Movements and Habitat Use of Pacific Arctic Seals and Whales via Satellite Telemetry and Ocean Sensing

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LONG-TERM GOALS

The purpose of this study was to work with Native subsistence hunters and government agencies in Alaska (North Slope Borough Department of Wildlife Management, NSB) and Canada (Department of Fisheries and Oceans, DFO) to cooperatively deploy satellite transmitters (tags) on three species of ice seals (ringed, *Pusa hispida*; bearded, *Erignathus barbatus*; and spotted seals, *Phoca largha*), and two species of whales (beluga, *Delphinapterus leucas*; and bowhead, *Balaena mysticetus*). We documented year-round movements and habitat use relative to oceanographic conditions and other factors such as ice cover and human-related disturbance. Satellite telemetry allowed movements of individual seals and whales to be tracked year-round and provided data for comprehensive analyses of distribution, movement, migration, diving behavior, as well as identified important feeding, summering, and wintering areas and the oceanographic conditions in those areas. Satellite transmitters used in this project included those that transmit animal locations, dive depth, dive duration, water temperature, and salinity. All tagging was conducted without interference to subsistence hunting activities.

OBJECTIVES

The overall objective of this study was to work with subsistence hunters and governments in Alaska and Canada to deploy satellite-linked transmitters on Arctic seals and whales. Objectives for ice seals included using data from transmitters to describe the movements and behavior of ringed, bearded, and spotted seals throughout their range in the Bering, Chukchi, and Beaufort seas. In doing so, we would identify important habitats, relate movements and behavior to oceanographic data collected by Conductivity-Temperature-Depth (CTD) tags manufactured by the Sea Mammal Research Unit (SMRU, St. Andrews, Scotland), and assess movements and behavior relative to changes in sea ice, and anthropogenic activity.

Objectives for Arctic whales (belugas and bowheads) included comparing oceanographic data between lingering and traveling behavior, comparing CTD data collected by whales with oceanographic model data, use dive and CTD data to determine the oceanographic conditions in the Bering Sea in winter and to determine whether bowhead whales are feeding there during bottom dives, and to explore whether a predictive model using oceanographic conditions to predict presence of bowhead and beluga whales in specific areas could be developed. The specific objectives are addressed below in the Accomplishment of Objectives section.

APPROACH

Ice Seals. The Alaska Department of Fish and Game (ADFG) worked with Alaska Native seal hunters from seven different communities to tag ringed, bearded, and spotted seals (Table 1, Fig. 1). We also worked with the NSB and their tagging crew to tag seals near Utqiaġvik (formerly Barrow), Dease Inlet, and the Colville Delta. Seals were captured in nets, physically restrained, and tagged with CTD satellite transmitters capable of providing location, dive, and oceanographic information. Tags were glued to the head or back depending on the size of the seal. These tags were expected to transmit at least 5 months. Some of the captured seals also received a SPOT flipper-mounted tag, provided by a co-occuring Bureau of Ocean Energy Management (BOEM) project. The flipper tag provided location and haulout information only, but transmitted up to 2 years, which allowed us to investigate seasonal site fidelity and more detailed haul-out behavior. We tagged all bearded and spotted seals caught regardless of sex or age and all ringed seals (except pups of the year that were determined to be too small). Seals caught that were too small to receive a CTD tag, however, were tagged with a SPLASH and SPOT flipper tag provided by the BOEM project.

Alaska Native subsistence hunters and other community members participated in all aspects of the project development and information from the project was shared directly with participants on a regular basis, through the Ice Seal Committee, and on the ADFG website.

Arctic Whales. ADFG worked with bowhead subsistence whalers and NSB staff to tag bowhead whales with CTD tags near Utqiaġvik. Bowhead whales were also tagged with CTD tags in the eastern Beaufort Sea along the Tuktoyaktuk Peninsula in Canadian waters with the assistance of local Hunters and Trappers Committees and DFO. Tags were deployed using a 2 or 4 m long fiberglass pole as a harpoon or jab-stick (Heide-Jørgensen et al. 2003).

Beluga whales, from the Eastern Chukchi Sea stock, were captured and tagged by ADFG, the NSB, and Alaska Beluga Whale Committee (ABWC) members near Point Lay during their annual community harvest. Belugas were herded into Kasegaluk Lagoon, near Point Lay, for subsistence harvest; belugas not harvested were then available for live-capture and tagging. Belugas were captured in shallow water and were either encircled with large-mesh seine nets deployed from boats or caught with hoop nets that were slipped over the head and pectoral fins, either from boats or by people standing in shallow water (Orr et al. 1998, Suydam et al. 2001, Suydam 2009). Once captured, whales were secured by placing a padded rope around the caudal peduncle (Orr et al. 2001) and then tagged with CTD tags. We also coordinated with DFO in Canada to try to work with Tuktoyaktuk hunters interested in capture efforts in the Mackenzie River Delta.

This report includes data specifically collected during this Office of Naval Research (ONR funded project, but we also incorporated data from two co-occuring BOEM projects, one focused on ice seals (OCS Study BOEM 2019-079, Quakenbush et al. 2019) and the second focused on bowhead whales (OCS Study BOEM 2019-076, Quakenbush and Citta 2019). Data from previous seal tagging projects were also used to increase sample sizes to better address this project's objectives. We developed and maintained an archive of all data collected during this project at ADFG. To comply with ONR's policy on Public Access to Research Results (PARR), data from this project have also been provided to the Animal Telemetry Network (ATN) through the Integrated Ocean Observing System (IOOS), and

CTD data have been provided through SMRU to the World Meteorological Organization via the Global Telecommunication System (WMO GTS).

Table 1. Marine mammals (ringed, bearded, and spotted seals and beluga and bowhead whales) instrumented with satellite-linked Conductivity-Temperature-Depth (CTD) transmitters from 2016 to 2019. CTD tags are attached to seals with epoxy and fall off during their annual pelage molt in spring. SPOT flipper tags (provided by a co-occurring Bureau of Ocean Energy Management project) were attached to seal hind flippers. Platform Terminal Transmitter (PTT) is the tag identification number (note: once a tag stops transmitting these numbers can be reused on future tags). Sexes of bowhead whales are determined from skin biopsy (DNA), when possible.

Map ID	Species	Sex	Age/ Length	Date Deployed	Tracking Duration[a] (Days)	Capture Location	CTD PTT #
RS16-02-M	Ringed	M	Adult	1-Jul-16	291/193	Utqiaġvik	120350
RS16-07-M	Ringed	M	Adult	1-Jul-16	110/214	Utqiaġvik	120353
RS17-02-M	Ringed	M	Adult	22-Jun-17	149/246	Kotzebue Sound	163041
RS19-01-M	Ringed	M	Adult	22-Jun-19	92/211	Utqiaġvik	163038
RS19-02-M	Ringed	M	Adult	22-Jun-19	293/A	Utqiaġvik	163028
RS19-04-M	Ringed	M	Adult	23-Jun-19	174/A	Utqiaġvik	163037
BS16-04-F [b]	Bearded	F	Pup	23-Jul-16	14/14	St. Michael Canal	120352
BS16-06-M	Bearded	M	Pup	20-Sep-16	158/264	Koyuk River	163036
BS16-08-M	Bearded	M	Sub	10-Nov-16	84/121	Cape Nome	163042
BS17-01-F	Bearded	F	Pup	10-Aug-17	221/591	Colville River (Nuiqsut)	169953
BS17-02-F	Bearded	F	Pup	20-Sep-17	147/652	Koyuk River	163034
BS17-03-M	Bearded	M	Pup	21-Sep-17	45/45	Koyuk River	169954
BS17-04-F	Bearded	F	Pup	22-Sep-17	164/307	Koyuk River	169955
BS17-05-F [b]	Bearded	F	Pup	20-Oct-17	135/213	Cape Nome	163044
BS18-01-F	Bearded	F	Pup	24-Sep-18	153/153	Koyuk River	163039
BS19-01-M	Bearded	M	Adult	9-Sep-19	182/A	Utqiaġvik	163025

SS16-01-F	Spotted	F	Sub	27-Jul-16	229/316	Dease Inlet (Utqiaġvik)	150996
SS16-03-M	Spotted	M	Adult	3-Aug-16	191/0	Dease Inlet (Utqiaġvik)	120349
SS16-05-M	Spotted	M	Sub	14-Aug-16	171/126	Dease Inlet (Utqiaġvik)	163029
SS16-06-F	Spotted	F	Adult	17-Aug-16	169/346	Dease Inlet (Utqiaġvik)	163031
SS16-07-M	Spotted	M	Adult	17-Aug-16	153/336	Dease Inlet (Utqiaġvik)	163030
SS16-08-M	Spotted	M	Sub	25-Aug-16	225/na	Dease Inlet (Utqiaġvik)	163026
SS16-09-F	Spotted	F	Adult	25-Aug-16	223/na	Dease Inlet (Utqiaġvik)	163032
SS16-10-F	Spotted	F	Sub	18-Oct-16	137/na	Scammon Bay	163046
SS16-11-F	Spotted	F	Sub	18-Oct-16	199/na	Scammon Bay	163045
SS17-02-M	Spotted	M	Adult	10-Jul-17	289/657	Scammon Bay	169952
SS17-05-M	Spotted	M	Sub	25-Jul-17	172/0	Dease Inlet (Utqiaġvik)	163033
SS17-06-F	Spotted	F	Pup	9-Aug-17	140/302	Colville River (Nuiqsut)	163035
SS17-07-M	Spotted	M	Sub	16-Aug-17	148/96	Fish Creek (Nuiqsut)	163020
SS17-08-F	Spotted	F	Sub	16-Aug-17	194/100	Fish Creek (Nuiqsut)	169956
SS18-01-M	Spotted	M	Sub	3-Jul-18	217/56	Scammon Bay	163048
SS18-03-F	Spotted	F	Sub	26-Jul-18	118/312	Dease Inlet (Utqiaġvik)	163040
SS18-05-F	Spotted	F	Adult	9-Sep-18	123/49	Fish Creek (Nuiqsut)	163024
SS18-06-M	Spotted	M	Pup	20-Sep-18	253/59	Dease Inlet (Utqiaġvik)	163022
SS18-07-F	Spotted	F	Sub	20-Sep-18	245/81	Dease Inlet (Utqiaġvik)	163043
SS18-08-F	Spotted	F	Sub	27-Sep-18	0/212	Dease Inlet (Utqiaġvik)	169951
SS19-01-M	Spotted	M	Adult	17-Sep-19	241 /A	Utqiaġvik	120351
SS19-02-M	Spotted	M	Sub	17-Sep-19	128/A	Utqiaġvik	163027

SS19-03-M	Spotted	M	Adult	17-Sep-19	220/A	Utqiaġvik	163023
SS19-04-M	Spotted	M	Adult	18-Sep-19	234/A	Utqiaġvik	163047
DL17-01	Beluga	M	3.5 m	29-Jun-17	0	Point Lay	163017
DL17-02	Beluga	M	2.8 m	29-Jun-17	0	Point Lay	163019
DL17-03	Beluga	M	2.8 m	6-Jul-17	0	Point Lay	163018
DL19-02	Beluga	F	3.5 m	8-Jul-19	71	Point Lay	150992
B17-04	Bowhead	unk	9 m	28-Aug-17	12	Tuktoyaktuk Canada	96425
B17-05	Bowhead	unk	8 m	28-Aug-17	0	Tuktoyaktuk Canada	96422
B17-06	Bowhead	unk	11 m	28-Aug-17	0	Tuktoyaktuk Canada	96424
B17-07	Bowhead	F	8 m	28-Aug-17	151	Tuktoyaktuk Canada	96426
B18-05	Bowhead	unk	9 m	21-Sep-18	102	Utqiaġvik	174876
B18-06	Bowhead	M	8 m	21-Sep-18	22	Utqiaġvik	174873
B18-07	Bowhead	unk	11 m	21-Sep-18	56	Utqiaġvik	174875
B18-08	Bowhead	F	9 m	25-Sep-18	38	Utqiaġvik	174874
B18-09	Bowhead	M	12 m	25-Sep-18	203	Utqiaġvik	96421
B18-10	Bowhead	F	12 m	25-Sep-18	71	Utqiaġvik	96423

[a] Tracking durations for seals include durations for CTD and SPOT flipper tags (CTD/SPOT).
[b] Harvested or found dead
n/a = no Spot tag
A = Active tag transmitting as of 15 June 2020
Unk = sex unknown

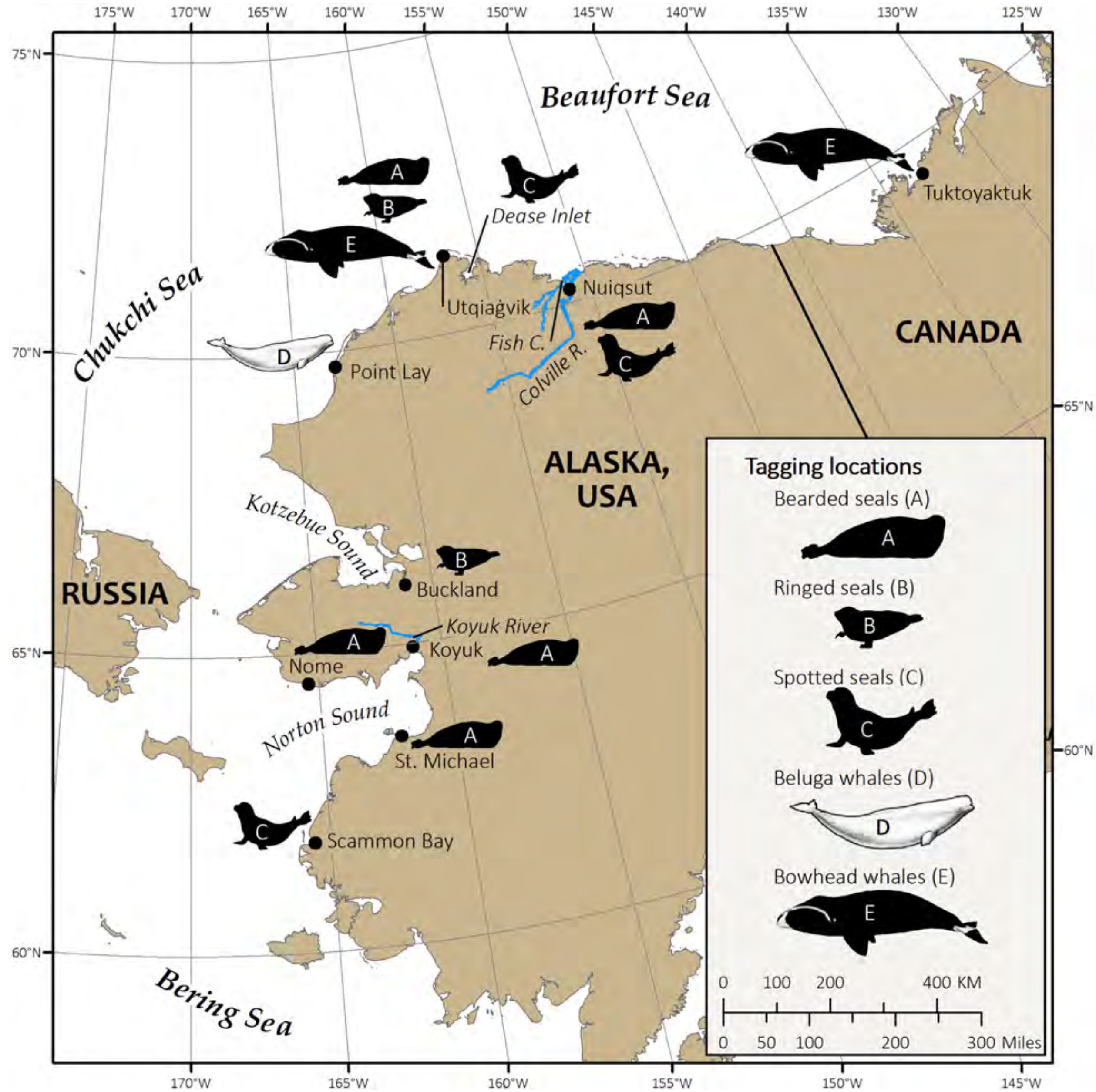


Figure 1. Locations where CTD tags were deployed on ringed, bearded, and spotted seals, and on beluga and bowhead whales during this study.

Key Individuals included:
Lori Quakenbush, Wildlife Biologist IV, ADFG, Fairbanks, AK
John Citta, Biometrician II, ADFG, Fairbanks, AK
Justin Crawford, Wildlife Biologist II, ADFG, Fairbanks, AK
Anna Bryan, Wildlife Biologist II, ADFG, Fairbanks, AK
Justin Olnes, Wildlife Biologist II, ADFG, Fairbanks, AK
Ryan Adam, Fish and Wildlife Technician II, ADFG, Fairbanks, AK
Andrew Von Duyke, Wildlife Biologist, NSB, Utqiaġvik, AK
Robert Suydam, Senior Wildlife Biologist, NSB, Utqiaġvik, AK
Stephen Okkonen, Oceanographer, UAF, Kasilof, AK
Matthew Druckenmiller, Research Scientist II, NSIDC, Boulder, CO
Greg Breed, Associate Professor, UAF, Fairbanks, AK
Ellen Lea, Biologist, DFO, Inuvik, NT, Canada

Students: none

WORK COMPLETED

During this ONR project, 22 September 2016 to 14 May 2020, we tagged 40 seals (6 ringed, 10 bearded, and 24 spotted seals) with CTD tags (Table 1). Ringed seals were tagged in Kotzebue Sound (Chukchi Sea) and near Utqiaġvik (boundary of the Chukchi and the Beaufort seas; Fig. 1). Bearded seals were tagged at five locations ranging from Norton Sound (Bering Sea) in the south, to the Colville River, which empties into the Beaufort Sea, in the north. Spotted seals were tagged in Scammon Bay (Bering Sea), and in Dease Inlet and the Colville River (Beaufort Sea; Fig. 1).

Ringed seal movements and behavior including two seals with CTD tags from this project were analyzed and published in a manuscript led by project key individual Von Duyke (Von Duyke et al. 2020, Appendix A). Bearded seal movements and behavior were analyzed, resulting in two manuscripts for publication (Olnes et al. 2020, Appendix B; and Olnes et al. *In review Marine Ecology Progress Series*). Spotted seal movements and behavior have been analyzed and a manuscript is in preparation (Crawford et al. *In prep*).

We attempted to capture beluga whales from the eastern Chukchi Sea stock near Point Lay in collaboration with the NSB and ABWC, during the annual community harvest in all years of the study. In 2017, three belugas where captured and tagged with CTD tags, one beluga was subsequently harvested and the tag was returned to us (Table 1, Fig. 1). The tag had not turned on, we could not turn it on, and the battery had no voltage. No transmissions were received from the other two tags, probably because they also did not turn on. This multi-tag battery failure caused us to retest all our CTD tags and we found problems with two additional beluga tags and five seal tags, all of which had to be replaced. In 2018, several attempts were made by hunters to bring belugas into the lagoon, but none were successful until very late in the season after the tagging crew had departed. Therefore, no belugas were tagged in 2018. In 2019, one adult female beluga was tagged; the tag transmitted for 71 days and provided detailed movement, dive, and oceanographic data for Barrow Canyon from July through September (Table 1, Fig. 1). Details from this tagged beluga have been analyzed and submitted for publication (Citta et al. *In review Deep Sea Research I*).

Also in 2019, we attempted to capture belugas from the eastern Bering Sea stock in southern Norton Sound near Stebbins with local beluga hunters and members of the ABWC. One beluga was captured and tagged with an ABWC funded SPLASH tag. Attempts were made to capture a second beluga to deploy a CTD tag, however no other belugas were captured. This is the first time that active netting captures have been tried in Norton Sound. We found that the lack of sandbars and lack of shallow water near shore made captures more difficult. What we learned in 2019, however, will be useful for captures there in the future.

In late August 2017, in collaboration with DFO and the Tuktoyaktuk Hunters and Trappers Committee we tagged four bowhead whales with CTD tags on the Tuktoyaktuk Shelf, Canada (Table 1, Fig. 1). Intermittent transmissions were received from two of the tagged whales (B17-05 and B17-06) indicating that the tags were working, but apparently the tags were deployed too low on the body to provide locations or other data. The other two tagged whales (B17-04 and B17-07) successfully transmitted locations and data; one for ~12 days and the other for ~5 months. In late September 2018, we tagged six bowhead whales with CTD tags near Utqiaġvik in collaboration with the NSB (Table 1, Fig. 1). All six CTD tags transmitted locations and data (duration 22 days to ~7 months). Data from CTD tags were included in a published paper on bowhead use of the Alaskan Beaufort Sea (Olnes et al. *In press*). We also provided data from all CTD tags on bowheads to the NSB and NOAA to determine the surface interval for use in developing a correction factor for the aerial abundance survey flown in 2019.

A total of 54 CTD tags were deployed of which 48 provided 154,917 locations, 13,779 CTD profiles, and 236,247 dive records for 1,488 days in the Bering, Chukchi, and Beaufort seas, including under sea ice in winter (Table 2).

Table 2. Number of locations, CTD profiles, dive records, and days with records from CTD tags by species.

Species	Locations	CTD Profiles	Dive Records	Days with Records
Seals	146,632	11,986	229,538	1,206
Belugas	1,451	255	492	45
Bowheads	6,834	1,538	6,217	237
Total	154,917	13,779	236,247	1,488

Two key individuals (Quakenbush and Crawford) attended the Alaska Ocean Observing System (AOOS) Animal Telemetry Network (ATN) workshop 5–6 December 2017 in Anchorage to provide 1) an overview of the types of data collected by satellite tags in our studies, 2) concern for the complexity of the metadata required to accurately analyze and interpret archived data of this type given the many tag settings parameterized prior to deployment and how those settings affect the interpretation of the data, and 3) an appreciation for the filtering and mapping required to present credible maps that do not show locations on land and do not show tracks crossing peninsulas and islands. In our experience, presenting crude maps of unfiltered locations and tracks that cross land to connect two sequential at sea locations creates concern among our collaborators regarding the ability of satellite telemetry to locate marine mammals accurately and thus, the validity of satellite telemetry data in general.

We filed deployment metadata forms online with the ATN Data Assembly Center (DAC) and Axiom and worked with them to receive, filter, plot, and archive our seal and whale location and CTD data. Our location data has been viewable on the ATN webpage since mid-June 2019. We also managed and archived all data collected from these tagged animals in our seal and whale databases at ADFG. In addition to providing the location and dive data directly to ATN, the CTD data were provided to the World Meteorological Organization via the Global Telecommunication System (WMO GTS) directly through SMRU for use by the Navy Oceanographic Office (NAVO) and ONR in close to real-time. We also archived the temperature and salinity profiles collected by these tags in our seal and whale databases at ADFG.

Two key individuals (Quakenbush and Citta) attended the ONR Program Review 23–26 April 2019 in Alexandria, VA, and provided a project overview (Quakenbush, Citta, and Okkonen. 2019, Appendix C). The Program Review was especially valuable to communicate directly with ONR, other researchers, satellite tag manufacturers (SMRU and Wildlife Computers), and users of these data. These direct communications helped us with tag calibration and guided our tagging priorities for the 2019 field season so that areas sampled by CTD tags were most useful to ONR. To accomplish this, we prioritized deploying CTD tags on ringed seals that were more likely to use the deeper water of the Chukchi and Beaufort seas, north of the continental shelf break, as ice receded north during summer.

RESULTS

Ice Seals. Six ringed seals, all of which were adult males, were tagged with CTD tags at two locations; near Utqiaġvik and in Kotzebue Sound (Table 1, Fig. 1). Data from two of these seals, both tagged in 2016, were included in an analysis of movements and dive behavior by the North Slope Borough (NSB) that was published in the journal *Ecology and Evolution* (Von Duyke et al. 2020, Appendix A). Ten bearded seals were tagged at five locations: four males and six females (Table 1, Fig. 1). One of the males was an adult, determined by claw annuli to be at least 11 years old. An analysis of movements and dive behavior for all but the adult bearded seal was published in the journal *Polar Biology* (Olnes et al. 2020, Appendix B) and a comparison of habitat use relative to changes in sea ice is in review by the journal *Marine Ecology Progress Series* (Olnes et al. *In review*). Twenty-four spotted seals, 13 males and 11 females of all age classes, were tagged at three locations (Table 1, Fig. 1). The transmission durations of CTD tags deployed on seals during this ONR project in all years ranged from 14–293 days (mean = 181 days; n = 39; Table 1). One CTD tag did not transmit.

Accomplishment of Objectives

Objective 1) Describe the movements and behavior (e.g., diving, haul-out, pupping, molting) of ringed, bearded, and spotted seals by species, generally and specifically within their range throughout the Bering, Chukchi, and Beaufort seas including movements within oil and gas exploration areas and shipping lanes. Test the hypothesis that tagged ringed, bearded, and spotted seals use the Bering, Chukchi, Beaufort seas in a random fashion. If use by seals is not random, identify how use is correlated with water depth, temperature, salinity, currents, sea ice, disturbance, or other factors.

Ringed seals. Ringed seal movements were strongly associated with seasonal patterns in sea ice. All six ringed seals were tagged in late June or early July, during the annual retreat of sea ice. In general, tagged ringed seals remained near their tagging location (in sea ice) until the southern ice margin moved north, at which time seals typically followed it northwards. Once the southern ice margin moved north of the shelfbreak, some seals ranged into the Arctic Basin, while others remained in the shelfwaters of the northern Chukchi and southern Beaufort seas (Fig. 2a). In fall (October–December), tagged ringed seals typically moved southwards with or in advance of the ice edge, with more use of coastal regions, both in Alaska and Russia. By December, the sea ice advanced south of their locations so that ringed seals wintered north of the ice edge (Fig. 2b). During January–March, ringed seals were mostly in the southern Chukchi and northern Bering Sea, however one ringed seal wintered in the northern Chukchi Sea near Icy Cape (Fig. 2c). During late spring and early summer (April–June), all ringed seals were north of Bering Strait, either in Kotzebue Sound, moving north along the Alaska coast, or in the central Chukchi Sea (Fig. 2d).

Although ringed seals are generally considered to be pelagic foragers, the tagged seals often frequented the seafloor. When in shallow Chukchi shelf waters < 100 m, the percentage of benthic dives ranged from 74% (mean depth = 35 m, mean duration = 7.6 min) during July–September to 63% in April–June (mean depth = 27 m, mean duration = 11.5 min). Ringed seals that traveled off the shelf in waters 200–300 m during July–October, still dove to the bottom during 47% of dives (mean depth = 247.0 m, mean duration = 11.1 min) and spent the majority of dive time at the bottom; 73.7% of these dives were considered foraging dives, i.e., ≥ 80% of the dive time was at the deepest depth reached during the dive.

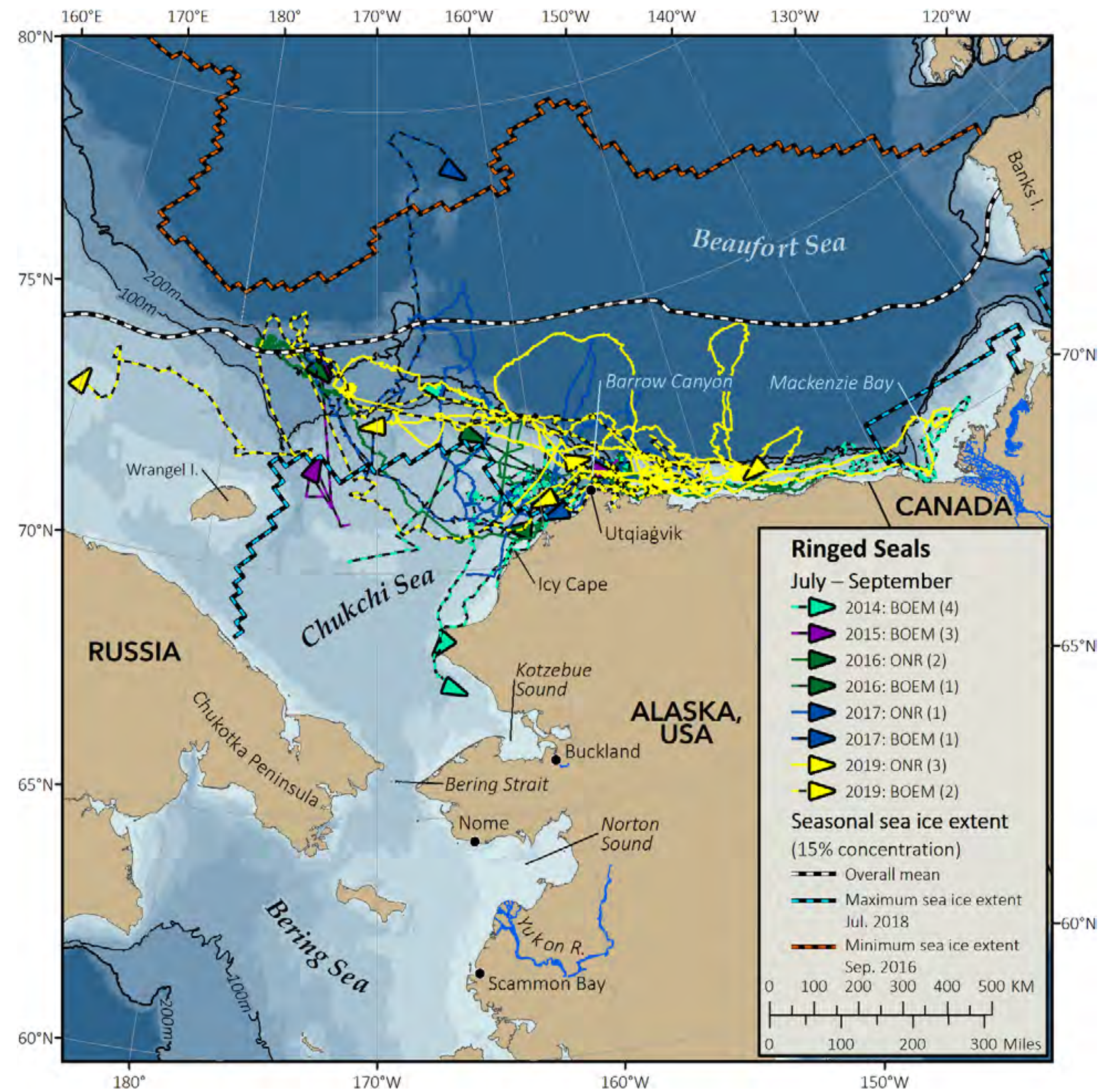


Figure 2a. July–September movements of six ringed seals with CTD tags (solid lines) from this project and nine with SPLASH tags from a co-occurring BOEM project (dashed lines), two of which had SPOT flipper-tags that provided locations during the season/year after their tag year. Seasonal sea ice extents represent the monthly mean 15% ice concentration based on Advanced Microwave Scanning Radiometer-Earth data (National Snow and Ice Data Center) for: (1) overall mean extent, average of all monthly mean extents during the period, (2) maximum sea ice extent, farthest monthly mean ice extent during each period, and (3) minimum sea ice extent, least monthly mean ice extent during each period, from 2014–2019.

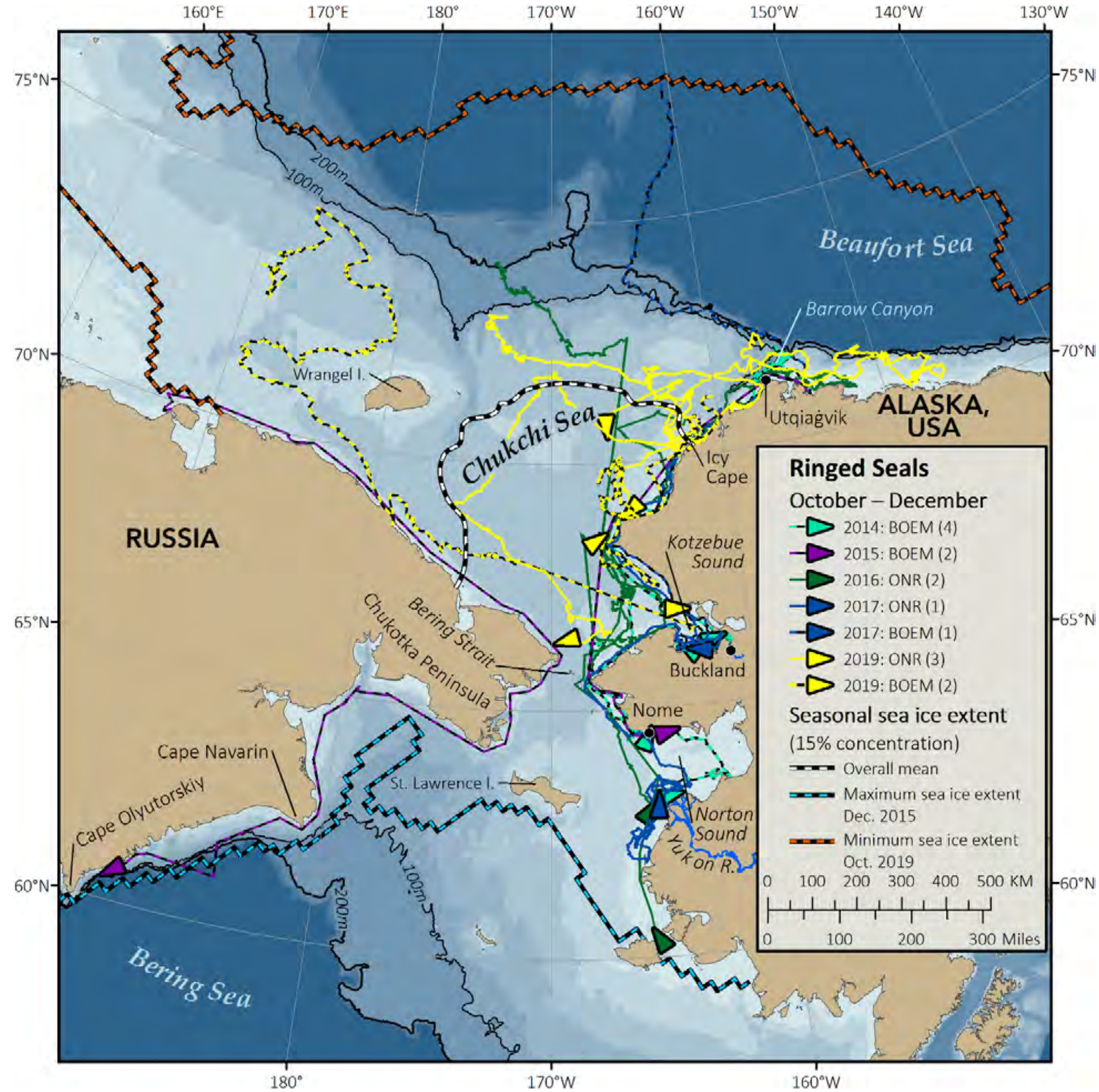


Figure 2b. October–December movements of six ringed seals with CTD tags (solid lines) from this project and eight with SPLASH tags from a co-occurring BOEM project (dashed lines), one of which had a SPOT flipper-tag that provided locations during the season/year after its tag year. Seasonal sea ice extents represent the monthly mean 15% ice concentration based on Advanced Microwave Scanning Radiometer-Earth data (National Snow and Ice Data Center) for: (1) overall mean extent, average of all monthly mean extents during the period, (2) maximum sea ice extent, farthest monthly mean ice extent during each period, and (3) minimum sea ice extent, least monthly mean ice extent during each period, from 2014–2019.

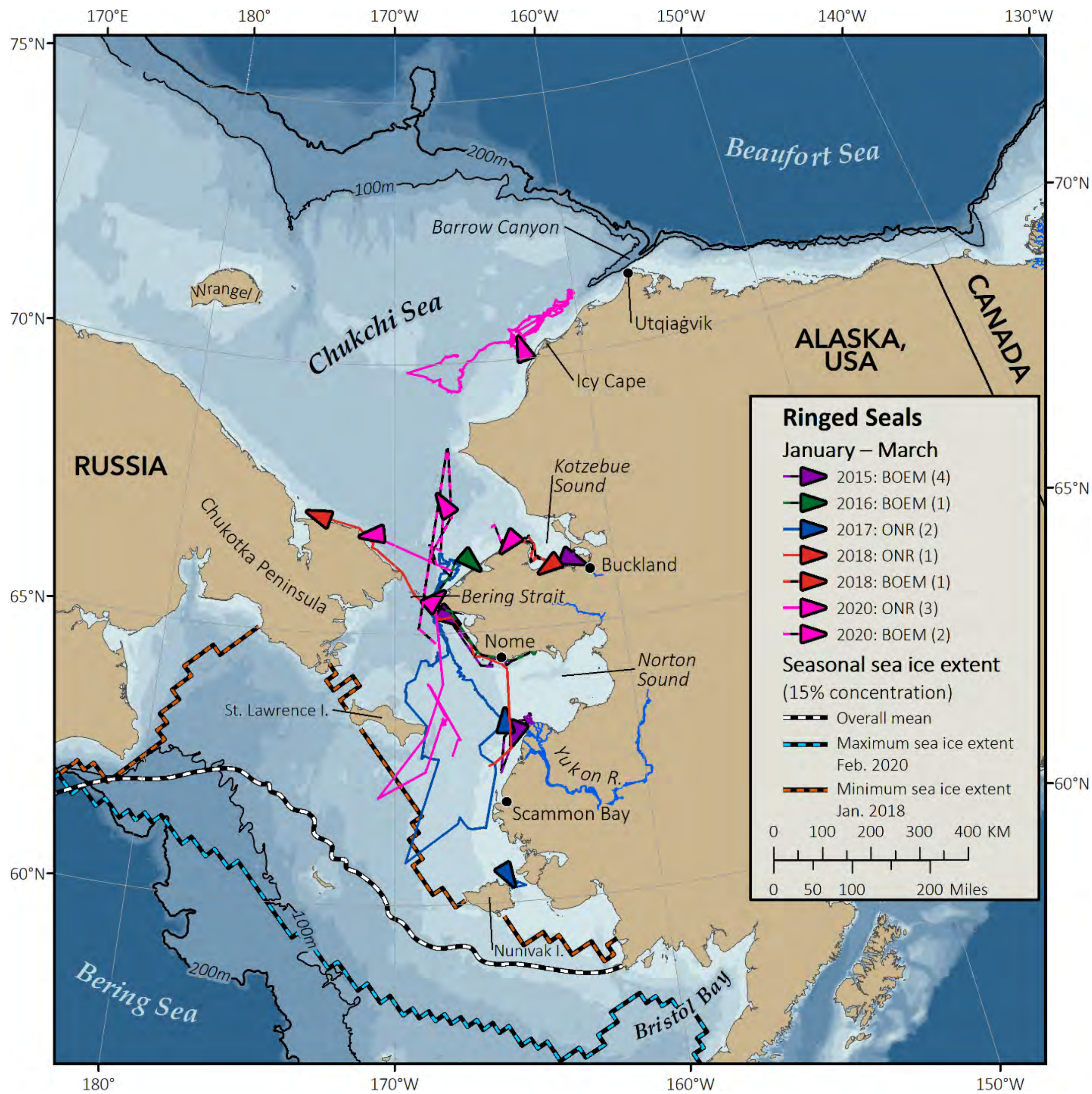


Figure 2c. January–March movements of six ringed seals with CTD tags (solid lines) from this project and seven with SPLASH tags from a co-occurring BOEM project (dashed lines), one of which had a SPOT flipper-tag that provided locations during the season/year after its tag year. Seasonal sea ice extents represent the monthly mean 15% ice concentration based on Advanced Microwave Scanning Radiometer-Earth data (National Snow and Ice Data Center) for: (1) overall mean extent, average of all monthly mean extents during the period, (2) maximum sea ice extent, farthest monthly mean ice extent during each period, and (3) minimum sea ice extent, least monthly mean ice extent during each period, from 2015–2020.

