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Ice Seal Movements and Foraging:

Village-Based Satellite Tracking and Collection of Traditional Ecological Knowledge Regarding Ringed and Bearded Seals – Final Report

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Cover photo: An adult male ringed seal (RS19-03-M) captured near Utqiaġvik, Alaska, on 23 June 2019 with a satellite-linked transmitter (SPLASH tag) epoxied to the hair on its back. Photo by Kevin Fisher.

Prepared under BOEM Contract M13PC00015

Pinniped Movements and Foraging:

Village-Based Satellite Tracking and Collection of Traditional Ecological Knowledge Regarding Ringed and Bearded Seals

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Project Organization Page

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Lori Quakenbush is a Wildlife Biologist IV and Program Leader for the Arctic Marine Mammal Program within the Alaska Department of Fish and Game. Her role in this project was that of Principal Investigator and Project Manager and her activities included coordination, communication, contracting, permitting, tagging, presentations, traditional knowledge interviews, report writing, and manuscript preparation.

Justin A. Crawford is a Wildlife Biologist II for the Arctic Marine Mammal Program within the Alaska Department of Fish and Game. His role in this project was that of Principal Investigator and his activities included coordination, tagging, tag and data management, archive, analysis, map production, and report and manuscript preparation.

Mark A. Nelson was a Fish and Wildlife Technician V for the Arctic Marine Mammal Program within the Alaska Department of Fish and Game. His role in this project was tagging and coordination, documentation, and reporting of traditional knowledge.

Justin R. Olnes is a Wildlife Biologist II for the Arctic Marine Mammal Program within the Alaska Department of Fish and Game. His role in this project was assistance with tagging, data management, analysis, and report, and manuscript preparation.

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Executive Summary

Four species of seals in Alaska are referred to as "ice-associated seals" or "ice seals" because they use sea ice for some important life history events such as pupping, nursing, molting, and resting. Three of these seals, bearded (*Erignathus barbatus*), ringed (*Pusa or Phoca hispida*), and spotted seals (*Phoca largha*) are important subsistence species used by coastal Alaska Natives for food, oil, materials, clothing, and handicrafts. Ribbon seals (*Histriophoca fasciata*), the fourth species, are less common in Alaskan waters and used less often by subsistence-based communities. Ice seal summer habitat coincides with areas of interest for oil and gas development and seasonal movements overlap with shipping lanes, therefore information is needed to better understand ice seal migration routes and feeding areas to plan lease sales, permit exploration and development activities, design shipping lanes, and provide effective mitigation measures. We combined satellite-linked transmitter technology, traditional and local knowledge and skills of Native subsistence seal hunters to greatly increase our understanding of ringed, bearded, and spotted seal movements and behavior. Objectives for this project from September 2013 to September 2019 included: 1) estimating movements and behavior of ice seals (including movements between haulouts and feeding areas) within shipping lanes and the Beaufort and Chukchi seas planning areas; 2) evaluating the effect of changes in ice seal behavior relative to changes in sea ice; 3) estimating ice seal use of haulouts by age class and other potential factors; and 4) documenting traditional knowledge of ice seal movements, behavior, and use of habitats. All objectives were successfully met, except for determining use of haulouts by age class for ringed and bearded seals due to low sample size for some age classes. Use of haulouts and haul-out behavior was described for each species but could only be analyzed by age class for spotted seals.

During this project we deployed 67 transmitters on 26 bearded, 16 ringed, and 25 spotted seals at eight locations; four locations in the Bering Sea, two locations in the Chukchi Sea and two locations in the Beaufort Sea. Primary (glue-on) tags (SPLASH10 and CTD tags) provided location, dive data and temperature profiles, and haul-out durations; flipper-mounted tags (SPOT tags) provided location and haul-out durations, but only when seals were hauled out. Transmitters deployed on ringed, bearded, and spotted seals provided information on movements, dive behavior, and hauling out behavior during all seasons, which allowed us to identify important high-use areas including feeding areas, use of sea ice, and potential interactions with oil and gas areas, seismic activities, and ship traffic. Local and traditional knowledge was documented for 13 communities, to further our understanding of seal behavior and how it may be changing. We finalized 11 reports of traditional knowledge that included ice seals and published two peer-reviewed papers on traditional knowledge in science journals. All reports are available to the public.

