**71**	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**	0	60	**0**	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**	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**
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**	7	60	**12**	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	0	-	0	62	**0**	0	62	**0**	0	62	**0**	0	62	**0**	0	62	**0**	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-
Fin	Feb	0	0	-	0	56	**0**	0	56	**0**	0	57	**0**	0	57	**0**	0	57	**0**	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-
Fin	Mar	0	0	-	0	62	**0**	0	62	**0**	0	62	**0**	0	62	**0**	0	62	**0**	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-
Fin	Apr	0	0	-	0	60	**0**	0	60	**0**	0	60	**0**	0	60	**0**	0	60	**0**	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-
Fin	May	0	0	-	0	62	**0**	0	62	**0**	0	45	**0**	0	50	**0**	0	62	**0**	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-
Fin	Jun	0	0	-	11	60	**18**	0	60	**0**	0	8	**0**	0	21	**0**	0	57	**0**	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-
Fin	Jul	0	0	-	13	62	**21**	14	62	**23**	0	0	-	0	0	-	0	31	**0**	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-
Fin	Aug	0	0	-	43	72	**60**	25	71	**35**	0	3	**0**	0	3	**0**	0	22	**0**	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-
Fin	Sep	0	0	-	61	75	**81**	45	84	**54**	0	51	**0**	0	51	**0**	0	49	**0**	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-
Fin	Oct	0	0	-	33	62	**53**	23	62	**37**	0	62	**0**	0	62	**0**	0	62	**0**	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-
Fin	Nov	0	0	-	2	60	**3**	0	60	**0**	0	60	**0**	0	60	**0**	0	60	**0**	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-
Fin	Dec	0	0	-	0	62	**0**	0	62	**0**	0	62	**0**	0	62	**0**	0	62	**0**	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	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	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
Ribbon	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
Ribbon	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
Ribbon	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	2	30	7	0	90	0	1	60	2	0	150	0
Ribbon	May	7	93	8	2	93	2	0	93	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	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	0	60	0	0	150	0
Ribbon	Jul	0	93	0	0	93	0	0	93	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	102	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	100	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	7	93	8	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	26	90	29	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	3	93	3	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	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
Killer	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
Killer	Mar	0	93	0	0	93	0	1	93	1	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	90	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	93	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	1	90	1	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	17	93	18	33	93	35	1	93	1	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	23	103	22	25	103	24	1	102	1	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	18	111	16	24	109	22	2	100	2	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	11	93	12	3	93	3	0	93	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	7	90	8	2	90	2	0	90	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	93	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	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
Boing	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
Boing	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	0	62	0	0	155	0
Boing	Apr	0	90	0	0	90	0	3	90	3	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	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
Boing	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	0	60	0	0	150	0
Boing	Jul	0	93	0	0	93	0	1	93	1	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	102	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	2	100	2	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	14	93	15	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	2	90	2	1	90	1	6	90	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	93	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	5	56	9	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	1	0	0	-	0	31	0	16	93	17	0	33	0	0	0	-	13	93	14	0	32	0	0	31	0	0	31	0	0	0	-	0	31	0	2	36	6	1	62	2
DblKnck	2	0	0	-	0	28	0	50	84	60	0	28	0	0	0	-	21	84	25	5	32	16	0	28	0	0	28	0	0	0	-	0	28	0	2	38	5	0	57	0
DblKnck	3	0	0	-	0	31	0	60	93	65	0	31	0	0	0	-	37	93	40	2	52	4	0	31	0	4	31	13	0	0	-	0	31	0	7	53	13	0	62	0
DblKnck	4	0	0	-	0	30	0	68	90	76	0	30	0	0	0	-	59	90	66	31	60	52	9	30	30	7	30	23	0	0	-	0	30	0	30	56	54	1	60	2
DblKnck	5	0	0	-	0	32	0	62	93	67	0	31	0	0	0	-	73	93	78	51	62	82	21	35	60	23	31	74	0	0	-	0	1	0	36	60	60	2	62	3
DblKnck	6	0	0	-	0	30	0	2	90	2	0	30	0	0	0	-	14	90	16	7	60	12	5	39	13	4	30	13	0	0	-	0	30	0	2	60	3	0	57	0
DblKnck	7	0	0	-	0	31	0	0	93	0	0	31	0	0	0	-	0	93	0	0	62	0	0	36	0	0	31	0	0	0	-	0	31	0	0	59	0	0	59	0
DblKnck	8	0	0	-	0	31	0	0	93	0	0	32	0	0	0	-	0	100	0	0	61	0	0	37	0	0	31	0	0	0	-	0	31	0	0	56	0	0	29	0
DblKnck	9	0	0	-	0	4	0	0	79	0	0	17	0	0	0	-	0	108	0	0	47	0	0	71	0	0	16	0	0	0	-	0	13	0	0	62	0	0	41	0
DblKnck	10	0	0	-	0	0	-	0	62	0	0	1	0	0	0	-	0	93	0	0	51	0	0	41	0	0	28	0	0	0	-	0	0	-	0	59	0	0	62	0
DblKnck	11	0	0	-	0	0	-	12	68	18	0	30	0	0	0	-	8	90	9	2	48	4	0	33	0	0	30	0	0	0	-	0	0	-	0	49	0	0	60	0
DblKnck	12	0	0	-	0	31	0	16	93	17	0	35	0	0	0	-	10	93	11	0	52	0	0	34	0	0	31	0	0	0	-	0	31	0	1	42	2	3	62	5
Airgun	1	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	2	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	3	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	4	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	5	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	6	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	7	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	8	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	9	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	10	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	11	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	12	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	1	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	2	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	3	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	4	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	0	90	0	1	60	2	0	150	0
Vessel	5	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
Vessel	6	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	7	60	12	16	150	11
Vessel	7	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	8	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	9	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	10	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	4	62	6	38	155	25
Vessel	11	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	0	60	0	10	150	7
Vessel	12	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	1	74	93	80	81	93	87	89	93	96	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	2	74	84	88	70	84	83	79	84	94	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	3	80	93	86	86	93	92	72	93	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	4	74	90	82	71	90	79	75	90	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	5	15	93	16	50	93	54	45	93	48	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	6	0	90	0	3	90	3	17	90	19	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	7	1	93	1	0	93	0	0	93	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	8	0	103	0	0	103	0	1	102	1	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	9	0	111	0	0	109	0	0	100	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	10	0	93	0	0	93	0	1	93	1	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	11	6	90	7	15	90	17	13	90	14	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	12	52	93	56	70	93	75	80	93	86	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	31	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	2	30	7	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	22	31	71	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	22	30	73	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	12	31	39	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	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	100	-	-	-	28	28	100	-	-	-	21	28	75	28	28	100	28	28	100	28	28	100
2014	3	31	31	100	31	31	100	31	31	100	31	31	100	31	31	100	31	31	100	-	-	-	31	31	100	-	-	-	25	31	81	31	31	100	31	31	100	31	31	100
2014	4	30	30	100	30	30	100	30	30	100	30	30	100	30	30	100	30	30	100	-	-	-	30	30	100	-	-	-	29	30	97	30	30	100	30	30	100	30	30	100
2014	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	31	31	100	31	31	100
2014	6	13	30	43	15	30	50	25	30	83	30	30	100	30	30	100	26	30	87	-	-	-	30	30	100	-	-	-	29	30	97	30	30	100	30	30	100	30	30	100
2014	7	0	31	0	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	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	3	29	10	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	9	31	29	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	25	30	83	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	14	31	45	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	16	31	52	27	31	87	29	31	94	29	31	94	31	31	100	31	31	100	26	31	84	-	-	-	28	31	90	30	31	97	27	31	87
2015	2	28	28	100	28	28	100	28	28	100	27	28	96	28	28	100	27	28	96	28	28	100	28	28	100	28	28	100	-	-	-	28	28	100	28	28	100	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	100	31	31	100	31	31	100	-	-	-	31	31	100	31	31	100	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	100	30	30	100	29	30	97	-	-	-	30	30	100	30	30	100	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	100	31	31	100	31	31	100	-	-	-	31	31	100	31	31	100	31	31	100
2015	6	13	30	43	12	30	40	14	30	47	28	30	93	30	30	100	28	30	93	30	30	100	30	30	100	30	30	100	-	-	-	28	30	93	27	30	90	30	30	100
2015	7	0	31	0	0	31	0	1	31	3	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	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	0	11	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	100	-	-	-	-	-	-	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	0	31	0	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	1	30	3	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	0	31	0	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	0	28	0	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	0	31	0	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	0	30	0	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	0	31	0	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	13	30	43	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	100	-	-	-	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	100	-	-	-	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	100	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	100	31	31	100	-	-	-	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	26	30	87	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	20	31	65	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	13	30	43	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	29	31	94	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	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	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
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	0	30	0	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	0	31	0	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	1	30	3	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	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	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. 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 mooring have not been analyzed yet.

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. 10. 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	31	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	2	30	7	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	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	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	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	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
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	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	0	30	0
2014	7	6	31	19	11	31	35	1	31	3	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	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
2014	9	7	30	23	7	29	24	0	29	0	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	6	31	19	0	31	0	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	3	30	10	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	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	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	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	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	0	31	0
2015	6	7	30	23	7	30	23	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
2015	7	5	31	16	6	31	19	0	31	0	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	9	31	29	7	31	23	0	31	0	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	11	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. Minke whale ‘boing call’ 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	2	31	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	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	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	-	-	-	0	30	0
2012	10	1	31	3	0	31	0	9	31	29	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	2	30	7	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	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
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	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	31	0	0	30	0	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	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	1	31	3	0	31	0	5	31	16	0	31	0	0	31	0	0	31	0	0	31	0	0	31	0	-	-	-	0	3	0	0	31	0	0	31	0	0	31	0
2013	11	0	30	0	1	30	3	4	30	13	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	3	30	10	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	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	7	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	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	0	31	0	0	31	0
2014	9	0	30	0	0	29	0	1	29	3	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	1	31	3	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	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	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	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	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	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	31	0	-	-	-	0	30	0	0	31	0	0	31	0
2015	9	0	21	0	0	20	0	0	11	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. 12. 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	31	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	30	0	0	29	0	9	28	32
2013	10	0	31	0	1	31	3	2	31	6	1	31	3	2	31	6	0	31	0	2	31	6	2	31	6	-	-	-	3	3	100	2	31	6	0	31	0	27	31	87
2013	11	0	30	0	5	30	17	10	30	33	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	3	31	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
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	-	-	-	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	-	-	-	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	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	-	-	-	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	-	-	-	0	31	0	-	-	-	5	31	16	0	31	0	0	31	0	2	31	6
2014	9	0	30	0	0	29	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	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	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	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	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	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	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	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	31	0	-	-	-	0	30	0	0	31	0	0	31	0
2015	9	0	21	0	0	20	0	0	11	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. 13. 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**

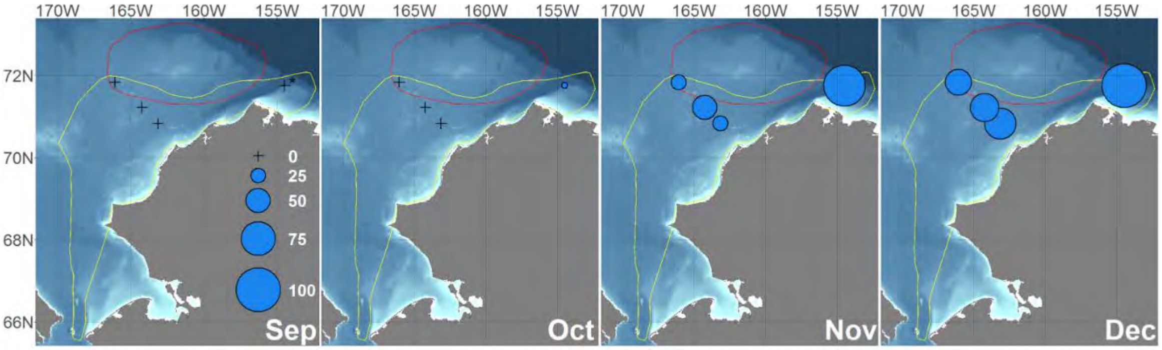
Appendix C. 14. Vessel noise activity 2010-2015 across all mooring locations. Number of days with calling activity (#), number of days with recordings (Eff), percent of days with calling activity per month (%)

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**	-	-	-	-	-	-	-	-	-	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**	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	**100**	-	-	-	-	-	-	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**	2	31	**6**	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**	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	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**	7	30	**23**	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**	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**	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**