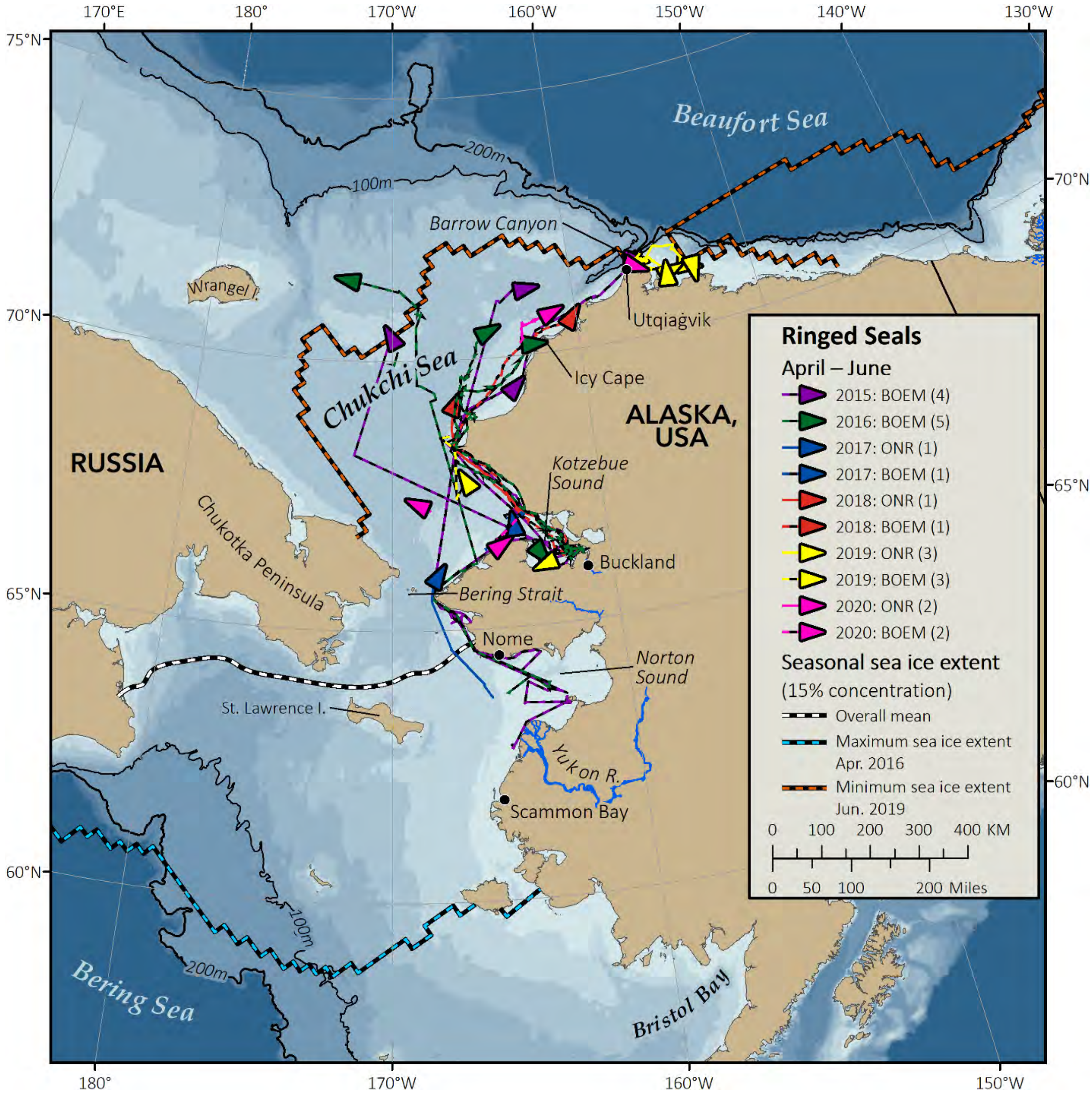


Figure 2d. April–June movements of five ringed seals with CTD tags (solid lines) from this project, two of which had SPOT flipper tags that provided locations during the season/year after their tag year, and eight with SPLASH tags from a co-occurring BOEM project (dashed lines), six of which had SPOT flipper tags that provided locations during the season/year after their tag year, and one that provided locations for three seasons/years. Seasonal sea ice extents represent the monthly mean 15% ice concentration based on Advanced Microwave Scanning Radiometer-Earth data (National Snow and Ice Data Center) for: (1) overall mean extent, average of all monthly mean extents during the period, (2) maximum sea ice extent, farthest monthly mean ice extent during each period, and (3) minimum sea ice extent, least monthly mean ice extent during each period, from 2015–2020.

Bearded seals. Bearded seal movements were less dependent upon season than other seals, and movements were not independent of where bearded seals were tagged. We analyzed movements, diving, and haul-out behavior of 24 tagged juvenile bearded seals; eight with CTD tags and 16 with non-CTD tags from our BOEM seal tagging project. We published these analyses in the journal *Polar Biology* (Olnes et al. 2020, Appendix B). We determined that juvenile bearded seals use a wide range of sea ice concentrations when ice is present, and primarily occupy coastal areas year-round (< 30 km from land), with occasional trips far from shore (> 100 km) (Figs. 3a–d). Juvenile bearded seals made annual north-south movements following the seasonal movements of sea ice and generally stayed on the continental shelf of the Bering and Chukchi seas (Figs. 3a–d), however, they used different latitudinal ranges depending on the latitude where they were tagged. For example, two juveniles and one adult bearded seal that were tagged in the Beaufort Sea remained in the Beaufort Sea throughout tag transmission, whereas juveniles tagged in the Bering Sea (Norton Sound) used both the Bering and Chukchi seas throughout the year. Such movement patterns highlight the importance of tagging seals in multiple regions annually to understand movements and habitat use throughout their range.

Few adult bearded seals have been captured in the Pacific Arctic, thus little is known about their movements and behavior. The adult male (BS19-01-M) tagged near Utqiaġvik in 2019 was relatively sedentary and remained in the Beaufort Sea year-round. This behavior, although not common among the tagged juveniles, was similar to a juvenile (BS-17-01-F) tagged in 2017 near Nuiqsut.

Bearded seals spent much of their time diving. We found that 85% of all dives from juvenile bearded seals were to the sea floor, where they spent ~50% of their time (Olnes et al. 2020, Appendix B). This dive behavior does not appear to change whether a seal is in a transiting or resident (presumably feeding) movement pattern, which suggests they are constantly sampling the sea floor and stop in areas where they find productive foraging. Like the juveniles, the adult bearded seal primarily made benthic dives.

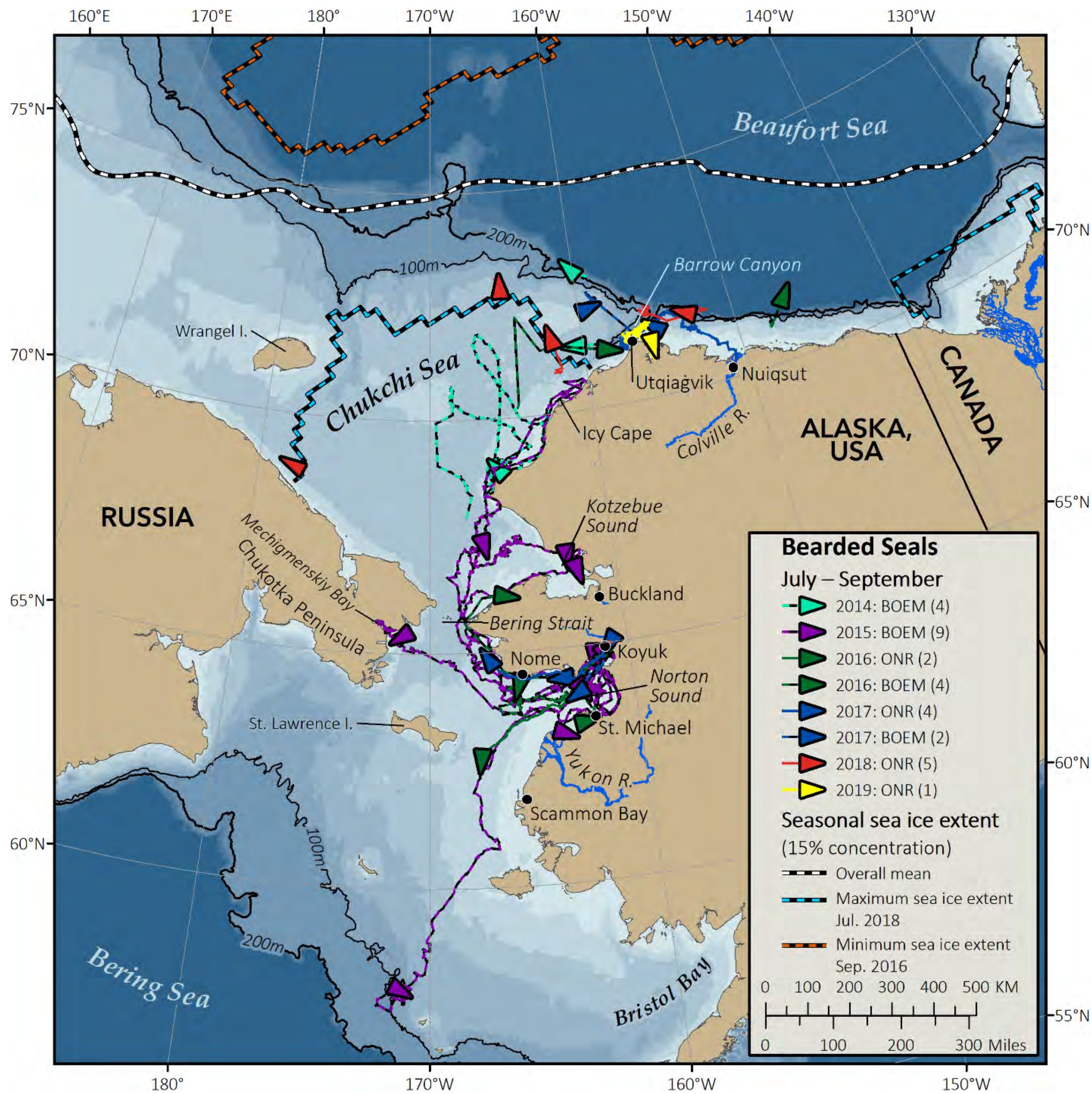


Figure 3a. Bearded seal movements July–September for seven juvenile and one adult bearded seal with CTD tags (solid lines) from this project, three of which had a SPOT flipper-tag that provided locations during the season/year after their tag year and one that provided locations for three season/years, and 15 with SPLASH tags from a co-occurring BOEM project, four of which had SPOT flipper-tags that provided locations during the season/year after being tagged (dashed lines). Seasonal sea ice extents represent the monthly mean 15% ice concentration based on Advanced Microwave Scanning Radiometer-Earth data (National Snow and Ice Data Center) for: (1) overall mean extent, average of all monthly mean extents during the period, (2) maximum sea ice extent, farthest monthly mean ice extent during each period, and (3) minimum sea ice extent, least monthly mean ice extent during each period, from 2014–2019.

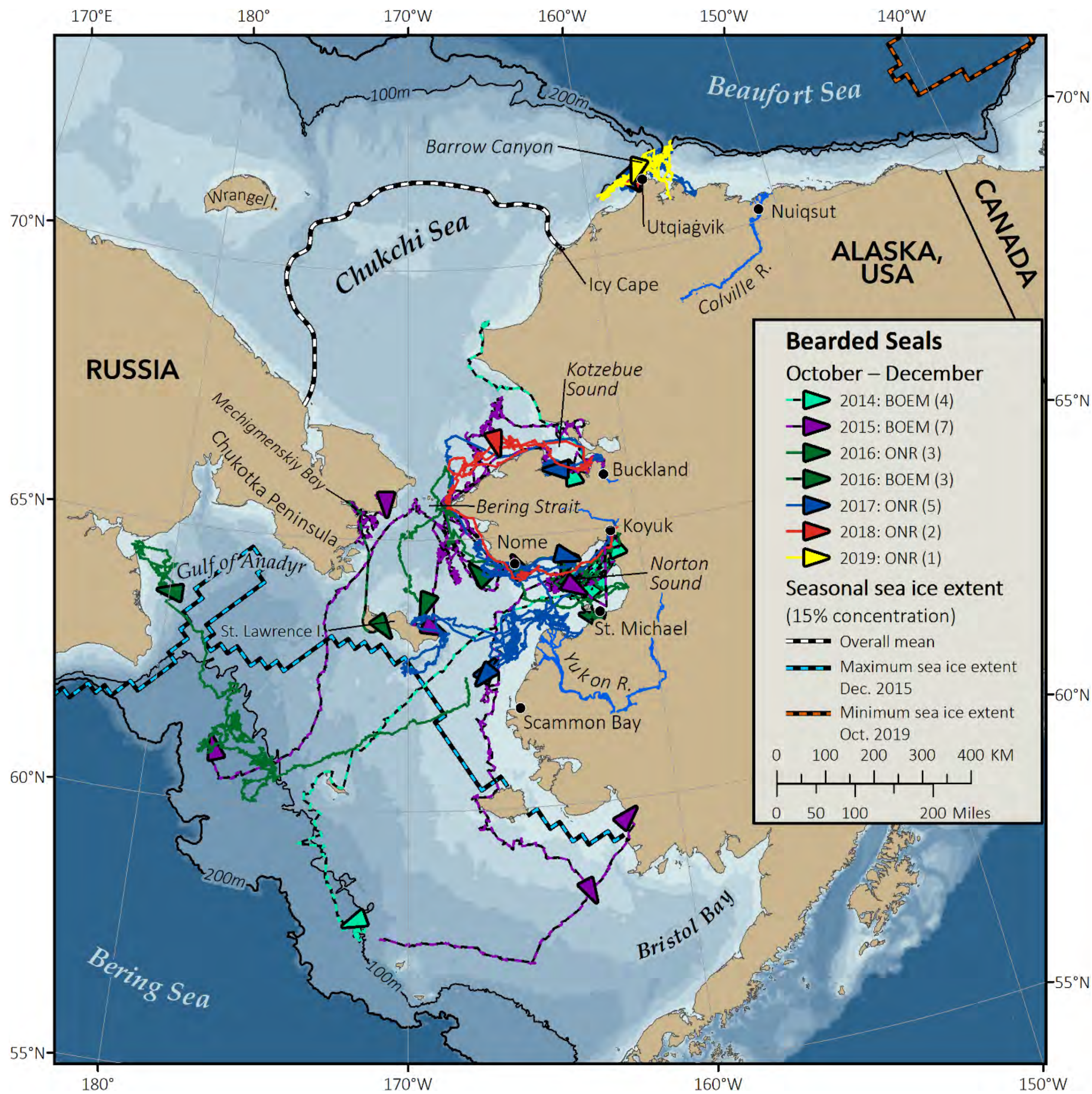


Figure 3b. Bearded seal movements October–December for nine juvenile and one adult bearded seal with CTD tags (solid lines) from this project, one of which had a SPOT flipper-tag that provided locations during the season/year its tag year, and 13 with SPLASH tags from a co-occurring BOEM project, one of which had a SPOT flipper-tag that provided locations during the season/year after its tag year (dashed lines). Seasonal sea ice extents represent the monthly mean 15% ice concentration based on Advanced Microwave Scanning Radiometer-Earth data (National Snow and Ice Data Center) for: (1) overall mean extent, average of all monthly mean extents during the period, (2) maximum sea ice extent, farthest monthly mean ice extent during each period, and (3) minimum sea ice extent, least monthly mean ice extent during each period, from 2014–2019.

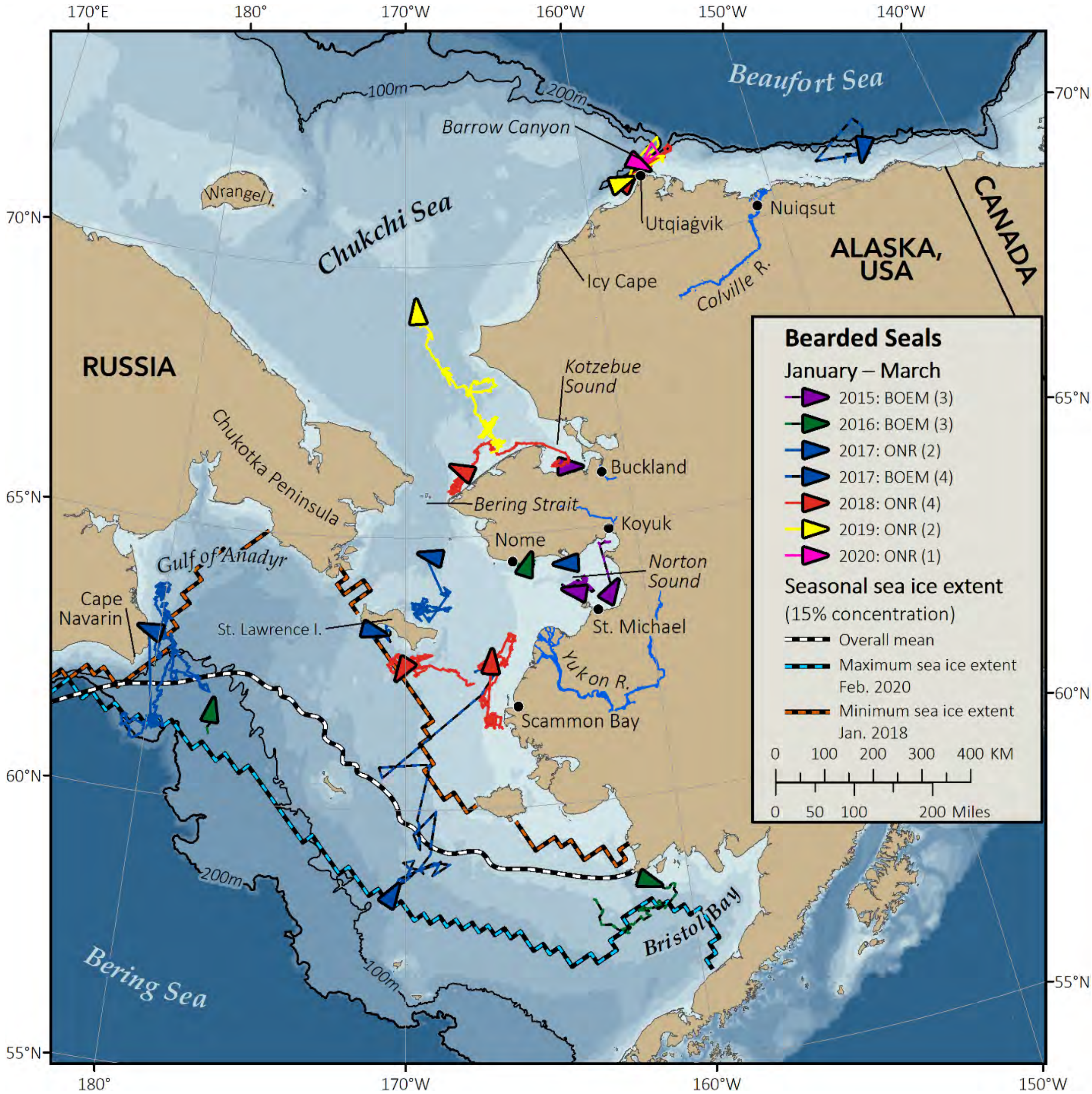


Figure 3c. January–March movements of one adult and seven juvenile bearded seals with CTD tags (solid lines) from this project, one of which had a SPOT flipper-tag that provided locations during the season/year after its tag year, and 10 with SPLASH tags from a co-occurring BOEM project (dashed lines). Seasonal sea ice extents represent the monthly mean 15% ice concentration based on Advanced Microwave Scanning Radiometer-Earth data (National Snow and Ice Data Center) for: (1) overall mean extent, average of all monthly mean extents during the period, (2) maximum sea ice extent, farthest monthly mean ice extent during each period, and (3) minimum sea ice extent, least monthly mean ice extent during each period, from 2015–2020.

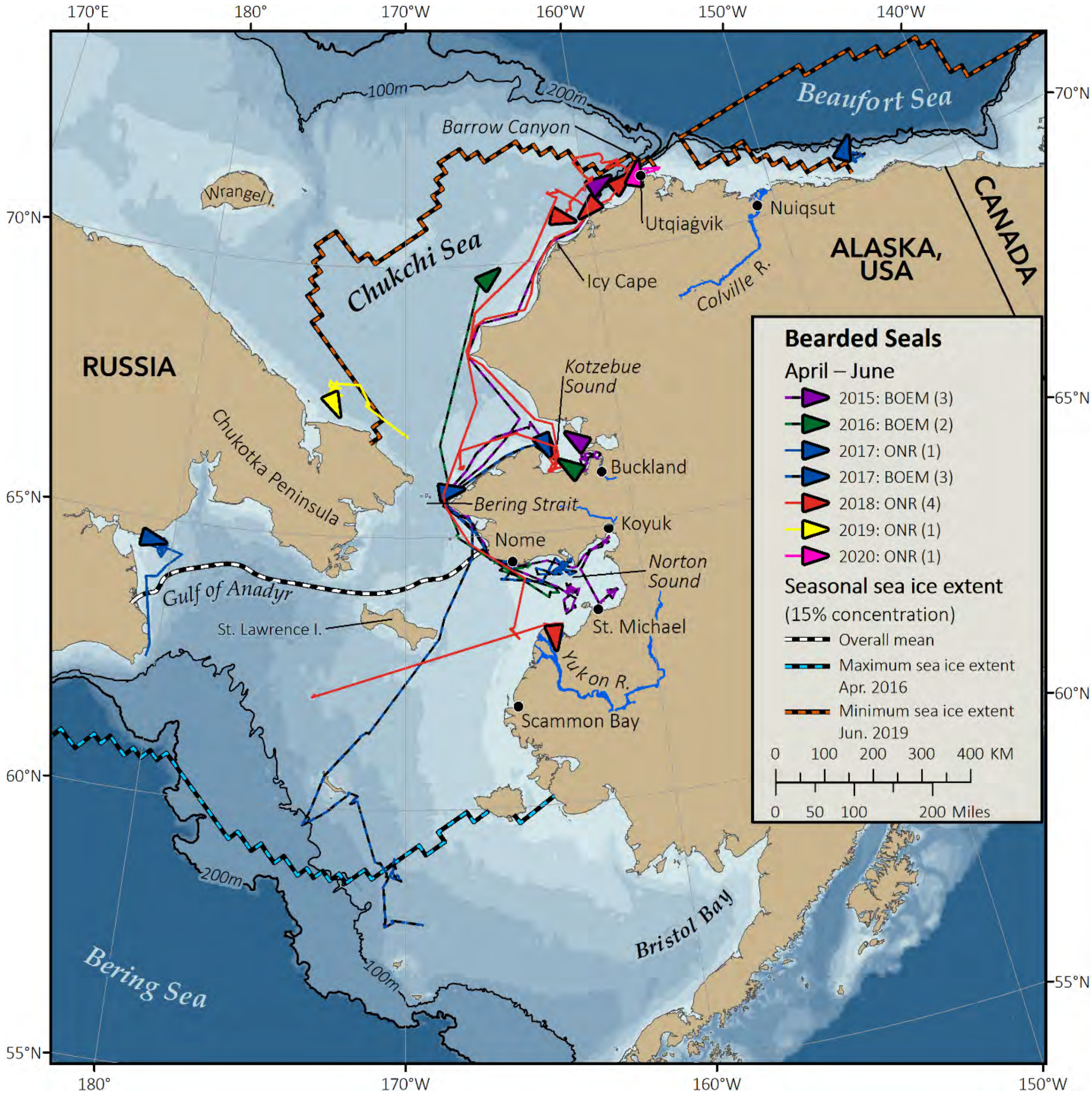


Figure 3d. April–June movements of one adult and six juvenile bearded seals with CTD tags (solid lines) from this project, one of which had a SPOT flipper-tag that provided locations during the season/year after its tag year, and seven with SPLASH tags from a co-occurring BOEM project (dashed lines), one of which had a SPOT flipper-tag that provided locations during the season/year after its tag year. Seasonal sea ice extents represent the monthly mean 15% ice concentration based on Advanced Microwave Scanning Radiometer-Earth data (National Snow and Ice Data Center) for: (1) overall mean extent, average of all monthly mean extents during the period, (2) maximum sea ice extent, farthest monthly mean ice extent during each period, and (3) minimum sea ice extent, least monthly mean ice extent during each period, from 2015–2020.

Spotted seals. Spotted seals tagged during this ONR project rarely left the continental shelf in the Beaufort, Chukchi, or Bering seas (Figs. 4a–d). The only spotted seal to use waters > 200 m did so while crossing Barrow Canyon (Fig. 4a). In summer, spotted seals made repeated east-west movements. For spotted seals tagged in the Beaufort Sea (near Utqiaġvik and Nuiqsut) these movements occurred between the Chukchi Sea coast out to > 100 km from shore to Herald Shoal in the Chukchi Sea. Spotted seals tagged in the Bering Sea (Scammon Bay) made similar movements from shore in the eastern Bering Sea (Fig. 4a). North-south movements were uncommon prior to October, when seals start migrating south into the Bering Sea in advance of the ice edge (Fig. 4b). During winter (January–March), spotted seals ranged widely across the Bering Sea near the ice edge (Fig. 4c). In summer, when sea ice was not present, spotted seals hauled out on land, primarily on barrier islands.

Spotted seals dove to the bottom more than expected and dive depths were similar for seals in the Chukchi and Bering seas. During July–November, 68% of dives were benthic, 20% were midwater, and 12% were near the surface. Most benthic dives (80%) were considered foraging (i.e., ≥ 80% of the dive time was at the deepest depth reached during the dive), while only 33% of midwater dives were considered foraging. Benthic dives during these months of open water, however, were deeper (31 m) and longer (3.3 min) in the Chukchi Sea than in the Bering Sea (23 m and 2.5 min). During December–April, when all spotted seals were in the Bering Sea, 64% of dives were benthic, 18% were midwater, and 18% were near the surface. Most benthic dives (77%) were considered foraging while only 21% of midwater dives were considered foraging. Benthic dives during these months of ice cover averaged 43 m deep and lasted 4.4 min. The deepest dive recorded by a CTD tag on a spotted seal (SS17-02-M) was 115 m, to the ocean floor, in the central Bering Sea ~170 km west of St. Matthew Island. The deepest dive recorded by a SPLASH tag on a spotted seal (SS19-05-M) was 185 m, also to the ocean floor, in western central-Bering Sea ~190 km southeast of Cape Navarin, Russia. Spotted seal general movements, diving and haul-out behavior, and oceanographic characteristics associated with foraging are being summarized for a manuscript (Crawford et al. *In prep*).

Other components of this objective are addressed below, including movements within oil and gas exploration areas and shipping lanes, and whether seal use of the Bering, Chukchi, and Beaufort seas is random or correlated with water depth, temperature, salinity, currents, sea ice, disturbance, or other factors.

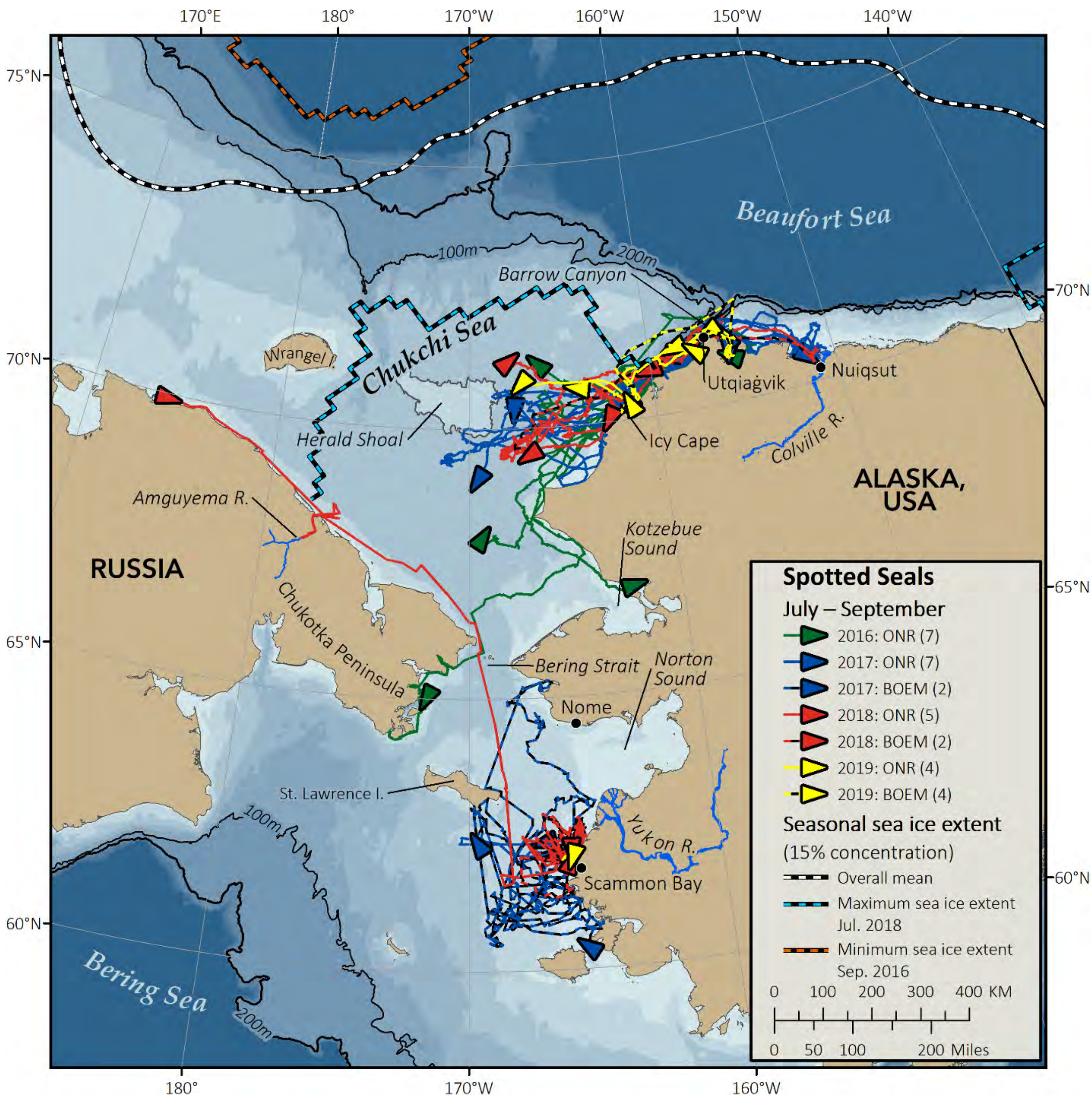


Figure 4a. July–September movements for 20 spotted seals with CTD tags (solid lines) from this project, three of which had SPOT flipper-tags that provided locations during the season/year after their tag year, and seven with SPLASH tags from a co-occurring BOEM project (dashed lines), one of which had a SPOT flipper-tag that provided locations during the season/year after its tag year. Seasonal sea ice extents represent the monthly mean 15% ice concentration based on Advanced Microwave Scanning Radiometer-Earth data (National Snow and Ice Data Center) for: (1) overall mean extent, average of all monthly mean extents during the period, (2) maximum sea ice extent, farthest monthly mean ice extent during each period, and (3) minimum sea ice extent, least monthly mean ice extent during each period, from 2016–2019.

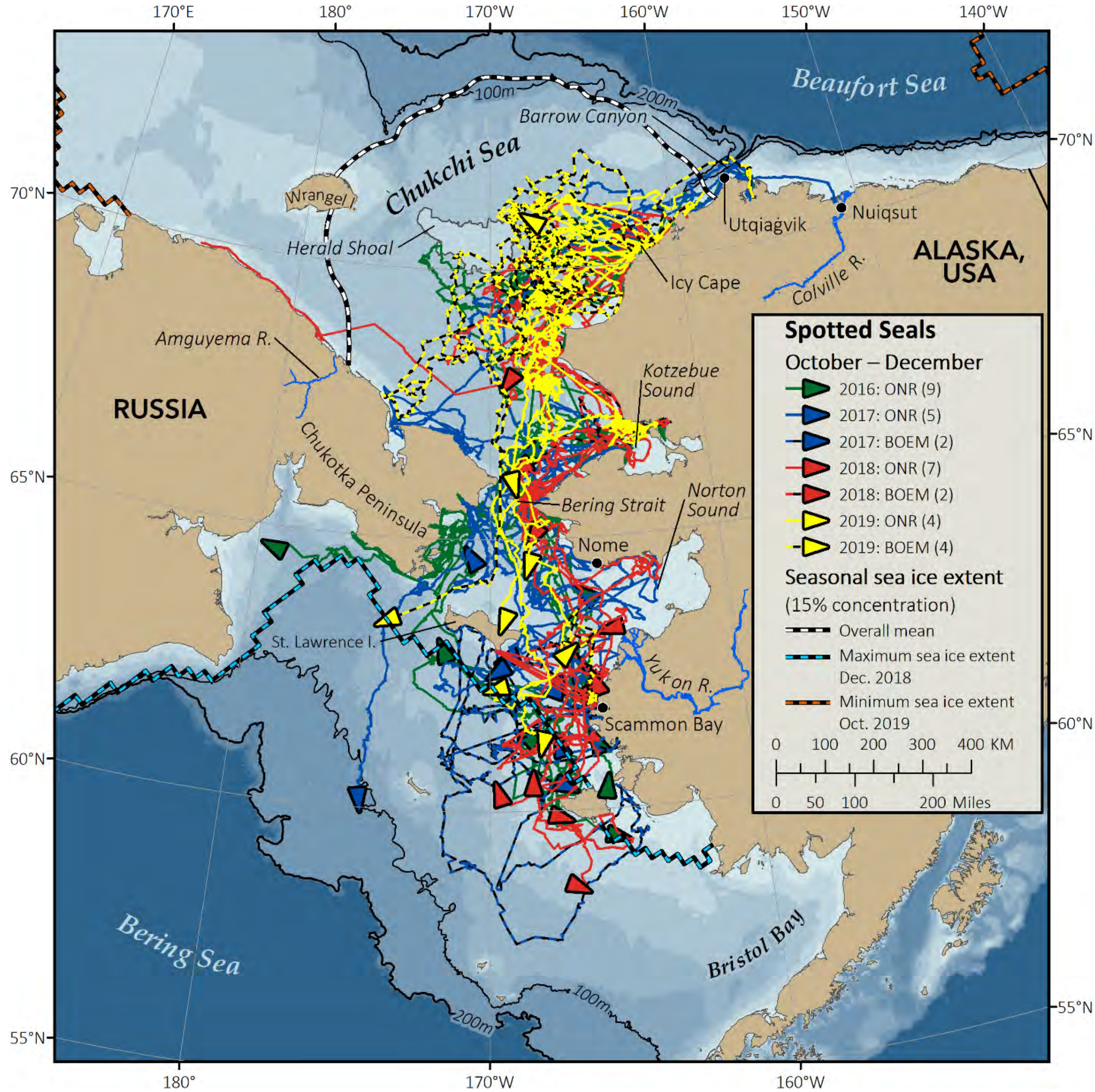


Figure 4b. October–December movements of 24 spotted seals with CTD tags (solid lines) from this project, one of which had a SPOT flipper-tag that provided locations during the season/year after its tag year, and seven with SPLASH tags from a co-occurring BOEM project (dashed lines), one of which had a SPOT flipper-tag that provided locations during the season/year after its tag year. Seasonal sea ice extents represent the monthly mean 15% ice concentration based on Advanced Microwave Scanning Radiometer-Earth data (National Snow and Ice Data Center) for: (1) overall mean extent, average of all monthly mean extents during the period, (2) maximum sea ice extent, farthest monthly mean ice extent during each period, and (3) minimum sea ice extent, least monthly mean ice extent during each period, from 2016–2019.

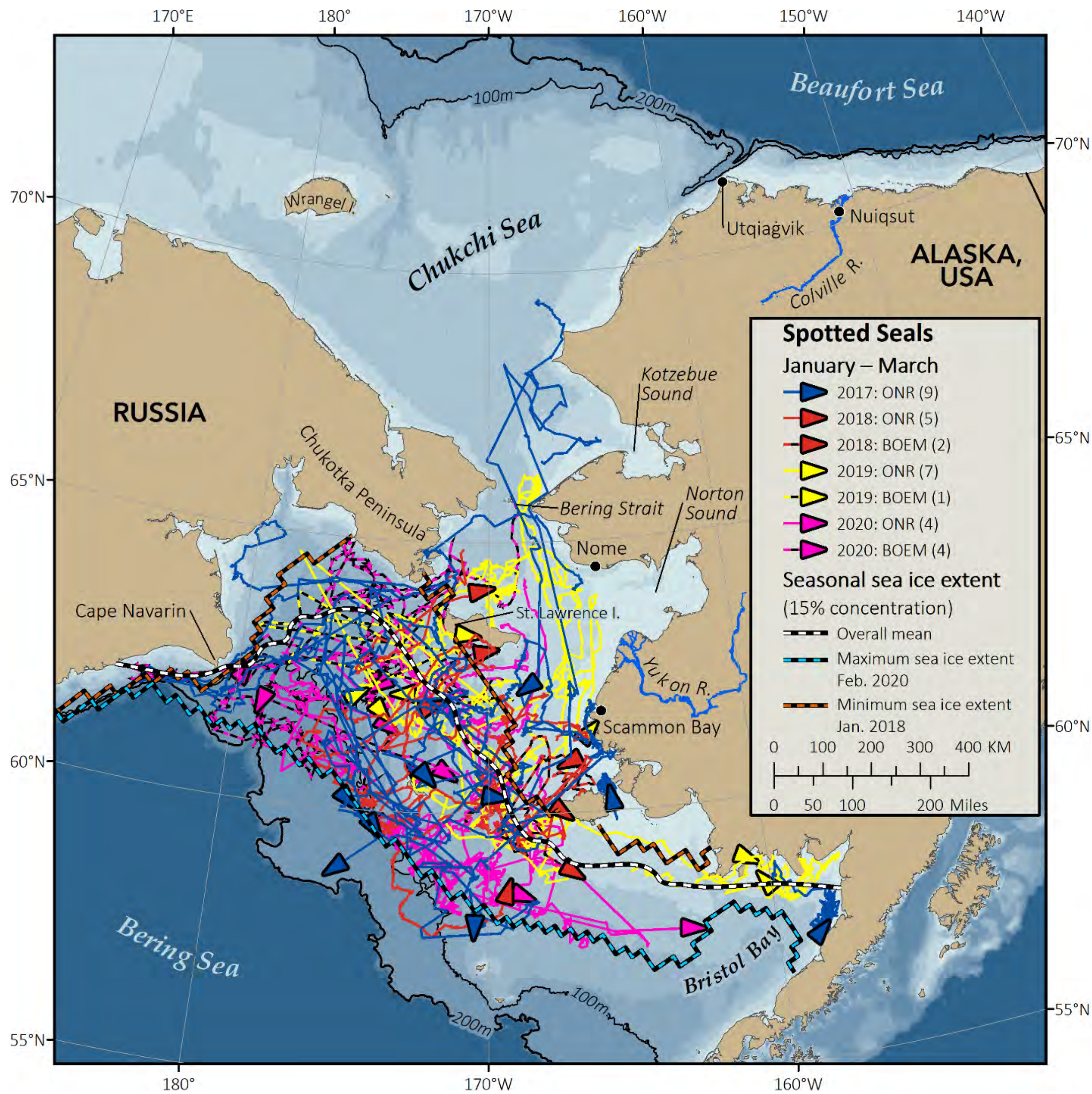


Figure 4c. January–March movements for 24 spotted seals with CTD tags (solid lines) from this project, one of which had a SPOT flipper-tag that provided locations during the season/year after its tag year, and six with SPLASH tags from a co-occurring BOEM project (dashed lines), one of which had a SPOT flipper-tag that provided locations during the season/year after its tag year. Seasonal sea ice extents represent the monthly mean 15% ice concentration based on Advanced Microwave Scanning Radiometer-Earth data (National Snow and Ice Data Center) for: (1) overall mean extent, average of all monthly mean extents during the period, (2) maximum sea ice extent, farthest monthly mean ice extent during each period, and (3) minimum sea ice extent, least monthly mean ice extent during each period, from 2017–2020.