Using data from this project we learned that young bearded seals tagged in the Bering and Chukchi seas made strong seasonal (north in summer and south in fall) movements, but those tagged in the Beaufort Sea did not travel south of ~70 °N. We would not have identified this difference in movement pattern had we not deployed tags over a large area of the species' range. Pup and yearling bearded seals were able to remain in open water without hauling out for several weeks at a time. Five young bearded seals were tracked in ice free waters for 26, 30, 36, 38, and

50 days between haul-out bouts. Foraging areas identified for bearded seals included Barrow Canyon, Kotzebue Sound, Bering Strait, Norton Sound, northeast and southeast of St. Lawrence Island, and along the 100 m isobath of the Bering Shelf.

All 16 tagged, mostly adult, ringed seals exhibited strong, seasonal, latitudinal patterns in movements throughout the year, using high-latitudes during the open-water season (July–November) and lower latitudes, near or south of the Bering Strait, when ice was present (December–June). Foraging areas identified for ringed seals included Barrow Canyon and the intercontinental shelf break in the northern Chukchi Sea.

All 17 spotted seals tagged in the Beaufort Sea made strong, seasonal movements between the Beaufort and Bering seas, but six of seven seals tagged in the Bering Sea stayed in the Bering Sea all year. By mid-January all spotted seals were in the Bering Sea. Foraging areas identified for spotted seals during the open water season included southern Barrow Canyon, Peard Bay, and between Icy Cape and Herald Shoals in the Chukchi Sea and between the Yukon-Kuskokwim Delta and St. Lawrence Island in the Bering Sea. Foraging during the ice-covered season included broad use of the Bering Sea shelf.

On average, bearded and ringed seals traveled less and were closer to land when ice was present than spotted seals. Bearded seals used ice and land to haul out during the open water season, however their haul-out durations were twice as long on ice. Ringed seals were more likely to haul out during the ice-covered season than the open water season, but we identified four times when ringed seals hauled out on land. Spotted seals regularly haul out on ice and land and regularly used land haulouts at Dease Inlet, Icy Cape, Kotzebue Sound, and Scammon Bay. In general, spotted seals spent 1–21 days foraging and 1–6 days hauled out. Spotted seals older than 1 year were more likely to haul out and to haul out longer than pups regardless of the season.

We documented several examples of within season and seasonal site fidelity. For example, some spotted seals returned to rest near areas they were tagged (Dease Inlet and Scammon Bay) one to two months later. Some seals returned to areas during the same season in consecutive years, including 5 of 6 bearded seals (67%), 3 of 5 ringed seals (60%), and 4 of 5 spotted seals (80%).

The three seal species differed in their use of ice. Bearded and ringed seals used ice when it was available, using higher concentrations during January–June (monthly average 50–75%) and open water during July–November. Spotted seals, however, used much lower ice concentrations (~40%) and remained much closer to the ice edge in winter when ringed and bearded seals were well into the ice. We identified changes in behavior of each species with decreasing sea ice. Ringed seals were found and captured in June in Kotzebue Sound in 2014 and 2017, but not after 2017. During years that sea ice did not advance into the central Bering Sea (2017 and 2018), bearded seals restricted their winter movements to the northern and eastern Bering Sea. Spotted seals continued to use the Bering Sea shelf in the east, staying near land, islands, and shorefast ice suitable for hauling out in winter until ice formed in the central Bering Sea, then they expanded their use to the western Bering Sea shelf break.

Almost half of all tagged seals (32 of 67, 48%) used the Chukchi Sea Lease Sale 193 area and were located within the area an average of 5 days (range = 1–37 days). The timing of entry differed by species; bearded seals generally entered earliest, using the area from 30 May to 19 September, ringed seals used the area later from 11 June to 19 October, and spotted seals entered latest using the area from 2 August to 31 December. While in the area, bearded and ringed seals ranged widely but were primarily located in the northeastern portion (in and near Hanna Shoal Walrus Use Area) while spotted seals primarily used the southern portion, south of 71.2°N.