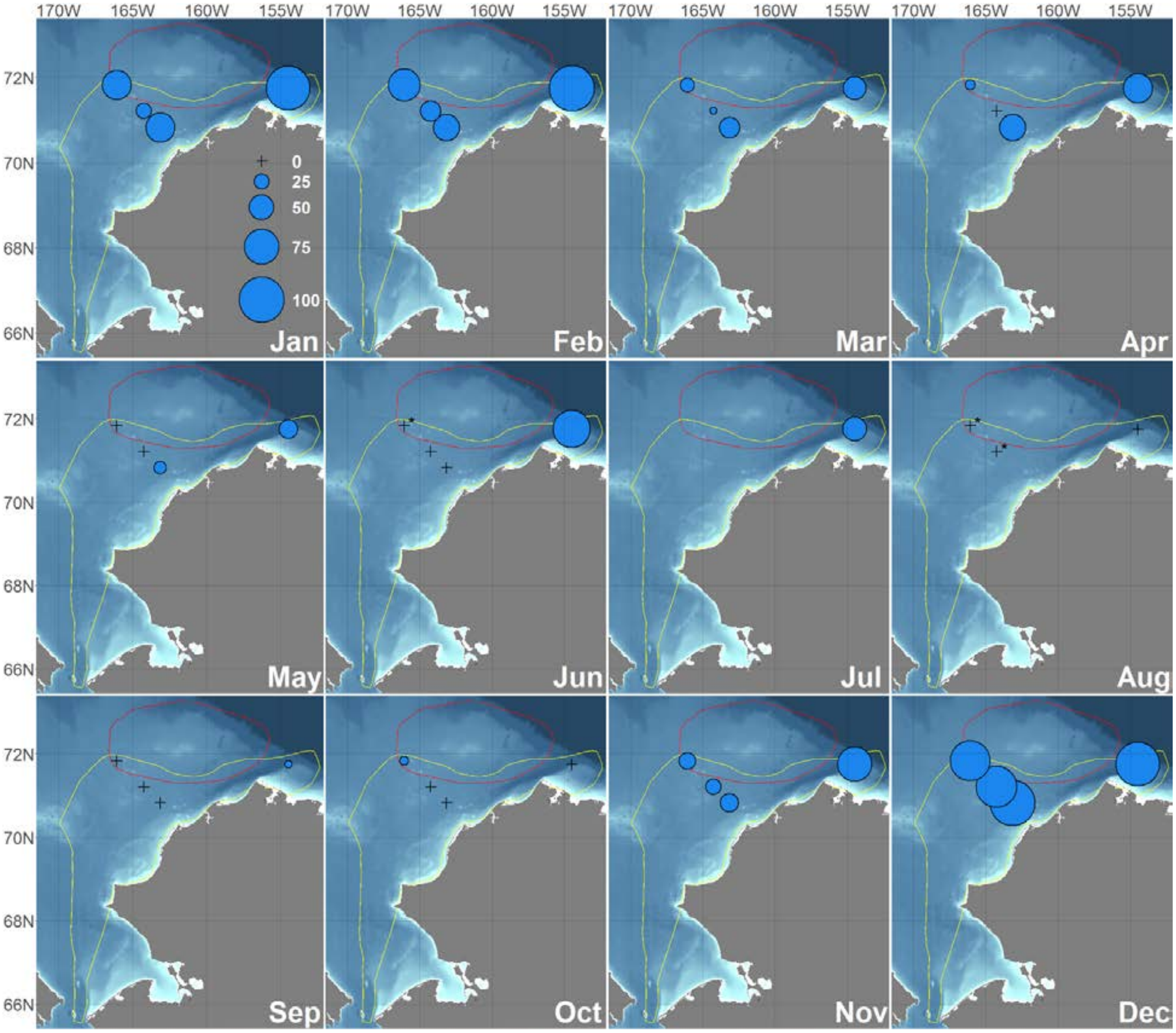
Appendix C. 15. Ice noise activity 2010-2015 across all mooring locations. Number of days with calling activity (#), number of days with recordings (Eff), percent of days with calling activity per month (%).

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	31	0	12	30	40	0	4	0	0	31	0	8	30	27	2	2	100	-	-	-	-	-	-	0	31	0	-	-	-	12	31	39
2013	9	0	30	0	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	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	2	30	7	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	18	31	58	29	31	94	26	31	84	22	31	71	-	-	-	31	31	100	-	-	-	24	31	77	22	31	71	26	31	84	31	31	100
2014	1	28	31	90	29	31	94	30	31	97	29	31	94	30	31	97	26	31	84	-	-	-	31	31	100	-	-	-	29	31	94	27	31	87	19	31	61	31	31	100
2014	2	22	28	79	24	28	86	25	28	89	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	27	31	87	30	31	97	31	31	100	25	31	81	-	-	-	31	31	100	-	-	-	29	31	94	21	31	68	24	31	77	28	31	90
2014	4	22	30	73	27	30	90	25	30	83	22	30	73	30	30	100	22	30	73	-	-	-	30	30	100	-	-	-	24	30	80	12	30	40	20	30	67	26	30	87
2014	5	3	31	10	13	31	42	17	31	55	31	31	100	29	31	94	2	31	6	-	-	-	31	31	100	-	-	-	20	31	65	3	31	10	24	31	77	23	31	74
2014	6	0	30	0	1	30	3	8	30	27	30	30	100	30	30	100	0	30	0	-	-	-	30	30	100	-	-	-	28	30	93	2	30	7	20	30	67	30	30	100
2014	7	0	31	0	0	31	0	0	31	0	24	31	77	18	31	58	0	31	0	-	-	-	31	31	100	-	-	-	22	31	71	3	31	10	15	31	48	31	31	100
2014	8	0	31	0	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	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	1	31	3	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	2	30	7	2	30	7	1	30	3	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	31	31	100	29	31	94	29	31	94	30	31	97	29	31	94	29	31	94	-	-	-	22	30	73	31	31	100	31	31	100
2015	1	24	31	77	27	31	87	28	31	90	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	27	28	96	25	28	89	28	28	100	24	28	86	28	28	100	28	28	100	21	28	75	-	-	-	24	28	86	22	28	79	26	28	93
2015	3	26	31	84	29	31	94	21	31	68	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	25	30	83	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	17	31	55	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	4	30	13	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	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	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	11	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

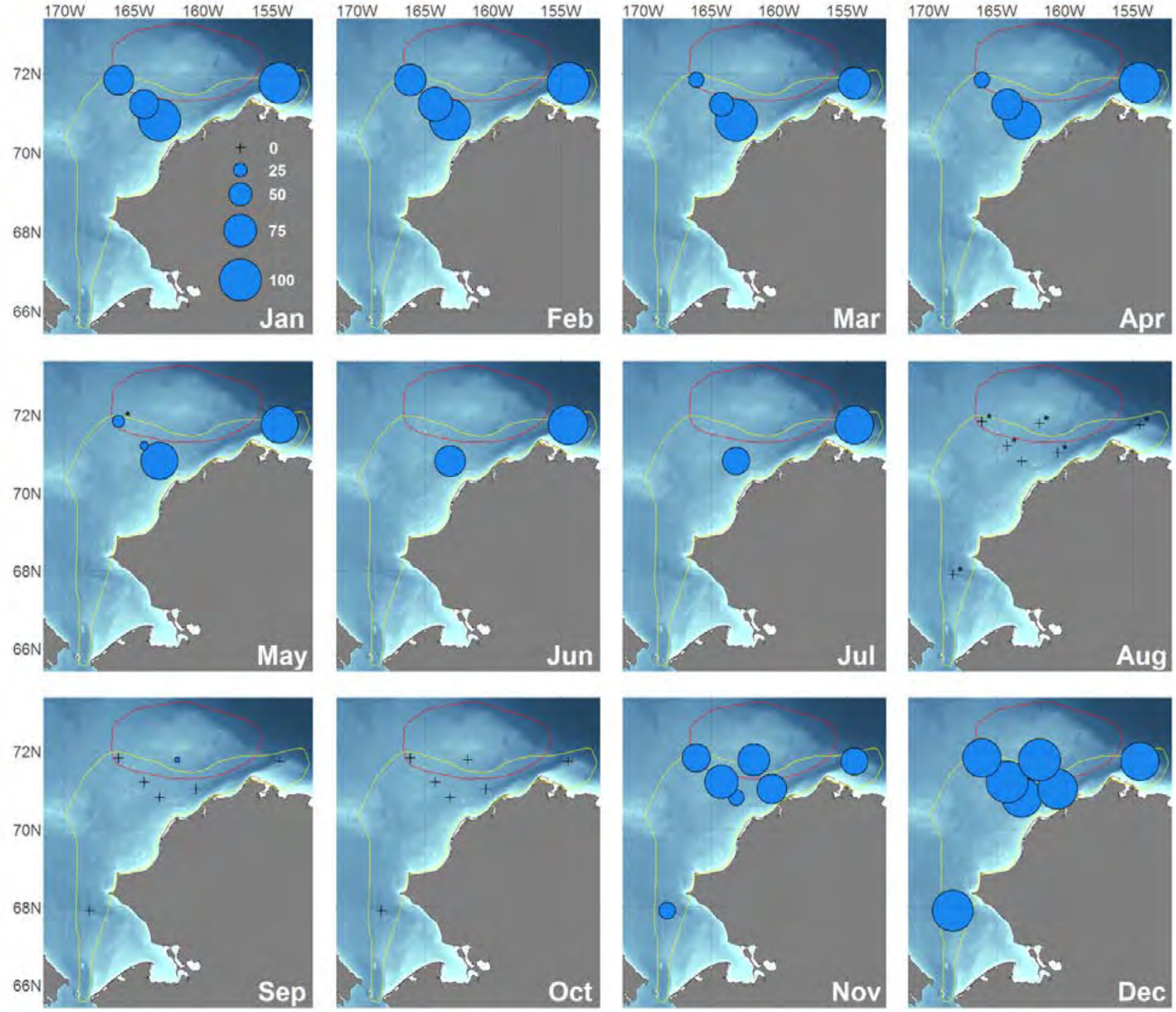
D. Additional passive acoustic monthly calling distribution maps



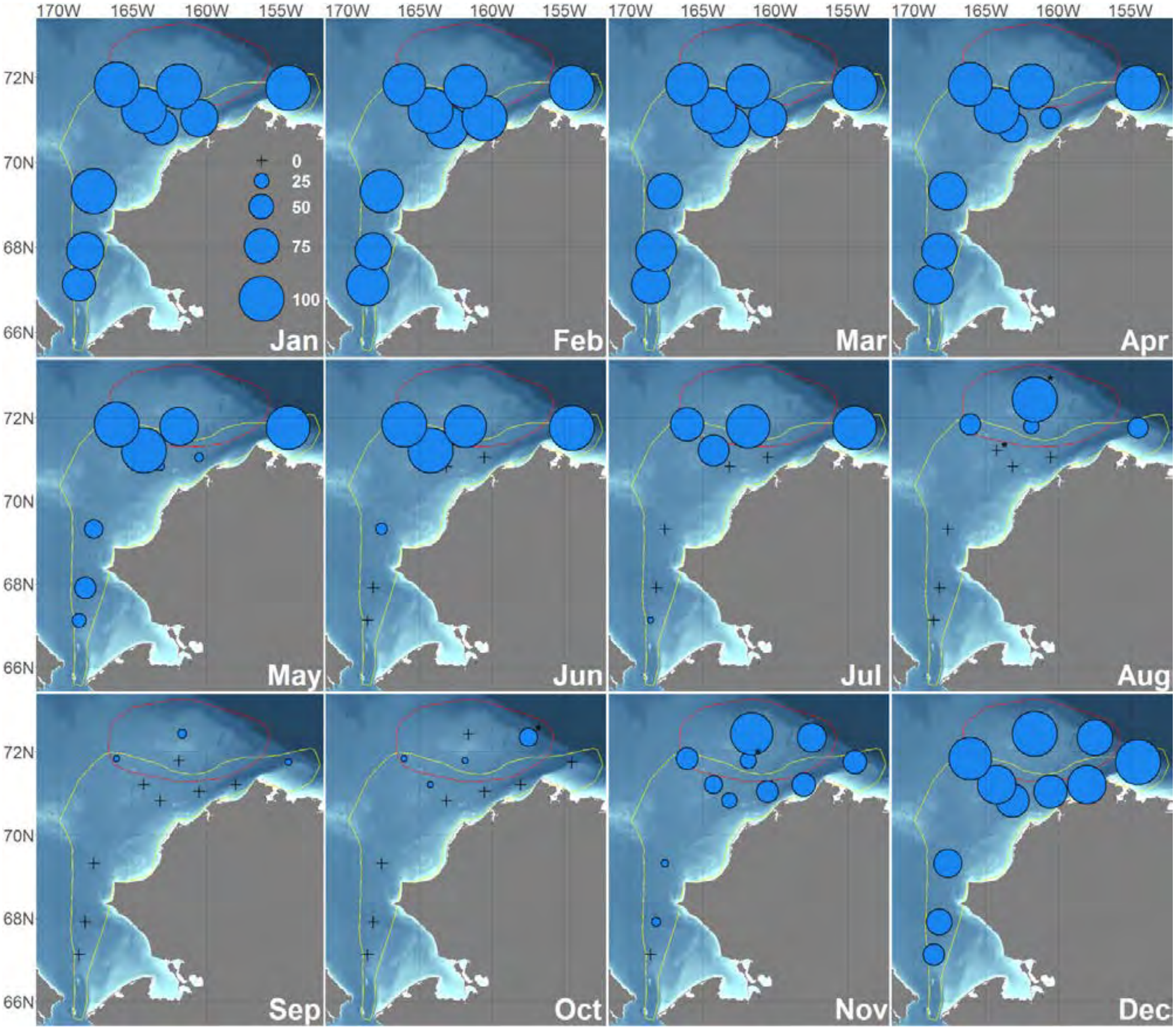
Appendix D. 1. Ice noise distribution 2010. Graduated scale in the September panel indicates % of days per month with ice noise. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 15 for numbers used to generate figure.