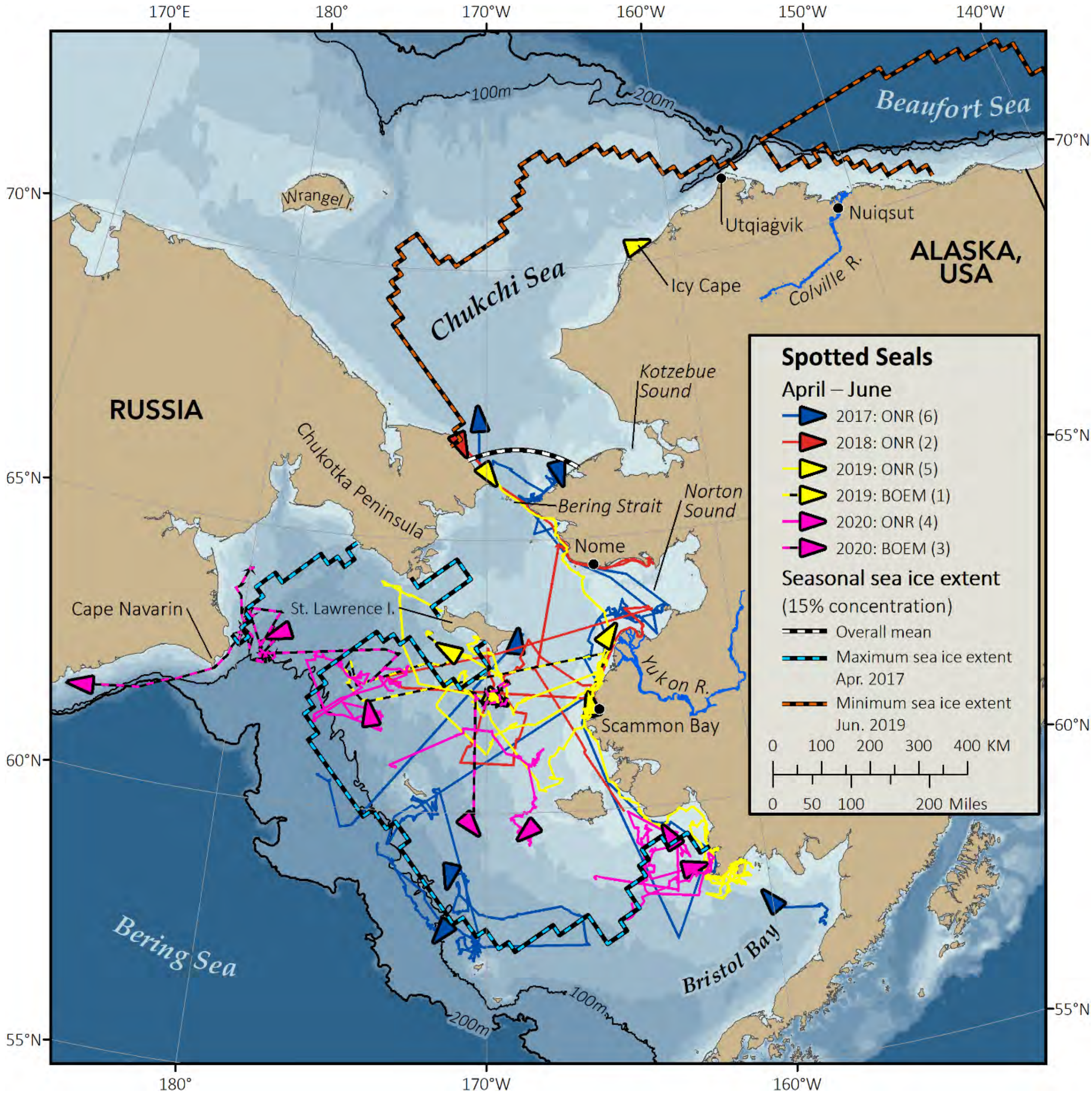


Figure 4d. April–June movements of 16 spotted seals with CTD tags (solid lines) from this project, one of which had a SPOT flipper-tag that provided locations during the season/year after its tag year, and four with SPLASH tags from a co-occurring BOEM project (dashed lines). Seasonal sea ice extents represent the monthly mean 15% ice concentration based on Advanced Microwave Scanning Radiometer-Earth data (National Snow and Ice Data Center) for: (1) overall mean extent, average of all monthly mean extents during the period, (2) maximum sea ice extent, farthest monthly mean ice extent during each period, and (3) minimum sea ice extent, least monthly mean ice extent during each period, from 2017–2020.

Objective 2) Identify important habitats used for feeding, pupping, mating, and molting of ringed, bearded, and spotted seals by species, generally and specifically within their range throughout the Bering, Chukchi, and Beaufort seas including areas within oil and gas exploration areas and shipping lanes.

Ringed seals. Ringed seal summer movements are strongly associated with sea ice indicating that sea ice is an important habitat. Trips north of the Chukchi Sea shelf break in summer generally ended at the ice edge (Fig 2a, also see Fig. 5 in Von Duyke et al. 2020, Appendix A). Whether this behavior is the result of ringed seals seeking sea ice to haul out on, or because their primary prey (Arctic cod, *Boreogadus saida*) is associated with sea ice is unclear because they hauled out on the ice and made repetitive dives to deep target depths that suggested feeding (See Objective 3 below).

We identified high use, presumably foraging, areas by estimating the density of ringed seal dive locations (i.e., utilization distribution). During the open-water period, from July to October, ringed seals primarily dove on the continental shelf in the northern Chukchi Sea and on the Beaufort Sea shelf, in water < 200 m deep (Fig. 5). The highest use area occurred in and near Barrow Canyon and in western Beaufort Sea waters and was used most while sea ice remained in the area, primarily in July and early August. Seven of the 12 ringed seals tagged were captured near Utqiaġvik, adjacent to the high-use area and thus the significance of this area may be inflated. During the ice-covered period, from December to May, tagged ringed seals used areas along the Chukchi Sea coast, and in Kotzebue and Norton sounds. The highest use area in winter occurred in southeastern Kotzebue Sound (Fig. 6).

Daily haul-out probability for adult ringed seals was higher during the ice-covered period (43.2%) than during the open-water period (33.4%, i.e., they hauled out for 30 minutes or more approximately every third day; Table 3). The mean haul-out duration was 6.0 hours and was highest in May (8.4 hours) and June (10.9 hours) and lowest in September (3.3 hours) and October (3.7 hours).

We identified four occasions when ringed seals hauled out on land. An adult male hauled out near Icy Cape in July, a female pup hauled out on the north shore of Russia, west of Pevek and Chaunskaya Bay in October, and two adult males hauled out on the north shore of the Seward Peninsula, near Shishmaref, in November during their southward migration. Overall, regardless of substrate, ringed seal pups hauled out more often and for longer periods of time than adults during the open-water season. Although adults hauled out more often during the ice-covered season, they hauled out for longer duration during the open water season (Table 3).

Pupping occurs in April when locations for tagged seals were centered around Bering Strait (Fig. 2d). The ringed seals we tagged with CTD tags were all adult males, which defend breeding territories around females with pups, breeding with those females before their pups are weaned. Therefore, the locations of adult males can be used to locate pupping areas during the breeding season. During April–June ringed seals moved north and were north of Bering Strait over Chukchi shelf waters (Fig. 2d).

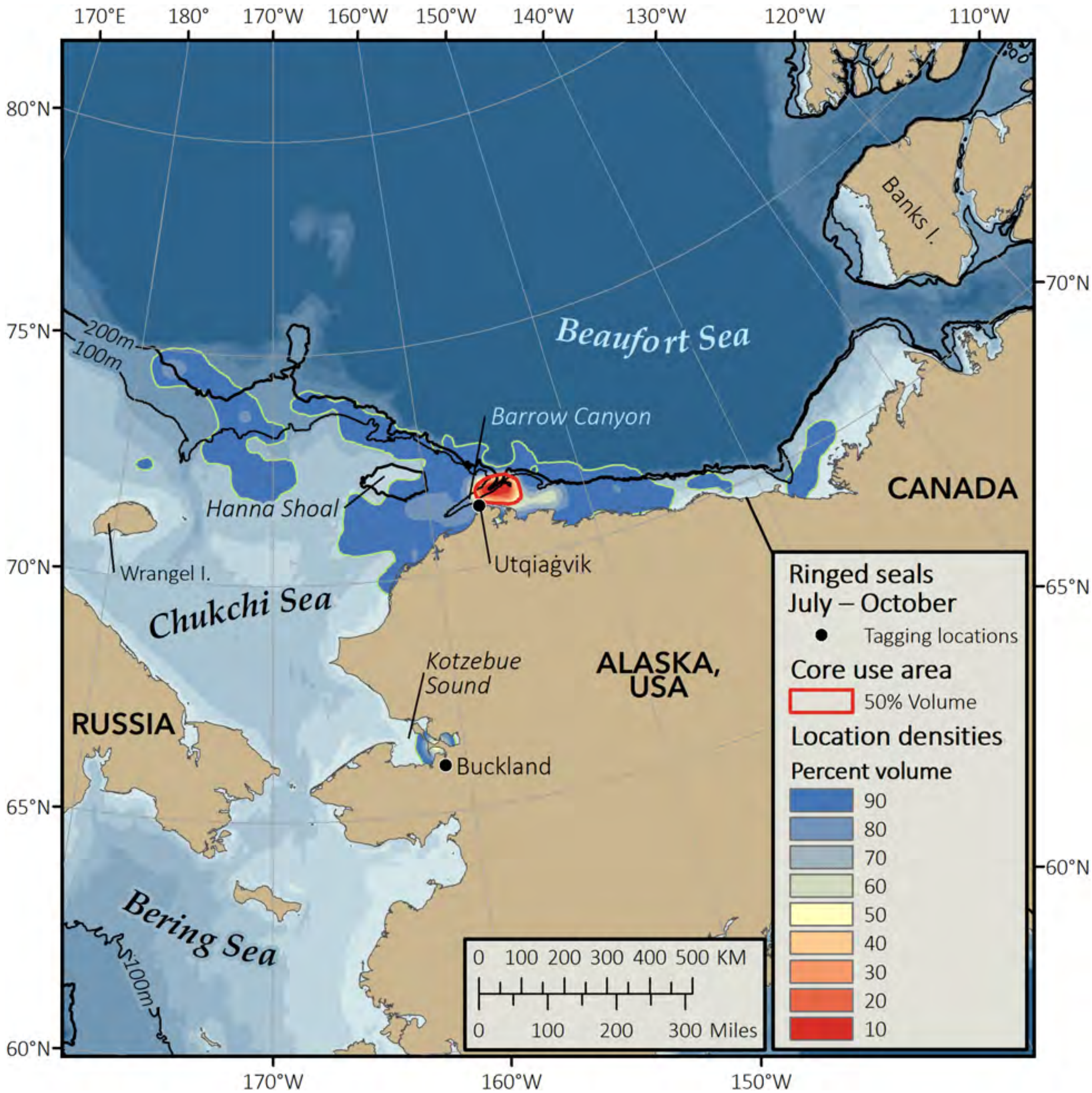


Figure 5. Distribution of ringed seal dive locations (assumed to be foraging locations) for 12 ringed seals during July–October 2014–2019. Seals were tagged near Utqiaġvik (n = 7) and in Kotzebue Sound (n = 5). The core-use area within the red circle represents the area with utilization distributions < 50% volume (i.e., areas with the highest density of locations) within the season and delineates the primary foraging area. Areas within the light green line represent utilization distributions < 90% volume (i.e., areas with lower densities of locations) also likely used for foraging.

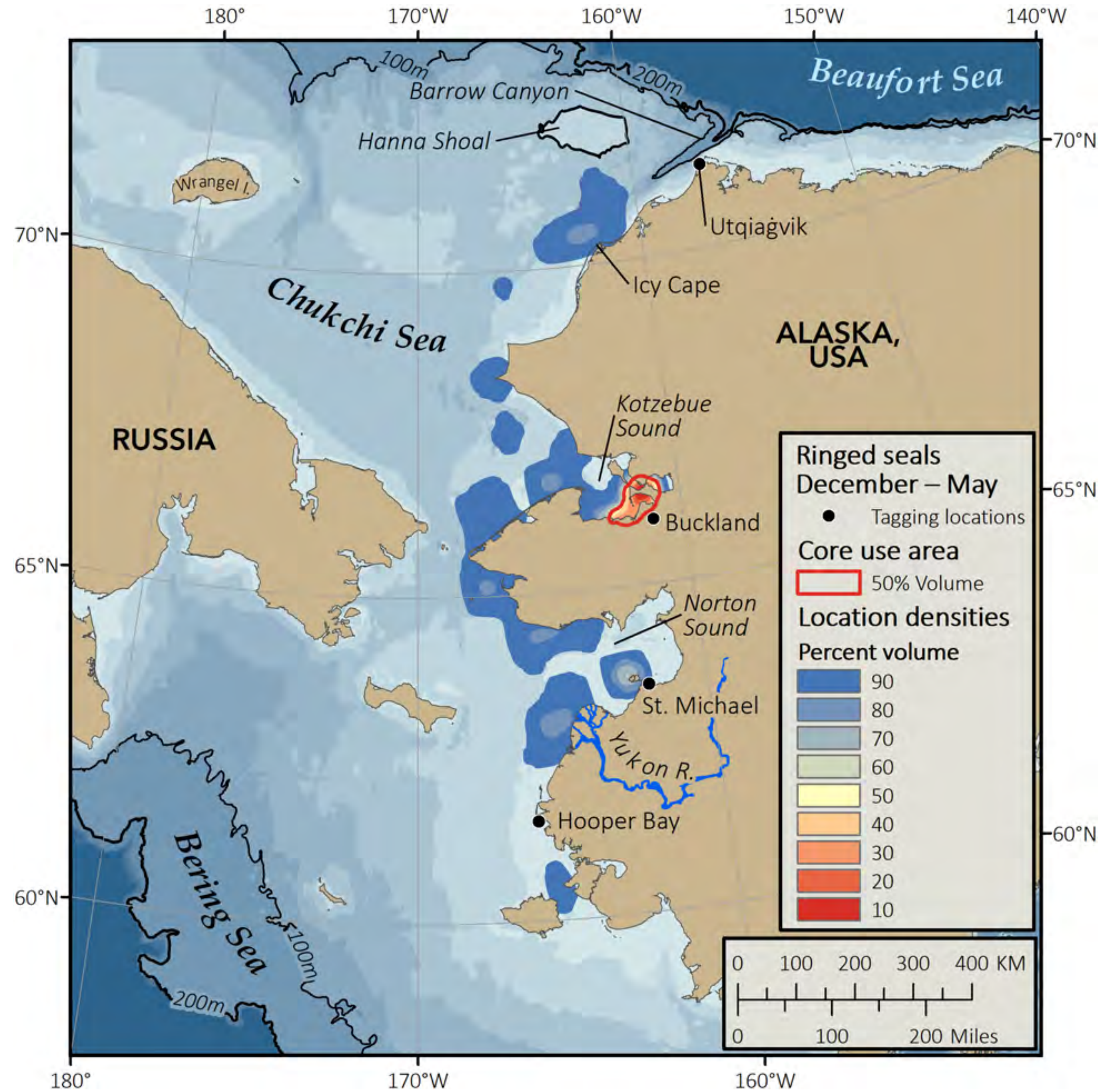


Figure 6. Distribution of ringed seal daily locations (assumed to be foraging locations) for 15 ringed seals during December–May 2014–2020. Seals were tagged near Utqiaġvik (n = 7), Kotzebue Sound (n = 6), St. Michael (n = 1), and Hooper Bay (n = 1). The core-use area within the red circle represents the area with utilization distributions < 50% volume (i.e., areas with the highest density of locations) within the season and delineates the primary foraging area.

Table 3. Haul-out duration and probability relative to seal species, season, and age class. The open-water season is May–November and the ice-covered season is December–April. Daily haul-out probability is the probability that a seal is hauled out for more than 30 minutes in a day.

Species	Season	Age class (*n*)	Mean duration (hours)	Max duration (hours)	Daily haul-out probability (%)
Bearded	Open-water	Adult (1)	7.1	58	48.7%
	Open-water	Young (24)	7.4	95	39.0%
	Ice-covered	Adult (1)	4.3	13	60.0%
	Ice-covered	Young (19)	5.9	53	44.4%
Ringed	Open-water	Non-pup (13)	6.0	51	33.4%
	Open-water	Pup (3)	7.0	26	82.3%
	Ice-covered	Non-pup (12)	5.4	23	43.2%
Spotted	Open-water	Non-pup (21)	8.4	146	36.5%
	Open-water	Pup (10)	7.2	115	27.7%
	Ice-covered	Non-pup (20)	8.6	119	38.4%
	Ice-covered	Pup (11)	7.6	52	27.3%

Bearded seals. Except for one adult male that was tagged in 2019, the bearded seals we tagged with CTD tags consisted of juveniles (< 2 years old). Therefore, we are only able to analyze habitat use and behaviors related to feeding and molting for juveniles, and briefly discuss patterns observed for the one tagged adult.

As mentioned above, movement patterns of juvenile bearded seals were highly variable. To potentially identify important habitats related to feeding, we fit a two-state switching, state space model to bearded seal movement data, which identified transiting or resident behavior. Transiting behavior consists of direct movements with longer step lengths and resident behavior consists of frequent turning and shorter step lengths (Olnes et al. *In review*). We found that distance from land, water depth, ice concentration, and distance from the ice edge did not influence seal behavior, and therefore suggest that resident behavior occurs when seals find suitable areas for foraging. Bearded seals appear to forage on the entire continental shelf, however, likely feeding hotspots include Barrow Canyon, Kotzebue and Norton sounds, and areas along the 100 m isobath in the Bering Sea (Fig. 7). It should also be noted that resident locations may sometimes include haul-out locations.

We found that bearded seals will haul out on land in addition to ice (Fig. 8). During the summer and early fall, when sea ice extent over the continental shelf is at its minimum, juvenile bearded seals either followed the ice north where they continued to use it as a haul-out platform, or used coastal haulouts where sea ice was not present. For seals with sufficient data to determine haul-out locations and durations during July–October, six seals hauled out on sea ice and seven seals hauled out on land. Two seals hauled out on both land and sea ice during these months, but in different years. Haul-outs on land appeared to mainly occur in bays near river outlets. Specific locations where seals hauled out on land included river outlets in Norton and Kotzebue sounds and in Mechigmenskaya Bay, Russia. The adult male also hauled out on land during this time, mainly near river outlets in Dease Inlet in the Beaufort Sea (Fig. 8).

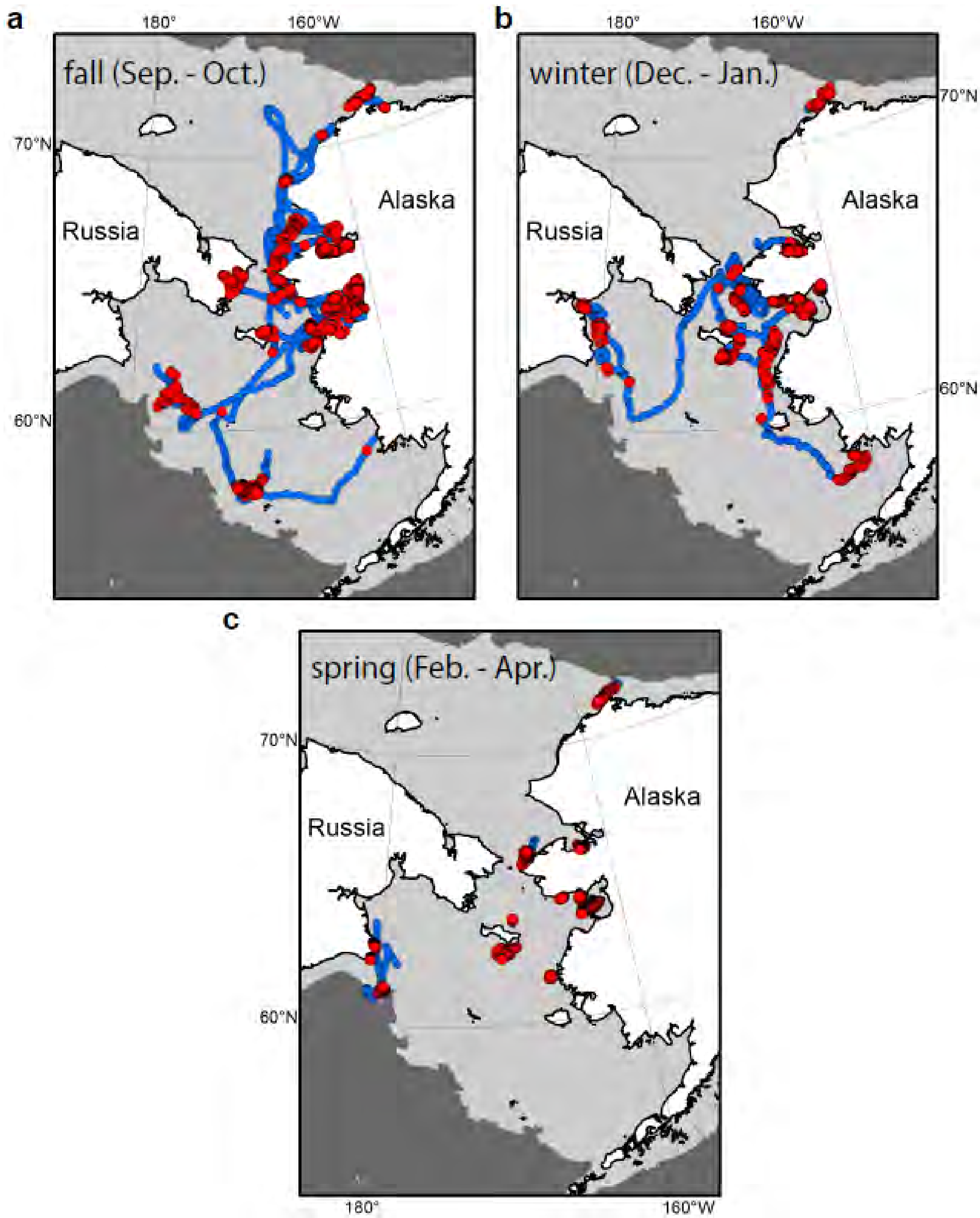


Figure 7. Locations where juvenile bearded seals exhibited transiting (blue) or resident (red) behavior during the (a) fall, (b) winter, and (c) spring. Areas where seals exhibited resident behavior are likely foraging areas. Light grey shading represents the continental shelf, where water is < 200 m deep.

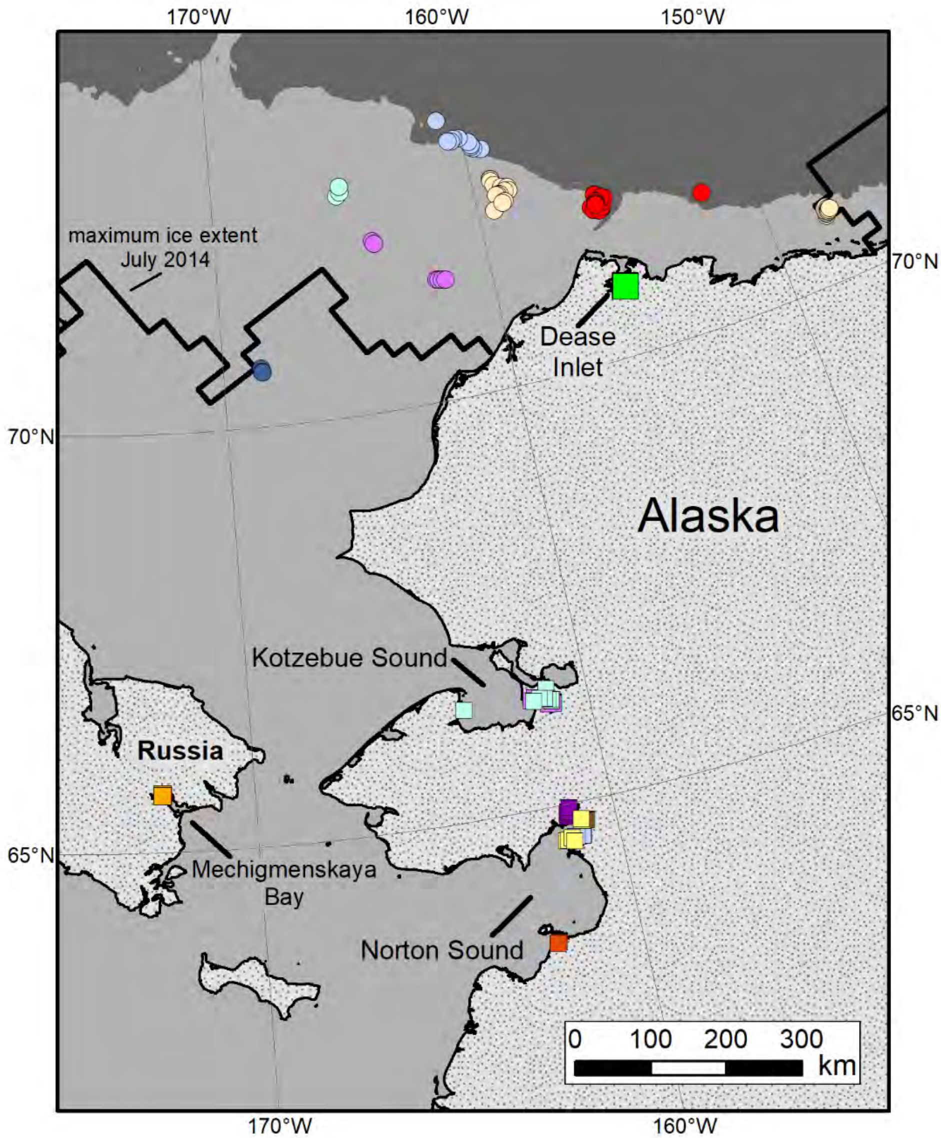


Figure 8. Haulout locations for 11 juvenile bearded seals (2014–2018) and one adult bearded seal (large green square, 2019) during the minimum ice period July–October. Circles represent haul-out location on sea ice and squares represent haul-out locations on land, all are color-coded by individual seal. The black line is the maximum monthly ice extent for July–October over the shelf during 2014–2018, which occurred in July 2014. Light grey shading represents the continental shelf, where waters are < 200 m deep.

Spotted seals. We identified high-use foraging areas by estimating the density of spotted seal daily locations (i.e., utilization distribution), throughout the Bering and Chukchi seas. To distinguish foraging areas offshore from resting areas onshore, we present separate densities for spotted seals locations > 5 km from shore (offshore) and < 5 km from shore (onshore). During the open-water season, the primary foraging area for seals tagged in the Beaufort Sea was between Herald Shoal and nearshore waters of the northeastern Chukchi Sea, from Icy Cape north to Barrow Canyon (Fig. 9) and their primary resting areas were near Icy Cape and Dease Inlet (Fig. 10). For spotted seals tagged in the

Bering Sea, the primary foraging area was offshore of their tagging location near Scammon Bay, in waters < 300 km from shore (Fig. 11) and they rested primarily on the barrier islands of Scammon Bay (Fig. 12). These movement patterns highlight the importance of tagging seals in multiple regions annually to understand movements and habitat use throughout their range.

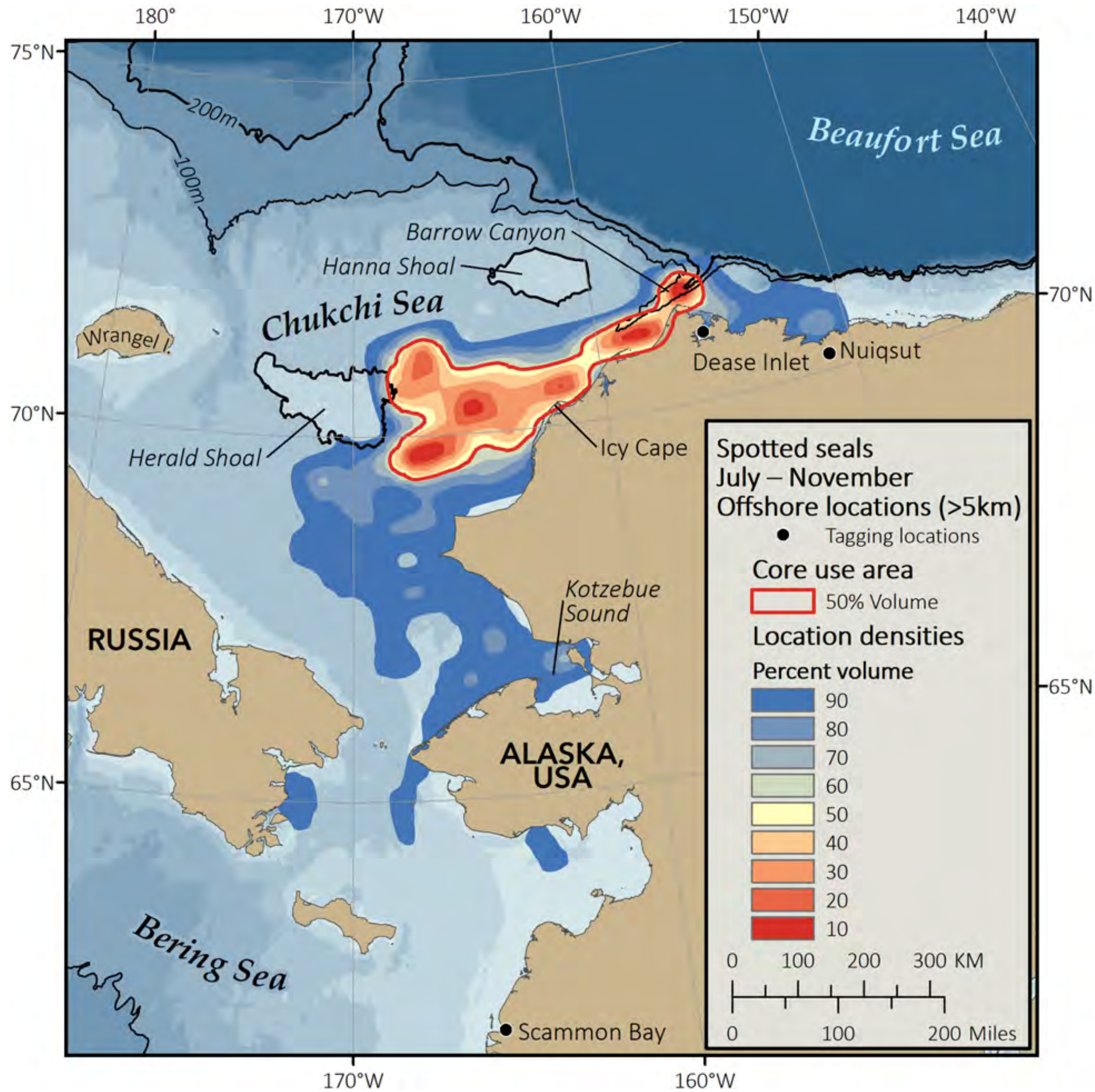


Figure 9. Offshore (> 5 km) distribution of spotted seals during the open-water seasons (July–November) of 2016–2019. Seals were tagged in the Beaufort Sea (n = 24; Dease Inlet and Colville River/Nuiqsut). The core-use area within the red circle represents the area with utilization distributions < 50% volume (i.e., areas with the highest density of locations) within the season and delineates the primary foraging area. Other colored areas represent utilization distributions < 90% volume (i.e., areas with lower densities of locations) also likely used for foraging.

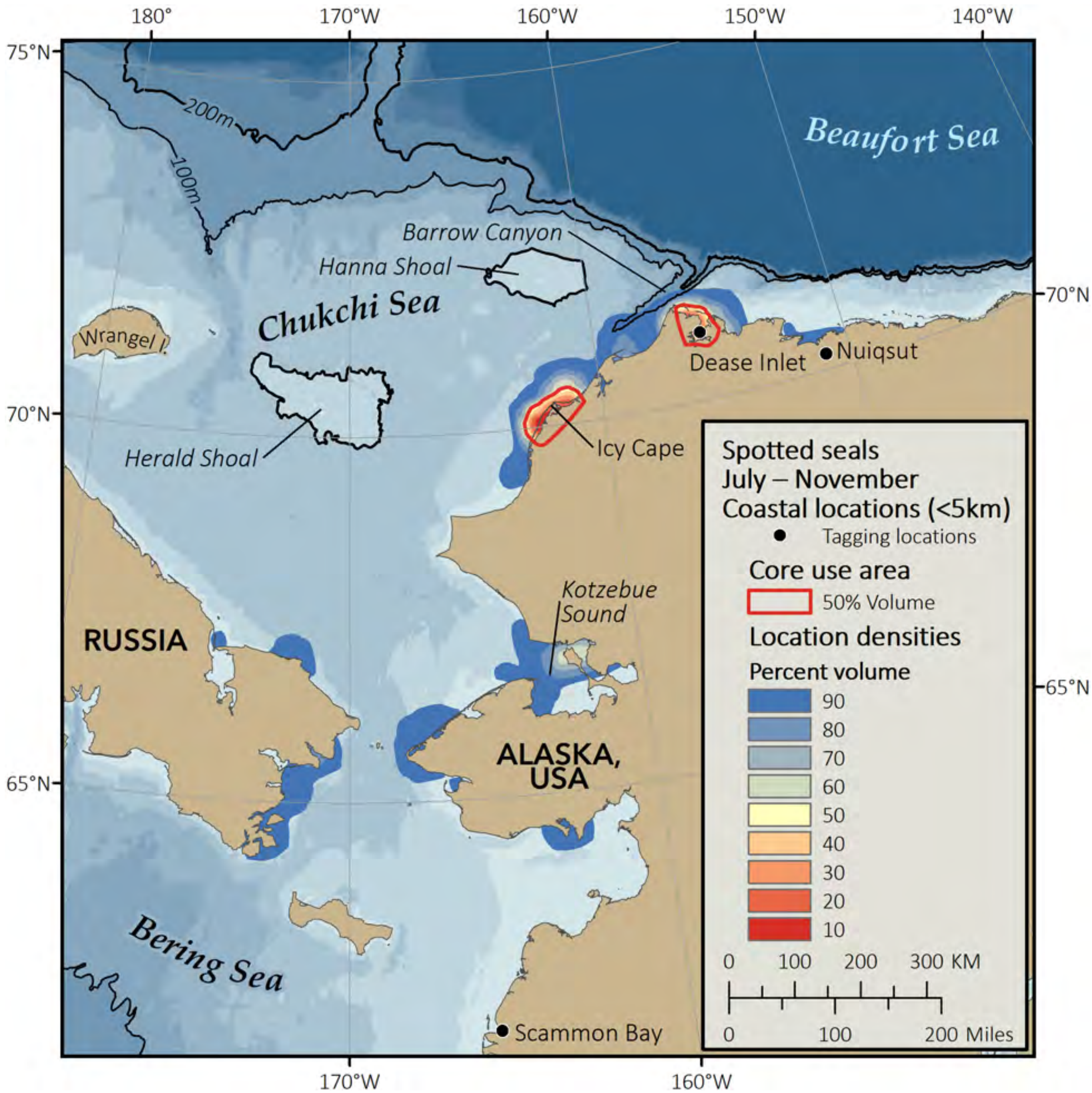


Figure 10. Nearshore (< 5 km) distribution (including terrestrial haulout locations) of spotted seals during the open-water seasons (July–November) of 2016–2019. Seals were tagged in the Beaufort Sea (n = 24; Dease Inlet and Colville River/Nuiqsut). Core-use areas within the red circles represent areas with utilization distributions < 50% volume (i.e., areas with the highest density of locations) within the season and delineate primary resting areas. Other colored areas represent utilization distributions < 90% volume (i.e., areas with lower densities of locations) also likely used for resting. Haul-out behavior data within these nearshore core-use areas further supported their identification as resting areas.