Far fewer tagged seals (8 of 67, 12%) used the Beaufort Sea leased blocks in part because few seals traveled east of the Colville Delta, even though six seals were tagged there. Two bearded, four ringed, and two spotted seals spent some time in, or near, Beaufort Sea leased blocks. One bearded seal spent six months in the area, while two ringed seals spent 3–16 days each while migrating through the area, to the east in July and returning west in August or September. Two spotted seals passed through to the west leaving the Colville Delta where they were tagged.

One tagged ringed seal (RS14-02-F) may have been in the vicinity of an active seismic survey conducted between 1 June and 30 September 2014. The seismic survey was a 3D airgun array, however, the dates within the time period the survey was conducted, and the location of the seismic lines, are proprietary to the company that conducted the operation and are not available to the public. This ringed seal passed within 10 km of the seismic project location, near Prudhoe Bay, during late July while making a long-distance movement east towards Mackenzie Bay, Canada. Until details about seismic operations are available, we cannot acquire the information needed to overlay seal locations with seismic operations before, during, and after seismic surveys to analyze seal behavior.

Bearded seals were most likely to encounter ship traffic in Norton Sound throughout the year, and along Alaska's northwest coast in the summer. Ringed seals were more likely to encounter ship traffic in Norton Sound in the spring, in the northeastern Chukchi Sea in the summer, and in Norton Sound and the Bering Strait region in the fall. Spotted seals were more likely to encounter ship traffic in the northeastern Chukchi Sea and along Alaska's northwest coast in the summer and along the Russian coast and Bering Strait region in the fall. Given their tendency to return to and forage near the Alaskan coast, spotted seals may overlap least with shipping on Northern Sea Route along the Russian coast but may overlap with ships hauling ore from Red Dog Mine or other traffic along the Alaskan coast.

Results from this study contributed to understanding distribution, movements, and overlap of bearded, ringed, and spotted seals. Bearded, ringed, and spotted seals made extensive seasonal latitudinal movements. The extent of those movements, however, depended on where seals were tagged. Data collected by this project can be, used to compare seal behavior to previous and future seal tagging projects and be used for mitigation and management actions, including assisting aerial surveys of abundance.

Sea ice in the Beaufort, Chukchi, and Bering seas has been decreasing and the trend is expected to continue and appears to be accelerating. The effects of decreasing sea ice coupled with oil and gas development and increased shipping traffic on ice seals are not well understood, however results from this study have greatly increased what we know about ice seal movements, habitat use, haul-out behavior, interactions with oil and gas and shipping and has identified important objectives for future studies.

Due to the changes in seal movements over time documented by this study, we recommend seal tagging studies continue to monitor movements to asses further changes in seal behaviors associated with a warming climate. We recommend local and traditional ecological knowledge be collected to document current observations of seal hunters so they can be compared to previous conditions and to augment information from telemetry studies. Offshore industrial activity and shipping creates noise that may negatively affect seal behavior within areas ice seals use. As sea ice declines and areas have open water conditions for longer durations, more killer whales are likely to summer in the Bering, Chukchi, and Beaufort seas and stay longer, potentially influencing seal movements and use areas. The satellite-linked acoustic tag (Acousonde 3S) developed during a BOEM bowhead study (see OCS Study BOEM 2019-076) should be field tested and deployed on bearded seals to measure vocalizations of the seals instrumented with this tag and ambient noise levels that may include shipping and other industrial noise; all from the seals' perspective.

Introduction

Bearded (*Erignathus barbatus*), ringed (*Pusa* or *Phoca hispida*), spotted (*Phoca largha*), and ribbon (*Histriophoca fasciata*) seals are the four species of seals in Alaska called "ice-associated seals" or "ice seals" because they use sea ice for some important life history events such as pupping, nursing, molting, and resting. Ice seals are an important wildlife resource and an important source of food, clothing, and materials to the subsistence culture of coastal Alaska Natives. Ice seals are also important components of the Bering, Chukchi, and Beaufort seas ecosystems because they feed at several trophic levels (Shustov 1965, Frost and Lowry 1980, Lowry et al. 1980, Burns 1981, Lowry et al. 1981, Antonelis et al. 1994), may compete with some commercial fisheries (Lowry et al. 1978, Bukhtiyarov et al. 1984, Lowry 1984), and are eaten by polar bears (*Ursus maritimus;* Amstrup and DeMaster 1988). Reductions in sea ice (Wang et al. 2018), coupled with oil and gas activities, and increases in maritime shipping activity may affect these seals through multiple pathways (Kovacs et al. 2011). Ribbon seals are less common in Alaskan waters; therefore, they are rarely observed near shore and unlikely to be captured during shore-based tagging studies.