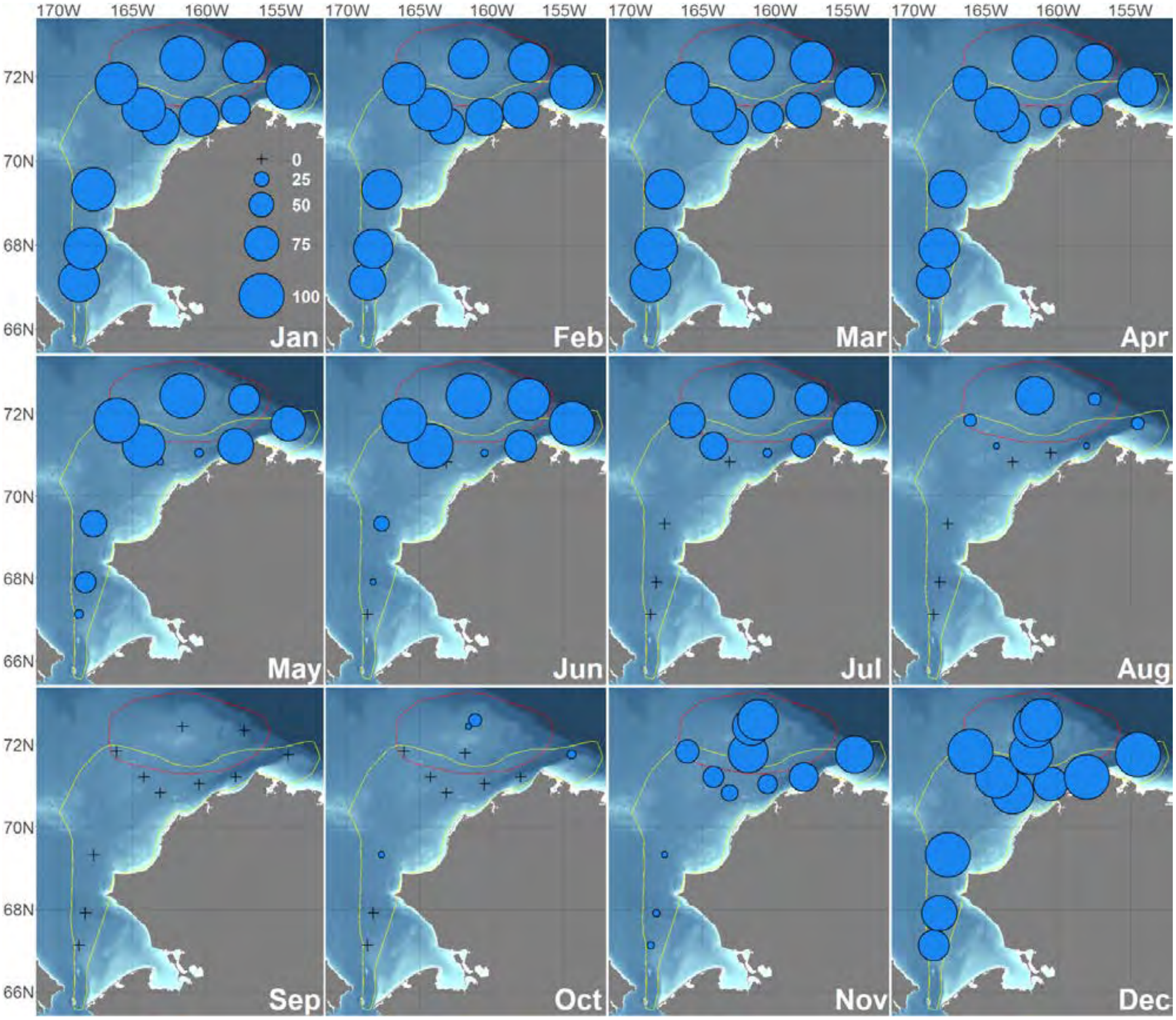
Appendix D. 2. Ice noise distribution 2011. Graduated scale in the January panel indicates % of days per month with ice noise. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 15 for numbers used to generate figure.



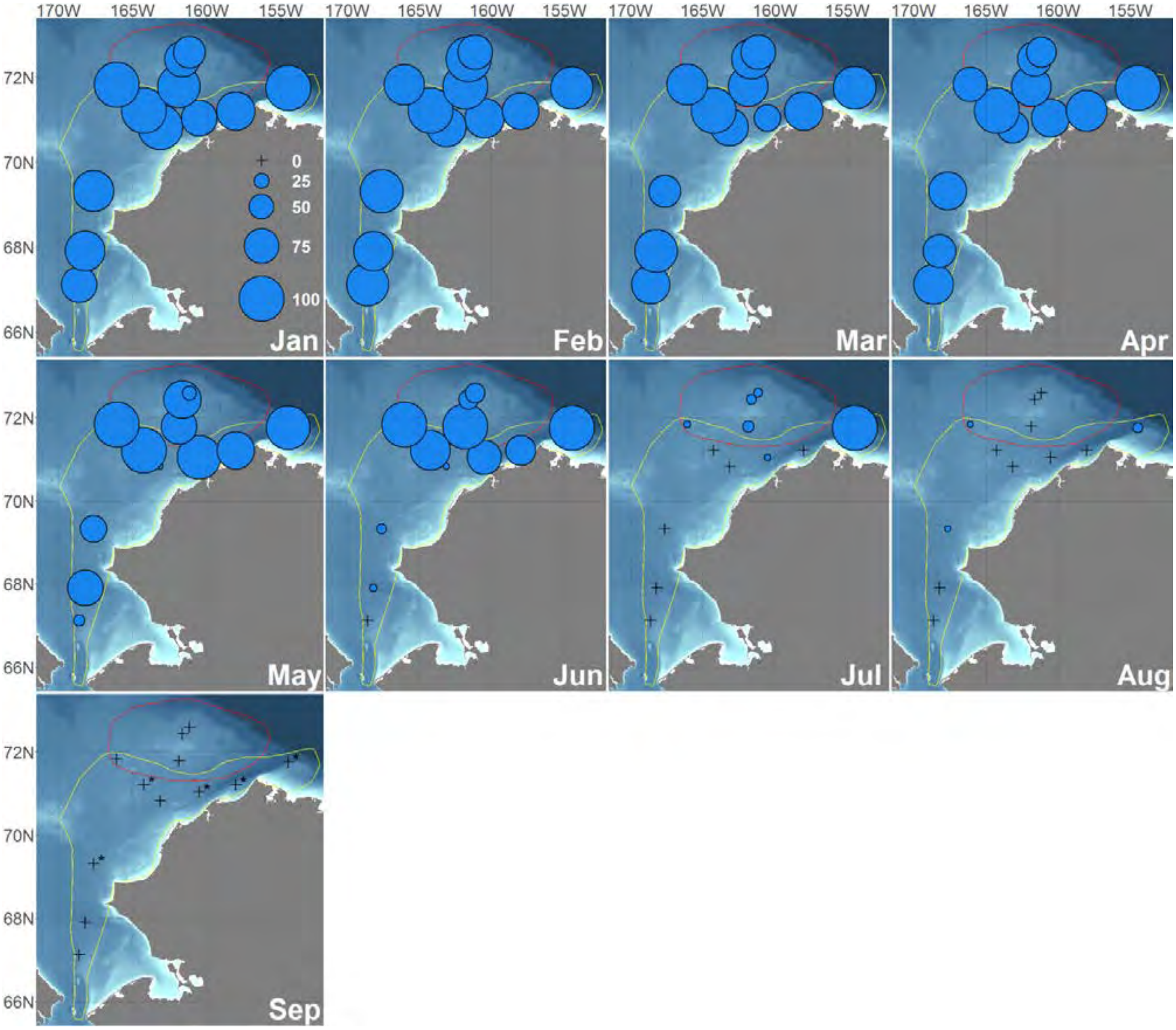
Appendix D. 3. Ice noise distribution 2012. Graduated scale in the January panel indicates % of days per month with ice noise. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 15 for numbers used to generate figure.



Appendix D. 4. 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.



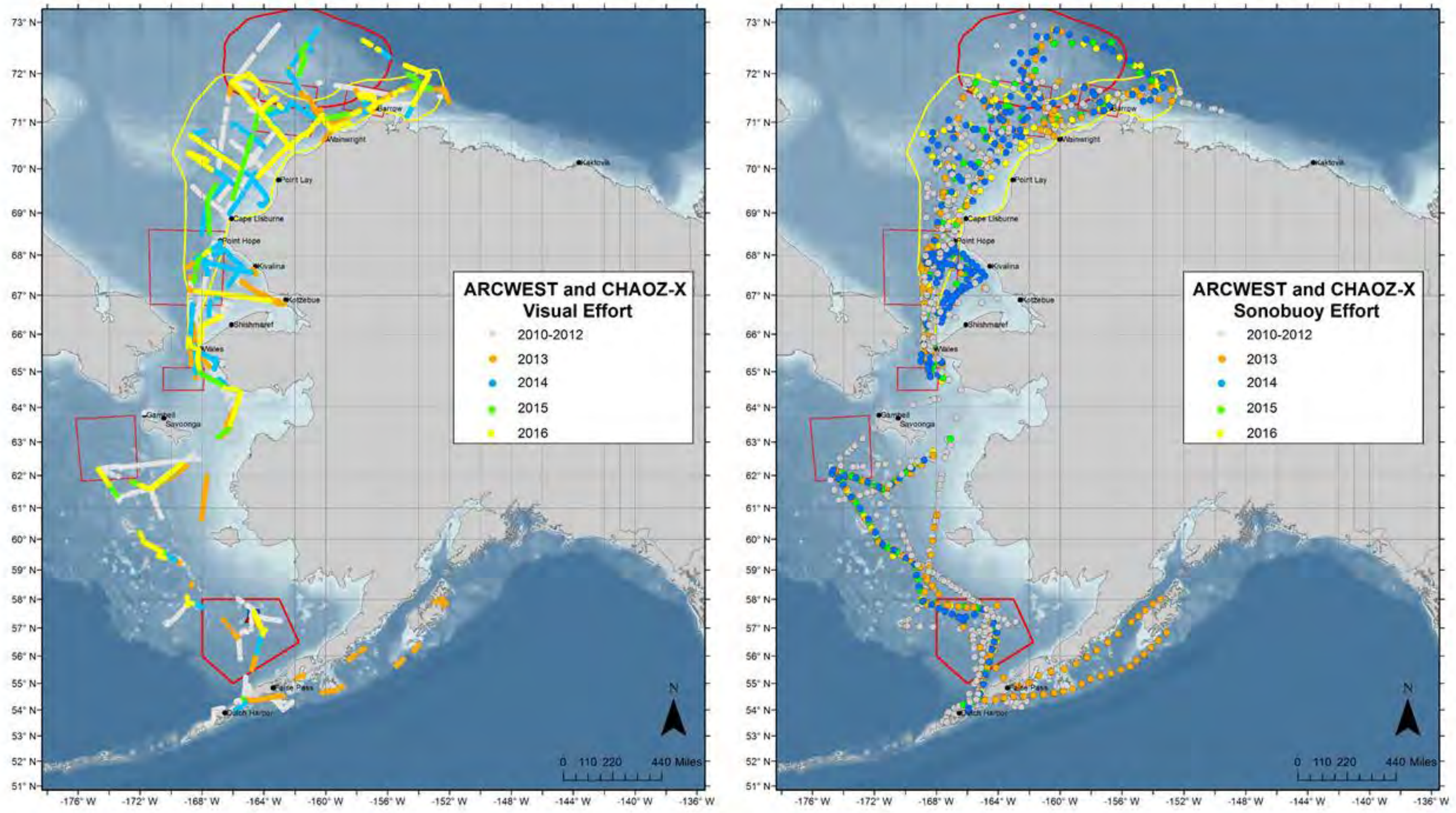
Appendix D. 5. Ice noise distribution 2014. Graduated scale in the January panel indicates % of days per month with ice noise. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 15 for numbers used to generate figure.



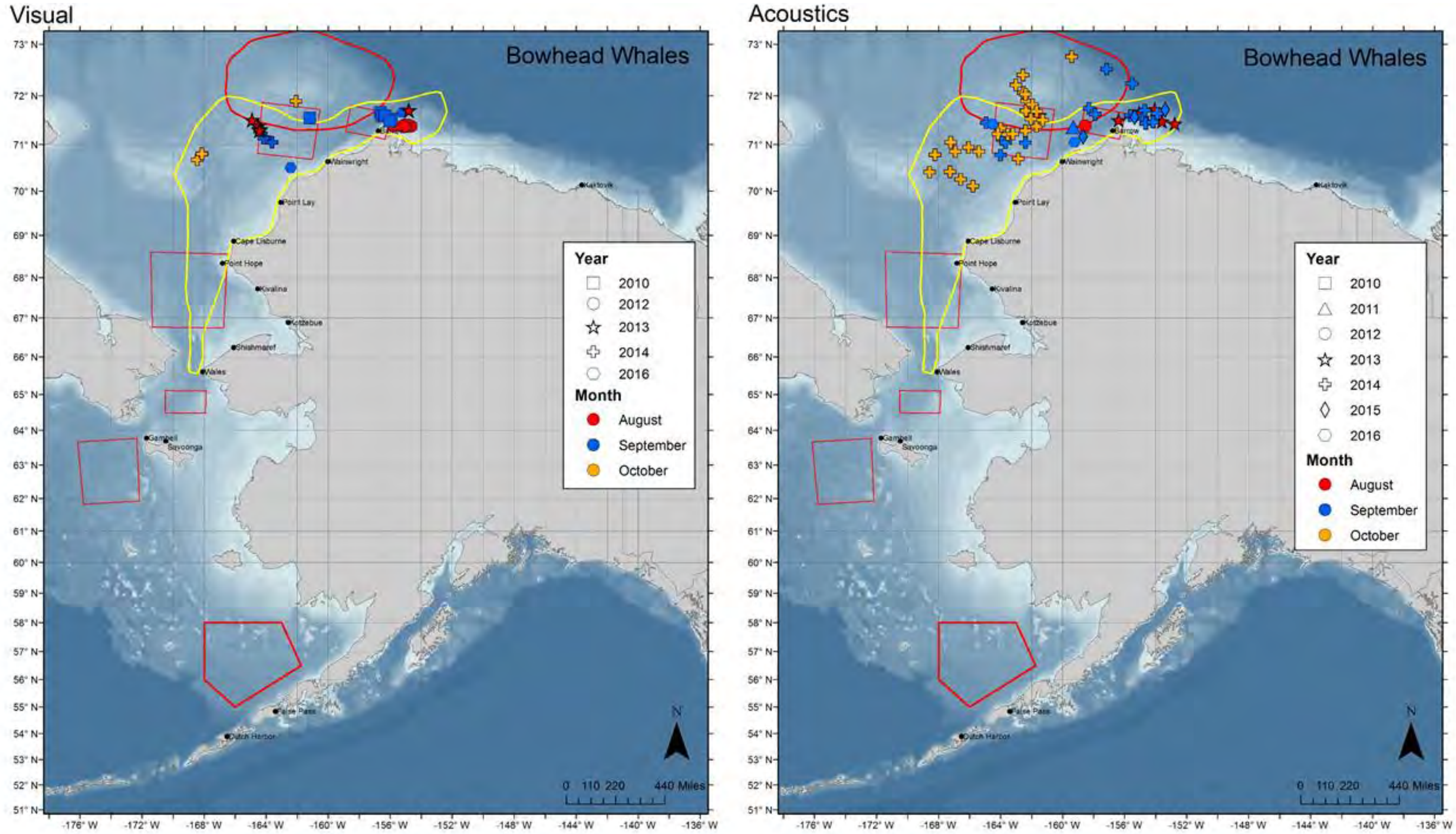
Appendix D. 6. Ice noise distribution 2015. Graduated scale in the January panel indicates % of days per month with ice noise. Red and yellow outlines indicate the CHAOZ-X and ARCWEST study areas, respectively. Moorings with less than half a month of effort are indicated with a *; see Appendix C. 15 for numbers used to generate figure.