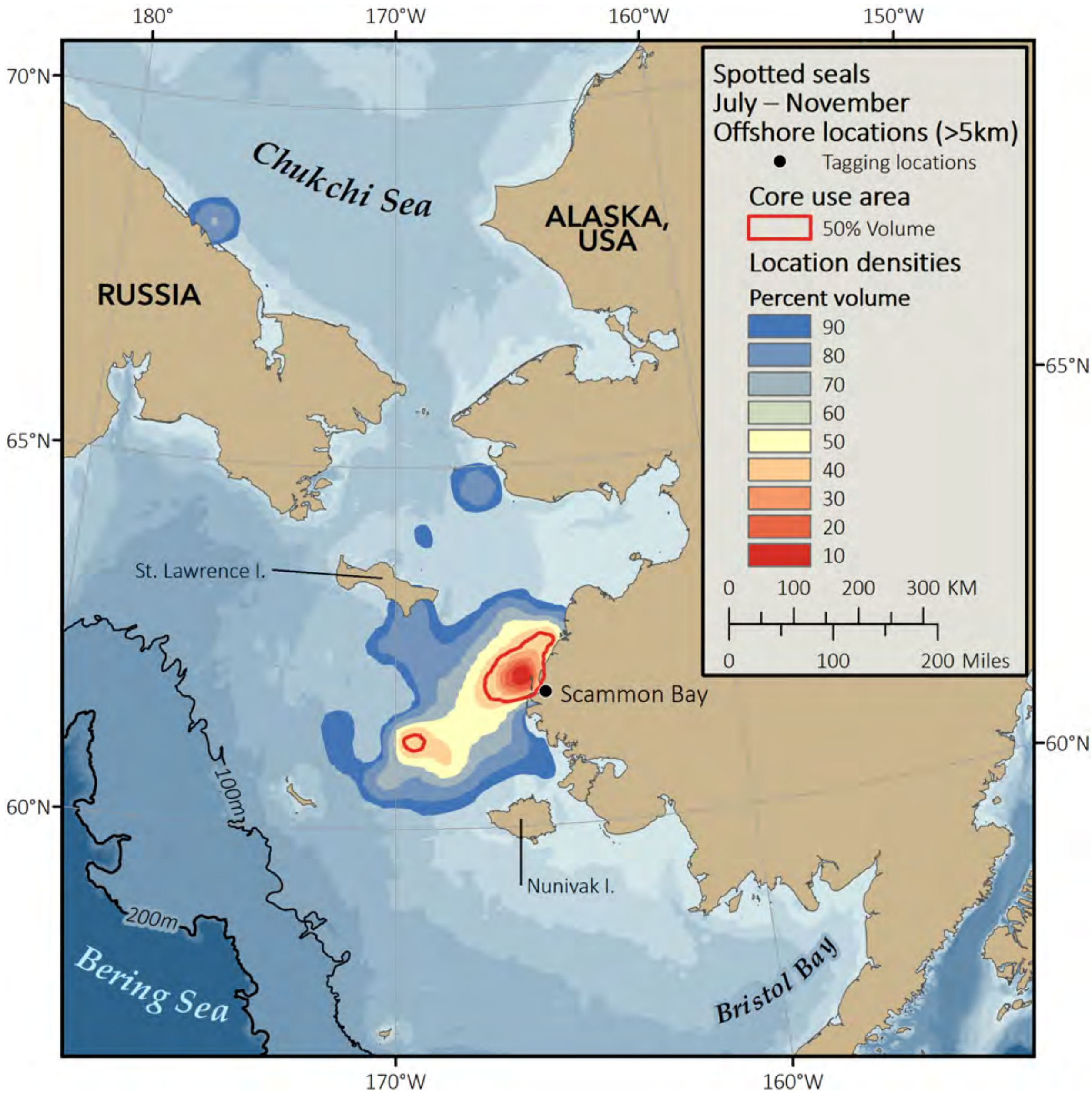


Figure 11. Offshore (> 5 km) distribution of spotted seals tagged in the Bering Sea (n = 7; Scammon Bay) during the open-water seasons (July–November) of 2016–2019. Core-use areas within the red circles represent areas with utilization distributions < 50% volume (i.e., areas with the highest density of locations) within the season and delineate primary foraging areas. Other colored areas represent utilization distributions < 90% volume (i.e., areas with lower densities of locations) also likely used for foraging.

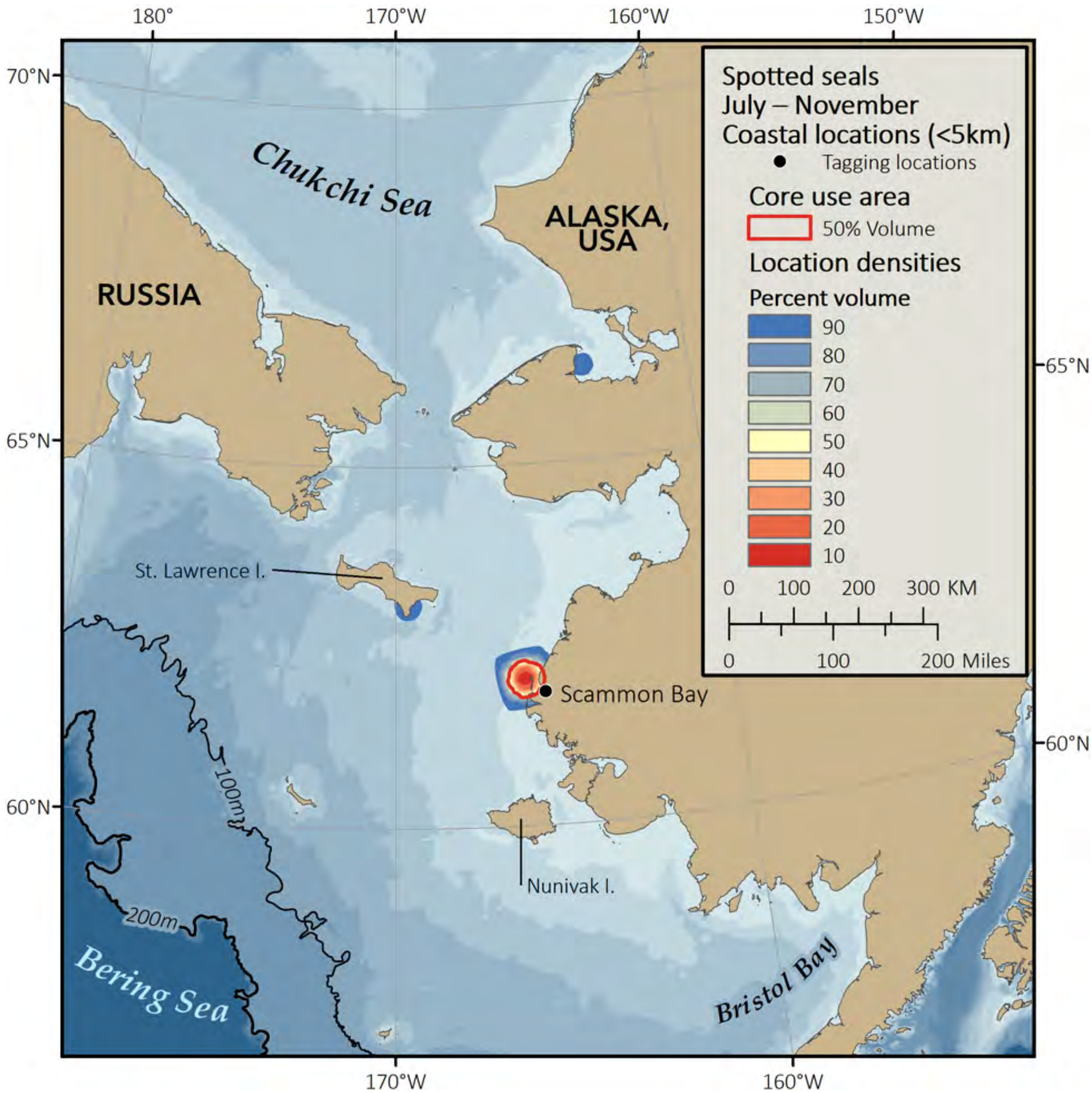


Figure 12. Nearshore (<5 km) distribution (including terrestrial haulout locations) of spotted seals tagged in the Bering Sea (n = 7; Scammon Bay) during the open-water seasons (July–November) of 2016–2019. The core-use area within the red circle represents the area with a utilization distribution < 50% volume (i.e., area with the highest density of locations) within the season and delineates the primary resting area. Haul-out behavior data within these nearshore core-use areas further supported their identification as primary resting areas.

During winter (December–April), when sea ice was present, all spotted seals, regardless of where they were tagged, moved into the Bering Sea and high-use areas were near Nunivak Island, Bristol Bay, and in the central Bering Sea, (Fig. 13). Winter high-use areas, however, were strongly dependent on sea ice. During winters when little sea ice formed late in the central Bering Sea (2016/17, 2017/18, and 2018/19), seals primarily used areas near shore (Fig. 14), whereas during a winter when sea ice coverage extended into the central Bering Sea and was more characteristic of historical ice extents

(2019/20), seals primarily used areas far from shore in the central Bering Sea (Fig. 15). These different uses of ice habitat highlight the importance of tagging seals annually to understand habitat use relative to changes in sea ice coverage.

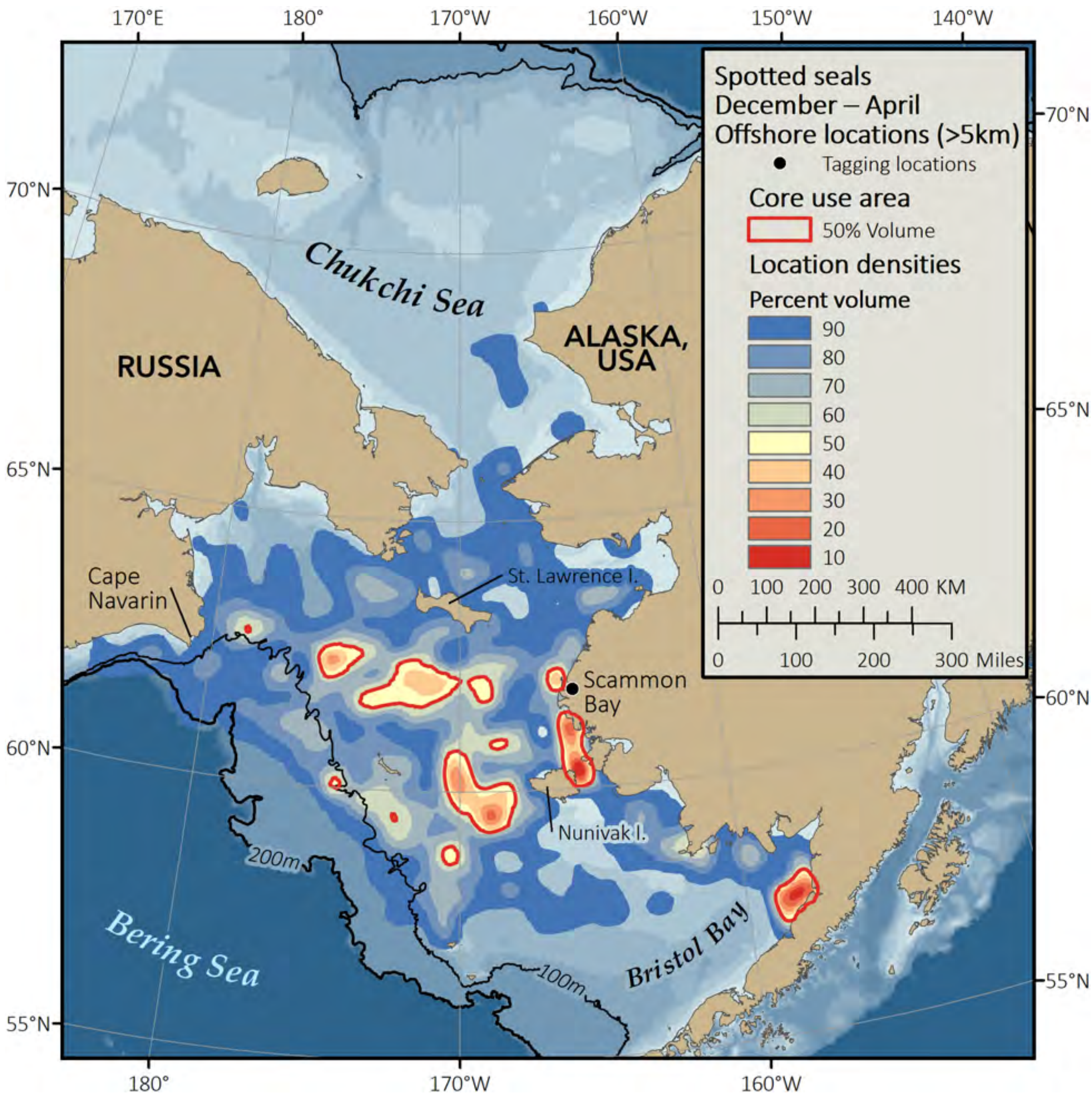


Figure 13. Offshore (> 5 km) distribution of all spotted seals during the ice-covered season (December–April) of 2016–2020. Seals were tagged in the Beaufort Sea (n = 24; Dease Inlet and Colville River/Nuiqsut) and Bering Sea (n = 7; Scammon Bay). Core-use areas within red circles represent areas with utilization distributions < 50% volume (i.e., areas with the highest density of locations) within the season and delineate primary foraging and resting areas. Other colored areas represent utilization distributions < 90% volume (i.e., areas with lower densities of locations) also likely used for foraging and resting.

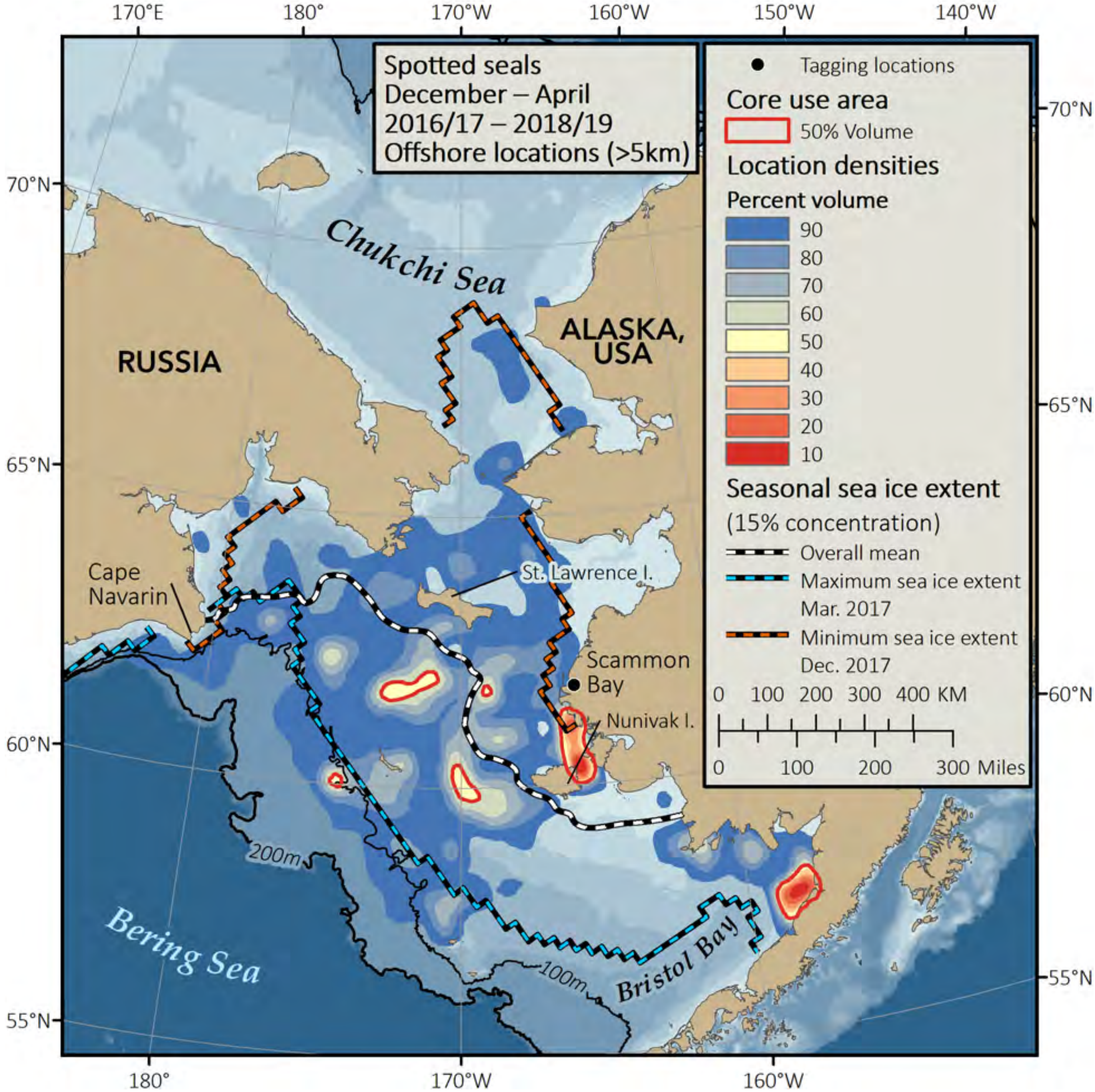


Figure 14. Offshore (> 5 km) distribution of all spotted seals during the ice-covered season (December–April) of light ice years, 2016–2019. Seals were tagged in the Beaufort Sea (n = 17; Dease Inlet and Colville River/Nuiqsut) and Bering Sea (n = 7; Scammon Bay). Core-use areas within red circles represent areas with utilization distributions < 50% volume (i.e., areas with the highest density of locations) within the season and delineate primary foraging and resting areas. Other colored areas represent utilization distributions < 90% volume (i.e., areas with lower densities of locations) also likely used for foraging and resting. Seasonal sea ice extents represent the monthly mean 15% ice concentration based on Advanced Microwave Scanning Radiometer-Earth data (National Snow and Ice Data Center) for: (1) overall mean extent, average of all monthly mean extents during the period, (2) maximum sea ice extent, farthest monthly mean ice extent during each period, and (3) minimum sea ice extent, least monthly mean ice extent during each period, from 2017–2019.

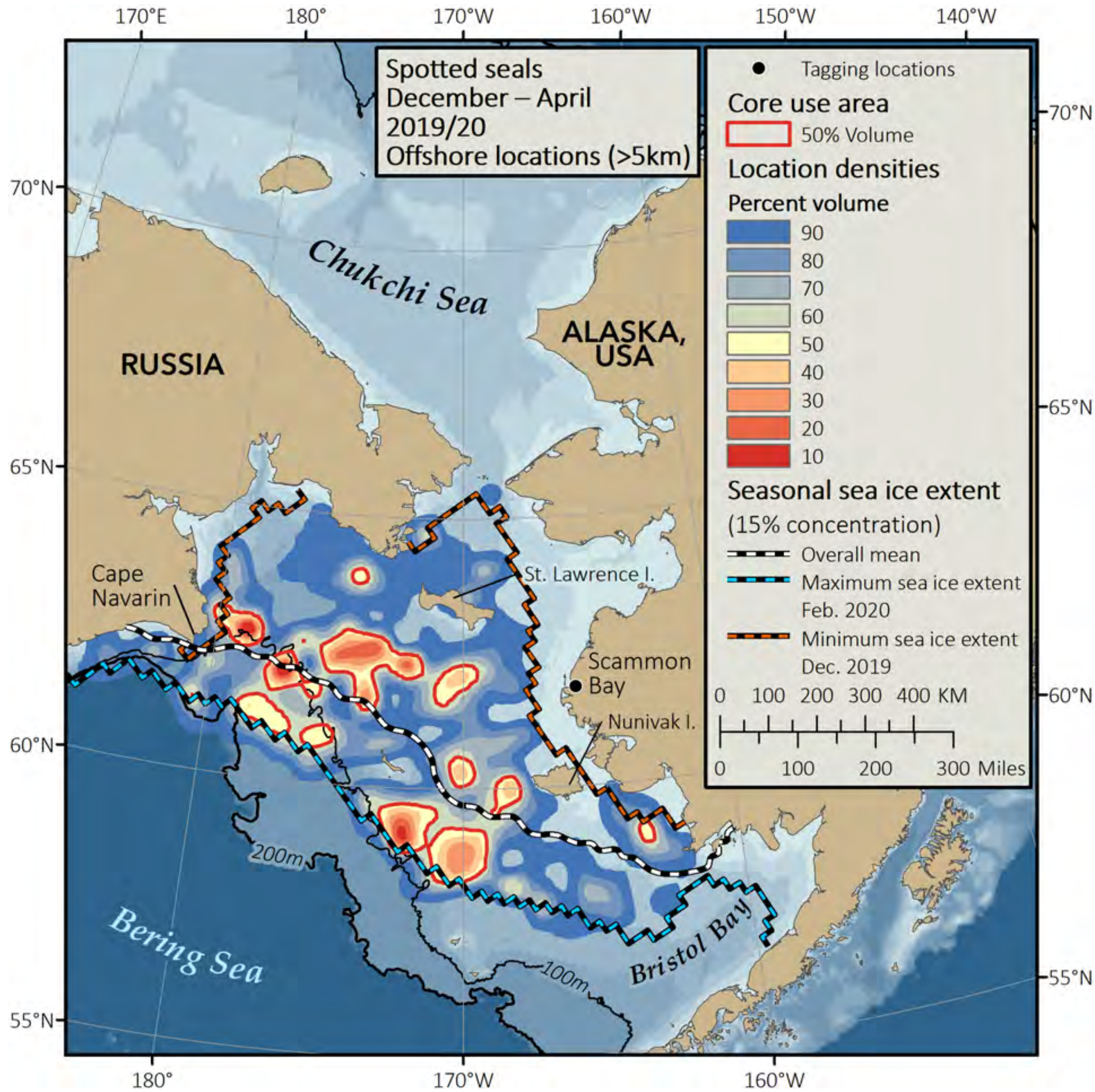


Figure 15. Offshore (> 5 km) distribution of all spotted seals during the ice-covered season (December–April) of a heavier ice year, 2019/20. Seals were tagged in the Beaufort Sea (n = 7; Dease Inlet and Colville River/Nuiqsut). Core-use areas within the red circles represent areas with utilization distributions < 50% volume (i.e., areas with the highest density of locations) within the season and delineate primary foraging and resting areas. Other colored areas represent utilization distributions < 90% volume (i.e., areas with lower densities of locations) also likely used for foraging and resting. Seasonal sea ice extents represent the monthly mean 15% ice concentration based on Advanced Microwave Scanning Radiometer-Earth data (National Snow and Ice Data Center) for: (1) overall mean extent, average of all monthly mean extents during the period, (2) maximum sea ice extent, farthest monthly mean ice extent during each period, and (3) minimum sea ice extent, least monthly mean ice extent during each period, from 2020.

During the open-water period, spotted seals regularly hauled out on land, primarily on barrier islands, to rest between foraging bouts. The daily haul-out probability was 36.5% for adults and 27.7% for pups (i.e., approximately every third day; Table 3). In the Bering Sea, these resting areas included Scammon Bay and St. Lawrence Island (Fig. 12) and seals spent an average of 36.8 hours resting (i.e., hauled out) between foraging trips. In the Chukchi Sea, resting areas included the barrier islands along the northwest coast of Alaska and in the Beaufort Sea, in Dease Inlet, and in the Colville River Delta near Nuiqsut (Fig. 10). Haulout locations were used interchangeably, with no apparent preference, and seals spent an average of 43.2 hours hauled out between foraging trips. Once sea ice started to advance south, spotted seals transitioned from hauling out on land to using sea ice between foraging bouts. Daily haul-out probability during the ice-covered season was similar to the open-water season (38.4% for adults vs. 27.3% for pups). As with the open-water season, both adults and pups hauled out approximately every third day; the mean haul-out duration was 8.4 hours for adults and 7.2 hours for pups (Table 3).

Spotted seals winter in the Bering Sea along the ice edge and are located farther from shore than during summer. During the winters of 2016/17, 2017/18, and 2018/19, when little sea ice formed in the Bering Sea, spotted seals used ice when it was available, but primarily hauled out on land at St. Lawrence, St. Matthew, and Nunivak islands, as well as coastal areas between the Yukon and Kuskokwim River deltas after foraging bouts to the south and west (Fig. 14). During the winter of 2019/20, when sea ice coverage in the Bering Sea was extensive, spotted seals were distributed across the central Bering Sea, with little use of land haulouts (Fig. 15).

Pupping occurs in March and April, within marginal sea ice (concentration 15–80%) in the Bering sea. Based upon the distribution of tagged seals in the spring, it is reasonable to assume that pupping occurs farther from shore when there is more sea ice than when there is less (i.e., compare Figs. 14 and 15). During years when sea ice advances to the central Bering Sea, spotted seals haul out and pup on the ice throughout the area (Fig. 15). During years sea ice is limited, spotted seals must use sea ice closer to the coast for pupping (Fig. 14).

Objective 3) Relate oceanographic data collected by CTD (conductivity, temperature, and depth) tags manufactured by the Sea Mammal Research Unit (SMRU), St. Andrews, Scotland) to seal movements and habitat use. Relate oceanographic data collected by CTD tags to behavior of known prey species (identified by Alaska Department of Fish and Game (ADFG) biomonitoring program) to investigate seal foraging patterns.

Ringed seals. During the open-water period, ringed seals that moved north of the shelf, into deeper water to follow the receeding pack ice, dove into water masses not available to them on the shelf. From July to October, ringed seals that dove deeper than 100 m (526 dives) dove to an average depth of 172.2 m (range: 100–321.5 m) in water averaging 767 m deep (range: 100–3,862 m) and often dove into Atlantic Water (AW; Fig. 16). For example, CTD profiles for ringed seal RS16-07-M during 10–16 September 2016 when the seal was in water ~ 200 m show that the seal mostly dove to the bottom presumably to forage in AW (salinity > 33.6 psu and temperature > -1.26° C) near the seafloor (Fig. 17). Arctic cod, a primary prey fish of ringed seals, are known to form large shoals within AW (Crawford, Vagal et al. 2012). During this same period, ringed seals that remained on the continental shelf dove to more water masses, primarily targeted Bering Summer Water (BSW), but also Alaskan Coastal Water (ACW) and Remnant Winter Water (RWW; Fig 18). For example, CTD profiles for ringed seal RS17-02-M during 4–11 September 2017 when the seal was on the continental shelf in water < 50 m show that the seal dove mostly to the sea floor to colder, saltier water (Fig. 19).

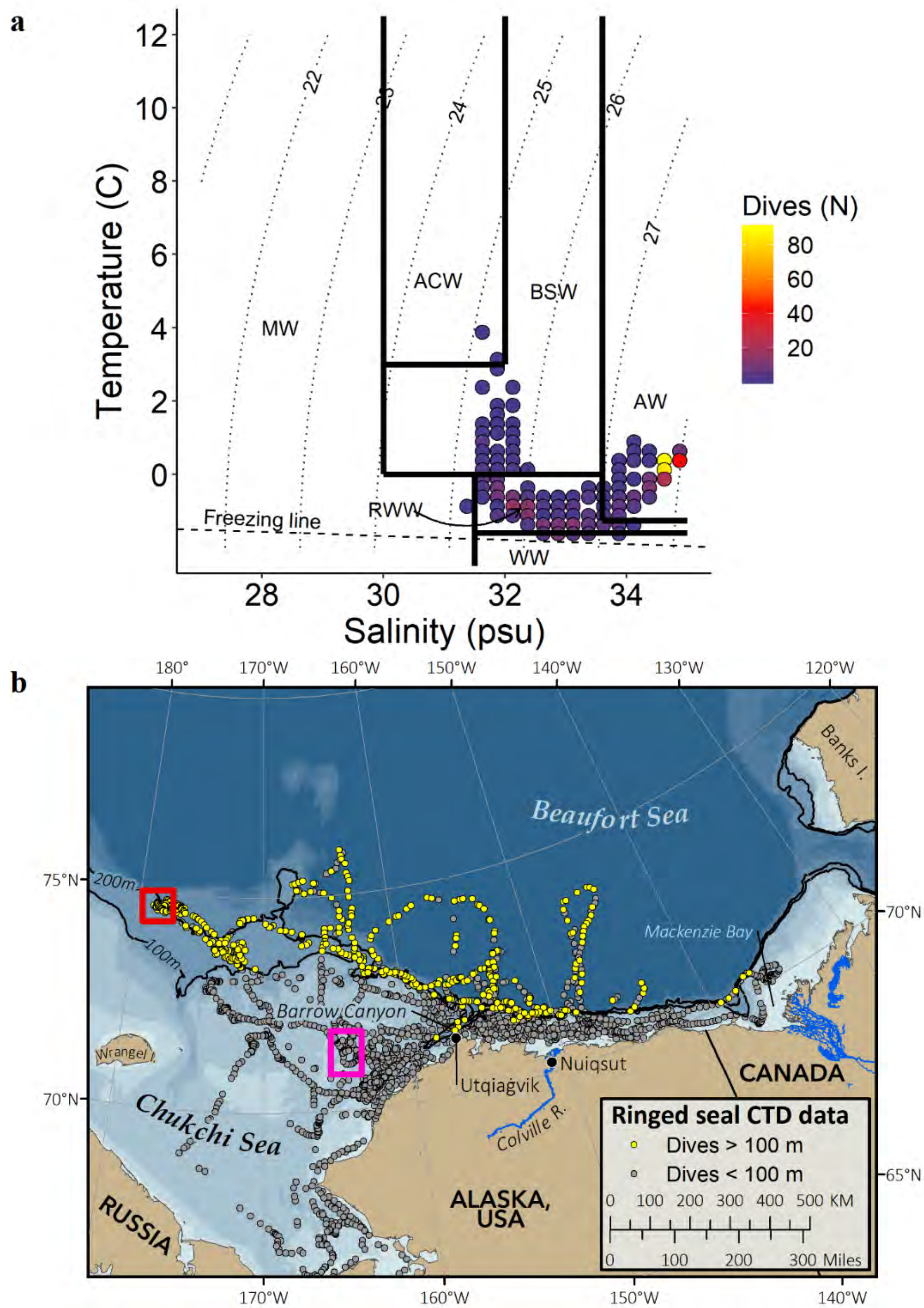


Figure 16. Temperature and salinity at maximum dive depths (a) from dive locations of ringed seals diving deeper than 100 m (yellow circles) from July to October 2016–2019 (b). Warm colors in (a) depict a greater number of dives. Solid black lines are defined water mass boundaries. Water masses are Melt Water (MW), Alaskan Coastal Water (ACW), Bering Summer Water and Siberian Shelf Water (BSW), Remnant Winter Water (RWW), Winter Water (WW), and Atlantic Water (AW). Curved dotted lines are water density values and the dashed line is the freezing point for sea water as salinity changes. Blue shading in (b) is bathymetric depth, where lighter colors are shallower waters and darker colors are deeper waters. Red box in (b) is location of CTD profile in Figure 17 and pink box is location of CTD profile in Figure 19.

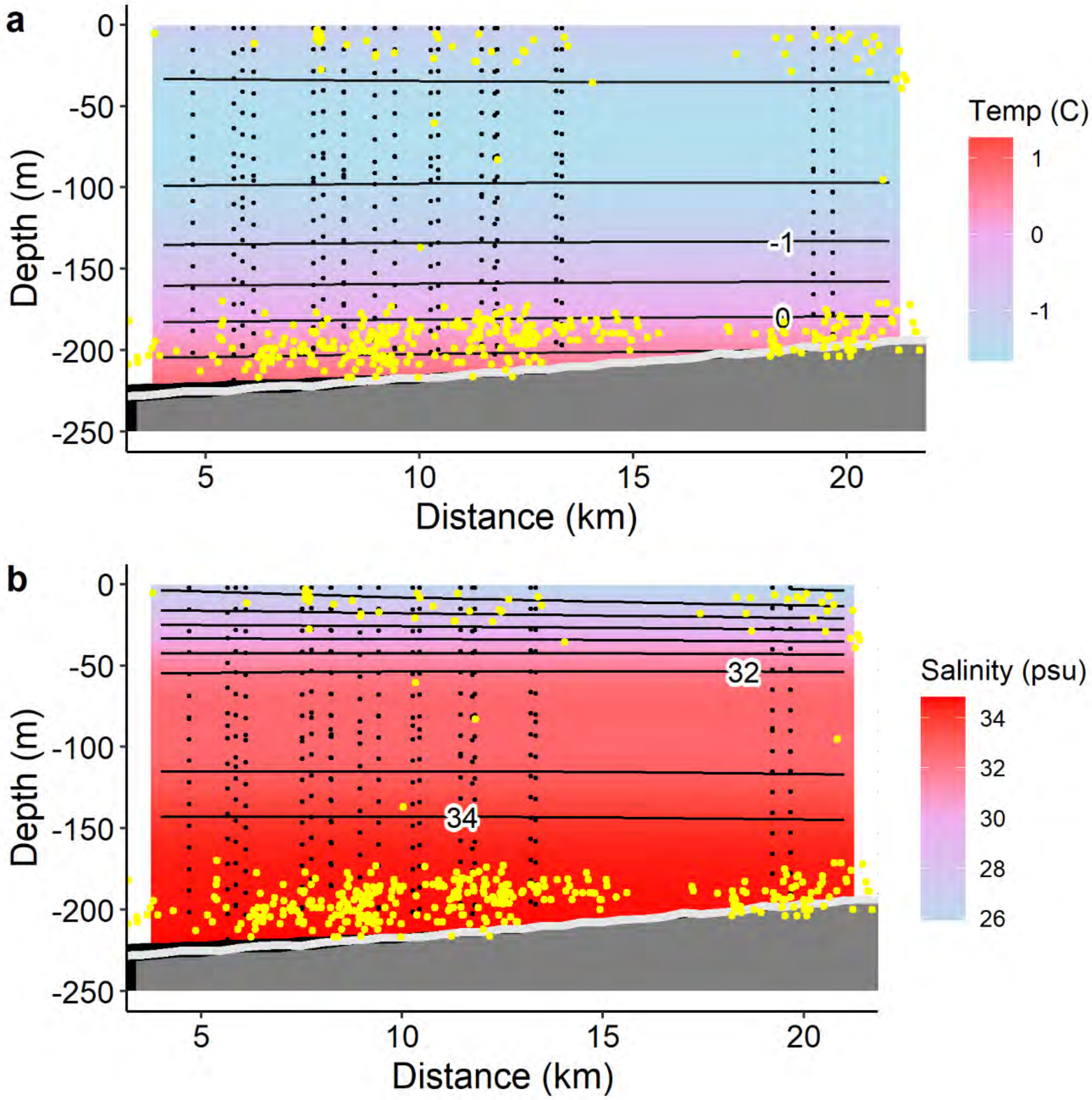


Figure 17. Temperature and salinity profiles along a cross section north of Wrangel Island, collected by a CTD tag deployed on an adult ringed seal (R16-07-M) during 10–16 September 2016. Black dots are CTD data collection points and yellow dots are the target depths of individual dives (i.e., depth where the seal spent the most time). Light grey line and dark grey and black bands represent how the bathymetry varied along this cross section that depicts a region 21 km wide (x-axis) and ~20 km long. Location of profile is shown as red box in Figure 16b. Viewing direction of profile is from NW to SE.

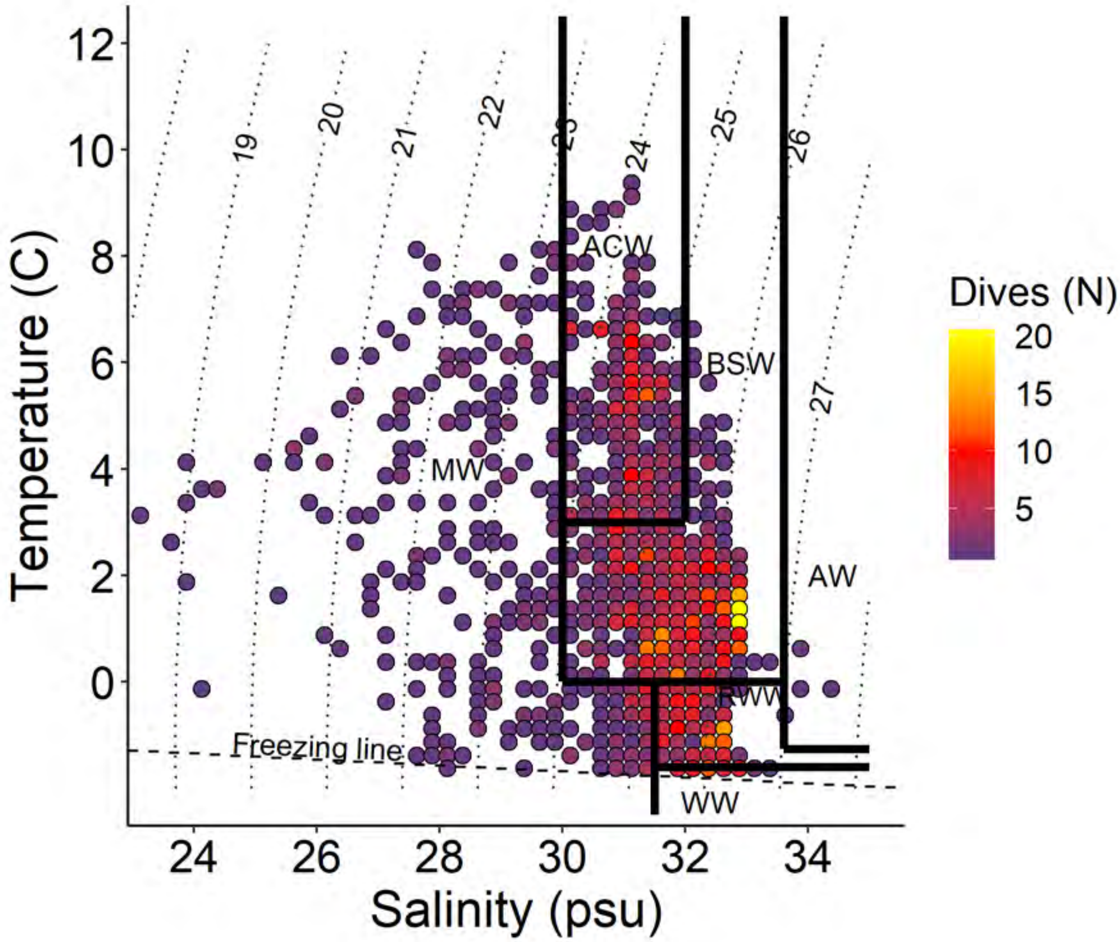


Figure 18. Temperature and salinity at maximum dive depths from dive locations of ringed seals diving less than 100 m (gray circles) on Figure 16b, from July to October 2016–2019. Warm colors depict a greater number of dives. Solid black lines are defined water mass boundaries. Water masses are Melt Water (MW), Alaskan Coastal Water (ACW), Bering Summer Water (BSW), Remnant Winter Water (RWW), Winter Water (WW), and Atlantic Water (AW). Curved dotted lines are water density values and the dashed line is the freezing point for sea water as salinity changes. Gray shading in (b) is bathymetric depth, where lighter colors are shallower waters and darker colors are deeper waters.