In 2012, bearded and ringed seals in Alaska were designated as threatened under the Endangered Species Act (ESA) because predicted changes in sea ice over the next century were expected to cause their populations to decline (U.S. Federal Register 2012a, b). At the time of listing there was no evidence that either population was declining, and subsistence harvests were considered sustainable and not a factor contributing to the listings.

Identifying important use areas, or habitats, and movements among habitats is necessary to ensure that oil and gas activities and other possible disturbances are minimized through mitigation and careful lease area planning. Satellite telemetry is a powerful tool to study the timing and location of migration routes, identify important habitats, determine interactions with industrial areas and shipping lanes and monitor seals' use of sea ice in a changing environment. Although a few satellite telemetry studies have been conducted in the past, sample sizes were small and more information is needed about ice seal movement, behavior, and habitat use in Alaska, especially how these change in response to rapid declines in sea ice.

Bearded Seals. Bearded seals are the largest of Alaska's ice seals and, although they can make breathing holes in heavy shore fast ice, they primarily use less consolidated pack ice. They are primarily benthic feeders and eat a variety of bottom-dwelling fish and invertebrates (Quakenbush et al. 2011b, Crawford et al. 2015). Bearded seals are also an important seal species for subsistence and are valued for their large size and good meat and oil. Their skins are used to cover boats (umiaks) used for bowhead whaling in some villages (e.g., Point Hope and Utqiaġvik) and 6,700–10,600 are harvested annually (Nelson et al. 2019). Due to their large size (up to 2.4 m (8 feet) long and > 230 kg (500 lbs.)) and their wariness, capturing adult bearded seals is challenging.

Only two adult bearded seals have been tagged in Alaska, both by NMFS personnel working with hunters from Kotzebue, (Boveng and Cameron 2013), therefore little is known about adult movements. Young bearded seals (pups and one-year-olds, locally called "ugrutchiaqs") are easier to catch; 35 were tagged in fall 2004–2006 and 2009 in Kotzebue Sound by a Native Village of Kotzebue project (funded by U.S. Fish and Wildlife Service Tribal Grants) and another was tagged near Point Barrow in September 2012 by NSB personnel. Tagged bearded seals moved south into the Bering Sea for the winter and north again in spring as the ice retreated (Kotzebue Marine Mammal News 2007, Breed et al. 2018, Cameron et al. 2018). Although bearded seals ranged widely, they occasionally made localized movements suggesting focused feeding and resting areas. Of seven bearded seals tagged in Kotzebue Sound with tags that transmitted for multiple years, three of them returned to the same area in the Bering Sea over two consecutive winters, showing remarkable winter site fidelity (Boveng and Cameron 2013). More movement data is needed to understand feeding and wintering areas, the importance of ice and how a changing ice environment will affect bearded seals.