E. Sonobuoy and visual survey data

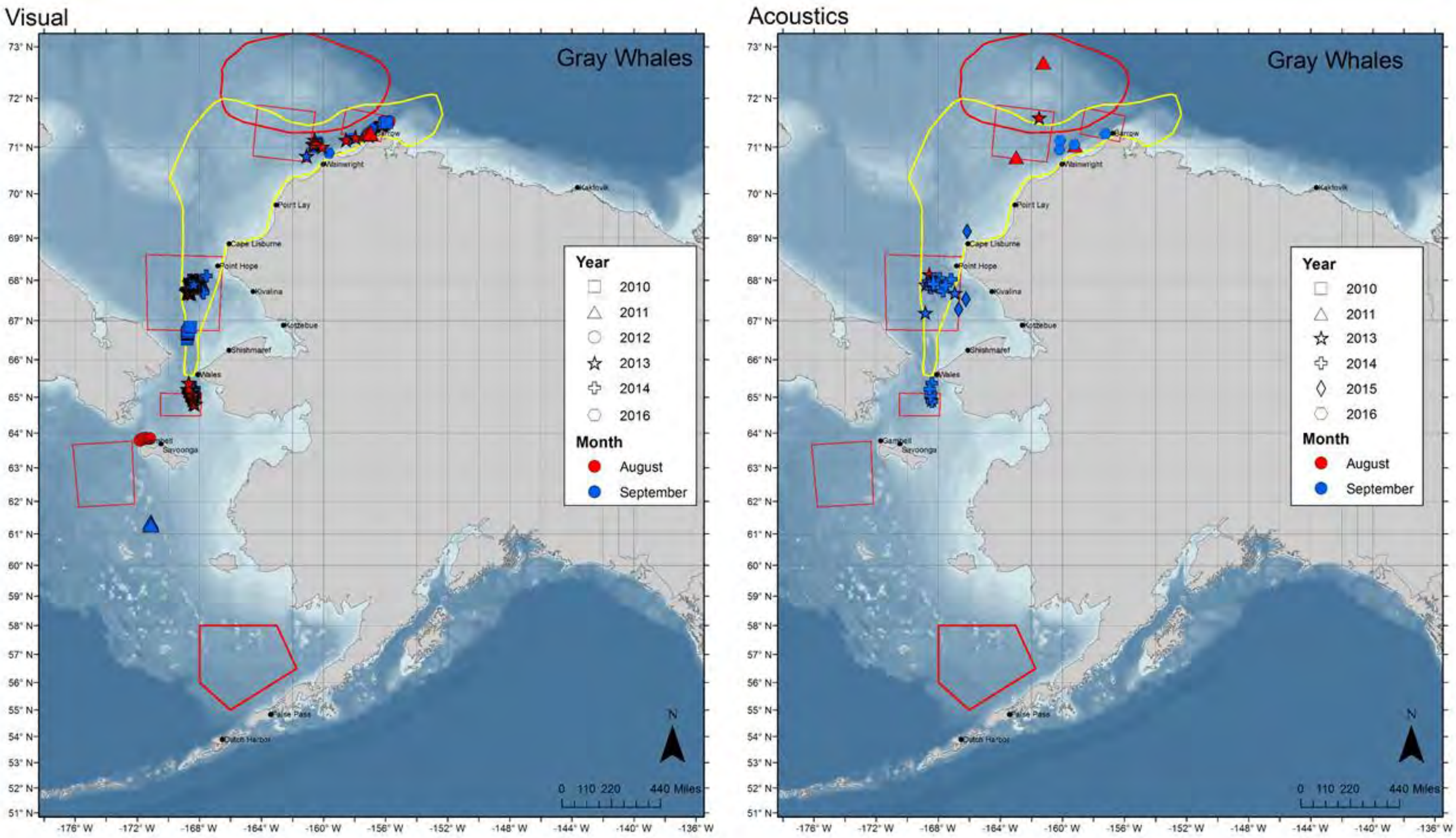
Visual sightings (left) and acoustic sonobuoy detections (right) of each species in the Bering, Chukchi, and Beaufort Seas by month for 2010-2016. Red squares = DBO regions. Red pentagon = North Pacific right whale critical habitat.



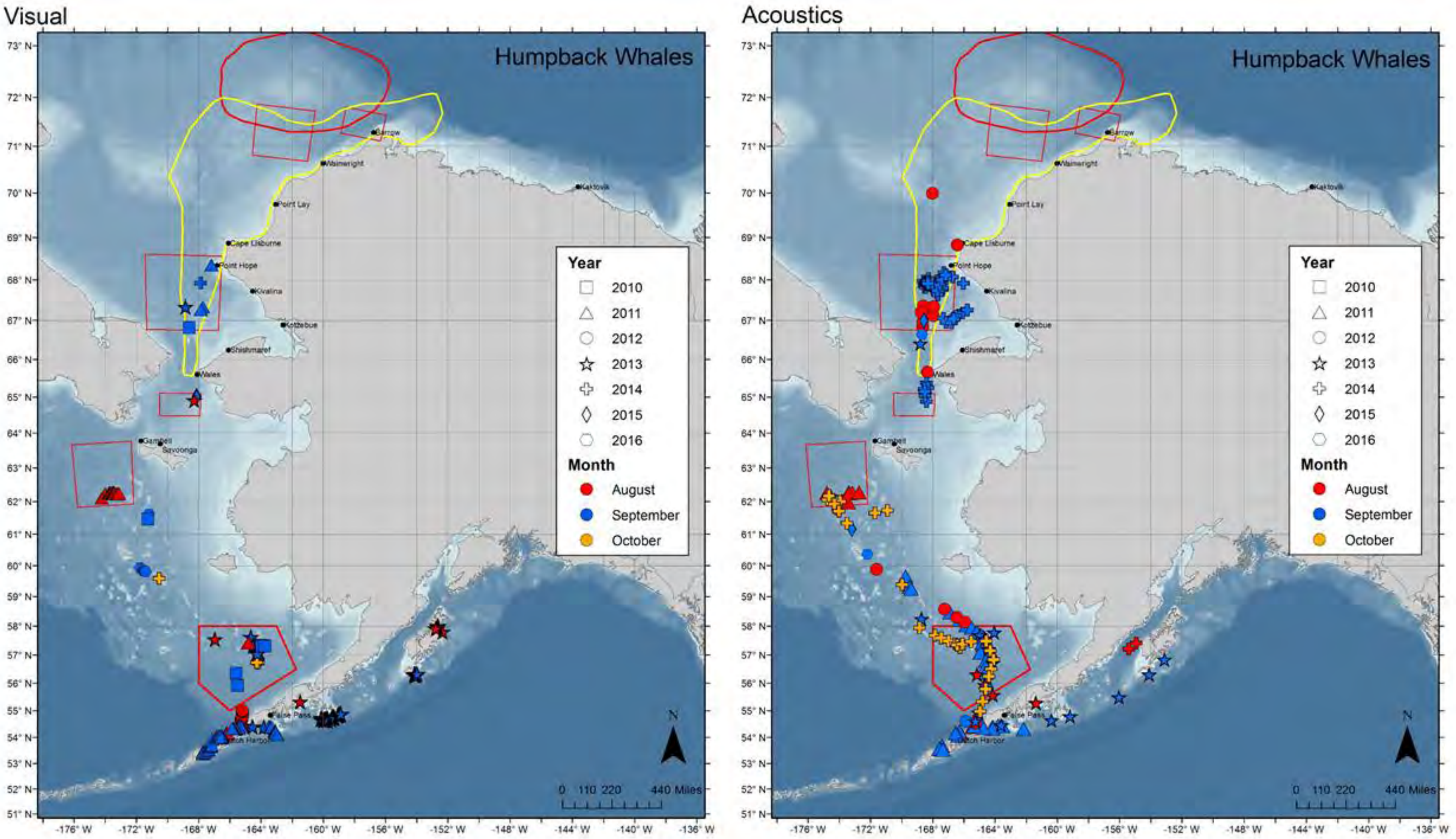
Appendix E. 1. Summary of total visual and sonobuoy effort, 2010-2016.



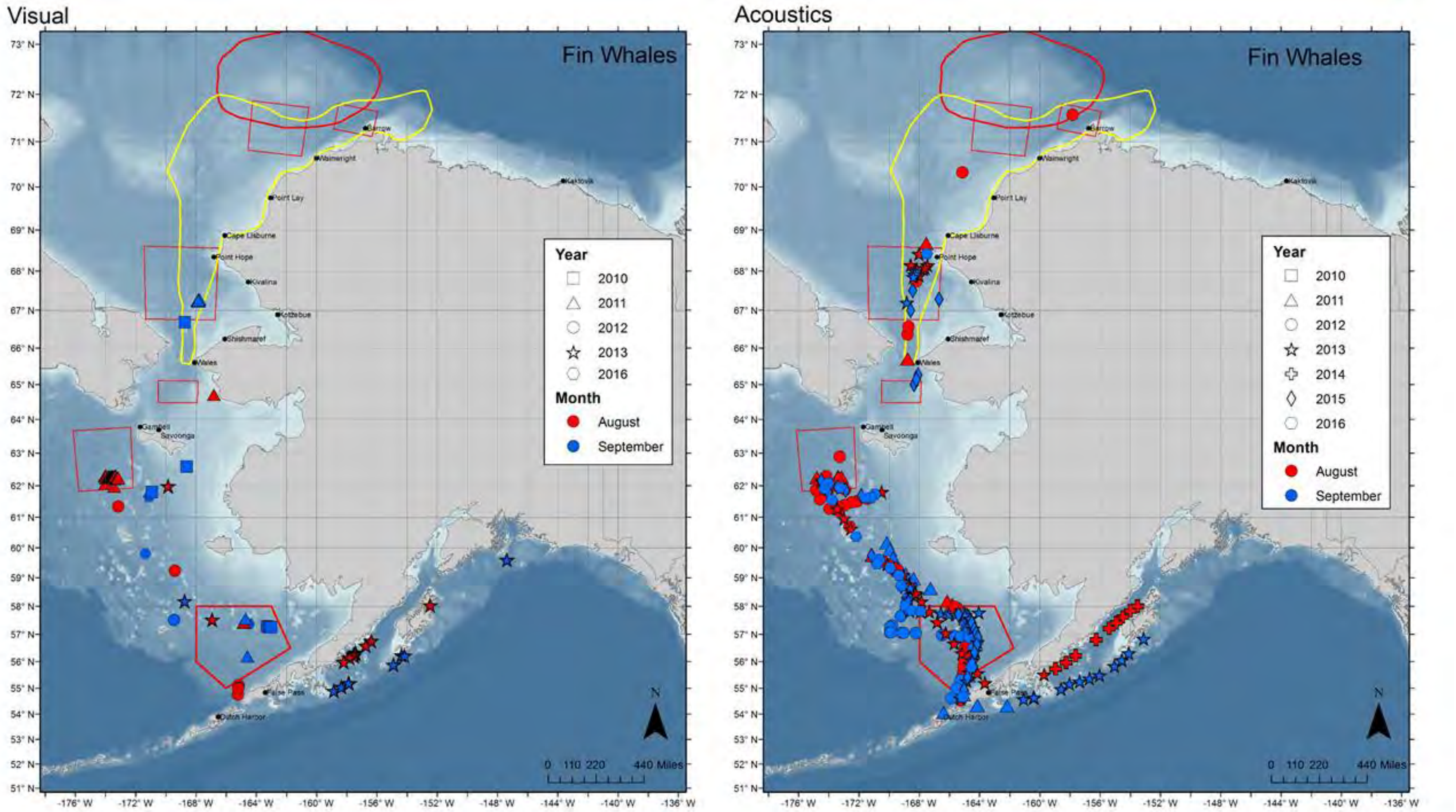
Appendix E. 2. Bowhead whale sightings and acoustic detections, 2010-2016.