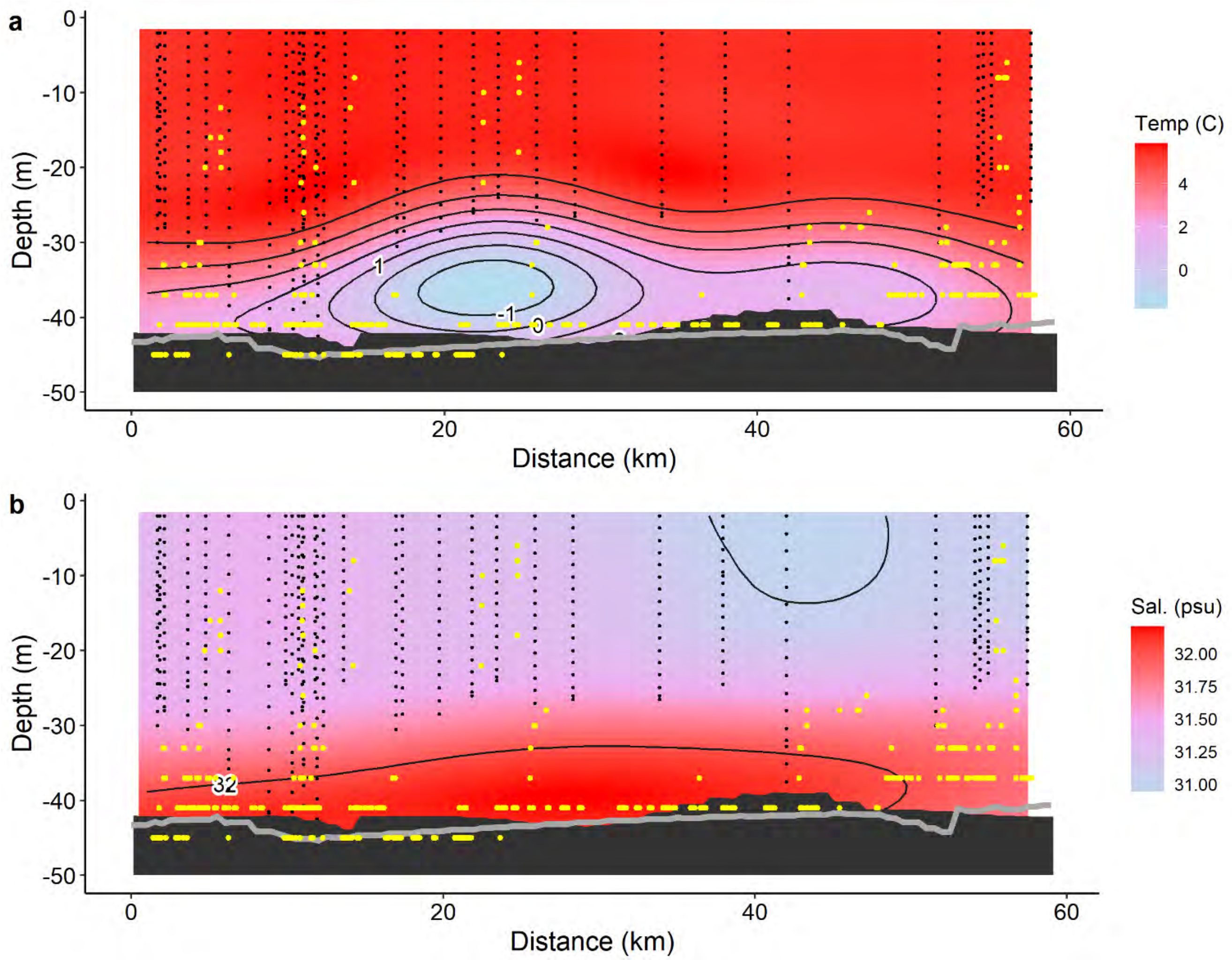


Figure 19. Temperature (a) and salinity (b) profiles along a cross section of the northeast Chukchi Sea, collected by a CTD tag deployed on an adult ringed seal (RS17-02-M) during 4–11 September 2017. Black dots are CTD data collection points and yellow dots are the target depths of individual dives (i.e., depth where the seal spent the most time). Light gray line and black band represent how the bathymetry varied along this cross section that depicts a region ~20 km wide (x-axis) and ~60 km long. Location of profile is pink box shown in Figure 16b. Viewing direction of profile is from N to S.

<u>Bearded seals</u>. As benthic foragers, bearded seals primarily dive to the sea floor. We found that 85% of all dives from juvenile bearded seals were to the sea floor, where they spent ~50% of their time (Olnes et al. 2020, Appendix B). This dive behavior does not appear to change whether a seal is in a transiting or resident (presumably feeding) state, which suggests they are constantly sampling the sea floor and stop in areas where they find productive foraging (see Fig. 7). However, CTD data may be able to clarify which water masses help support productive benthic communities upon which bearded seals feed. In addition, CTD data may also help identify water masses bearded seals target when making pelagic dives, presumably to feed in the water column.

For example, two bearded seals with CTD tags, one adult and one juvenile, primarily used Barrow Canyon. Barrow Canyon is of interest because it is one of the primary pathways by which zooplankton rich water from the Bering Sea enters the Arctic Ocean (e.g., Berline et al. 2008). Zooplankton are thought to be deposited within the canyon, accounting for the productive benthic community that occurs there (Rand et al. 2018).

Juvenile bearded seal, BS17-01-F, used the east side of Barrow Canyon from early August 2017 to late February 2018, and during that time its CTD tag collected and transmitted 729 CTD profiles. Plotting these profiles together demonstrates the abundance of data collected by an individual seal in an area of ecological importance (Barrow Canyon). These data represent almost continuous CTD profiles in Barrow Canyon to depths of at least 100 m for ~7 months (Fig. 20). Interpreting data presented this way is challenging, however, because changes in temperature or salinity could be derived from movements along the canyon or from water conditions that change over time. Nonetheless, two notable patterns are apparent. A clear cooling trend is identifiable from August 2017 to February 2018, and clustering of data values by month suggests that the seal remained in specific water masses over long periods of time (Fig. 20).

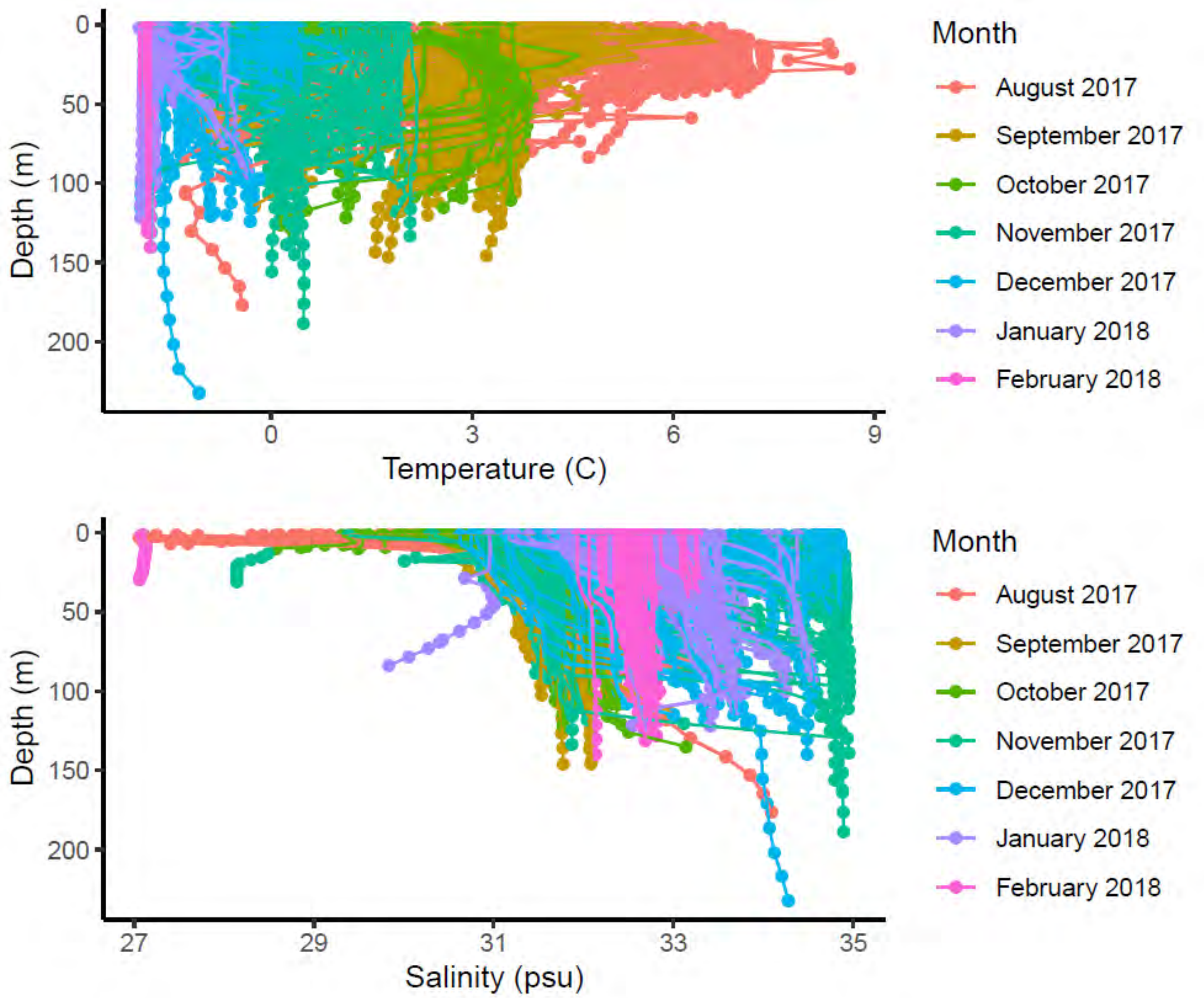


Figure 20. Temperature and salinity values from 729 CTD profiles collected from a CTD tag deployed on a juvenile bearded seal (BS17-01-F) along the east side of Barrow Canyon, August 2017–February 2018.

Water masses for this region have only been defined, based upon temperature and salinity, for the ice-free periods of June–November by oceanographic surveys and moorings (e.g., Corlett and Pickart 2017). Temperature and salinity values at the maximum depth of each CTD profile collected by this juvenile bearded seal showed that it mainly dove into BSW during the months August–November (Fig. 21). In November, the seal also frequently used the upper layer of AW.

Although bearded seals primarily dive to the sea floor, this juvenile made a considerable number of pelagic dives. During the period of 13–28 September, this seal made benthic and pelagic dives that targeted colder, more saline BSW that was below warmer and fresher ACW (Fig. 22). The Alaska Coastal Current (which consists of ACW), often extends to depths of 100–150 m along the east side of Barrow Canyon during the summer and fall. However, east winds push the current away from the eastern edge of Barrow Canyon, causing ACW to occur at shallower depths in this area (Stafford et al. 2016). This latter pattern was apparent during this two-week period (Fig. 22) when winds were predominantly from the east (11 of 15 days).

The adult bearded seal (BS19-01-M) also used the east side of Barrow Canyon during the fall of 2019, during which its tag collected 393 CTD profiles. Water masses targeted by the adult during this time (Fig. 23) were similar to that targeted by the juvenile in 2017 (Fig. 21), although the adult appeared to target ACW more in October and AW more in November (compare Fig. 23 with Fig. 21).

Interestingly, during 13–28 September 2019, the adult bearded seal frequently used an area directly adjacent to the area used by the juvenile bearded seal during that period in 2017. CTD data from the adult shows oceanographic conditions in 2019 were similar to those in 2017 in this area (Compare Figs. 22 and 24). In 2019, winds were more variable than in 2017, but still predominantly from the east. As a result, the warmer, less saline ACW transitioned to BSW at shallower depths than if winds were not predominantly from the east. The most notable difference between the two time periods, however, is that ACW was significantly warmer (> 6° C) in 2019 (Fig. 24) than surface temperatures in 2017 (< 4° C; Fig. 22). A notable difference regarding seal behavior is that the adult appeared to make only benthic dives (Fig. 24) during this time whereas the juvenile made numerous pelagic dives when oceanographic conditions were similar (Fig. 22).

Within Barrow Canyon, pelagic dives made by the juvenile bearded seal targeted cooler, saltier water masses from the Bering Sea, which have been identified as preferred habitat for Arctic cod in Barrow Canyon (Logerwell et al. 2018). Bearded seals do eat Arctic cod (Quakenbush et al. 2011) and it is possible this juvenile was targeting this fish in Barrow Canyon.

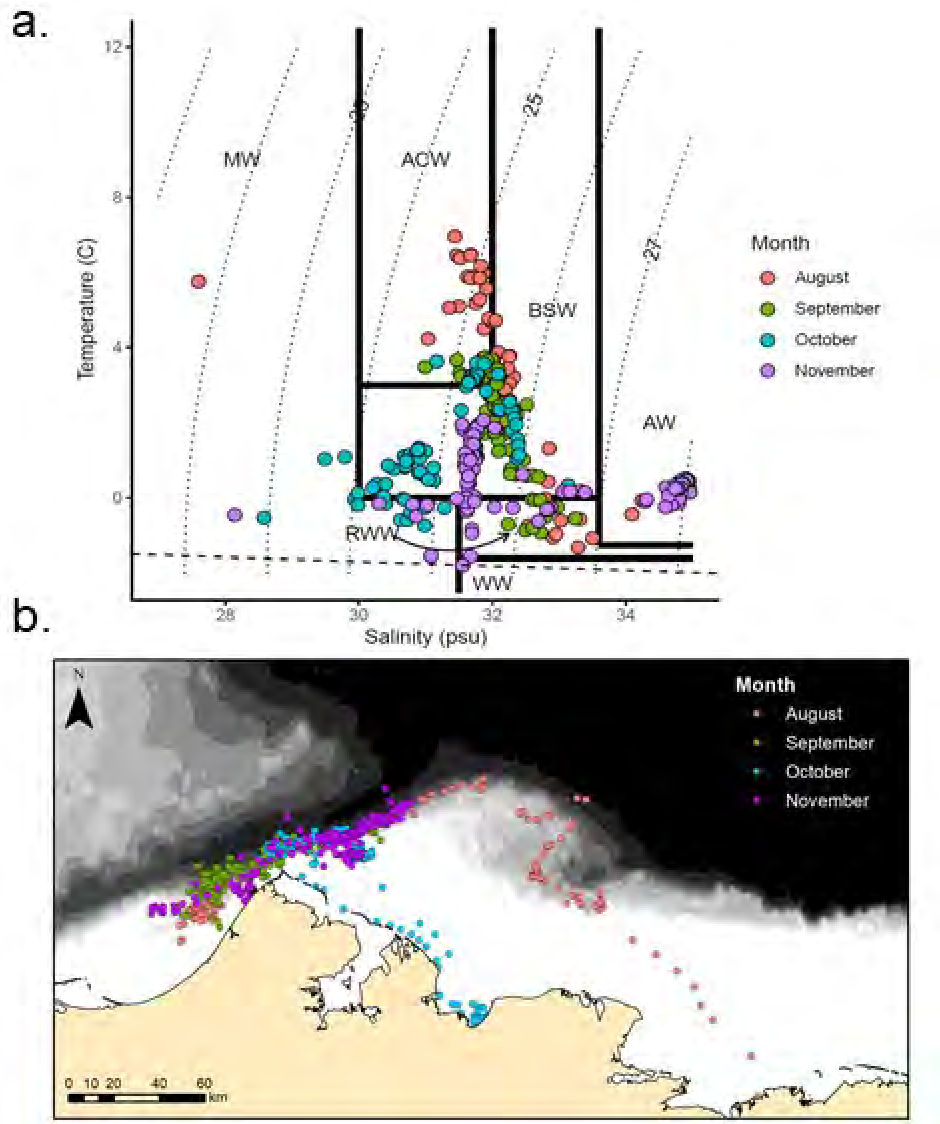


Figure 21. Temperature and salinity at maximum dive depths (a) from dive locations of a juvenile bearded seal (BS17-01-F) along the east side of Barrow Canyon (b). Solid black lines in (a) are defined water mass boundaries. Water masses are Melt Water (MW), Alaska Coastal Water (ACW), Bering Summer Water (BSW), Remnant Winter Water (RWW), Winter Water (WW), and Atlantic Water (AW). Curved dotted lines are water density values and the dashed line is the freezing point for sea water as salinity changes. Gray shading in (b) is bathymetric depth, where lighter colors are shallower waters and darker colors are deeper waters.

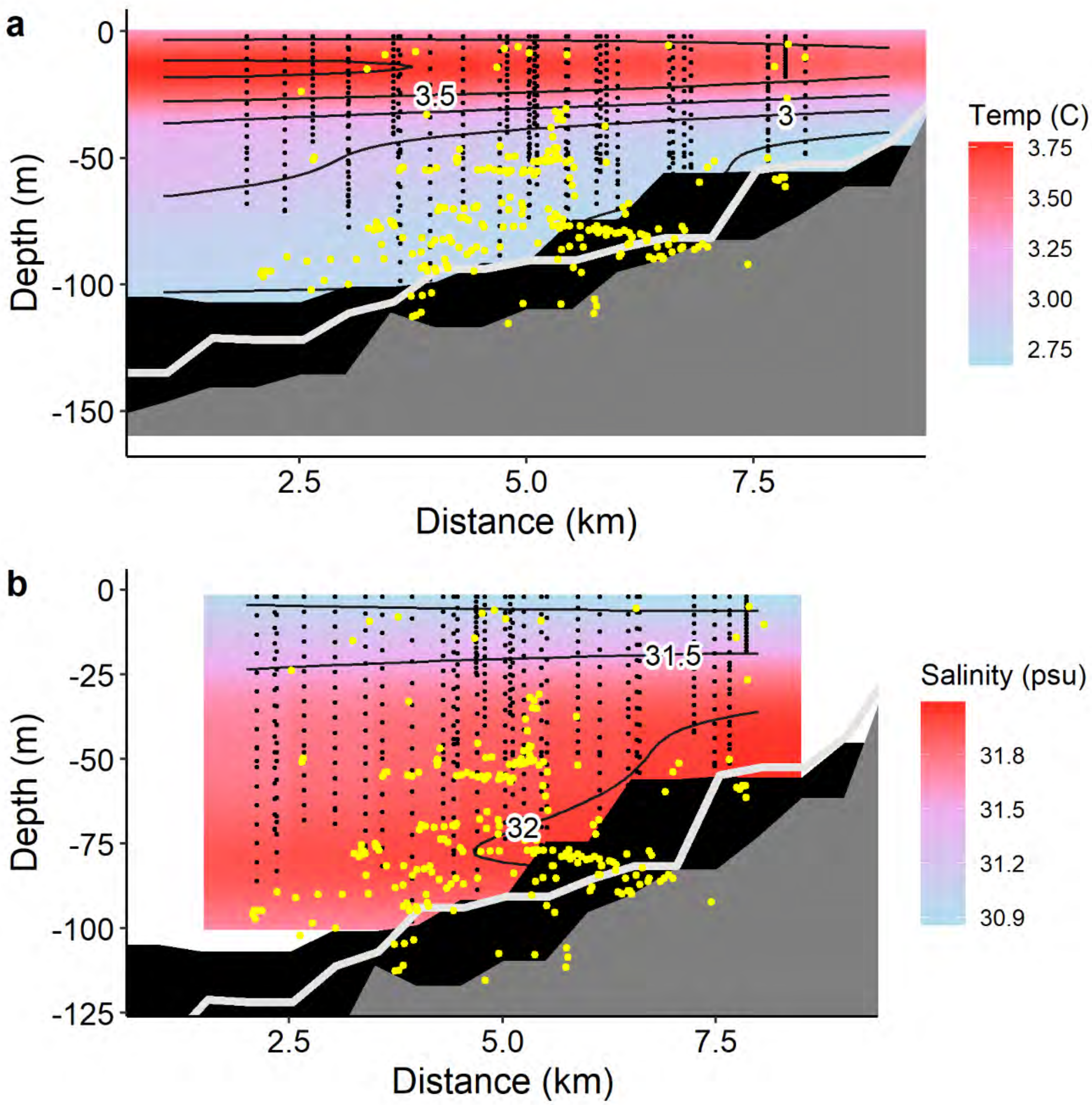


Figure 22. Temperature (a) and salinity (b) profiles along a cross section of the east side of Barrow Canyon collected by a CTD tag deployed on a juvenile bearded seal (BS17-01-F) during 13–28 September 2017. Black dots are CTD data collection points, yellow dots are target depths of individual dives (depth where the seal spent the most time). Light gray line and dark gray and black bands represent how the bathymetry varied along this cross section that depicts a region 9 km wide (x-axis) and ~12 km long.

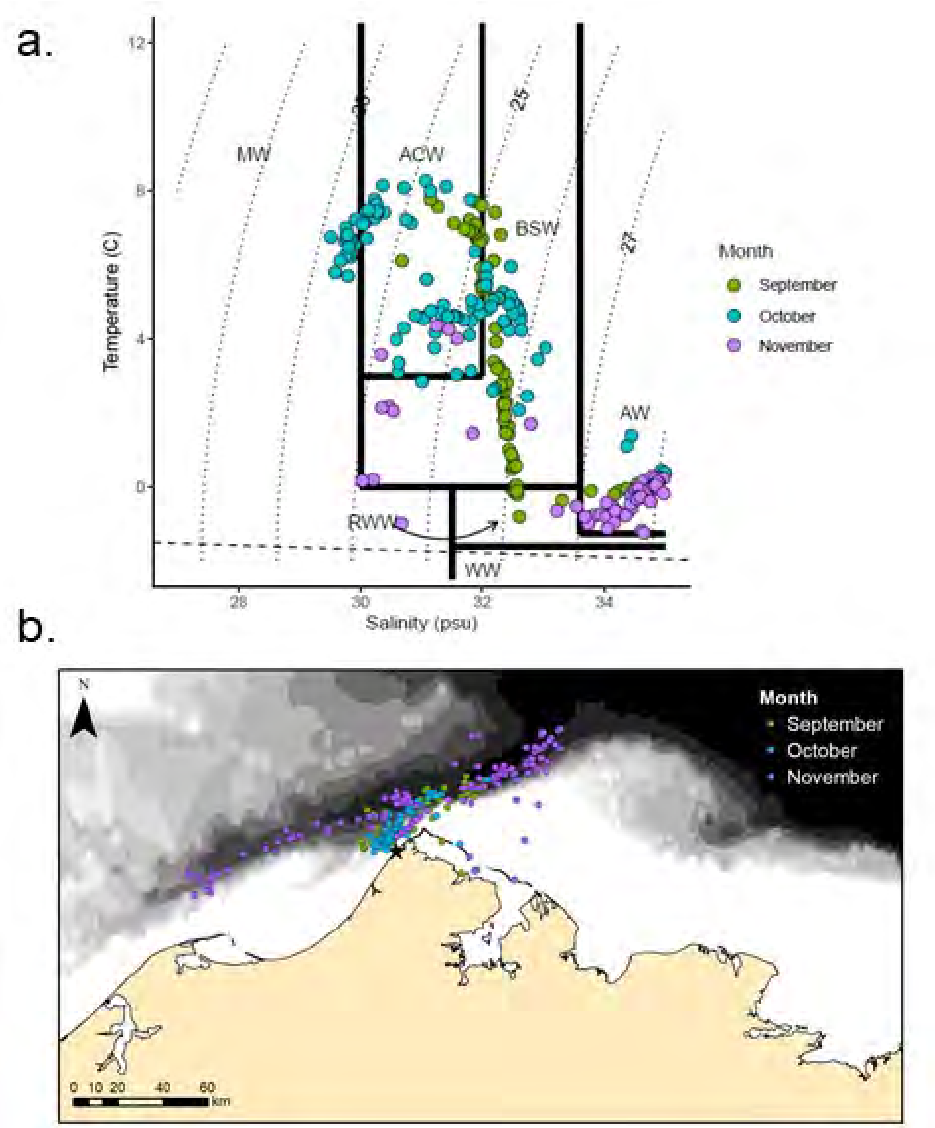


Figure 23. Temperature and salinity at maximum dive depths (a) from dive locations of an adult bearded seal (BS19-01-M) along the east side of Barrow Canyon (b). Solid black lines in (a) are defined water mass boundaries. Water masses are Melt Water (MW), Alaska Coastal Water (ACW), Bering Summer Water (BSW), Remnant Winter Water (RWW), Winter Water (WW), and Atlantic Water (AW). Curved dotted lines are water density values and dashed line is the freezing point for sea water as salinity changes. Gray shading in (b) is bathymetric depth, where lighter colors are shallower waters and darker colors are deeper waters.

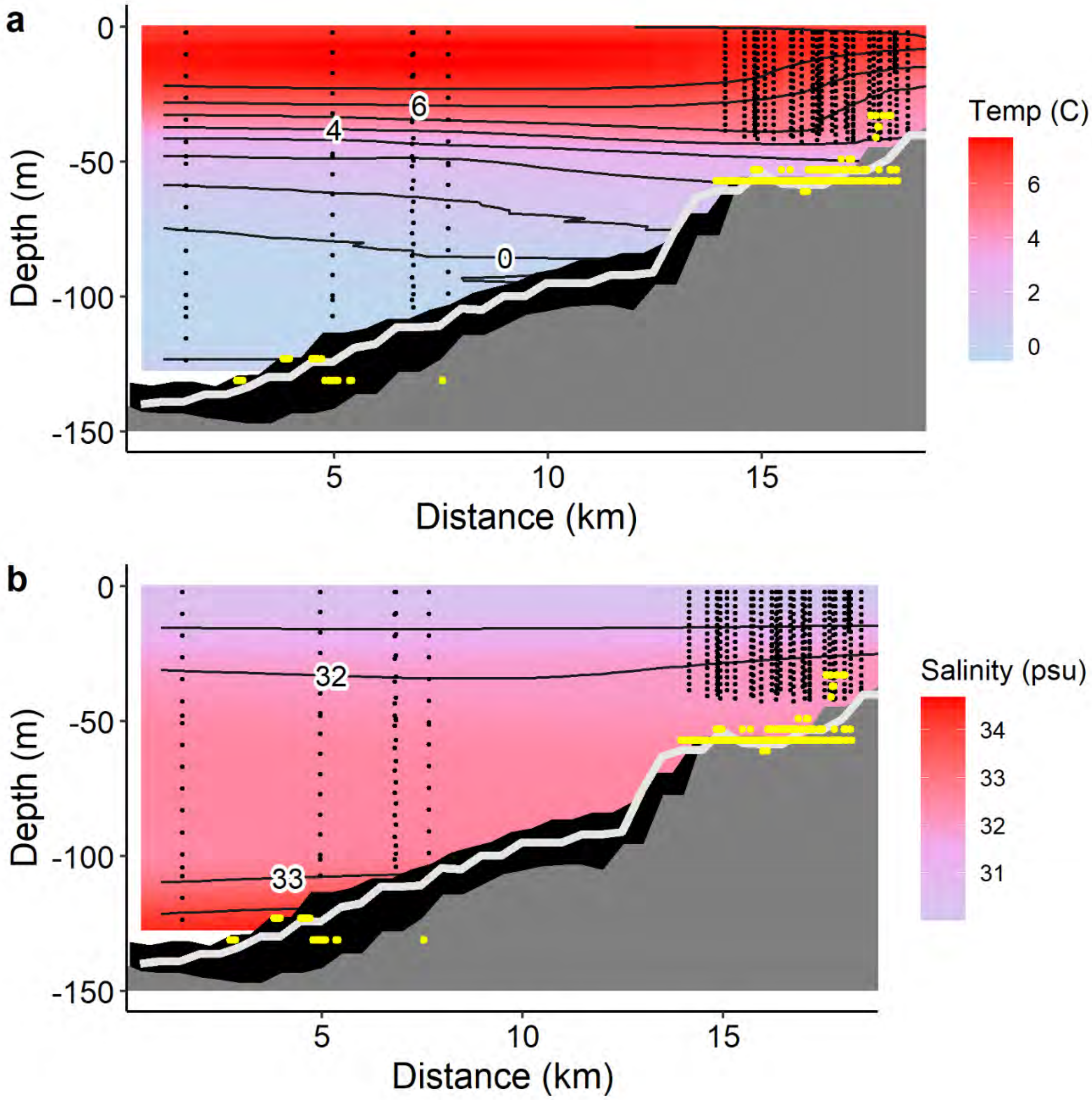
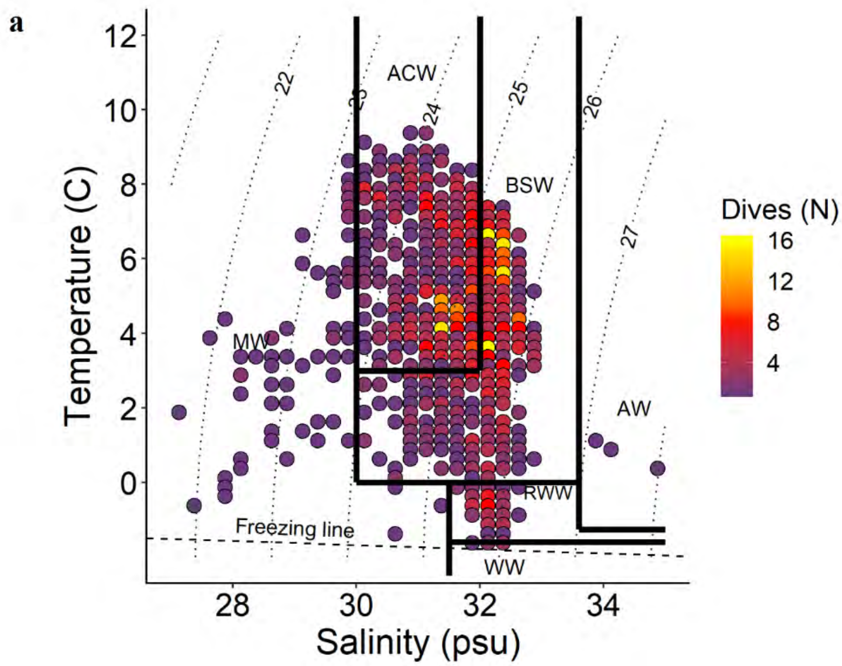


Figure 24. Temperature (a) and salinity (b) profiles along a cross section of the east side of Barrow Canyon collected by a CTD tag deployed on an adult bearded seal (BS19-01-M) during 13–28 September 2019. Black dots are CTD data collection points and yellow dots are the maximum depths of individual dives. Light gray line and dark gray and black bands represent how the bathymetry varied along this cross section that depicts a region 18 km wide (x-axis) and ~10 km long.

Spotted seals. In the Bering and Chukchi seas, spotted seals mostly used either ACW or BSW. Interestingly, in the Bering Sea, there was more use of colder BSW while in the Chukchi Sea there was more use of warmer ACW (Fig. 25). Although the water mass definitions we have been using (Corlett and Pickart 2017) are more applicable to the Chukchi Sea, both ACW and BSW exist in the Bering Sea. Why spotted seals used ACW more in the Chukchi Sea may be related to the origin of ACW; it is mainly nearshore river discharge from the Yukon and Kuskokim rivers that moves to the north. The Yukon River enters the Bering Sea north of the spotted seal core use area, and so much (but certainly not all) of the distribution of tagged spotted seals was south and west of where we would expect ACW to occur in the Bering Sea (Fig. 11).



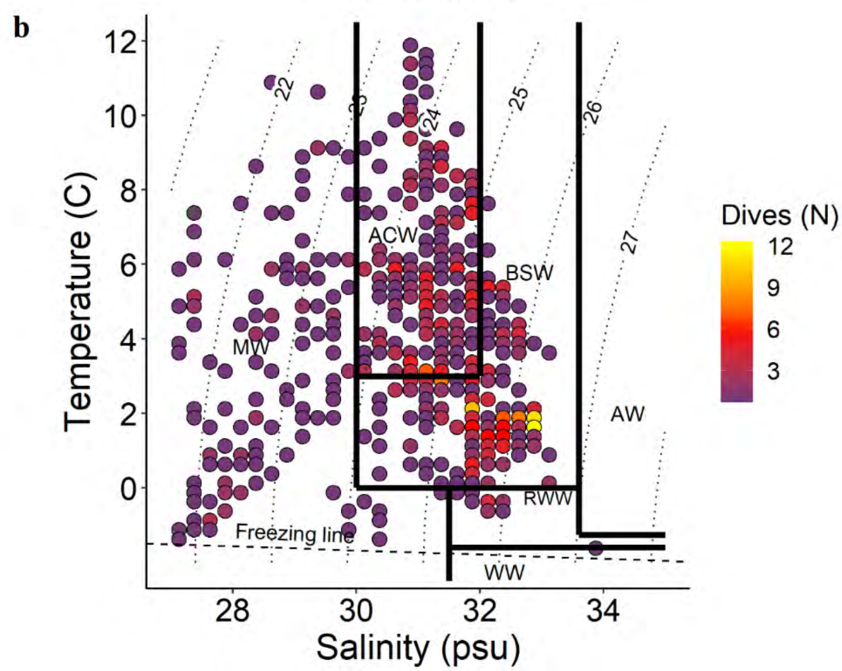


Figure 25. Temperature and salinity at maximum dive depths of spotted seal dive locations from July to November, 2016–2019 for seals foraging in the Chukchi Sea (tagged in the Beaufort Sea) (a) and seals foraging in the Bering Sea (tagged in the Bering Sea (b). Warm colors depict a greater number of dives. Water masses are Melt Water (MW), Alaskan Coastal Water (ACW), Bering Summer Water and Siberian Shelf Water (BSW), Remnant Winter Water (RWW), Winter Water (WW), and Atlantic Water (AW). Curved dotted lines are water density values and the dashed line is the freezing point for sea water as salinity changes.

Stomachs collected from spotted seals in the Bering and Chukchi seas indicate some differences in diet between those seas. Primary prey items, as determined from frequency of occurrence (%FO) in stomach contents in the Chukchi Sea are 48% Pacific herring (*Clupea harengus*), 43% saffron cod (*Eleginus gracillis*), 40% rainbow smelt (*Osmerus mordax*) and 32% Arctic cod. Primary prey items in the Bering Sea are 53% Arctic cod, 31% saffron cod, 27% capelin (*Mallotus villosus*), and 16% pollock (*Theragra chalcogramma*) (Quakenbush et al. 2009). Hence, some primary prey items, such as Arctic and saffron cod, are common to both seas, while rainbow smelt were primary prey in the Chukchi Sea and capelin and pollock were primary prey in the Bering Sea. The relationship between prey, water masses, and seal distribution warrants further examination.

In winter, spotted seals are found near the southern margin of the sea ice. During the project period, sea ice conditions varied from historic lows (winters of 2016/17, 2017/18, 2018/19) to a winter with extensive sea ice (2019/20), more typical of historic extents, providing an opportunity to examine how oceanography changes with sea ice extent. During the winter of 2019/20, tagged seals targeted an intrusion of deep Aleutian Basin water that upwelled onto the shelf (Fig. 26). This is to be expected, because typically, ice extent in the Bering Sea is partially determined by north winds, which push the ice margin southward, but also create upwelling along the shelf break. Bowhead whales also sometimes target upwelled water in winter, near the shelf break (Citta et al. 2015).

During years with low sea ice, CTD profiles look much different (compare Figs. 26 and 27). First, water temperatures are generally warmer. Second, there is no intrusion of upwelled water from the Aleutian Basin. In these years, seals used more of the water column, perhaps because there is no upwelling to target. Preliminary work with bowhead whales suggests that the low ice years were associated with a strong Aleutian Low that created winds and vector forces that push sea ice northwards and create downwelling instead of upwelling.

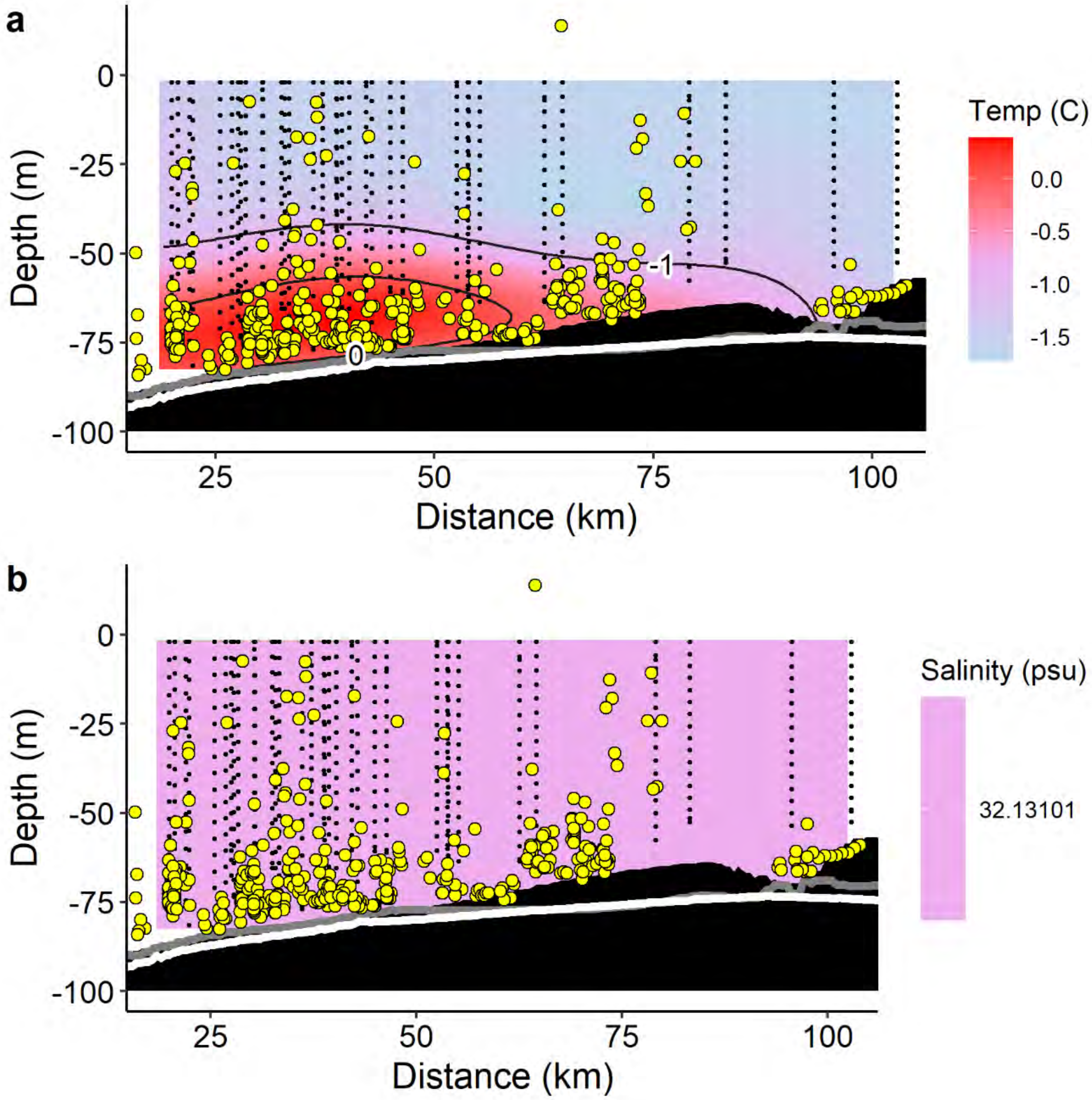


Figure 26. Temperature (a) and salinity (b) profiles for an area in the central Bering Sea, collected by a CTD tag deployed on an adult spotted seal (SS19-01-M) during 8–21 February 2020. Black dots are CTD data collection points and yellow dots are the target depths of individual dives (i.e., depth where the seal spent the most time). Gray lines and black bands represent how the bathymetry varied along this cross section that depicts a region 125 km wide (x-axis) and ~80 km long. Viewing direction of profile is from SE to NW.