Ringed Seals. Ringed seals are the smallest of the ice seals and their life history strategies are most closely associated with sea ice. They can live under 2 m or more of sea ice through which they maintain breathing holes by scratching ice with their claws. Ringed seals in Alaska waters eat fish (mostly Arctic cod, *Boreogadus saida*) and invertebrates (mostly crustaceans) (Quakenbush et al. 2011a, Crawford et al. 2015). Ringed seals are important for Alaska Native subsistence and 6,500–11,600 are harvested annually in Alaska (Nelson et al. 2019). The thick shore fast ice is used as breeding habitat by adults where both sexes build snow caves or "lairs" in snow drifts that form above their breathing holes (McLaren 1958, Smith 1973). At least in some regions, adults annually return to the same area for breeding where they appear to restrict their movements during spring (Kelly et al. 2010). Young ringed seals (mostly subadults) tagged near Paulatuk, in Northwest Territories, Canada, in September 2001 and 2002, made extensive movements westward past Point Barrow to the northern coast of Chukotka, Russia, and then south into the Chukchi and Bering seas (Harwood et al. 2012). During a cooperative project, the Native Village of Kotzebue, the University of Alaska, and the Alaska Department of Fish and Game (ADFG) tagged 37 ringed seals near Kotzebue, Alaska in 2007–2009 and identified differences in movements between age-classes, especially in winter. Adult seals tended to stay in the Chukchi Sea and northern Bering Sea during winter, while the subadults moved to the southern extent of the ice to winter along the ice edge (Crawford et al. 2012, Kotzebue Marine Mammal News 2012). Where subadults and adults occurred together, they dove to similar depths; although subadults were commonly located in deeper waters where they generally dove deeper than adults. Both age classes hauled out less and dove deeper, longer, and more frequently during midday than at other times of day (Crawford et al. 2019). The North Slope Borough (NSB) tagged 32 ringed seals near Utqiaġvik during July–October 2011. These seals moved north to the ice edge until late October when they began moving south and west. By mid-December, the seals were approaching or through Bering Strait (NSB, unpubl. data). ADFG tagged four ringed seals with a local subsistence hunter near Hooper Bay in June 2012. Although ringed seal distribution has been strongly correlated with the presence of sea ice in all months of the year, during the open-water season, ringed seals do occur in ice-free waters of the Beaufort, Chukchi, and Bering seas (Burns et al. 1981, Crawford et al. 2012).

Spotted seals. Spotted seals are less reliant on ice than ringed or bearded seals and they only maintain breathing holes in thin ice (Fay 1974). Thus, they use loose pack near the ice edge in winter and pups are born on top of the ice in spring. Spotted seals haul out on barrier islands and sandbars, in coastal areas, and in rivers during summer and their diet is more piscivorous than that of ringed and bearded seals (Quakenbush 1988, Quakenbush et al. 2009). Studies of spotted seal movements include 12 seals tagged at barrier island haulouts near Point Lay between 1991 and 1993 (Lowry et al. 1998). These seals moved between the coastal haulouts and offshore areas in August–November before migrating south to winter in the Bering Sea (Lowry et al. 1998). Spotted seals use nearshore areas and coastal haulouts in summer and fall, and when the ice forms in the winter they move offshore and haul out on ice (Lowry et al. 2000). Spotted seals tagged in Russian waters made similar movements (Lowry et al. 2000). In recent collaborations (2012–2015) with the NSB, spotted seals were tagged in the northern Chukchi Sea near Peard Bay (n = 3) and in the western Beaufort Sea in Dease Inlet (n = 20). Summer movements of spotted seals tagged in the 2000s varied from staying near the Alaskan coast to moving across the Chukchi Sea to Russia. Most of the tagged spotted seals moved west, into the Chukchi Sea, after leaving Dease Inlet and, although a few went east, they did not move east of the Colville River Delta; none entered Canadian waters in the eastern Beaufort Sea. Spotted seals also mix with harbor seals (*Phoca vitulina*) in the southern extent of their range in Bristol Bay, Alaska.

Satellite Telemetry. Satellite telemetry is a powerful tool for studying marine mammals that spend most of their time offshore in dark, remote, and icy locations during much of the year and often migrate long-distances (e.g., Quakenbush et al. 2010, Crawford et al. 2012 and 2019, Harwood et al. 2012, Citta et al., 2013, 2015, 2018). Once deployed, tags provide the seal's location and diving behavior in almost real time. Sample sizes in marine mammal telemetry studies tend to be low due to the short season for captures, often unsafe weather, and the cost of transmitters and data acquisition, however, the information received from each tag adds a remarkable amount of data that can be analyzed to address many questions. Sample sizes of tagged animals accumulate through time, which contributes to understanding behavior and variability of behavior seasonally, interannually, and eventually at the population level.

Feeding. ADFG has a subsistence harvest sampling program that analyzes stomach contents of ringed, bearded, and spotted seals. We use this extensive diet database to guide our interpretations of diving behavior collected by the tags (Quakenbush et al. 2009, Quakenbush et al. 2011a, Quakenbush et al. 2011b, Crawford et al. 2015 and 2019). Diet information from the stomachs of subsistence harvested seals is collected in the same years and in some of the same locations as the satellite tag deployments, as well as in some areas tagged seals move through.