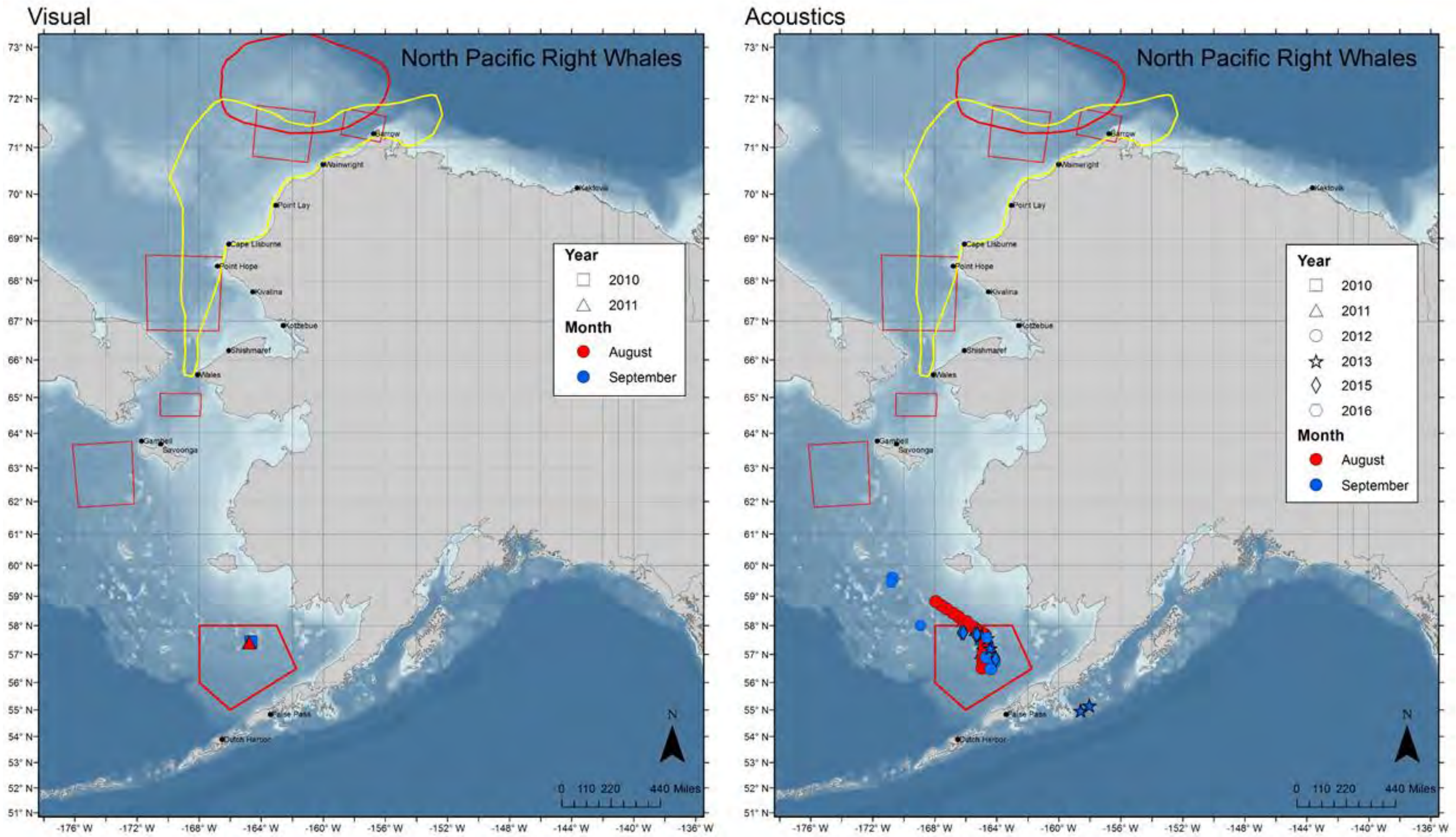
Appendix E. 3. Gray whale sightings and acoustic detections, 2010-2016.



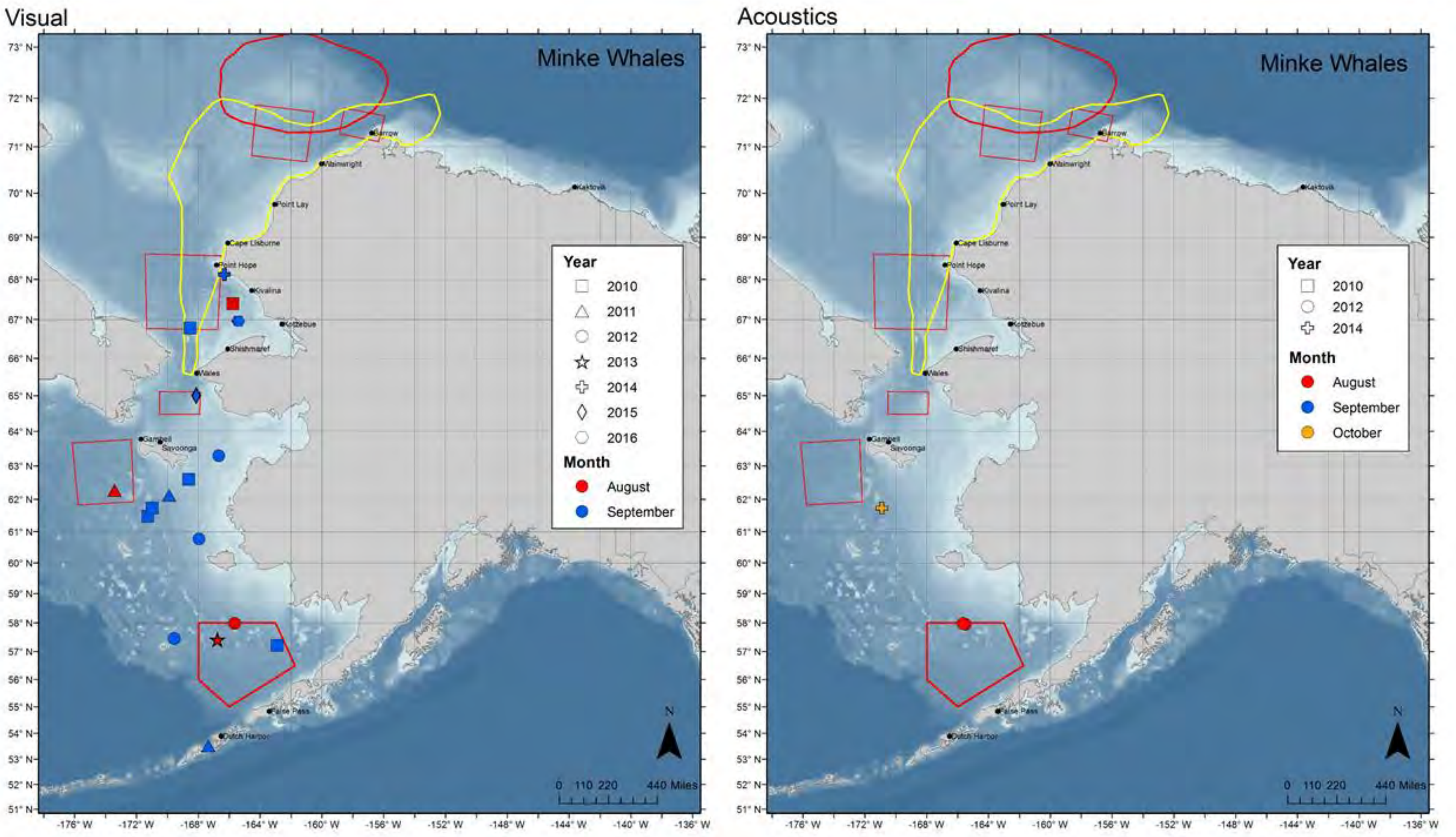
Appendix E. 4. Humpback whale sightings and acoustic detections, 2010-2016.



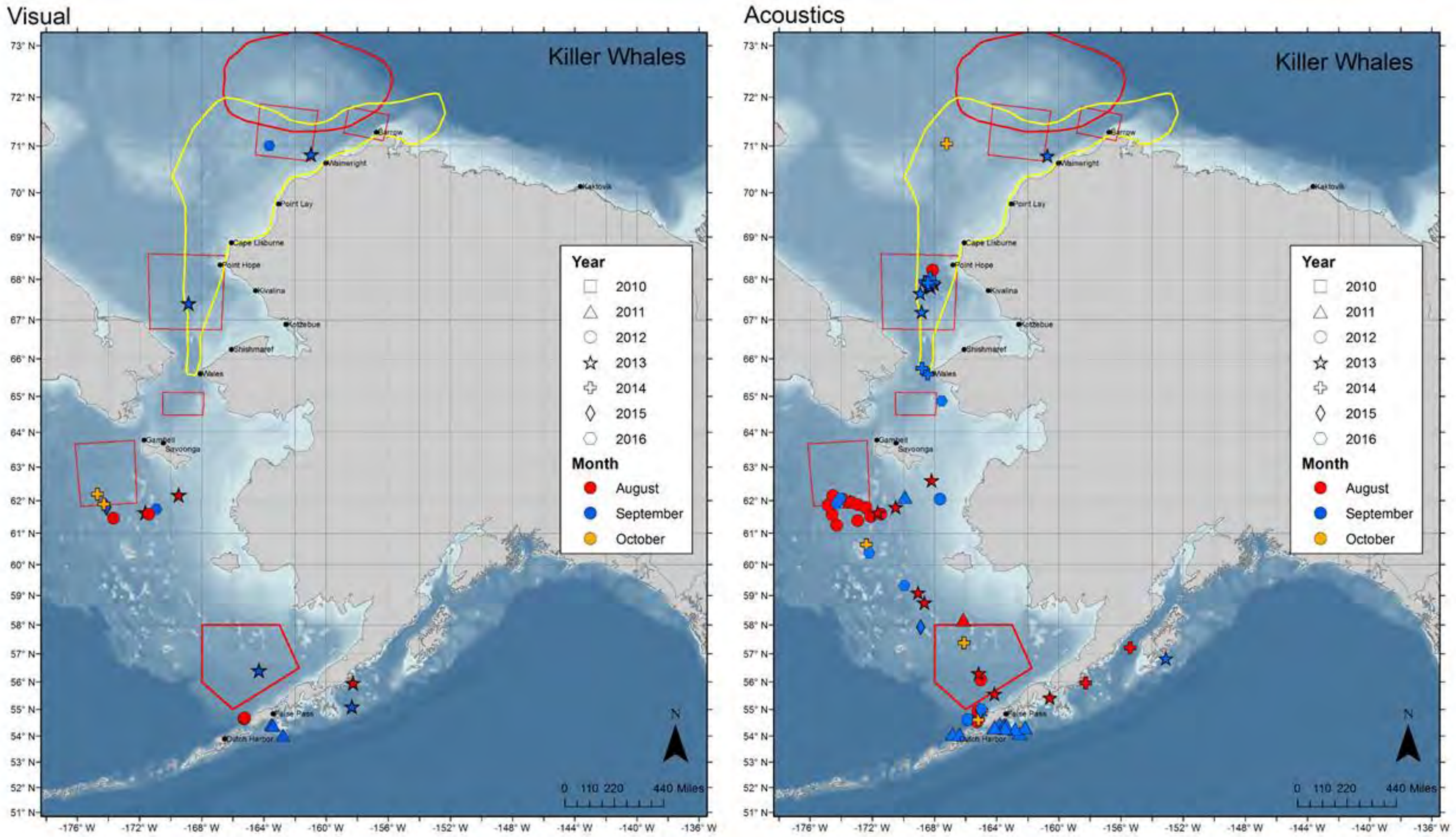
Appendix E. 5. Fin whale sightings and acoustic detections, 2010-2016.



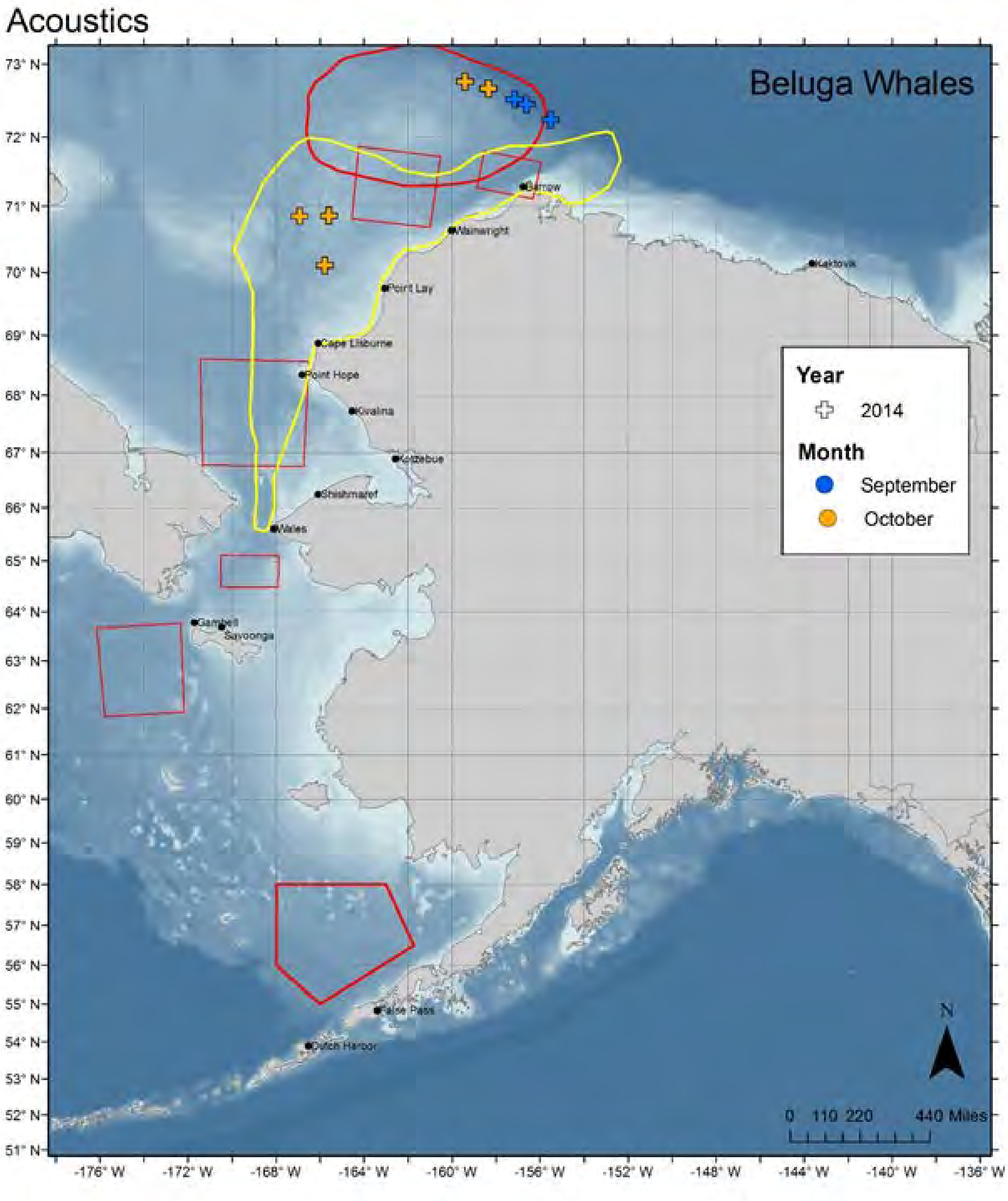
Appendix E. 6. Right whale sightings and acoustic detections, 2010-2016.