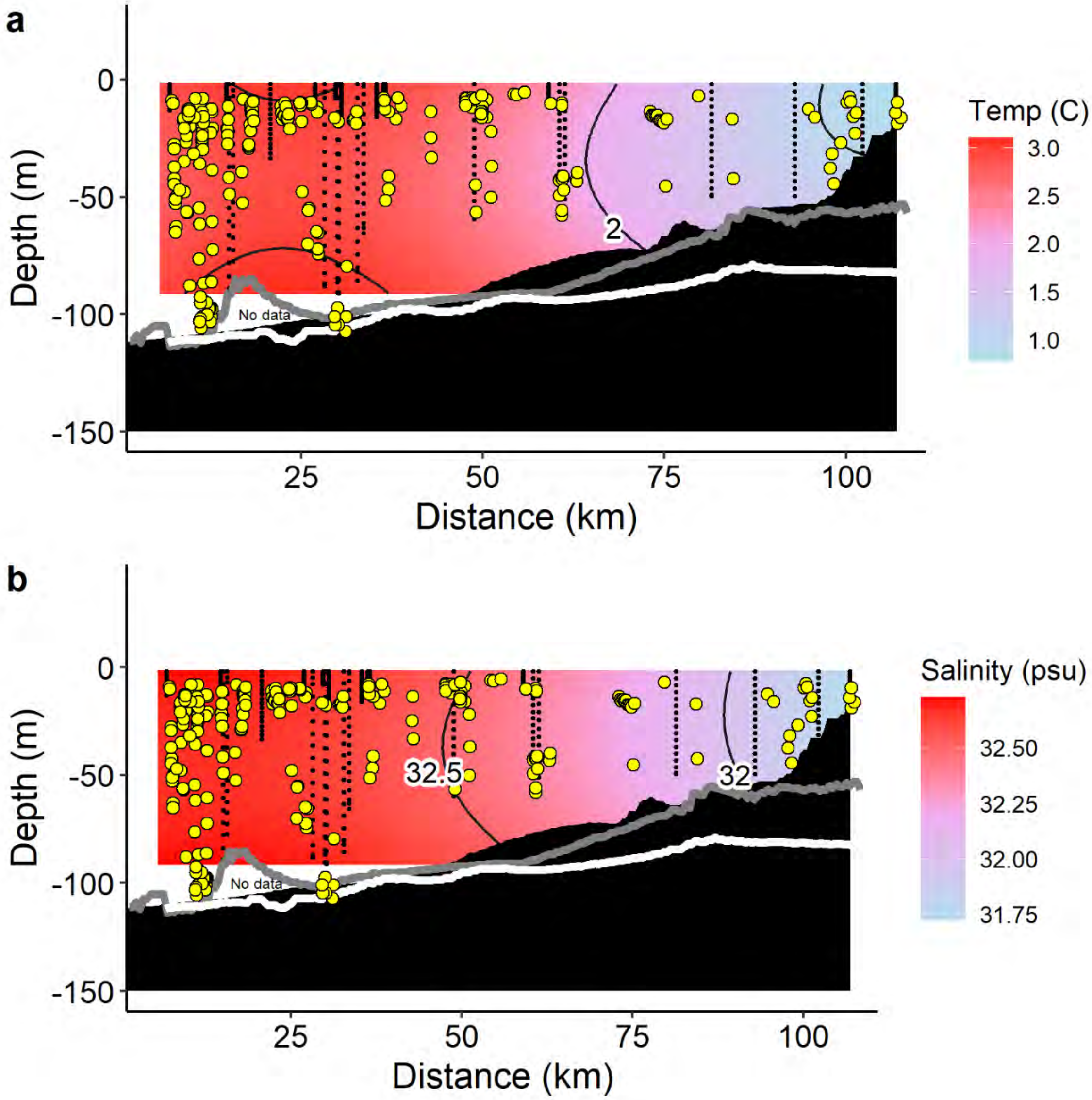


Figure 27. Temperature (a) and salinity (b) profiles for an area in the central Bering Sea, collected by a CTD tag deployed on an adult spotted seal (SS17-08-F) from 29 December 2017 to 10 January 2018. Black dots are CTD data collection points and yellow dots are the target depths of individual dives (i.e., depth where the seal spent the most time). Gray lines and black bands represent how the bathymetry varied along this cross section that depicts a region 106 km wide (x-axis) and ~90 km long. Viewing direction of profile is from the SE to NW.

Objective 4) Estimate and evaluate the effect of any changes in ice seal behavior and habitat use related to changes in ice cover in the Bering, Chukchi, and Beaufort seas. Test the hypothesis that ringed, bearded, and spotted seals remain near (within 25 km) ice when ice is present and do not haul out on land even when the sea is ice free. Test the hypothesis that ringed, bearded, and spotted seal movements do not differ by ice concentration or by month.

Ringed seals. Movements of ringed seals were strongly associated with sea ice as they migrated north with the receding sea ice during the spring and summer and migrated south with the advancing sea ice during fall and winter (Fig. 2a–d). Adult ringed seals stop moving south with the sea ice in winter well north of the ice front (Fig. 2c). During this project period (2014–2020) we tagged ringed seals in June and early July, during their northward migration. During these years, sea ice receeded north of the continental shelf break each summer and some ringed seals followed the ice north of the shelf in summer (Fig. 2a). During earlier studies, however, sea ice remained close to the shelf break and ringed seals mostly remained on the continental shelf (Crawford, Frost et al. 2012). During January–March when sea ice had advanced south into the Bering Sea, 8 of 13 tagged ringed seals wintered in the Chukchi Sea (Fig 2c). Tagged ringed seals (3 adults, 1 pup) did haul out on land (see Objective 2 above).

Bearded seals. To address whether juvenile bearded seal habitat use has changed relative to changes in environmental factors including sea ice, we used the methods and results from Breed et al. (2018) to compare the habitat preferences of juvenile bearded seals they tagged in 2004–2009 with that of seals tagged during our projects (2014–2018). In agreement with Breed et al. (2018), we found that juvenile bearded seals prefer intermediate ice concentrations (~50–60%). However, unlike Breed et al. (2018), we did not see preference for the ice edge. We also found that prefered ice concentrations occurred farther from the ice edge in recent years and concluded this likely explained why juvenile bearded seals were also found farther from the ice edge in recent years. In effect, the ice habitat that juvenile bearded seals prefer has shifted north of the ice edge and the seals have shifted their distribution in response (Fig. 28). A manuscript describing these results has been submitted to the journal *Marine Ecology Progress Series* (Olnes et al. *In review*).

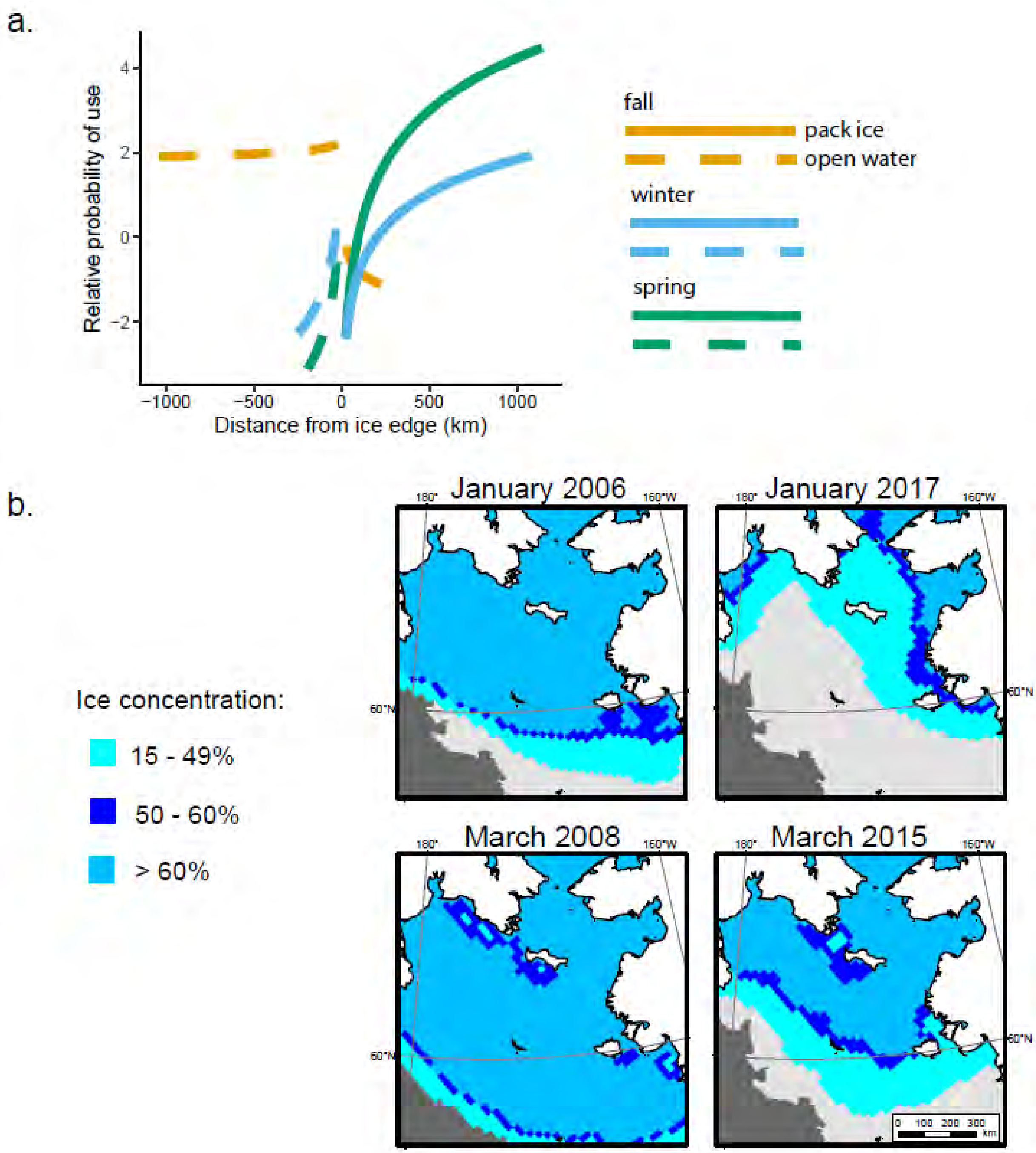


Figure 28. Results from a habitat selection function showing juvenile bearded seal habitat preferences relative to the ice edge (15% ice concentration) for seals tagged 2014–2018 (a). Examples of monthly mean ice concentration for winter (January) and spring (March) for two time periods 2004–2009 and 2014–2018 (b). Juvenile bearded seal habitat preferences between these two periods are compared in Olnes et al. (In review). *This figure shows that the relative probability of use increases as seals move away from the ice edge, when in pack ice (a), and that this is likely because the intermediate ice concentrations they prefer (50–60%, dark blue) now occur further away from the ice edge (b).*

Seals that were tagged in the Chukchi or Beaufort seas did not show strong changes in latitudinal movement associated with changing sea ice extent. These movements are detailed in Olnes et al. (2020, Appendix B). Although our analyses reflect a preference for using sea ice when it is available, we also found that bearded seals commonly remain in areas that are ice-free during the summer and fall months. As detailed under Objective 2, we found that bearded seals will haul out on land when sea ice is not available (Fig. 8).

Spotted seals. Our analysis of spotted seal high-use areas during winter (December–April) included location data during three winters of low sea ice extent (2016/17, 2017/18, and 2018/19; (Fig. 14). During this period, spotted seals primarily used coastal areas, near Nunivak Island and the southwestern Alaska coast. A previous study of spotted seal locations during 1993–2015, when sea ice extent was greater, identified areas in the central Bering sea (between St. Matthew Island and the Gulf of Anadyr and east of St. Lawrence Island), as high-use areas during the winter (Fig. 4 in Citta et al. 2018). During the winter of 2019/20, sea ice coverage in the central Bering Sea was extensive; as a result, spotted seals high-use areas shifted back to the central Bering Sea (Fig. 15). The different use patterns identified appear to indicate that spotted seals are more likely to use the central Bering Sea when pack ice is present to haul out on, but use coastal areas when ice in the central Bering Sea is limited.

Overall, in summer months, ringed seals stay close to sea ice (Fig. 2a), bearded seals may or may not be close (Fig. 3a), and spotted seals are far from sea ice (Fig. 4a).

Objective 5) Estimate hauling out behavior, on ice and on land, by demographic class and relate hauling out duration with weather, disturbance, and other potential factors. Test the hypothesis that hauling out behavior is not related to demographic class, weather, availability of sea ice, or disturbance factors.

Ringed seals. Thirteen of 16 tagged ringed seals were adults; therefore, we do not have the sample size to make statistical comparisons between demographic classes regarding haul-out behavior. For ringed seals, daily haul-out probability, defined as the probability a seal hauls out for at least a half-hour during a day, was slightly higher when sea ice was present. Adult ringed seals were more likely to haul out during the ice-covered season (daily haul-out probability = 43%) than the open-water season (33%; $P = 0.0189$) and haul-out periods averaged 5.4 and 6 hrs for each season, respectively (Table 3). Four ringed seals hauled out on land on four occasions; once in July, once in October, and twice in November (see Objective 2 above for details). Although it is rare for adults to use terrestrial haulouts, three of the four seals that hauled out on land were adults.

Bearded seals. Of all bearded seals tagged, only one was an adult; therefore, we cannot address haul-out behavior by demographic class. Juvenile bearded seals, however, hauled out more often during the ice-covered season (December–April: daily haul-out probability = 44%) than during the open-water season (May–November: 39%), however, seals hauled out for longer durations in the open-water season than in the ice-covered season (Table 3). The highest probabilities and durations occurred during the spring (March – May) coinciding with the annual molt and primarily occurred on ice. Daily haul-out probabilities during molt ranged from 63 to 77% and haul-out durations ranged from 5.9 to 9.8 hours/day. Mean haul-out durations of the adult were similar to juveniles, although the adult was more likely to haul-out on any given day than the juveniles (Table 3).

In the summer and fall (July–October), bearded seals hauled out on both ice and land. For juveniles, we found that haul-outs on land (mean ± S.E.: 5.0 ± 1.4 hours) tended to be shorter than haul-outs on sea ice (10.1 ± 1.4 hours) (Fig. 29). This difference is likely because seals that are hauled out on land are more likely to be disturbed than seals hauled out on ice.

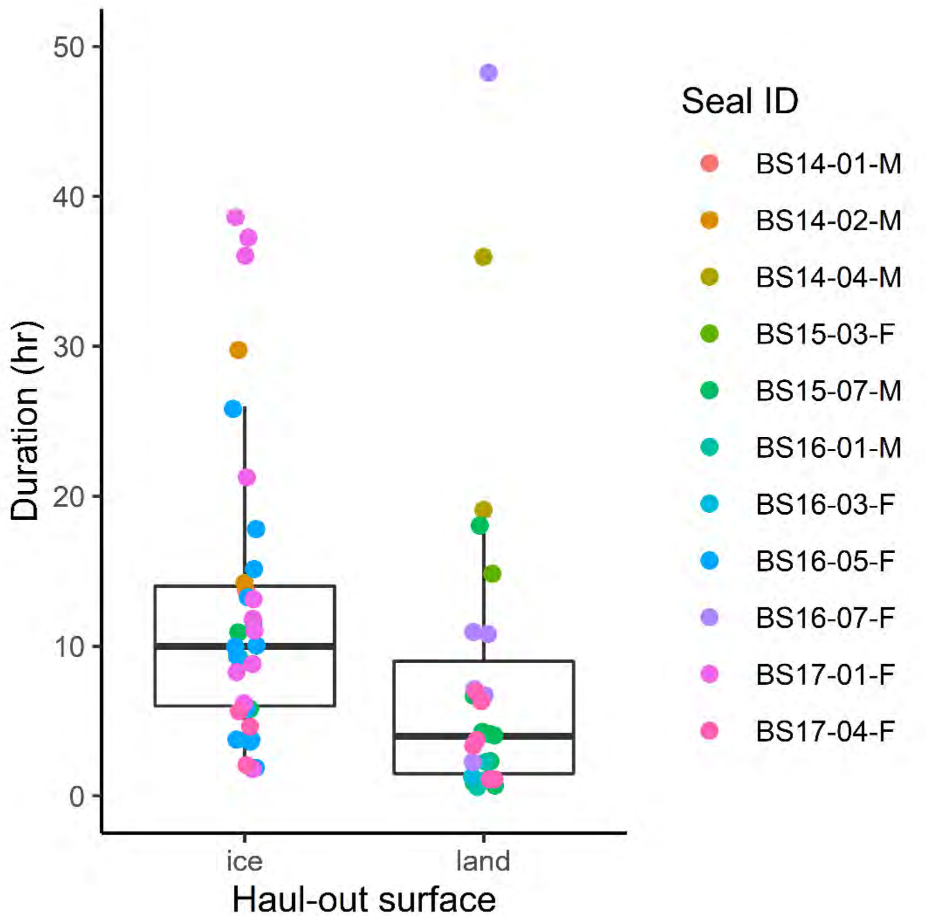


Figure 29. Haul-out durations for juvenile bearded seals that hauled out on land were significantly shorter than haul-out durations when seals were on sea ice. Thick line is the median haul-out duration, boxes represent the interquartile range.

Spotted seals. Spotted seals hauled out on land and ice regardless of demographic class. Overall daily haul-out probability (regardless of substrate) was similar for adults between the open-water and ice-covered periods (36.5 and 38.4%, respectively) and was similar for pups at ~ 27% (Table 3). During the open-water period (2016–2018), spotted seals in the Chukchi Sea foraged at sea for 1–27 days ($\bar{x}$ = 9.7 days) and then returned to land to rest for 0.5–8 days ($\bar{x}$ = 2.6 days); seals in the Bering Sea foraged for 1–25 days ($\bar{x}$ = 5.9 days) and then returned to land to rest for 0.5–9 days ($\bar{x}$ = 2.8 days). Resting bouts between foraging trips were similar for spotted seals foraging in the Chukchi Sea and those foraging in the Bering Sea, even though foraging bouts in the Chukchi Sea were longer.

Oil and gas and shipping

All three seal species used the Chukchi Sea Lease Sale 193 Area during the open-water season when industrial activity would be highest (Figs. 30 and 31). Use of land by spotted seals and their frequent offshore-nearshore movements suggest they could be more affected by industrial traffic between the 193 Area and shore facilities at Wainwright (between Peard Bay and Utqiaġvik). Specific land haulout sites used by spotted seals have been identified and can be included in analyses for the potential consequences of disturbance. Our spotted seal data were collected (beginning in 2016) after activity within the 193 Area ended and so did not overlap with the activity that occurred there.

Ship traffic is highest during July–September and bearded seals appear to have the highest potential to be affected as their movements overlap with high-use shipping lanes in Norton Sound and in the eastern Chukchi Sea (Fig. 30). Ringed and spotted seals overlap with ship traffic most in fall in the Chukchi Sea when traffic is lighter along the Alaskan coast (Fig. 31). Inferences regarding overlap between seal movements and the shipping traffic data presented must be made with caution because seal distribution is based upon a limited sample and patterns of ship traffic may have changed since the data were collected (2013–2015). Although ship traffic in the northeastern and central Chukchi Sea likely diminished after 2016, due to the end of oil and gas activity in the 193 area, traffic in other areas, such as nearshore shipping between communities, likely increased due to a longer open water period.

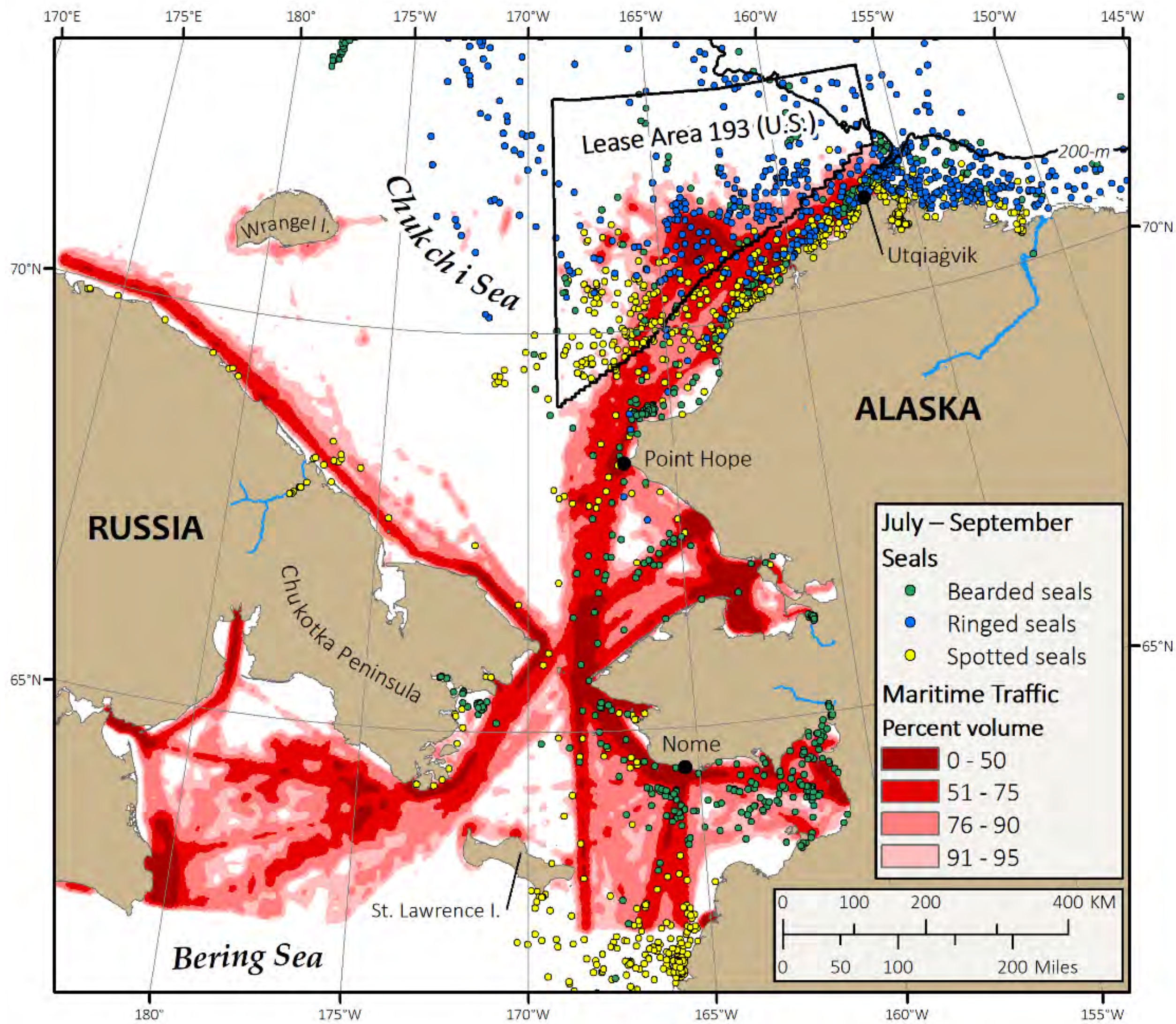


Figure 30. Locations of tagged bearded (n = 20), ringed (n = 15), and spotted seals (n = 20) and density estimates (red) for ship traffic derived from Automatic Identification System (AIS) data in the northern Bering and Chukchi seas from July to September during 2013–2015. Colored circles are daily seal locations estimated using the CRW model.

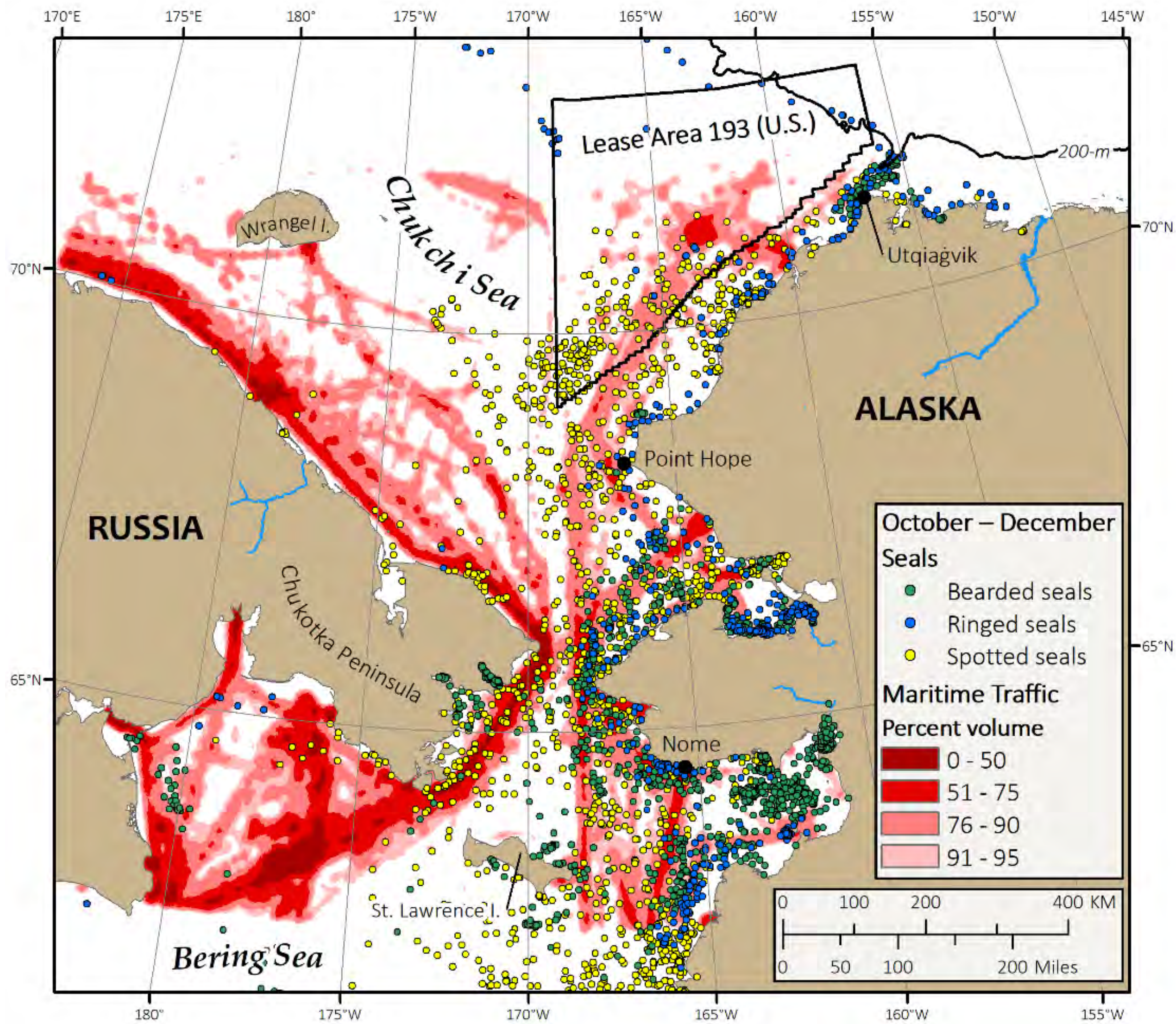


Figure 31. Locations of tagged bearded (n = 21), ringed (n = 9), and spotted seals (n = 24) and density estimates (red) for ship traffic derived from Automatic Identification System (AIS) data in the northern Bering and Chukchi seas from October to December during 2013–2015. Colored circles are daily seal locations estimated using the CRW model.

Factors that influence habitat use

Although we still have a lot to learn about the drivers of seal habitat use, we can say that seals do not use the Bering, Chukchi, and Beaufort seas randomly and we have identified differences in use among species. Ringed seals generally remained within or near sea ice when possible. When on the shelf, ringed seals targeted mostly BSW (Fig. 18). Although generally considered to be pelagic foragers, we found they commonly dove to the seafloor (in 57–78% of dives on the shelf). When sea ice retreated north of the shelf break in summer, ringed seals commonly targeted deeper AW along the shelf break and in the Arctic Basin.

Prior tagging studies of juvenile bearded seals described them as selecting the southern ice edge in winter (Breed et al. 2018, Cameron et al. 2018). We found that juveniles selected regions farther from the ice edge but selected similar ice concentrations. After examining how ice has changed over time, we discovered that the distribution of preferred ice concentrations has changed. Primarily benthic foragers, we found that bearded seals used a variety of water masses, including deeper AW in Barrow Canyon and along the shelf break.

In contrast to bearded and ringed seals, spotted seals almost exclusively used shelf waters. Spotted seals also dove more in ACW and BSW than ringed or bearded seals, which also used RWW and AW (compare Figs. 16, 18, 21, and 23). Interestingly, spotted seals used the southern ice edge more than other seals and, at least in some years, target upwelling that occurs near the shelf break in winter.

Arctic Whales. We deployed four CTD tags on beluga whales near Point Lay; three in 2017, which failed, and one in 2019 (Table 1). The 2019 tag was deployed on an adult female and transmitted for 71 days in summer. An analysis of dive behavior relative to water temperature and salinity translated into water masses was prepared and submitted to the journal *Deep Sea Research I* for publication (Citta et al. *In review*).

Given our successful collaboration with Canadians on our BOEM and ONR bowhead whale projects, we tried to extend that collaboration to beluga whales. Initial contacts and meetings went well and there was keen interest in the data that could be collected for beluga whales. However, the members of the Hunters and Trappers Associations wanted full control over the data collected. Although we made it clear that we would all receive the data at the same time and they could analyze it how they wanted, they would not agree. They then requested and received money to fund their own beluga tagging program.

We deployed a total of 10 CTD tags on bowhead whales, four near Tuktoyaktuk, Canada, in August 2017 (Table 1), working with subsistence hunters affiliated with the Tuktoyaktuk Hunters and Trappers Association and six near Utqiaġvik, Alaska, in August 2018 working with NSB and local whalers. The transmission durations of CTD tags deployed on bowheads in 2018 (n = 6) ranged from 22–203 days, including into 2019. The last location received from a CTD tag deployed in 2018 was on 16 April 2019 from B18-09 deployed on 25 September 2018.

Accomplishment of Objectives

Objective 1) Compare CTD data collected by tagged whales during different behavioral states (i.e., traveling vs. lingering) to further describe the oceanographic features that do and do not concentrate prey.

<u>Beluga</u>. An adult (white) female beluga with a standard length of 343 cm and an axillary girth of 171 cm was captured and tagged on 8 July 2019 near Point Lay. She was accompanied by an immature whale, which may have been her offspring. The transmitter provided location data from 8 July until 17 September 2019 (i.e., 71 days). Upon release, the beluga remained in the vicinity of Point Lay for six days and then headed northeast, arriving at Barrow Canyon on 17 July (Fig. 32). The beluga spent the remainder of July diving in the northern end of Barrow Canyon and adjacent shelf waters. The beluga traveled east along the shelf break in early August, looped back over shelf waters north of Point Lay in mid-August, and then looped out over the Arctic (aka Canada) Basin in late August. For most of September, the beluga ranged back and forth in Barrow Canyon and adjacent shelf waters; on 15 September the beluga left Barrow Canyon and was heading west across the continental shelf when the tag stopped transmitting on 17 September (Fig. 32).

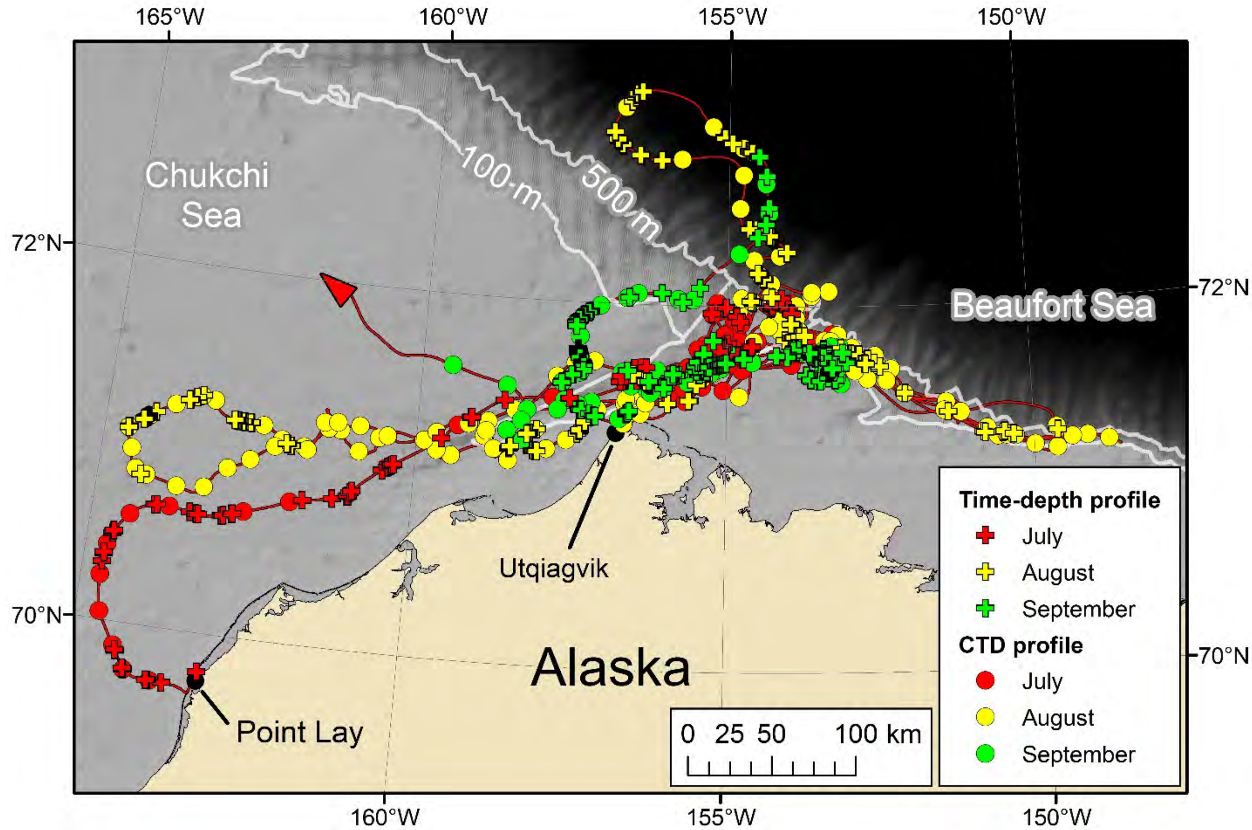


Figure 32. Track (red line) of an adult female beluga tagged near Point Lay on 8 July 2019. Crosses are the location of time-depth profiles and circles the location of CTD profiles, both color-coded by month. The tag transmitted until 17 September and yielded 255 CTD profiles.

A total of 492 time-depth profiles were transmitted, of which 483 were either > 20 m depth or 1-min duration. Most target depths were ≤ 100 m (n = 411; 85%); dives > 100 m (n = 72; 15%) were less common. Average duration of these dives was 4.1 min (SD = 1.5). Deeper dives were longer in duration; dives ≤ 100 m averaged 3.9 min (SD = 1.4), those > 100 m averaged 6.0 min (SD = 0.9). Maximum dive depth, taken from a CTD profile, was 384 m; maximum dive duration was 7.7 min. Dives were typically square or U-shaped, where belugas spent the majority of their dive time near the maximum depth (Fig. 33). On average, target depths (i.e., the depth that the beluga spent the most time) were 72.7% of the maximum dive depth (SD = 0.13).

We fitted behavioral state-space models to the beluga movement data; however, this beluga did not linger in any specific location. Hence, movement models are unable to discern behaviors associated with Area Restricted Searches (ARS, also referred to as resident or lingering behavior) from directed movements. Because of this, we focused on the association between beluga diving (i.e., target depth and duration at target depth) and oceanographic features at those depths.

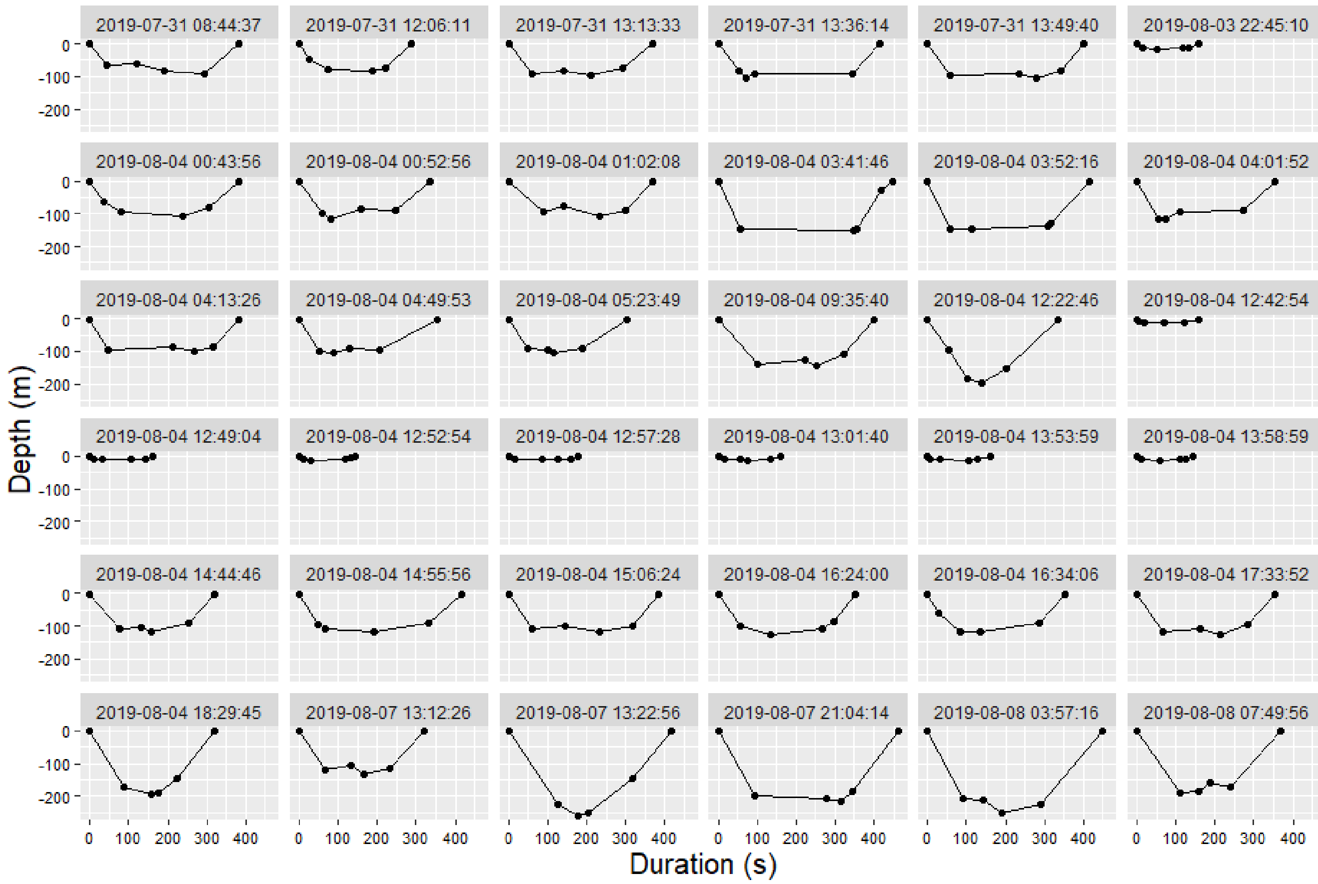


Figure 33. Dive shapes for an adult female beluga whale during 31 July–8 August 2019 near Barrow Canyon.