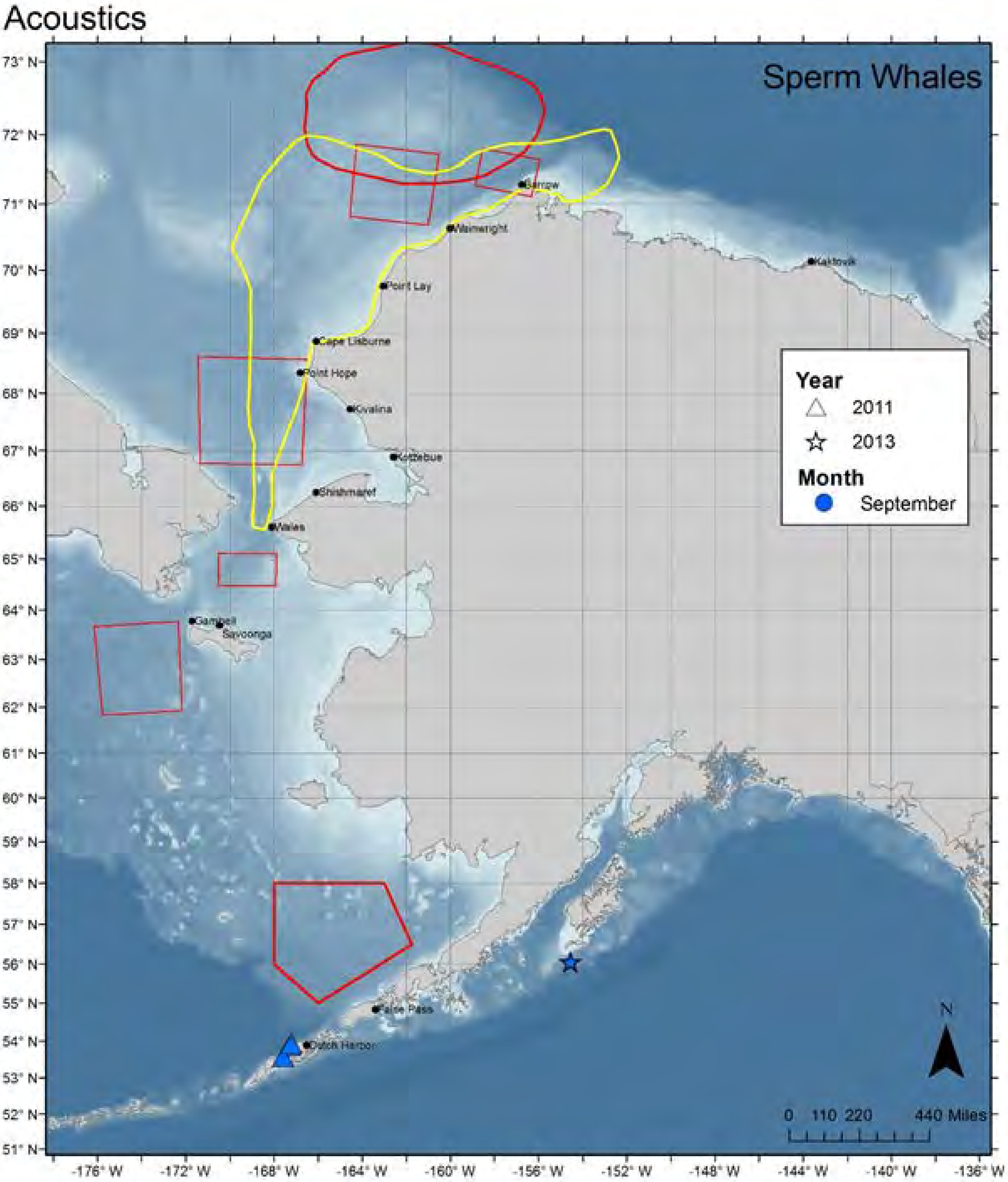
Appendix E. 7. Minke whale sightings and acoustic detections, 2010-2016.



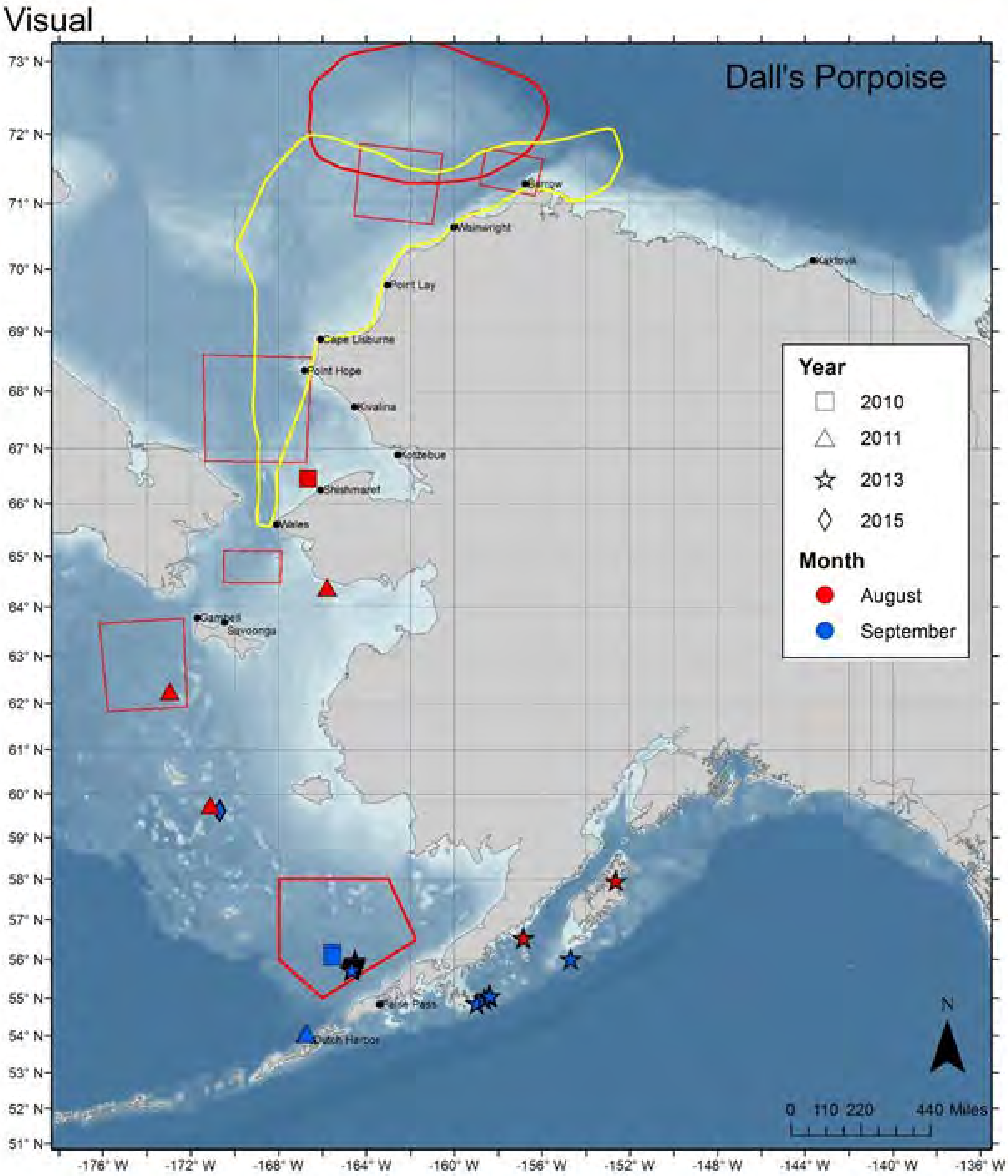
Appendix E. 8. Killer whale sightings and acoustic detections, 2010-2016.



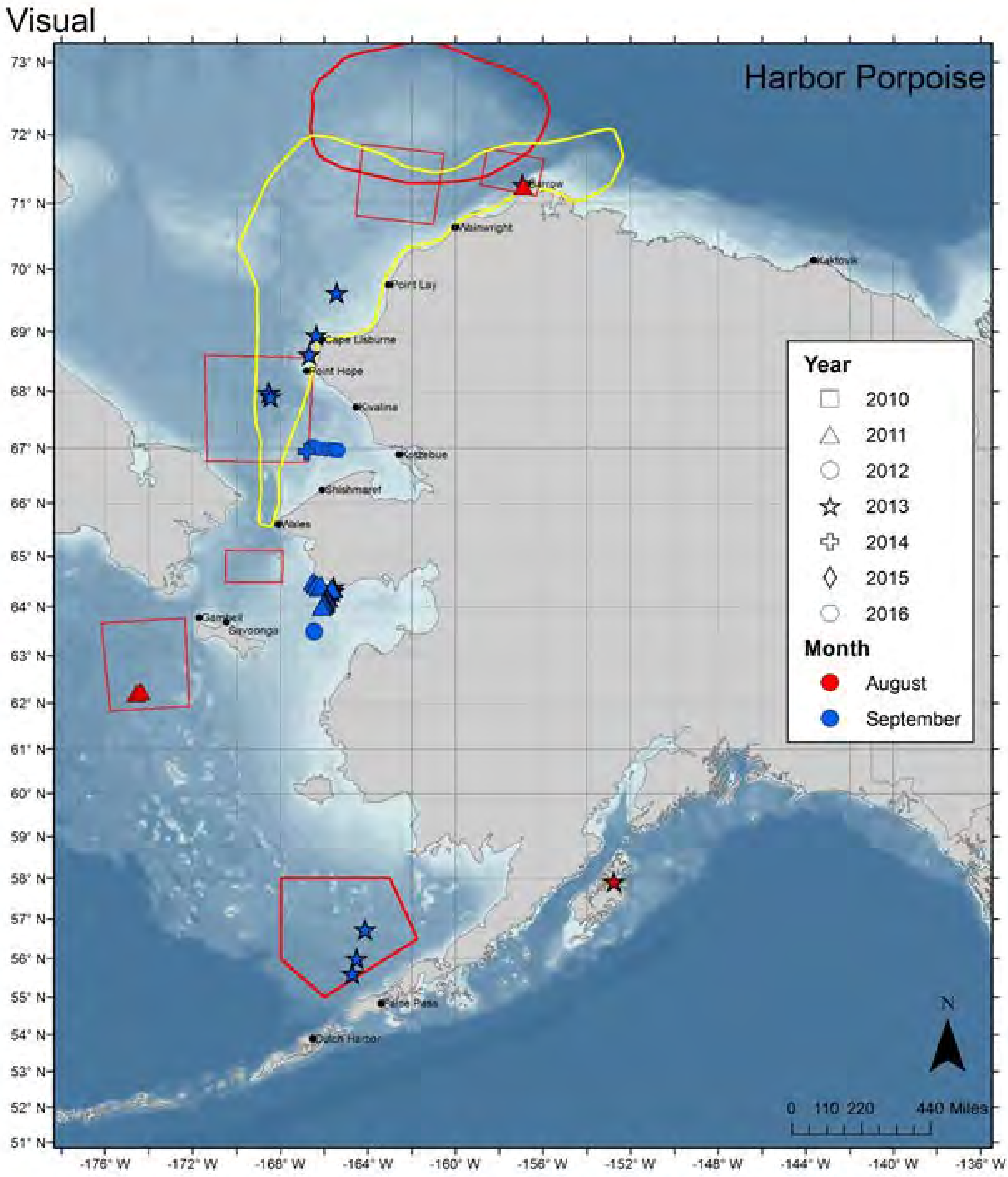
Appendix E. 9. Beluga whale sightings and acoustic detections, 2010-2016.