Prior work has shown that beluga movement and dive behavior is related to wind patterns within Barrow Canyon and along the adjacent shelf break (Stafford et al. 2013, 2016). In summer, the dominant circulation feature in the region is the Alaskan Coastal Current (ACC) which carries relatively warm (T > 3 °C), fresh (30 psu < S < 32 psu) Alaskan Coastal Water (ACW; mainly river discharge) into the Arctic Basin (Paquette and Bourke, 1974). Various other water masses of Pacific origin also exist in the Chukchi and Beaufort seas, typically occurring farther offshore or beneath ACW. Newly-ventilated Pacific Winter Water (WW) overwinters in the northern Bering Sea and is near the freezing point of seawater (T < -1.6 °C); Remnant Winter Water (RWW) is WW that has warmed throughout the summer season (-1.6°C < T < 0 °C). Anadyr Water and Bering Shelf Water combine north of Bering Strait to form Bering Summer Water (BSW; Corlett and Pickart 2017) which has a similar signature to RWW that has warmed during the summer and is sometimes known as Chukchi Summer Water (Gong and Pickart, 2015). In the Arctic Basin, warmer, saltier water of Atlantic origin (T > -1.26 °C, S > 33.6 psu; Atlantic Water; AW) generally resides below 200 m (Corlett and Pickart 2017), although upwelling may bring AW closer to the surface. Last, meltwater (MW) occupies the surface layer and is derived from ice melt and precipitation (Gong and Pickart, 2015; Corlett and Pickart 2017).

Within Barrow Canyon, ACW occurs above and typically inshore of WW/RWW thereby creating a front between these two water masses (Okkonen et al., 2009). Stafford et al. (2013) showed that when along-canyon winds are from the west-southwest (WSW), the ACC is intensified and use of Barrow Canyon and the adjacent shelf break by belugas increases. Specifically, Stafford et al. (2013) documented increases in aerial sightings, group sizes, and hours with vocalizations with WSW winds. Using the same satellite telemetry dataset used by Citta et al. (2013) and Hauser et al. (2015), Stafford et al. (2016) showed that when the ACC is intensified that belugas respond by targeting shallower depths (10–100 m) associated with the expected location of the front. In contrast, winds from the east-northeast (ENE) displace the ACC westward and cause the frontal feature in Barrow Canyon to weaken or dissipate. Under this wind regime, belugas are more likely to target depths > 200 m, within the polar halocline and upper Atlantic layer, and beluga distribution shifts towards the Arctic Basin (Stafford et al., 2013, 2016).

The satellite transmitters used in the studies described above did not collect salinity data, thereby precluding identification of water masses used by belugas. Although these tags collected temperature data, software on-board the tag was designed to summarize data for easy transmission to a satellite. Temperature data was summarized as the percentage of time falling within temperature categories (typically 0.5 or 1 °C) and these readings were not paired with depth. As such, the oceanographic features associated with beluga dive behavior were taken from other sources and, although reasonable, were largely speculative. Here, with data from a CTD tag attached to a beluga in Barrow Canyon, we have the opportunity to document what water masses the beluga was using and if fronts and stratified layers were targeted for foraging.

A total of 255 CTD profiles were transmitted (mean = 3.9 profiles/day; see circles on Fig. 32) and 234 were usable. Twenty-one profiles were removed because salinity profiles were unrealistic; salinity data varied wildly with depth or were evaluated as too fresh given their depth and temperature. Surface waters were exclusively classified as ACW or MW, however, these water masses were often not the water masses the beluga was targeting during dives. The beluga most commonly targeted RWW (39.8% of all dive profiles), followed by ACW (26.9%) and BSW (17.2%) (Fig. 34). Visual inspection of salinity profiles indicated that the polar halocline was present in lower Barrow Canyon (closest to Utqiaġvik), and in Slope and Basin regions between ~ 175 and 200 m depth; these depths were targeted by the beluga in 6.7% of dives in Barrow Canyon, 12.7% in the Slope, and 14.5% of dives in the Basin regions.

We created five sectional plots that illustrate the beluga's association with frontal features (Fig. 35). Because the polar halocline was rarely targeted by the beluga, and targeted fronts and stratifications are easily seen in temperature plots, depth-salinity profiles are not presented. In upper Barrow Canyon and on the shelf in the Chukchi Sea (Fig. 36a), the beluga mostly targeted RWW, although a few (14 of 64; 23%) target depths (white diamonds with red outlines in Fig. 36a) were associated with the vertical front between ACW (reddish shading) and BSW/RWW (bluish shading) on the east side of Barrow Canyon. Within the main Barrow Canyon use area, the majority of CTD (75%) and time-depth profiles (81%) are co-located with this front (Fig. 36b). Most target dive depths were either clearly within the front (60%) or located along the western flank of this front, within BSW/RWW (21%). Within the Basin (Fig. 36c), target depths either occurred in RWW (< 0 °C) or were co-located with near-surface temperature stratifications within MW or ACW. Along the shelf break, east of Barrow Canyon (36d-e), beluga dive behavior was markedly different during July and August versus September. During July and August (Fig. 36d), target depths were typically associated with the interface between ACW and BSW (~ 3 °C) or at deeper depths in RWW (< 0 °C). During September

(Fig. 36e), the beluga still used the interface between ACW and BSW (~ 3 °C); however, most use shifted onto the shelf where relatively warm ACW was present (> 6 °C).

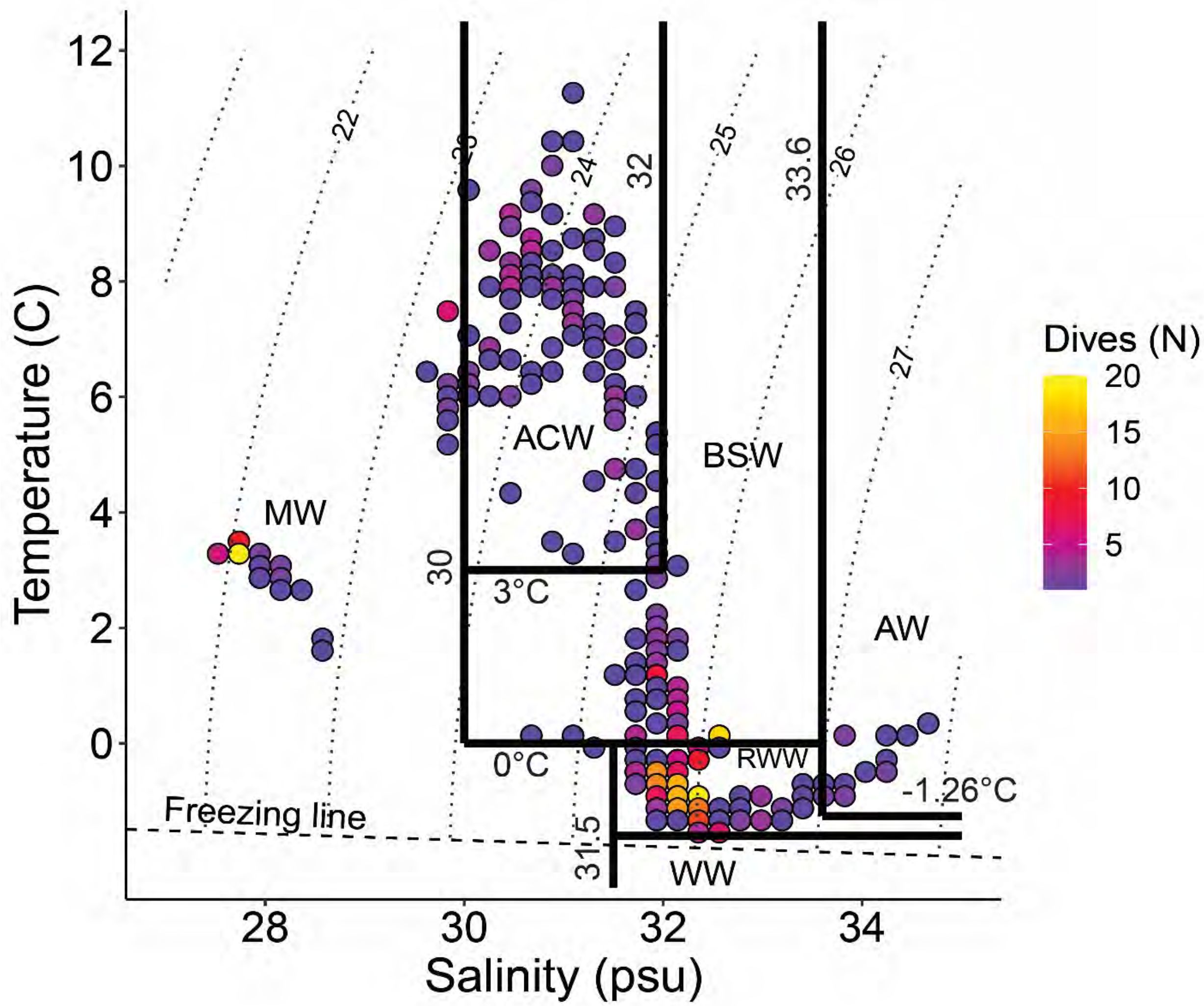


Figure 34. Temperature-salinity plot taken from the target depth in each beluga dive profile. Warm colors represent a greater number of dives occurring in grid cells 0.2 °C by 0.2 psu. Solid lines are boundaries between water masses as defined by Corlett and Pickart (2017). MW = Melt Water; ACW = Alaskan Coastal Water; BSW = Bering Summer Water; RWW = Remnant Winter Water; WW = newly ventilated Winter Water; AW = Atlantic Water. Curved dotted lines are water density values (sigma-t) and the dashed line is the freezing point for sea water as salinity changes.

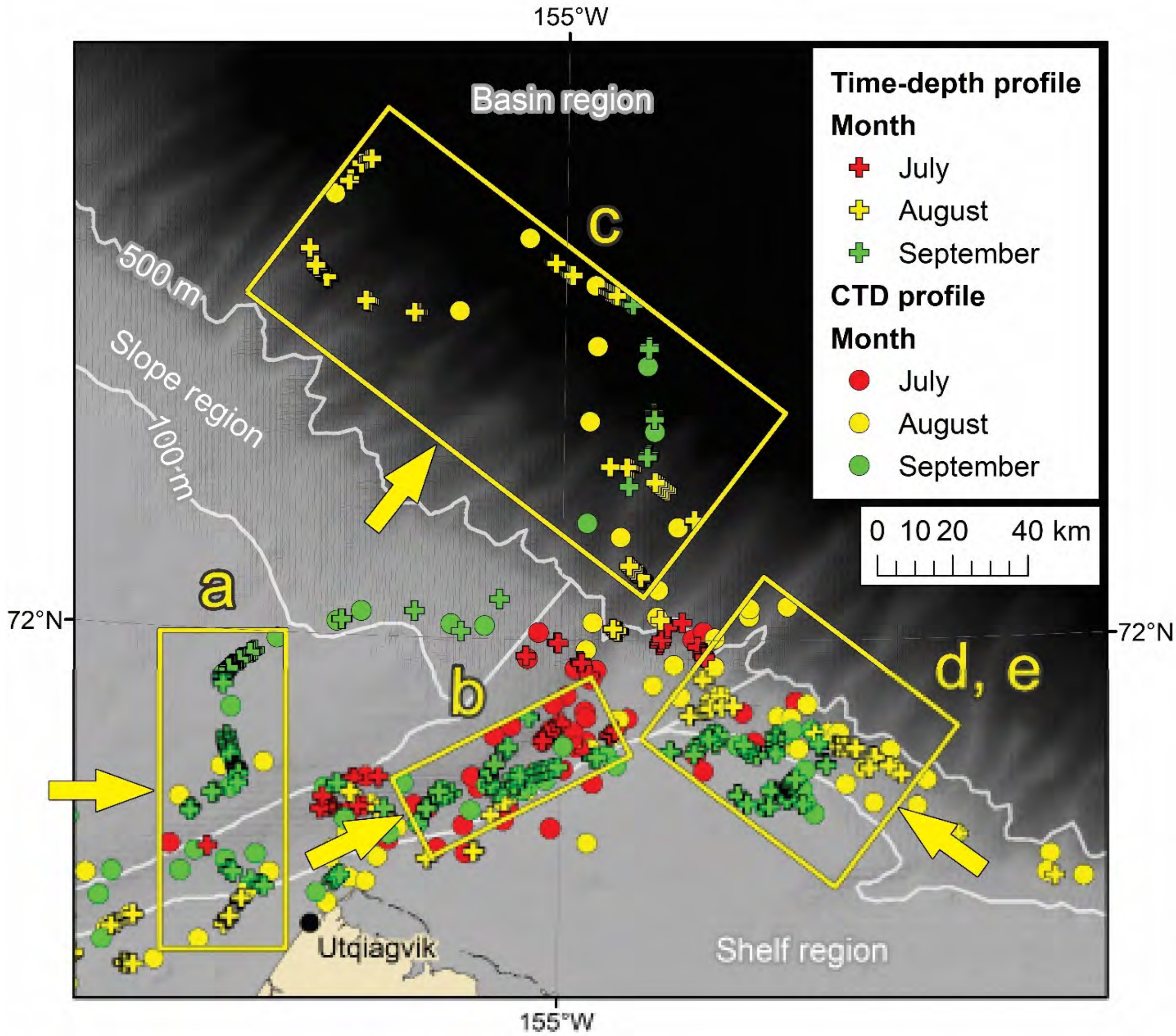


Figure 35. Bounding boxes for depth-temperature sectional plots (a–e) shown in Figure 36. Crosses are the location of time-depth profiles and circles the location of CTD profiles, both color-coded by month. Yellow arrows indicate the direction of view for each cross-section in Figure 36.

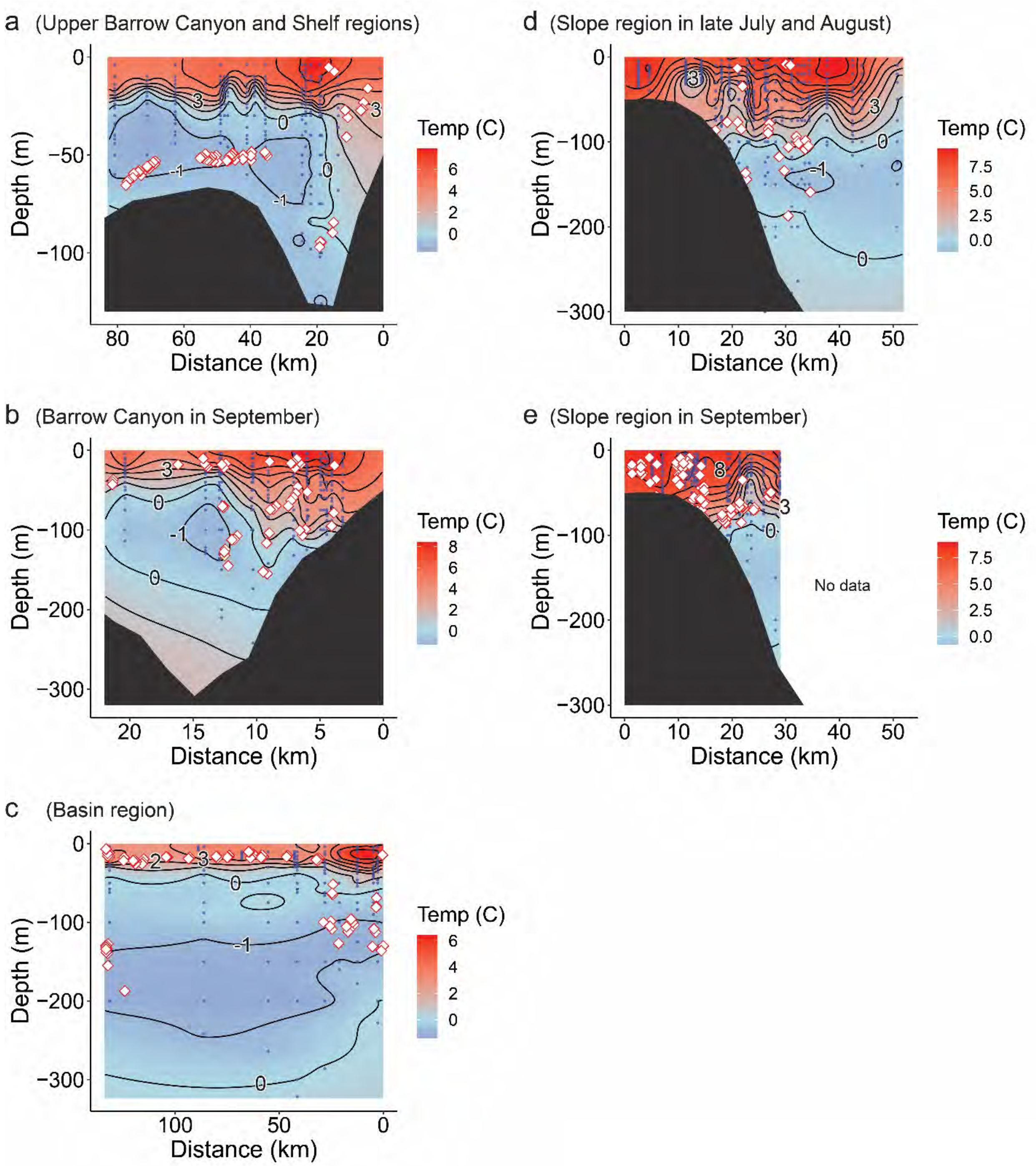


Figure 36. Depth-temperature sectional plots for the yellow boxes shown in Figure 35. Blue dots are CTD data collection points; white diamonds with red outlines are target depths from beluga time-depth profiles. The direction of view for each cross-section is indicated via the yellow arrows in Figure 35. Unless noted in figure captions, sectional plots are time-averaged over the study duration. Ocean stratification is most easily seen with temperature; hence, we do not present depth-salinity sectional plots.

Clearly, the tagged beluga targeted fronts and stratified layers between water masses or targeted colder water masses of Pacific origin. We found that within the main use area in Barrow Canyon, the beluga targeted the frontal zone between relatively warm ACW and colder BSW and RWW (Fig. 36b). As such, our findings build upon those of Stafford et al. (2016) who speculated that the reason why belugas may be more common in Barrow Canyon during periods with WSW winds was that the ACC becomes enhanced and strengthens the front between ACW and BSW/RWW. ENE winds strong enough to displace the ACC ($\tau < -0.07$ Pa; Stafford et al., 2016) occurred on 18 of 79 days (22.8%), but typically lasted only a day or two. Hence, WSW winds were dominant and the beluga's behavior was largely what would be predicted based upon the findings of Stafford et al. (2013, 2016). The beluga also targeted the near-surface temperature stratification in the Basin region (Fig. 36c) and the front between ACW and colder BSW/RWW in the slope region (Fig. 36d and e).

That the beluga did not target the polar halocline between Pacific and Atlantic waters, or the upper Atlantic layer was surprising, as was the general lack of deep diving behavior when the beluga was within Slope and Basin regions. Prior studies indicated that diving ≥ 200 m was common for the eastern Chukchi Sea stock of belugas when along the shelf break and in the Arctic Basin (Citta et al., 2013; Hauser et al., 2015). The tagged beluga may have belonged to a group that included calves, which may have constrained dive depths. Age dependent diving behavior in belugas is not well-understood. A manuscript describing this work is currently in review by the journal *Deep Sea Research I* (Citta et al. *In review*).

<u>Bowhead</u>. For seven CTD tags on bowhead whales that transmitted in the Chukchi Sea, we fit locations to a two-behavior (travel and foraging) state-space model using 'bsam' in R (Fig. 37) and then predicted the occurance of foraging as a function of environmental covariates (i.e., predictor variables) that accounted for winds, temperature, salinity, bottom slope, and the presence of stratified layers (in temperature and salinity). Specifically, we modeled the probability of lingering (presumably foraging) with a logit-link and a binomial error distribution. To account for repeated measurements from a limited number of whales, we treated whales as a random effect and fit errors to a spatial power model. The spatial power model is an extension of a AR1 autocorrelation model that allows measurements to have unequal spacing in time. Predictor variables included temperature and salinity at the surface and at the seafloor, the squared terms of both temperature and salinity (to make functions more non-linear), east winds (U-component winds), east winds that are conducive to upwelling (U-component winds < -5 m/s), and a set of variables aimed at examining gradients and stratifications in the water column. We examined the total gradient in salinity and temperature, defined as the absolute value of surface temperature and salinity minus bottom temperature and salinity, divided by the depth. Maximum gradient in temperature and salinity was defined as the maximum difference in temperature or salinity between two adjacent measurements in the water column. We examined 18 combinations of these variables and ranked models using AIC (Table 4). The most parsimonious model included surface temperature and bottom temperature; whales were more likely to stop and forage when both surface and bottom temperatures were relatively cold (Fig. 38), which is indicative of Bering Shelf/Anadyr Water and Pacific Winter Water, which are known to contain zooplankton from the Bering Sea. This relationship can be seen in Figures 39 and 40, for whale B18-07, note how locations associated with lingering behavior (red plus signs above the temperature plot) are more common in areas with blue or light blue shading. Areas with green shading (≥ 3 °C) are composed of Alaska Coastal Water (ACW). In Figure 40, whale B18-06, traveled north of the shelf break and almost all locations associated with lingering behavior are associated with colder surface and bottom (bottom of the dive) temperatures.

Table 4. Models for the probability that bowhead whales pause migratory movements, presumably to feed. All models include a spatial power covariance structure to account for temporal autocorrelation and treat individual whales as a random effect. Total gradients are calculated as the absolute value of the surface value minus the bottom value (temperature or salinity), divided by the total change in depth during a dive. The largest gradient in temperature or salinity encountered during a dive was calculated between adjacent depth readings within a dive, divided by the change in depth. All temperature and salinity variables come from CTD tag data.

Explanatory variables	**AIC**	**ΔAIC**
temperature at the bottom + surface temperature	**2769.780**	**0.0**
temperature at the surface	2770.404	0.6
largest temperature gradient in the water column + temperature at the bottom + temperature at the surface	2770.739	1.0
temperature at the bottom	2771.816	2.0
total salinity gradient in the water column	2772.213	2.4
largest temperature gradient in the water column + surface temperature	2772.405	2.6
largest temperature gradient in the water column	2773.029	3.2
total temperature gradient in the water column	2773.185	3.4
gradient of depth	2773.715	3.9
intercept only	2773.991	4.2
largest salinity gradient in the water column	2774.87	5.1
east winds < -5m/s (upwelling conducive)	2776.439	6.7
salinity at the surface	2777.874	8.1
salinity at the bottom	2778.579	8.8
temperature at the bottom + temperature at the bottom squared	2779.674	9.9
east winds (U component)	2781.199	11.4
salinity at the bottom + surface salinity	2782.126	12.3
salinity at the bottom + salinity at the bottom squared	2786.485	16.7

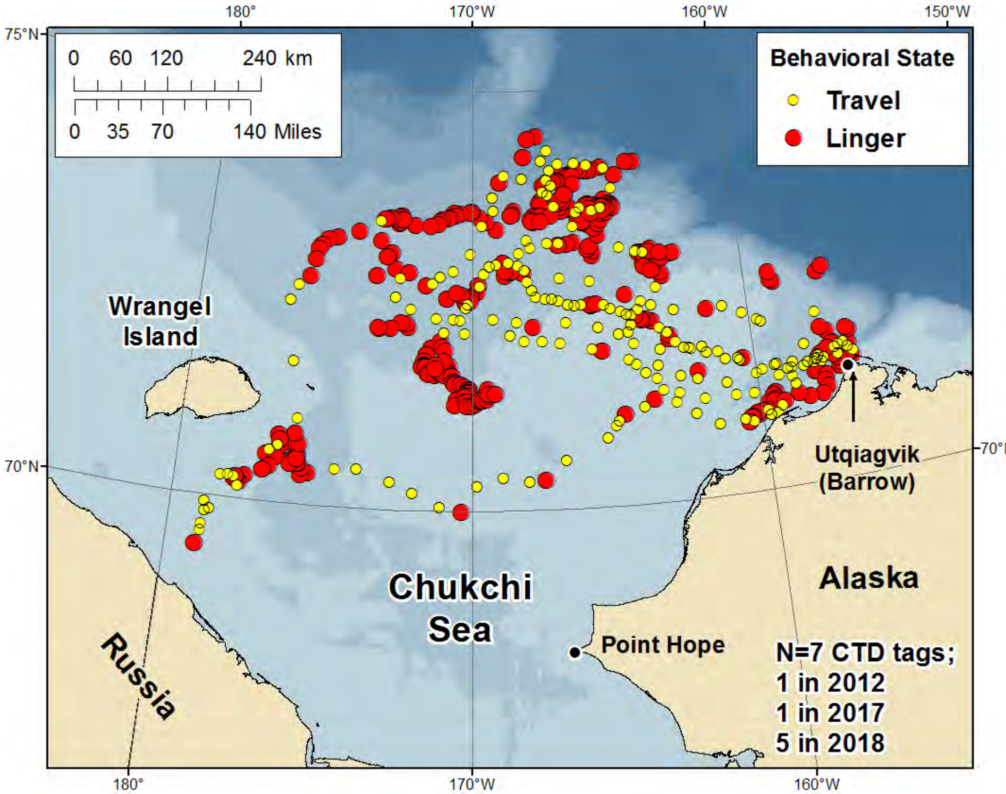


Figure 37. Behavioral state-space locations for seven bowhead whales in the Chukchi Sea, 2012–2018.

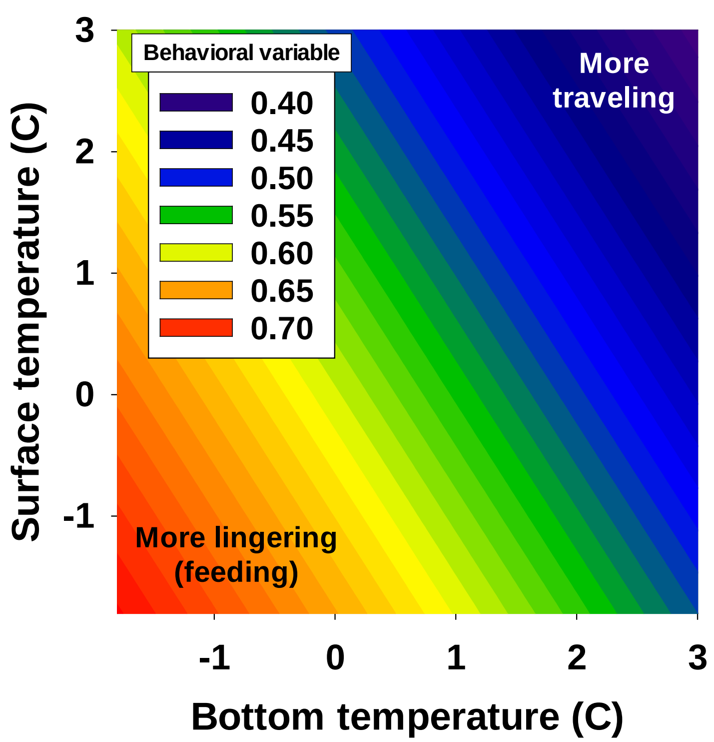


Figure 38. Probability of lingering (presumed feeding) as a function of surface temperature and bottom temperature.

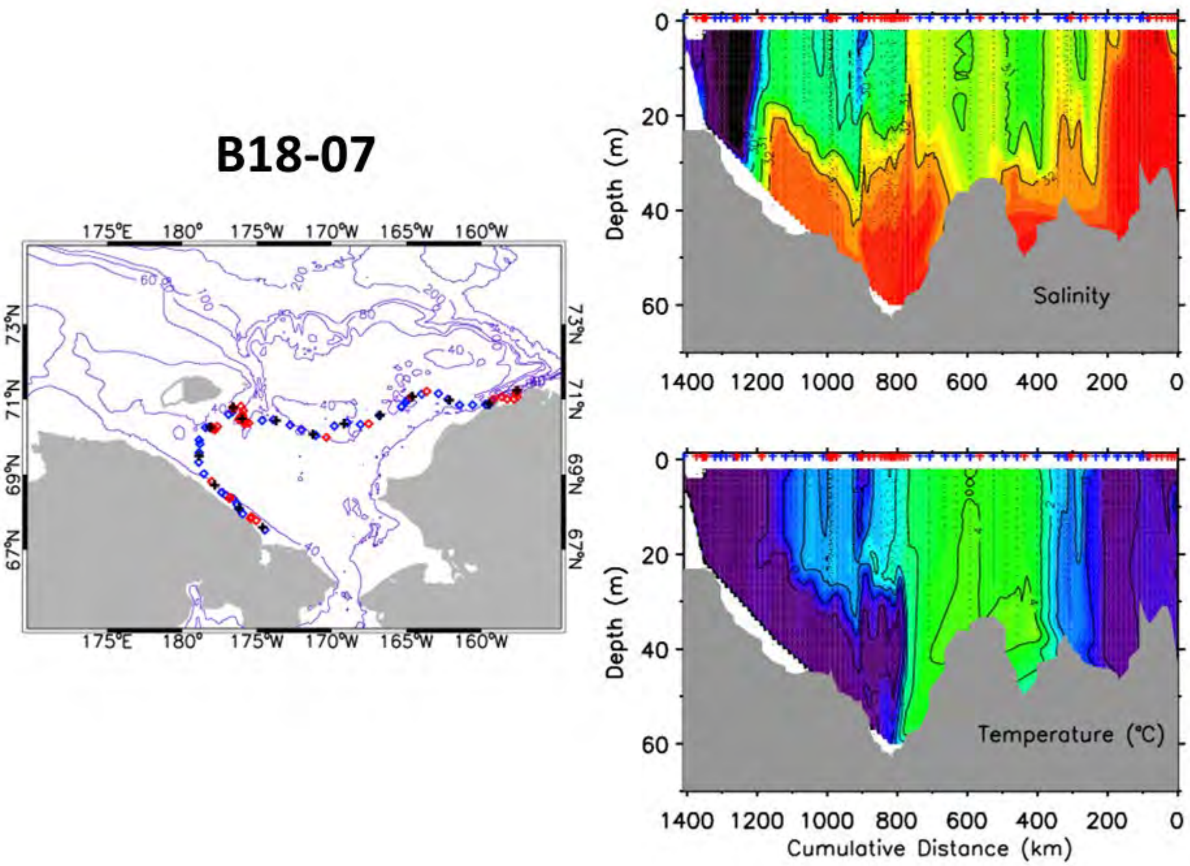


Figure 39. Track, salinity, and temperature plots for bowhead B18-07, tagged near Utqiaġvik, Alaska, in 2018. Blue dots on the trackline denote positions associated with directed movements and red dots denote locations associated with lingering (presumed foraging) behavior. These behavioral classifications are also shown above the salinity and temperature plots. Note how relatively few lingering locations fall in water warmer than 3 °C. Also note the cluster of dive locations directly east of the front formed by warmer coastal water (which has blown offshore) and colder winter water at approximately 800 km.

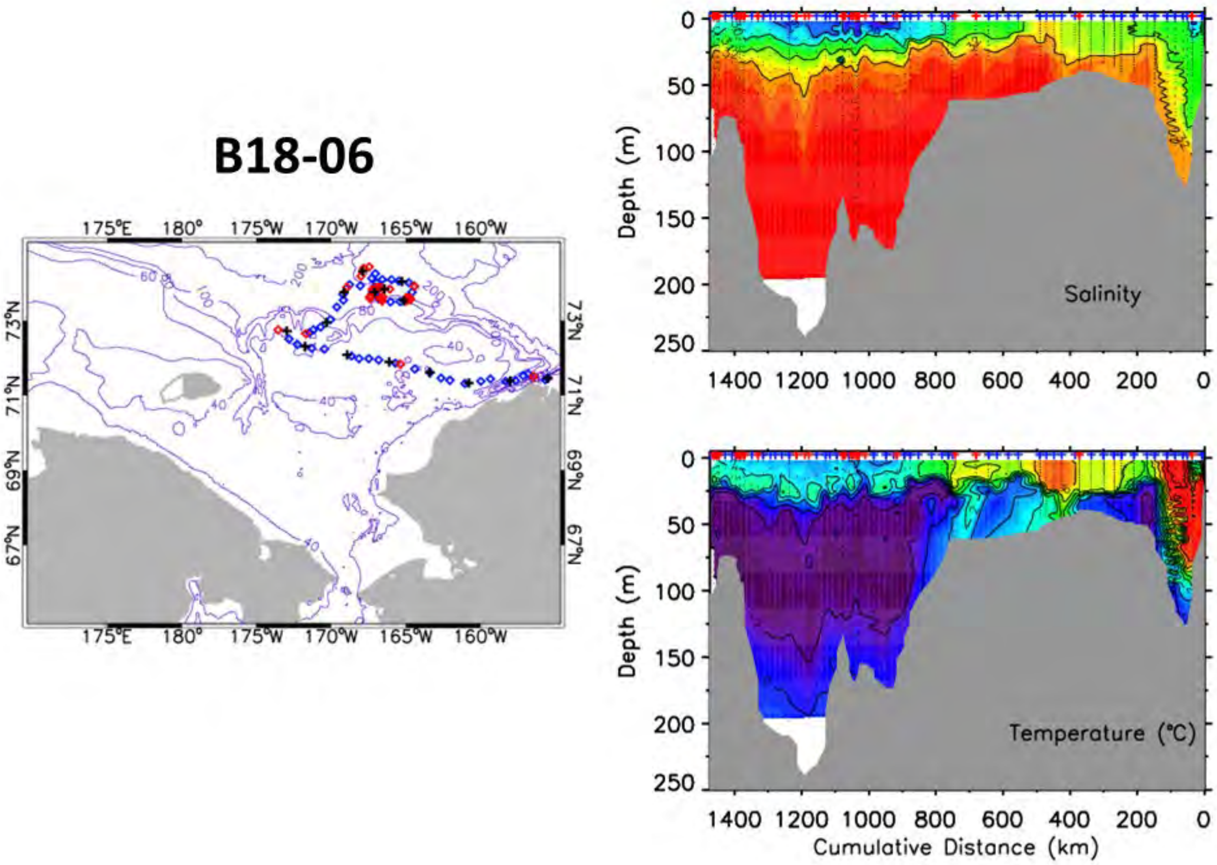


Figure 40. Track, temperature, and salinity plots for bowhead B18-06, tagged near Utqiaġvik, Alaska, in 2018. Blue dots on the trackline denote positions associated with directed movements and red dots denote locations associated with lingering (presumed foraging) behavior. These behavioral classifications are also shown above the salinity and temperature plots. Note how relatively most lingering locations were in locations with relatively cold bottom and surface temperatures (mostly north of the shelf break).

Interestingly, none of the vertical gradients we modeled had much explantory power. We expect this is because bowhead whales typically frequent the seafloor while on the continental shelf and that zooplankton largely aggregate at the seafloor in autumn. Also interesting is that surface temperature had more predictive power than bottom temperature; in single variable models, surface temperature was 1.4 AIC units better than a model with only bottom temperature. We did not expect this because prior analyses indicated that bottom temperature was important and that whales followed Pacific Winter Water and Bering Sea/Anadyr Water while crossing the Chukchi Sea. We suspect that whales largely stay in areas where bottom water is colder, because this is where they find zooplankton, and this behavior weakens the effect of bottom temperature relative to surface temperature. In short, because whales position themselves such that they are typically in areas with colder bottom waters of Pacific origin, bottom temperature is no longer the strongest predictor of where whales stop to forage.

Other interesting oceanographic features are apparent in the temperature and salinity profile plots. In particular, note the strong freshwater front along the Russian coast in Figure 39 (at 1200 km on the x-axis). This is where Siberian Coastal Water, mostly river discharge from the Kolyma River, carried in the Siberian Coastal Current, meets saltier waters from the Bering Sea. Also note the strong warm-water front on the east side of Barrow Canyon in Figure 40 (0–100 km on the x-axis). This is where the Alaska Coastal Water, carried by the Alaska Coastal Current is typically encountered (e.g., Okkonen et al. 2009). This information is being prepared for publication (Citta et al. *In prep*).

Objective 2) Use CTD data collected by bowhead whales to compare with oceanographic model data and for use as model input data.

The volume and quantity of CTD data collected by this project are valuable for comparison with existing oceanographic models used to predict over large areas. We will combine all of our CTD tag data from all species and will make formal comparisons as part of upcoming analyses.

Objective 3) Use dive and CTD data to determine the oceanographic conditions in the Bering Sea in winter to see if it can be determined that bowhead whales are feeding there during bottom dives.

There was one CTD tag transmitting during the winter of 2017/18; this whale primarily wintered north of Bering Strait due to anomalously light ice conditions. The whale spent the winter diving to the bottom in Bering Shelf/Anadyr Water and Pacific Winter Water, which are known to contain zooplankton from the Bering Sea. Three CTD tags transmitting during the winter of 2018/19, in the northern Bering Sea, also showed that bowhead whales were foraging in Bering Sea/Anadyr Water and Pacific Winter Water. These data provide further evidence that bowhead whales are feeding near the bottom in the Bering Sea in winter.

Objective 4) Explore the utility of a predictive model that would use oceanographic conditions to predict presence of bowhead and beluga whales in specific areas.

Beluga. Although a predictive model that would use oceanographic conditions to predict the presence of belugas in specific areas is possible, we were not able to collect enough data to address this objective. However, we did contribute information on how belugas target the front between Alaska Coastal Water and other waters of Pacific origin in Barrow Canyon when southwest winds dominate (Citta et al. *In review*).

Bowhead. We have begun to work on a model predicting the occurance of bowhead presence and foraging in the Chukchi Sea as a function of wind and oceanography. Because zooplankton have limited capacity for locomotion, they are essentially passive drifters. Hence, the distribution of zooplankton within the Chukchi Sea is largely determined by the temporal and geographic characteristics of wind forcing. We examined bowhead foraging behavior within two principal circulation pathways in the Chukchi Sea, Herald Valley (HV) and the Central Channel (CC) (Fig. 41). We first fit behavioral state-space models to track data during their fall migrations (2008–2017) and then calcualted the fraction of lingering locations (presumably foraging) that occurred within the CC vs. HV. We then used an iterative correlation method to identify the start and end dates of wind averaging periods that maximized the geographical extent over which correlations between time-averaged winds and foraging behaviors were statistically significant. The iterative correlation method suggested that foraging in the CC during 21 September–27 November was largely dependent upon an averaging window for winds that began in July (Fig. 42). Specifically, the proportion of foraging that occurred in CC versus HV was most correlated with a 28-day averaging window that started on 22 July. Our results indicate that fall foraging was more likely to occur in CC (2009, 2010, 2012, 2017) when summer winds over the Chukchi and Beaufort seas were southerly, weak and variable (Fig. 43, top). Conversely, fall foraging was more likely to occur in HV (2008, 2014, 2015) when summer winds over the northern Chukchi and southern Beaufort were northeasterly, strong and persistent (Fig. 43, bottom). These results, consistent with results of numerical particle trajectory experiments (Berline et al., 2008), suggest that southerly winds preferentially promote northward transport of zooplankton through CC rather than through HV. We are currently expanding these results to include other important foraging regions, such as Barrow Canyon and the coast of Chukotka, Russia. CTD tag data will be incorporated into this analysis, along with model data, to examine how currents in the central Chukchi shift away from the Alaskan Coast, towards the central Chukchi, when east winds dominate.