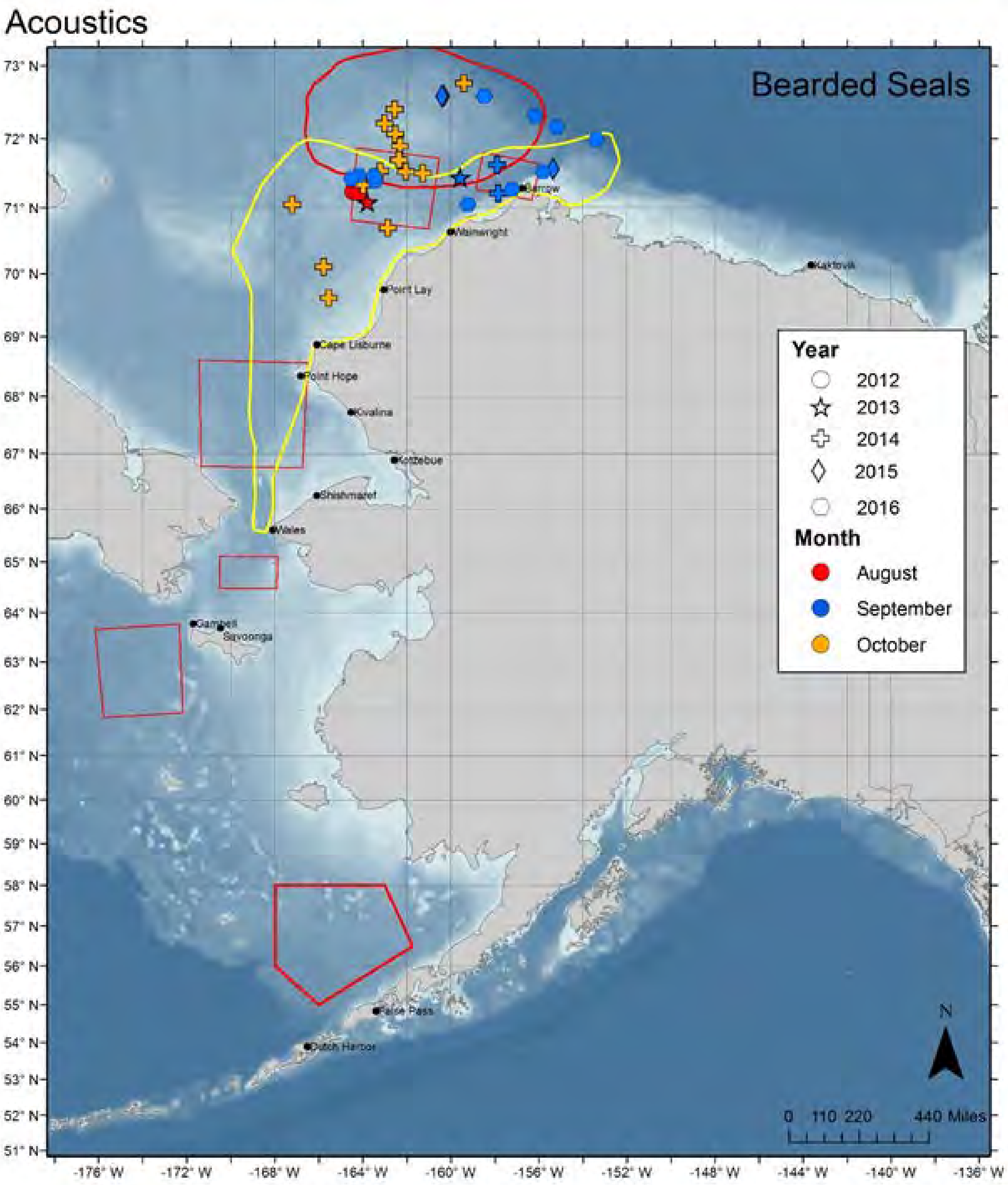
Appendix E. 10. Sperm whale sightings and acoustic detections, 2010-2016.



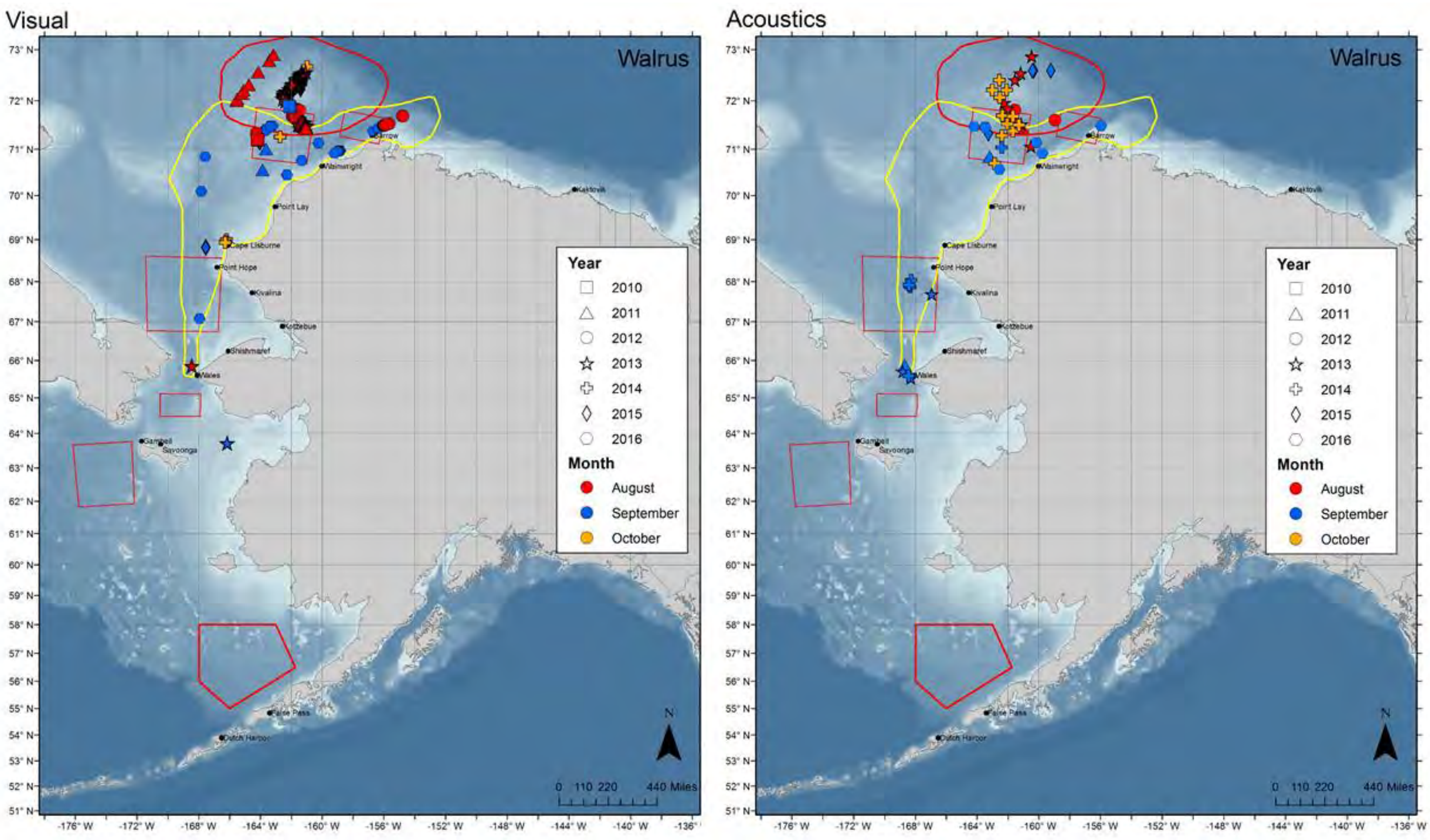
Appendix E. 11. Dall's porpoise sightings and acoustic detections, 2010-2016.



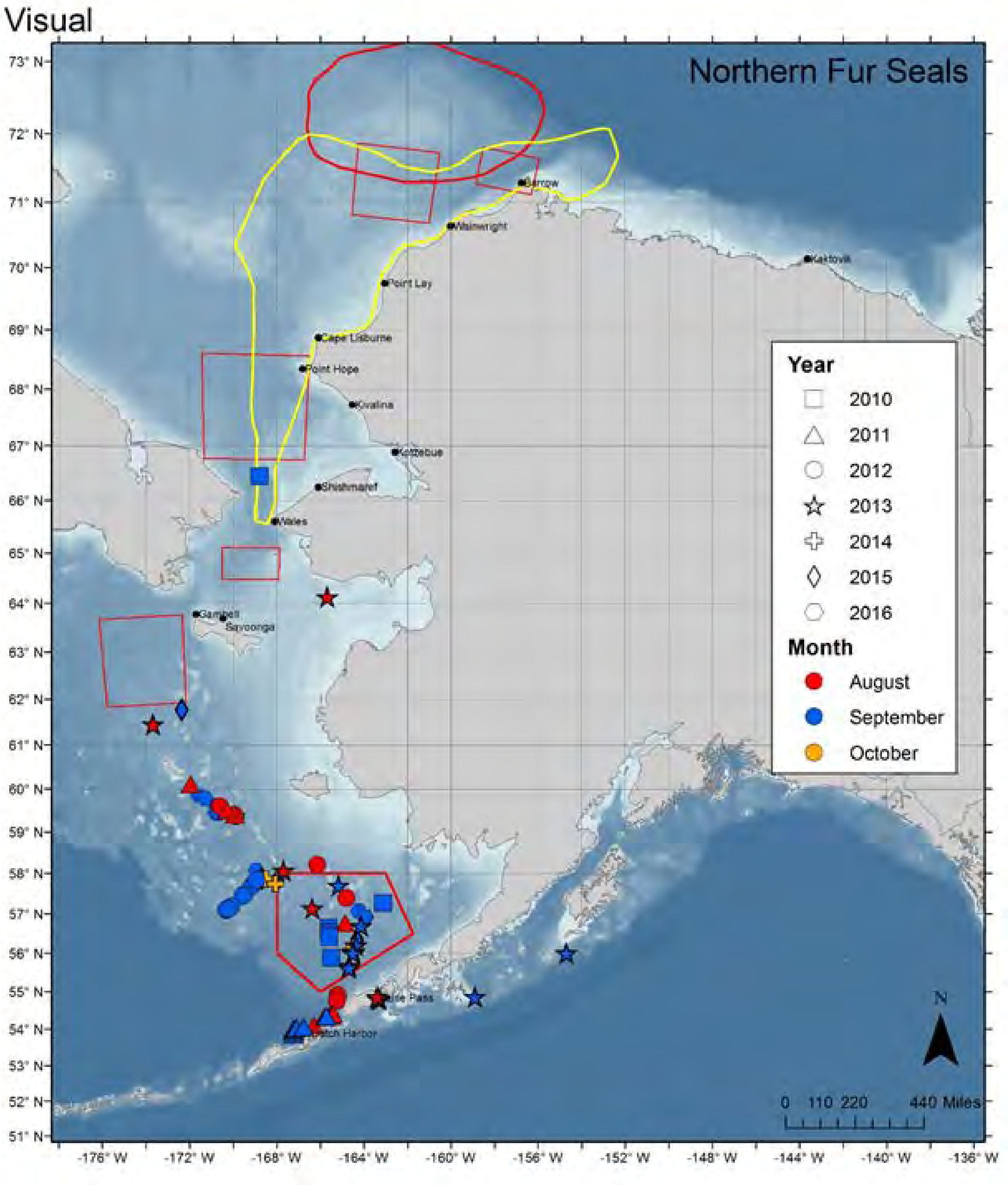
Appendix E. 12. Harbor porpoise sightings and acoustic detections, 2010-2016.



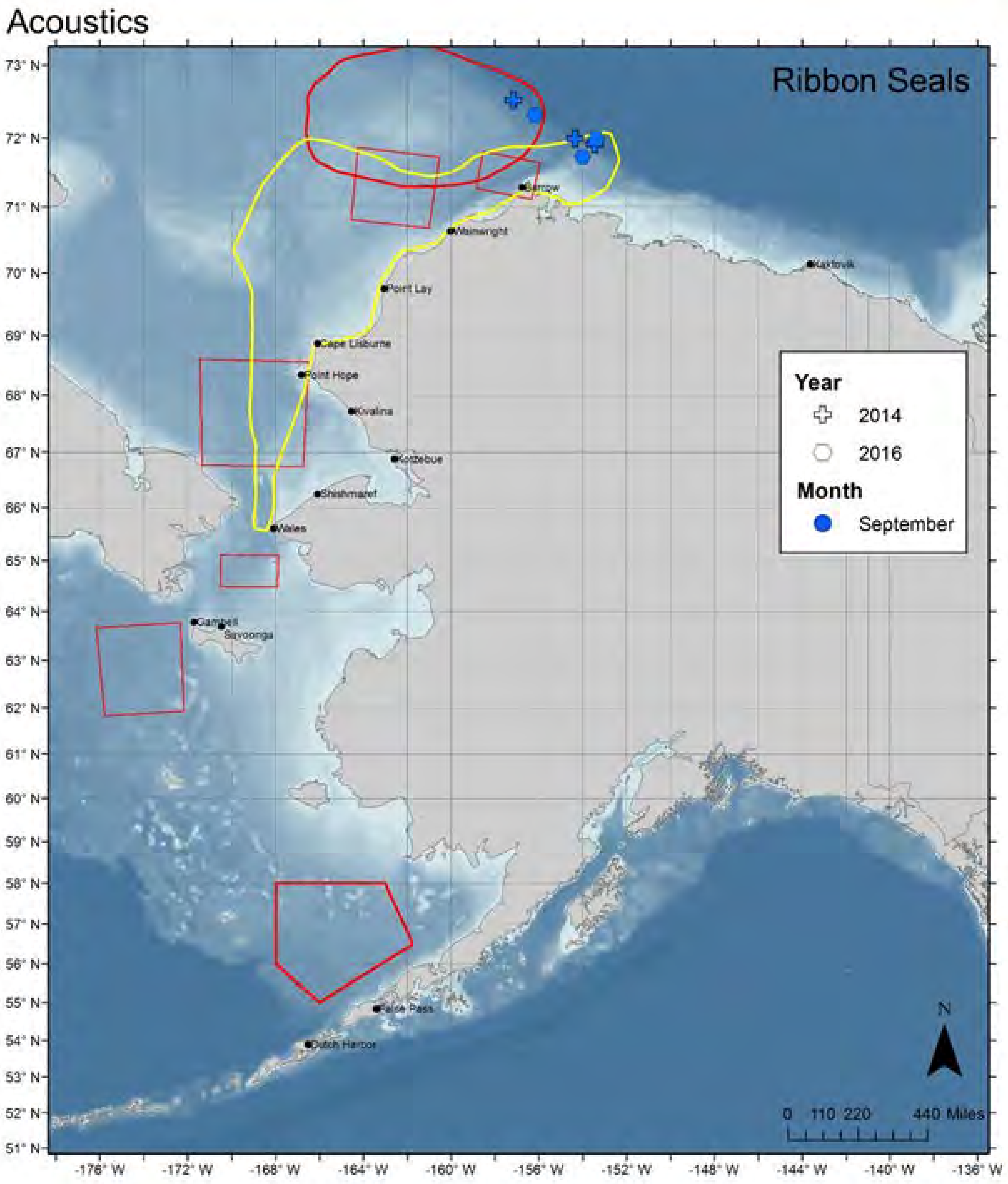
Appendix E. 13. Bearded seal sightings and acoustic detections, 2010-2016.



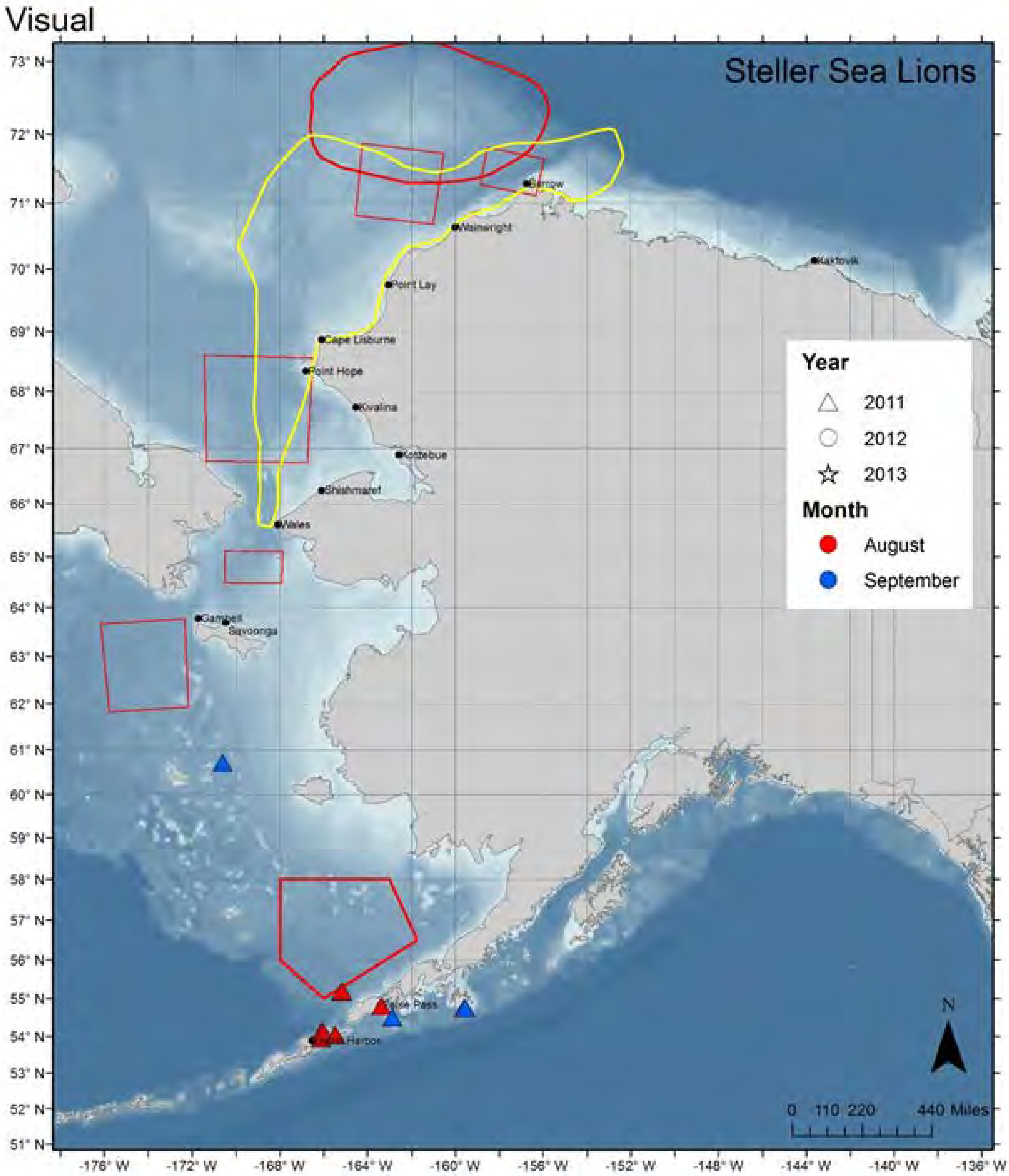
Appendix E. 14. Walrus sightings and acoustic detections, 2010-2016.



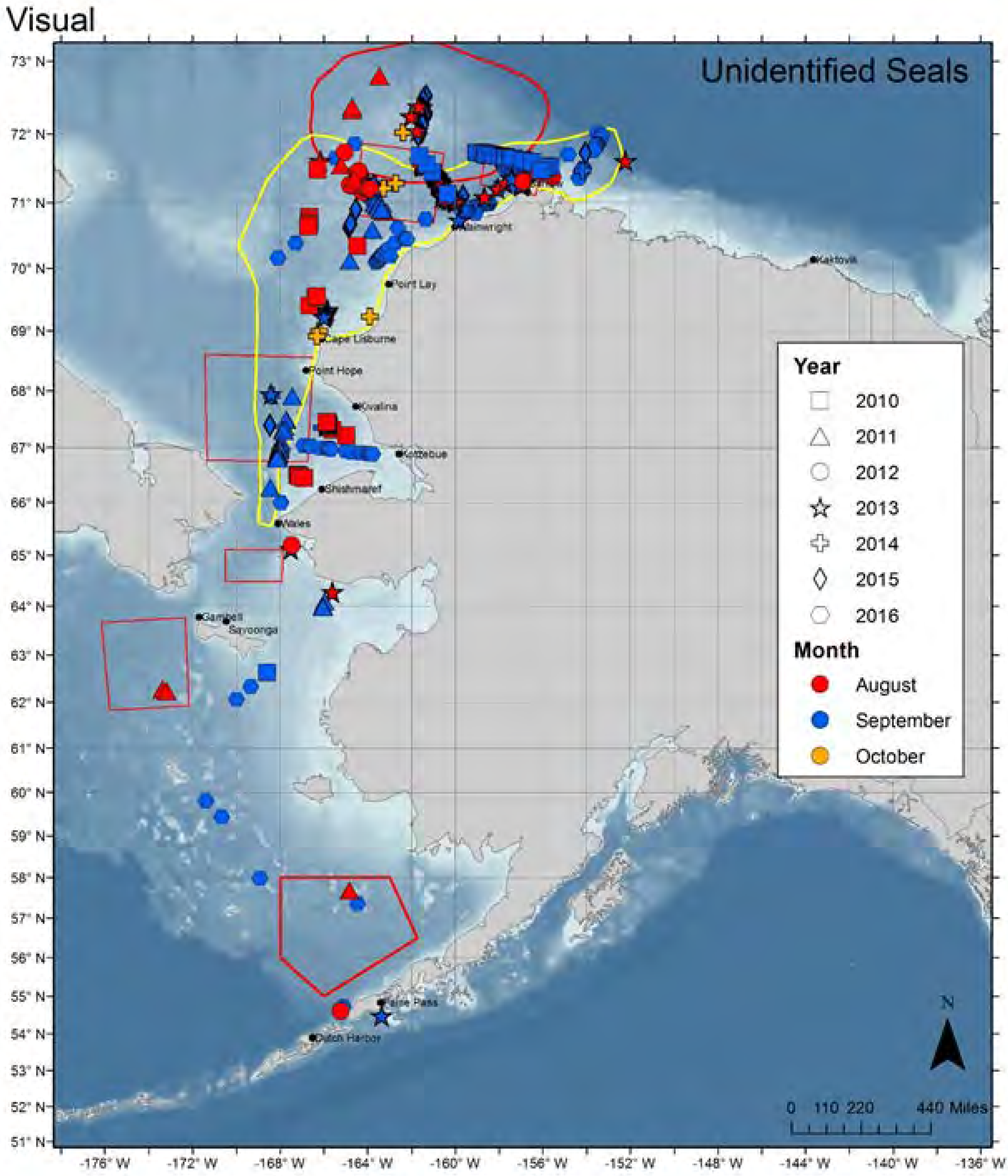
Appendix E. 15. Fur seal sightings and acoustic detections, 2010-2016.



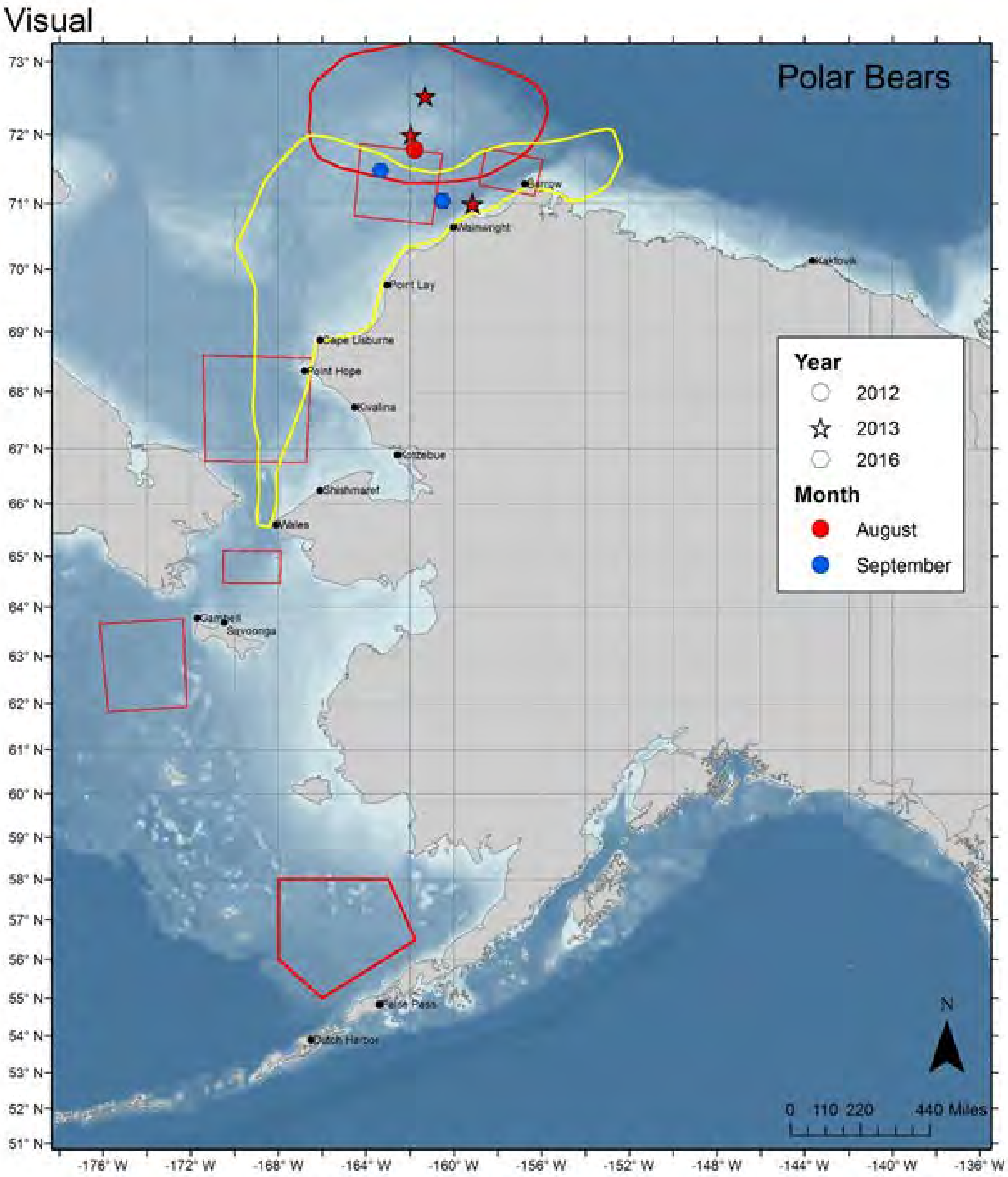
Appendix E. 16. Ribbon seal sightings and acoustic detections, 2010-2016.



Appendix E. 17. Steller sea lion seal sightings and acoustic detections, 2010-2016.



Appendix E. 18. Unidentified seal sightings and acoustic detections, 2010-2016.



Appendix E. 19. Polar bear sightings and acoustic detections, 2010-201

F. List of electronic files

1. Sonobuoy deployment tables. These are tables showing every sonobuoy deployed during the ARCWEST cruises, as well as species detected, for 2013-2016. File name:
    a. 2013: "ARCWEST 2013 sonobuoy deployments.pdf"
    b. 2014: "ARCWEST 2014 sonobuoy deployments.pdf"
    c. 2015: "ARCWEST 2015 sonobuoy deployments.pdf"
    d. 2016: "ARCWEST 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 2013-2015 field surveys.
    a. 2013: "ARCWEST_2013_CTD&planktonReport.pdf"
    b. 2014: "ARCWEST_2014_CTD&planktonReport.pdf"
    c. 2015: "ARCWEST_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: "ARCWEST Archived Samples List.pdf"
8. Technical Summary. This is a brief (3-4 page) summary report of the CHAOZ-X project. File name: "ARCWEST M12PG00021 Technical Summary.pdf"

MARCH 3, 1849

The Department of the Interior Mission

Protecting America's Great Outdoors and Powering Our Future

The U.S. Department of the Interior protects America’s natural resources and heritage, honors our cultures and tribal communities