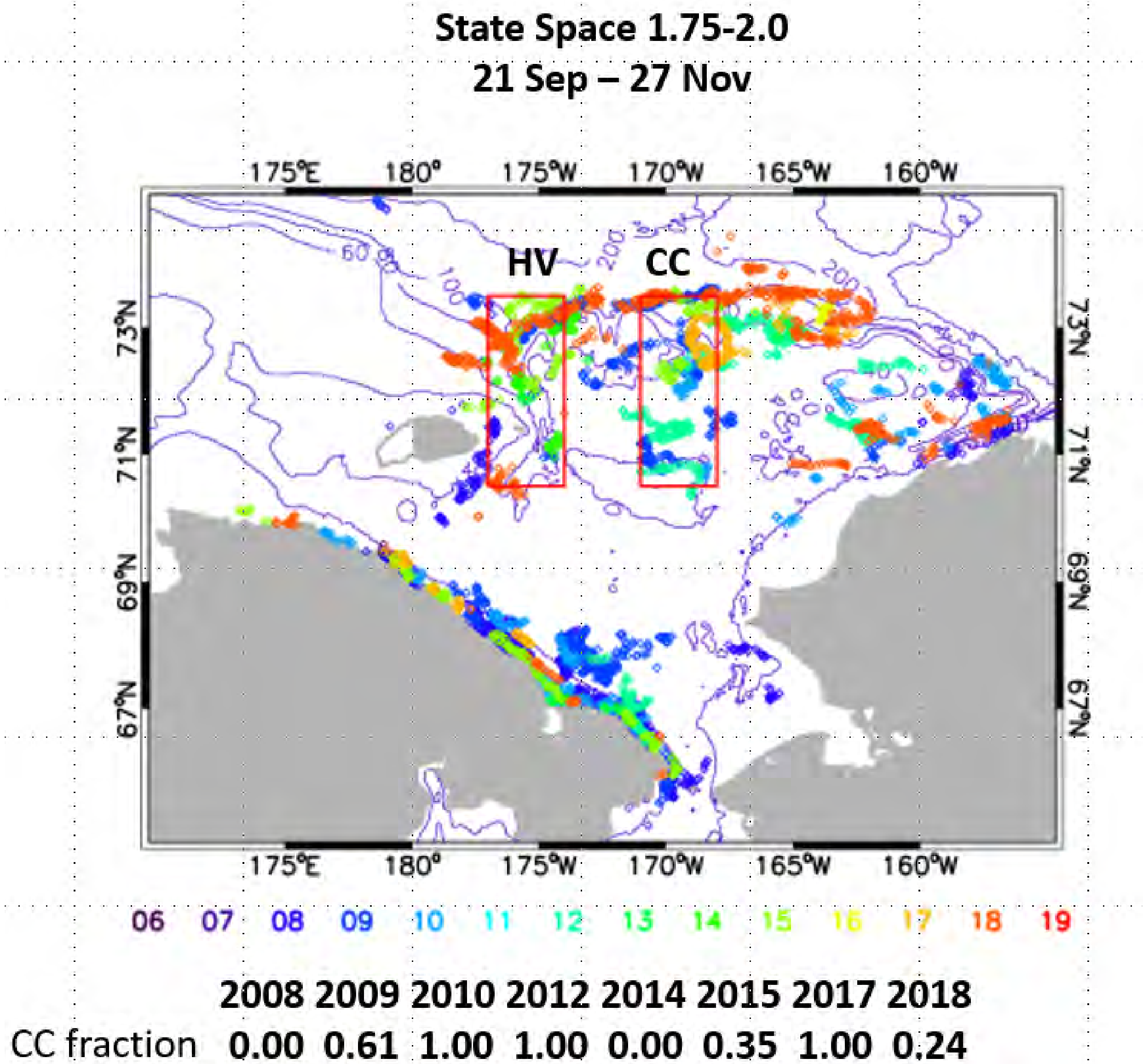


Figure 41. Plot of behavioral state-space locations classified as "lingering/feeding" in the Chukchi Sea, during 21 September–27 November 2008–2018. The fraction of lingering locations in the Central Channel (CC) versus Herald Valley (HV) is presented by year below the plot. For example, 100% of lingering locations occurred in the CC and 0% in the HV in 2010, 2012, and 2017.

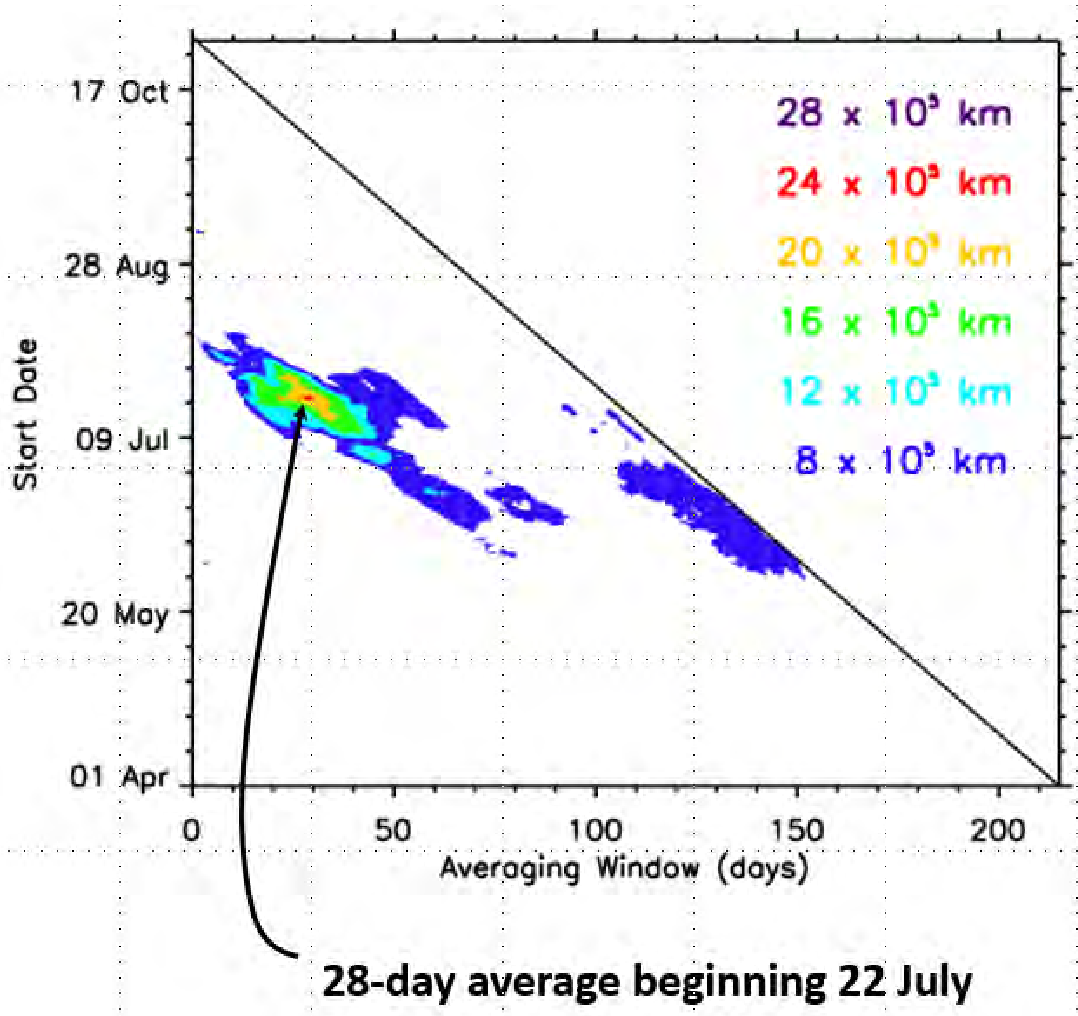


Figure 42. Area of the Bering, Chukchi, and Beaufort seas over which time-averaged winds are significantly correlated with the fraction of Central Channel foraging. Winds averaged over a 28-day window, starting on 22 July, best predict foraging in the Central Channel.

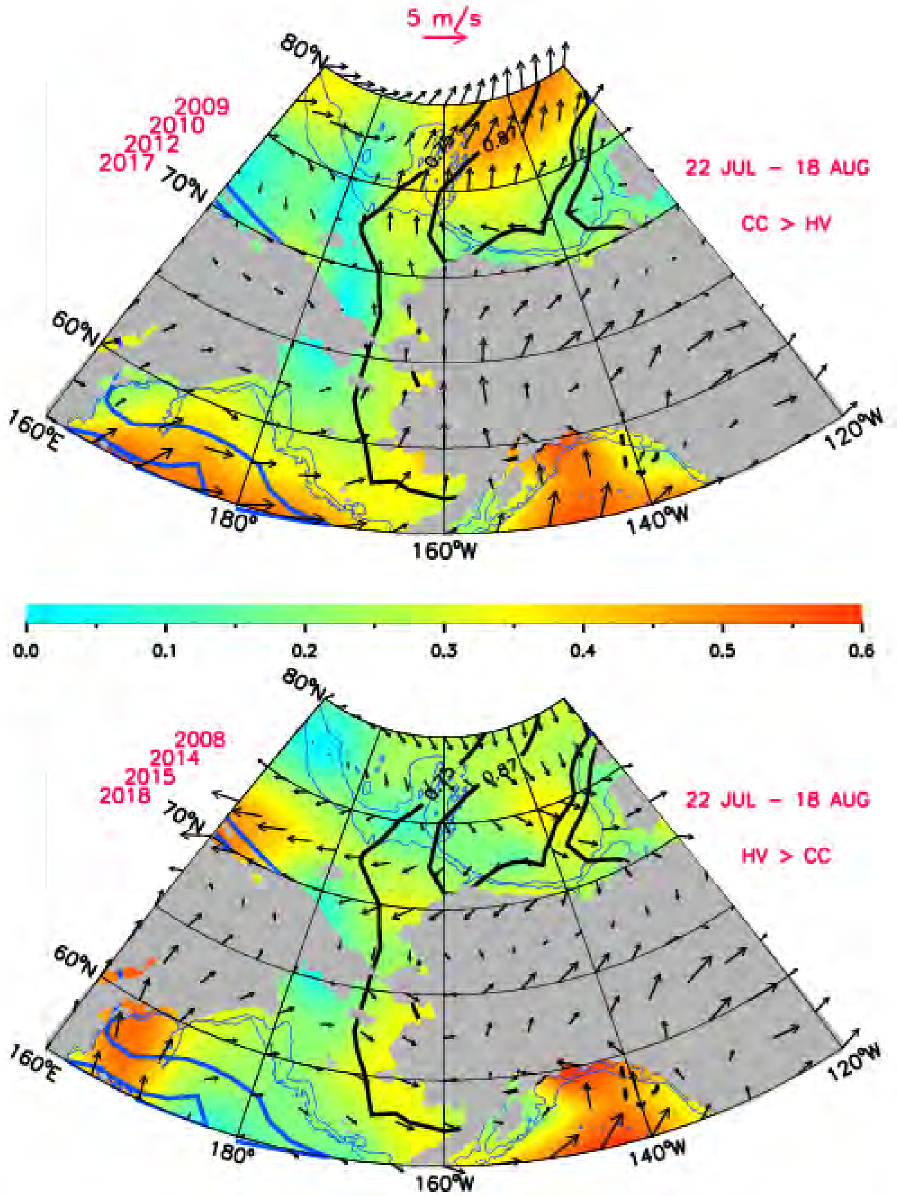


Figure 43. Wind conditions during 22 July–27 November that are associated with foraging fraction in the Central Channel (CC) versus the Herald Valley (HV), 21 September–27 November. Top: foraging fraction is higher in the CC when south winds dominated 22 July–27 November. Bottom: foraging fraction is higher in the HV when east winds dominated during 22 July–27 November.

IMPACT/APPLICATIONS

Satellite telemetry is a powerful tool for studying movements of marine mammals that spend the majority of their time offshore in dark, remote, and ice-covered waters during much of the year. These tags allow us to track movements of individual seals (Crawford, Frost et al. 2012; Harwood et al. 2012) and whales year-round (Citta et al. 2012, 2015; Hauser et al. 2014; Quakenbush et al 2010) and provide data for comprehensive analyses of distribution, movement, migration, and interactions with human activities (Citta et al. 2014). Documenting where marine mammals spend time, combined with diving behavior can identify important feeding, summering, and wintering areas (Olnes et al. 2020, Hauser et al. 2015, Citta et al. 2013). Combining real-time oceanographic conditions (i.e., CTD data; temperature and salinity at known depths) with location and animal behavior is greatly advancing our understanding of how marine mammals operate in an Arctic marine environment.

For example, CTD data indicates that seals and whales often target colder, saltier waters occurring below warmer water masses, or the stratified layers in between them. These are likely the areas where they find prey. The associations we have documented between CTD data and patterns of movement and diving show that oceanographic conditions contribute to the non-random use of the Bering, Chukchi and Beaufort seas by these animals. Given that CTD tags are a relatively recent technology, and that we are developing approaches for analyzing this kind of data, we expect many more advances in the near future.

Telemetry data are now available over sufficient time scales that comparisons can be made to assess how marine mammals may be responding to changing environmental conditions. For example, data from this study contributed to an analysis comparing juvenile bearded seal habitat preferences between two time periods (2004–2009 and 2014–2018). This analysis found that juvenile bearded seal preferences for certain ice conditions has not likely changed, instead these conditions now occur in different areas (Olnes et al. *In review*). We also found that the distribution of spotted seals in the Bering Sea in winter changes relative to historically low or normal ice years, with increased use of coastal areas, and less use of the central Bering Sea, when sea ice extent is minimal.

On a shorter time scale, our analyses of winds, oceanography, and whale movements have shown that both belugas and bowhead whales alter their movement and diving patterns relative to oceanographic conditions that are driven by wind. We also found preliminary evidence that wind and sea ice conditions that drive upwelling altered spotted seal behavior near the shelf break in the Bering Sea. Documenting these relationships now is critically important as climate change is altering patterns of wind, sea ice, and subsequently, the distribution of water masses. We therefore consider it likely that as oceanographic conditions change in the region, the distribution of marine mammals will also change.

RELATED PROJECTS

Other related studies conducted by ADFG included two co-occurring satellite telemetry studies funded by BOEM:

1) OCS Study BOEM 2019-079 titled "*Pinniped movements and foraging: village-based satellite tracking and collection of traditional ecological knowledge regarding ringed and bearded seals.*" This project later added spotted seals. The final report for this project (Quakenbush et al. 2019) is available at https://www.boem.gov/sites/default/files/documents/regions/alaska-ocs-

region/environment/BOEM%202019-079.pdf and other information is available on the ADFG website at http://www.adfg.alaska.gov/index.cfm?adfg=marinemammalprogram.icesealmovements.

2) OCS Study BOEM 2019-076 titled "*Satellite tracking of bowhead whales: habitat use, passive acoustic, and environmental monitoring.*" The final report for this project (Quakenbush and Citta 2019) is available at https://www.boem.gov/sites/default/files/documents/regions/alaska-ocs-region/environment/BOEM%202019-076.pdf other information is available on the ADFG website at http://www.adfg.alaska.gov/index.cfm?adfg=marinemammalprogram.bowhead.

These studies included the deployment of satellite transmitters on ringed, bearded, and spotted seals, and bowhead whales to document movements, diving behaviors, habitat use, as well as identify important foraging, summer, and winter areas. A third ongoing project is conducted by the NSB (funded by Shell Oil) to tag ringed, bearded, and spotted seals to better understand movements and habitat use in the Chukchi Sea oil and gas activity area. The transmitters used in these related projects are not capable of collecting oceanographic data (salinity and temperature), such as is collected by CTD tags deployed during the ONR project.

Training and Professional Development

Key individuals presented project results at the Alaska Marine Science Symposium, Anchorage, AK, USA, in January of all years of the project. Key individuals also presented at the Marine Mammal Society Biennial Conferences in 2017 (Halifax, Nova Scotia) and 2019 (Barcelona, Spain). Both Biennial Conferences held training workshops that were attended by key individuals.

Dissemination of Results

Seal location data were made available on the ATN webpage and on a dedicated seal tagging project webpage on the State of Alaska, Division of Wildlife Conservation website (http://www.adfg.alaska.gov/index.cfm?adfg=marinemammalprogram.icesealmovements). This webpage was updated weekly with maps of seal movements when tags are active and includes updates of our tagging events. The weekly maps were also sent to an extensive email distribution list of interested entities (~185) including individual seal hunters, village council offices, ONR, NOAA, USFWS, University of Alaska, NSB, BOEM, USCG, DFO, and oil and gas industry personnel.

Project objectives and tagging plans were presented to the Ice Seal Committee (Alaska Native co-management group) in June 2016 and updates have been presented at annual meetings since then. Project progress and results were presented as posters at the Alaska Marine Science Symposium in January 2017, 2018, 2019, and 2020 in Anchorage, Alaska (see Products).

Beluga whale location data were made available on the ATN webpage and were sent out to an email distribution list. Updates were provided to the ABWC and maps were also posted on the ABWC Facebook page.

Bowhead whale location data were made available on the ATN webpage and on a dedicated bowhead tagging project webpage on the State of Alaska, Division of Wildlife Conservation website (http://www.adfg.alaska.gov/index.cfm?adfg=marinemammalprogram.bowhead). This webpage is updated weekly with maps of bowhead movements when tags are active and includes updates of our tagging events. The weekly maps area also sent to an extensive email distribution list of interested entities (~120) including individual whalers, Alaska Eskimo Whaling Commission, village council offices, ONR, NOAA, USFWS, University of Alaska, NSB, BOEM, USCG, DFO, and oil and gas industry personnel. Project objectives, tagging plans, and updates were presented to the Alaska Eskimo Whaling Commission annually.

Products

1. Publications

Olnes Polar Biology

a. Article Title: Movement, diving, and haul-out behaviors of juvenile bearded seals in the Bering, Chukchi and Beaufort seas, 2014–2018
b. Journal: Polar Biology
c. Authors: Justin Olnes, Justin Crawford, John Citta, Matthew Druckenmiller, Andrew Von Duyke, Lori Quakenbush
d. Keywords: Alaska, *Erignathus barbatus*, Pacific Arctic, sea ice, satellite telemetry
e. Distribution Statement: Distribution will be restricted by the copyright rules of the publisher
f. Publication Status: Published
g. Publication Identifier Type: DOI: 10.1007/s00300-020-02710-6
h. Publication Identifier: The unique identifier for the publication
i. Publication Date: 25 June 2020
j. Volume: Online
k. Issue: Online
l. First Page Number: Online
m. Publication Location: Online
n. Acknowledgement of Federal Support? Yes
o. Peer Reviewed? Yes

Olnes Arctic

a. Article Title: Use of the Alaskan Beaufort Sea by bowhead whales (*Balaena mysticetus*) tagged with satellite transmitters, 2006–2018
b. Journal: Arctic
c. Authors: Justin Olnes, John Citta, Lori Quakenbush, John Craig George, Lois Harwood, Ellen Lea, and Mads Peter Heidi-Jørgensen
d. Keywords: bowhead whale, Alaska, Beaufort Sea, satellite telemetry, dive behavior, feeding, Western Arctic, migration
e. Distribution Statement: Distribution will be restricted by the copyright rules of the publisher
f. Publication Status: In press
g. Publication Identifier Type: In press
h. Publication Identifier: In press
i. Publication Date: In press
j. Volume: In press

k. Issue: In press
l. First Page Number: In press
m. Publication Location: In press
n. Acknowledgement of Federal Support? Yes
o. Peer Reviewed? Yes

Olnes Marine Ecology Progress Series

a. Article Title: Juvenile bearded seal response to a decade of sea ice change in the Bering, Chukchi, and Beaufort seas
b. Journal: Marine Ecology Progress Series
c. Authors (first name last name with multiple authors separated by comma): Justin Olnes, Greg Breed, Matthew Druckenmiller, John Citta, Justin Crawford, Andrew Von Duyke, Kathryn Frost, and Lori Quakenbush
d. Keywords: Pacific Arctic, satellite telemetry, resource selection, state space models, climate change
e. Distribution Statement: Distribution will be restricted by the copyright rules of the publisher
f. Publication Status: Under review
g. Publication Identifier Type: Under review
h. Publication Identifier: Under review
i. Publication Date: Under review
j. Volume: Under review
k. Issue: Under review
l. First Page Number: Under review
m. Publication Location: Under review
n. Acknowledgement of Federal Support? Yes
o. Peer Reviewed? Yes

Citta Deep Sea Research

a. Article Title: Beluga dive behavior relative to stratified ocean layers near Point Barrow, Alaska
b. Journal: Deep Sea Research I
c. Authors John Citta, Stephen Okkonen, Robert Suydam, Lori Quakenbush, Anna Bryan, Justin Olnes
d. Keywords: Beluga whale, *Delphinapterus leucas*, Chukchi Sea, Beaufort Sea, Barrow Canyon, satellite telemetry, dive behavior
e. Distribution Statement: Distribution will be restricted by the copyright rules of the publisher
f. Publication Status: Under review
g. Publication Identifier Type: Under review
h. Publication Identifier: Under review
i. Publication Date: Under review

j. Volume: Under review
k. Issue: Under review
l. First Page Number: Under review
m. Publication Location: Under review
n. Acknowledgement of Federal Support? Yes
o. Peer Reviewed? Yes

Von Duyke Ecology and Evolution

a. Article Title – Ringed seal (*Pusa hispida*) seasonal movements, diving, and haul-out behavior in the Beaufort, Chukchi, and Bering seas (2011–2017).
b. Journal: Ecology and Evolution
c. Authors: Andrew Von Duyke, David Douglas, Jason Herreman, Justin Crawford.
d. Keywords: Alaska, Arctic, ecotype, marine mammals, phocid, satellite telemetry, spatial ecology, unusual mortality event
e. Publication Status: Published
f. Publication Identifier Type: NA
g. Publication Identifier: DOI: 10.1002/ece3.6302
h. Publication Date: 1 April 2020
i. Volume: NA
j. Issue: NA
k. First Page Number: NA
l. Publication Location: Wiley Publishing
m. Acknowledgement of Federal Support? Yes
n. Peer Reviewed? Yes

Crawford Manuscript

a. Article Title: Oceanographic characteristics, dive and haul-out behavior associated with movements and high-use areas of spotted seals (*Phoca largha*) in the Chukchi Sea.
b. Journal: to be determined
c. Authors: Justin Crawford, Lori Quakenbush, John Citta, Justin Olnes, Andrew Von Duyke, and Stephen Okkonen.
d. Keywords: Spotted seals, Alaska, Beaufort Sea, Chukchi Sea, satellite telemetry, CTD data, high-use areas, terrestrial haulouts, dive behavior, feeding, movements
e. Distribution Statement: Distribution will be restricted by the copyright rules of the publisher.
f. Publication Status: In preparation
g. Publication Identifier Type: In preparation
h. Publication Identifier: In preparation
i. Publication Date: In preparation
j. Volume: In preparation
k. Issue: In preparation
l. First Page Number: In preparation
m. Publication Location: In preparation

n. Acknowledgement of Federal Support? Yes
o. Peer Reviewed? Yes

Okkonen Manuscript

a. Article Title: The influence of wind on bowhead whale foraging behavior in the Chukchi Sea.
b. Journal: To be determined
c. Authors:, Stephen R. Okkonen, John J. Citta, Lori Quakenbush, John “Craig” George, Lois Harwood, and Mads Peter Heide-Jørgensen.
d. Keywords: Arctic, bowhead whale, Chukchi Sea, satellite telemetry, dive behavior, feeding, Western Arctic, migration
e. Publication Status: In preparation
f. Publication Identifier Type: To be determined
g. Publication Identifier: DOI: To be determined
h. Publication Date: To be determined
i. Volume: NA
j. Issue: NA
k. First Page Number: NA
l. Publication Location: To be determined
m. Acknowledgement of Federal Support? Yes
n. Peer Reviewed? Yes

Citta Manuscript

a. Article Title: Oceanographic influences on bowhead whale migration in the Chukchi Sea as inferred by animal-borne CTD sensors.
b. Journal: Deep Sea Research
c. Authors:, John J. Citta, Stephen R. Okkonen, Lori Quakenbush, John “Craig” George, and Mads Peter Heide-Jørgensen.
d. Keywords: Arctic, bowhead whale, Chukchi Sea, satellite telemetry, dive behavior, feeding, Western Arctic, migration
e. Publication Status: In preparation
f. Publication Identifier Type: To be determined
g. Publication Identifier: DOI: To be determined
h. Publication Date: To be determined
i. Volume: NA
j. Issue: NA
k. First Page Number: NA
l. Publication Location: To be determined
m. Acknowledgement of Federal Support? Yes
n. Peer Reviewed? Yes

2. Conference Papers:

Citta AMSS

a. Title: How do winds influence occurrences of bowhead foraging in the Chukchi Sea?
b. Authors: John J. Citta, Stephen R. Okkonen, Lori T. Quakenbush, John “Craig” George, Lois Harwood, and Mads Peter Heide-Jørgensen
c. Conference Name: Alaska Marine Science Symposium.
d. Conference Date: 27–31 January 2020
e. Conference Location: Anchorage, Alaska, USA
f. Publication Status: Accepted
g. Publication Date: 27–31 January 2020
h. Publication Identifier Type
i. Publication Identifier: NA
j. Acknowledgement of Federal Support? Yes

Crawford AMSS

a. Title: Oceanographic characteristics associated with movements and high-use areas of spotted seals (*Phoca largha*) in the Chukchi and Bering seas.
b. Authors: Justin Crawford, Lori Quakenbush, Mark Nelson, Ryan Adam, Anna Bryan, John Citta, Andrew Von Duyke, and Stephen Okkonen
c. Conference Name: Alaska Marine Science Symposium
d. Conference Date: 27–31 January, 2020
e. Conference Location: Anchorage, Alaska, USA
f. Publication Status: Accepted
g. Publication Date: 27–31 January 2020
h. Publication Identifier Type: NA
i. Publication Identifier: NA
j. Acknowledgement of Federal Support? Yes

Olnes AMSS

a. Title: Movement and haul-out behaviors of bearded seals during minimum ice extent, July – October
b. Authors: Justin Olnes, Justin Crawford, and Lori Quakenbush
c. Conference Name: Alaska Marine Science Symposium.
d. Conference Date: 27–31 January 2020
e. Conference Location: Anchorage, Alaska, USA Publication Status: Accepted
f. Publication Date: 27–31 January 2020
g. Publication Identifier Type: NA
h. Publication Identifier: NA
i. Acknowledgement of Federal Support? Yes

Crawford AMSS

a. Title: Seasonal movements and high-use areas of spotted seals (*Phoca largha*) in the Pacific Arctic.

b. Authors: Justin Crawford, Lori Quakenbush, Anna Bryan, Mark Nelson, and Andrew Von Duyke.
c. Conference Name: Alaska Marine Science Symposium.
d. Conference Date: 28–31 January 2019
e. Conference Location: Anchorage, Alaska, USA Publication Status: Accepted
f. Publication Date: 28–31 January 2019
g. Publication Identifier Type: NA
h. Publication Identifier: NA
i. Acknowledgement of Federal Support? Yes

Quakenbush AMSS

a. Title: Movements and habitat use of Pacific Arctic seals and whales via satellite telemetry and ocean sensing
b. Authors: Lori Quakenbush, Stephen Okkonen, John Citta, Justin Crawford, Andrew Von Duyke, John "Craig" George, Billy Adams, Ellen Lea, Mark Nelson, and Anna Bryan
c. Conference Name: Alaska Marine Science Symposium.
d. Conference Date: 28–31 January 2019
e. Conference Location: Anchorage, Alaska, USA
f. Publication Status: Accepted
g. Publication Date: 28–31 January 2019
h. Publication Identifier Type: NA
i. Publication Identifier: NA
j. Acknowledgement of Federal Support? Yes

Quakenbush ONR Review

a. Title: Movements and habitat use of Pacific Arctic seals and whales via satellite telemetry and ocean sensing
b. Authors: Lori Quakenbush, John Citta, and Stephen Okkonen
c. Conference Name: Office of Naval Research Review.
d. Conference Date: 23–25 April 2019
e. Conference Location: Alexandria, Virginia, USA
f. Publication Status: Accepted
g. Publication Date: 23 April 2019
h. Publication Identifier Type: NA
i. Publication Identifier: NA
j. Acknowledgement of Federal Support? Yes

Citta Society of Marine Mammalogy

a. Title: Declining winter sea ice is associated with a northward shift of bowhead whale winter range.
b. Authors: John Citta, Lori Quakenbush, Stephen Okkonen, Matthew Druckenmiller, John "Craig" George, Billy Adams, Ellen Lea, and Mads Peter Heide-Jørgensen

c. Conference Name: 23rd Society of Marine Mammalogy and 2nd World Marine Mammal Joint Conference.
d. Conference Date: 9–12 December 2019
e. Conference Location: Barcelona, Spain
f. Publication Status: Accepted
g. Publication Date: 9–12 December 2019
h. Publication Identifier Type: NA
i. Publication Identifier: NA
j. Acknowledgement of Federal Support? Yes

Crawford Society of Marine Mammalogy

k. Title: Oceanographic characteristics associated with movements and high-use areas of spotted seals (*Phoca largha*) in the Chukchi and Bering seas.
l. Authors: Justin Crawford, Lori Quakenbush, Mark Nelson, Ryan Adam, Anna Bryan, John Citta, Andrew Von Duyke, and Stephen Okkonen
m. Conference Name: 23rd Society of Marine Mammalogy and 2nd World Marine Mammal Joint Conference.
n. Conference Date: 9–12 December 2019
o. Conference Location: Barcelona, Spain
p. Publication Status: Accepted
q. Publication Date: 9–12 December 2019
r. Publication Identifier Type: NA
s. Publication Identifier: NA
t. Acknowledgement of Federal Support? Yes

Crawford AMSS

a. Title: Movements and dive behavior of young bearded seals as related to sea ice in the Pacific Arctic.
b. Authors: Justin Crawford, Mark Nelson, Lori Quakenbush, Anna Bryan, Andrew Von Duyke, Merlin Henry, Alexander Niksik, John Goodwin, Alex Whiting, Matthew Druckenmiller
c. Conference Name: Alaska Marine Science Symposium.
d. Conference Date: 22–26 January 2018
e. Conference Location: Anchorage, Alaska, USA
f. Publication Status: Accepted
g. Publication Date: 22–26 January 2018
h. Publication Identifier Type: NA
i. Publication Identifier: NA
j. Acknowledgement of Federal Support? Yes

Quakenbush AMSS

a. Title: Seal-Borne Satellite Transmitters Provide Ocean Conditions in the Pacific Arctic.

b. Authors: Lori Quakenbush, Stephen Okkonen, John Citta, Justin Crawford, Mark Nelson, Anna Bryan, Ryan Adam, Andrew Von Duyke
c. Conference Name: Alaska Marine Science Symposium.
d. Conference Date: 22–26 January 2018
e. Conference Location: Anchorage, Alaska, USA
f. Publication Status: Accepted
g. Publication Date: 22–26 January 2018
h. Publication Identifier Type: NA
i. Publication Identifier: NA
j. Acknowledgement of Federal Support? Yes

Crawford Society of Marine Mammalogy

a. Title: Seasonal movements, habitat use, and dive behavior of pup and yearling bearded seals in the Pacific Arctic.
b. Authors: Justin Crawford, Mark Nelson, Lori Quakenbush, John Goodwin, Kathy Frost, Alex Whiting, and Matthew Druckenmiller
c. Conference Name: 22^{nd} Society of Marine Mammalogy Conference.
d. Conference Date: 22–27 October 2017
e. Conference Location: Halifax, Nova Scotia, Canada
f. Publication Status: Accepted
g. Publication Date: 22–27 October 2017
h. Publication Identifier Type: NA
i. Publication Identifier: NA
j. Acknowledgement of Federal Support? Yes

Quakenbush Society of Marine Mammalogy

a. Title: Seal-borne satellite transmitters provide ocean conditions along seal tracks in the Pacific Arctic.
b. Authors: Lori Quakenbush, Stephan Okkonen, John Citta, Justin Crawford, Mark Nelson, Anna Bryan, Andrew Von Duyke
c. Conference Name: 22^{nd} Society of Marine Mammalogy Conference.
d. Conference Date: 22–27 October 2017
e. Conference Location: Halifax, Nova Scotia, Canada
f. Publication Status: Accepted
g. Publication Date: 22–27 October 2017
h. Publication Identifier Type: NA
i. Publication Identifier: NA
j. Acknowledgement of Federal Support? Yes

Crawford AMSS

a. Title: Update of hunter-assisted seal tagging and traditional knowledge studies of Pacific Arctic seals, 2016 and beyond.

b. Authors: Justin Crawford, Mark Nelson, Lori Quakenbush, Andrew Von Duyke, Merlin Henry, Alexander Niksik, John Goodwin, Alex Whiting, Kathy Frost, Josh London, and Peter Boveng
c. Conference Name: Alaska Marine Science Symposium.
d. Conference Date: 23–27 January 2017
e. Conference Location: Anchorage, Alaska, USA
f. Publication Status: Accepted
g. Publication Date: 23–27 January 2017
h. Publication Identifier Type: NA
i. Publication Identifier: NA
j. Acknowledgement of Federal Support? Yes

Websites:

1) Title: Ice Seal Research, Movements and Habitat Use Studies
   a) URL: http://www.adfg.alaska.gov/index.cfm?adfg=marinemammalprogram.icesealmovements),
   b) Description: There are four species of seals in Alaska that are referred to as "ice associated seals" or "ice seals" because they use sea ice for important life history events such as pupping, nursing, molting, and resting. Ringed (*Pusa hispida*), bearded (*Erignathus barbatus*), spotted (*Phoca largha*), and ribbon (*Histriophoca fasciata*) seals are all used for subsistence by coastal Alaska Natives for food, oil, materials, clothing, and handicrafts. These ice seals live in the Bering, Chukchi, and Beaufort seas but little is known about the timing of each species' movements and even less is known about how these movements may differ by sex and age classes, whether individuals return to the same places seasonally, and the location and characteristics of important habitats they use. Reductions in sea ice have intensified interest in shipping and oil and gas activities, which amplifies the need to understand ice seal movements and habitat use to plan shipping lanes, oil and gas lease sales, and to develop effective mitigation measures for their protection. A combination of satellite transmitter technology and the skills of Native subsistence seal hunters to capture seals and instrument them with transmitters will greatly improve our knowledge of seal movements and behavior. The focus of this study is to work with interested seal hunters in multiple villages along the west and north coasts of Alaska to capture and instrument (tag) ringed, bearded, spotted, and possibly ribbon seals with satellite transmitters. Tracking seals tagged at multiple locations, potentially as far south as Bristol Bay and as far north as Kaktovik, will allow us to better understand the range and timing of movements, use of sea ice including haul-out behavior, important habitats, degree of seasonal site fidelity, and behavior near ships, including seismic and other petroleum related activities. Funding for seal tagging has been provided by BOEM (SPLASH and SPOT tags, Wildlife Computers, Redmond, WA) and the Office of Naval Research (CTD tags, Sea Mammal Research Unit, University of St. Andrews, UK). Seal research is conducted under a NMFS Permit issued to ADF&G and an ADF&G Animal Care and Use Permit.
2) Title: Bowhead Whale Research, Satellite Tracking of Western Arctic Bowhead Whales
   a) URL: http://www.adfg.alaska.gov/index.cfm?adfg=marinemammalprogram.bowhead

b) Description: Bowhead whales are the most important subsistence species for coastal and island communities in the Bering, Chukchi and Beaufort seas. We work with subsistence whalers to attach satellite transmitters to bowheads to study their movements, habitat use, and behavior throughout their range including migration routes and timing, feeding areas, diving behavior, time spent within the spring and summer ranges. We also study how bowhead whales interact with oil and gas activities. We are investigating the use of tags that record oceanographic information to identify ocean features, such as fronts where whales prefer to feed. We are developing an acoustic tag that will record ambient sound and the vocal behavior of the whales to better understand the effects of high noise level activities such as seismic surveys and drilling activity.

   This project began in 2006 and is a collaboration among the Alaska Department of Fish and Game, the Alaska Eskimo Whaling Commission, Whaling Captain's Associations of Barrow, Kaktovik, Gambell, and Savoonga, the Aklavik and Tuktoyaktuk Hunters and Trappers Committees, the North Slope Borough, the Barrow Arctic Science Consortium, the Department of Fisheries and Oceans Canada and the Greenland Institute of Natural Resources. The project is funded by the Bureau of Ocean Energy Management.

3) Title: Movements and Habitat Use of Pacific Arctic Seals and Whales via Satellite Telemetry and Ocean Sensing, 2016-2020.
   a) URL: https://portal.atn.ioos.us/#metadata/ae1ea78a-2dbf-4294-908c-77580f92d5fd/project
   b) Description: Animal location data are provided to the Integrated Ocean Observing System Animal Telemetry Network (IOOS ATN) to serve as an access point to see, search, and access animal telemetry data, from a wide variety of species and platforms. The development of this website was led by scientists from the Block Lab at Stanford University, working in collaboration with colleagues from the NOAA Environmental Research Division, the University of California Santa Cruz, the US IOOS Program Office, Axiom, and the Office of Naval Research. Telemetry data from the CTD tags deployed for this project are available to view on this webpage.
4) Title: Sea Mammal Research Unit Database
   a) URL: http://www.smru.st-and.ac.uk/protected/technical.html
   b) Description: The Sea Mammal Research Unit (SMRU) manages animal location, dive, haul out, and associated oceanographic data collected by the CTD tags. These data are accessible to co-investigators in close to real time. Oceanographic data are also shared directly with the World Meteorological Organization via the Global Telecommunication System (WMO GTS) for use by the Navy Oceanographic Office (NAVO) and ONR in close to real time.

Plans for Next Reporting Period

This is the final report.

Honors

None

Technology Transfer

None

APPENDICES

Appendix A. Von Duyke, A.L., D.C. Douglas, J.K. Herreman, and J.A. Crawford. 2020. Ringed seal (*Pusa hispida*) seasonal movements, diving, and haul-out behavior in the Beaufort, Chukchi, and Bering seas (2011–2017). Ecology and Evolution. http://dx.doi.org/10.1002/ece3.6302

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