Disturbance. The primary source of disturbance to seals is most likely man-made noise produced by ships, barges and tugs, small boats, air traffic, and seismic and drilling operations. It is not clear how important sound is to ice seals; ringed and spotted seals are not known to be very vocal. Male bearded seals, however, advertise their breeding territory by singing in the spring (Ray et al. 1969, Burns 1981, Van Parijs and Clark 2006) and one study determined that male bearded seals are vocal year-round (MacIntyre et al. 2013). An acoustic study found that individual males could be identified by their vocalizations and found the same six adult male bearded seals singing near Point Barrow over a 16 year period (Van Parijs and Clark 2006) indicating that, at least seasonally, vocal communications are important for bearded seals and adult males are territorial showing long-term seasonal site fidelity.

Seals are curious and often surface near a vessel to look at it, but it is not known if seals are attracted to man-made noise or vessels. It is also not known how seals react to drill ships or airgun arrays used during seismic testing. The movements and dive behavior of tagged seals could provide information regarding whether seals are attracted to or displaced from high-noise areas.

Understanding the extent and timing of ice seal movements will be important for planning lease sale areas, oil and gas activities, and shipping lanes so that they minimize impacts to the populations. Although some seals make long-distance movements during summer they may return to a commonly used area during other times of the year. Locating these high-use areas and determining how they are used may identify important areas in need of protection for each species.

Offshore leases have been sold by Minerals Management Service (MMS), now Bureau of Ocean Energy Management (BOEM), for oil and gas exploration and development in the Outer Continental Shelf (OCS) east of Point Barrow, in the Beaufort Sea, and west of Point Barrow in the Chukchi Sea. These leases have overlapped with areas used by ice seals. Although leases in the Chukchi Sea were quite active during four years (2013–2016) of this six-year (2013–2019) seal study, all were relinquished by 2017, however, some leases continue to be active in the Beaufort Sea. Thus, a more thorough and current understanding of ice seal movements and habitat use is important for providing information used in 1) environmental impact statements and environmental assessments under the National Environmental Policy Act, the Marine Mammal Protection Act, and the ESA; 2) planning future lease sales; 3) permitting exploration, development, production and their related activities; and 4) designing effective mitigation for activities.

Methods

Coordination

Meetings with the Ice Seal Committee (ISC), local hunters, tribal councils, communities, and the North Slope Borough (NSB) were fundamental to this tagging project. Communications with National Marine Fisheries Service, Marine Mammal Lab (MML), and NSB regarding research and tagging activities were important for coordination and for increasing sample sizes. Meetings with tag manufacturers were also important for solving technical issues with the tags.

Tagging

The timing and location of tag deployments were guided by interested hunters, community subsistence activities, timing of the seal molt, and access to seals. As with all our Arctic marine mammal studies, this work was conducted in a manner that did not interfere with subsistence activities.

We used a combination of tag types to collect short-term (months) location, dive, haul-out, and oceanographic data as well as long-term (years) location and haul-out data. SPLASH tags (also known as MK10 tags, Wildlife Computers, Redmond, WA, USA) provide location, dive data, and haul-out behavior, and were purchased for this BOEM project (Fig. 1). We also deployed CTD tags (Conductivity-Temperature-Depth, Sea Mammal Research Unit, St. Andrews, Scotland) with funding from the Office of Naval Research (ONR) for a concurrent study focused on seal movements relative to oceanographic parameters. CTD tags provided location, dive, haul-out, and ocean salinity and temperature data (conductivity and temperature at depth intervals). By combining movement and dive data from tags purchased by BOEM and ONR, we increased the number of seals caught, the number of locations we deployed tags, and the type of information we collected from tagged seals, which strengthened the inferences we were able to make for tagged seals to the benefit of both supporters. We include data from BOEM tags in our ONR reports, when appropriate, for the same reasons.

Either a SPLASH or CTD tag was glued (with epoxy) to the hair of the seal's back (and occasionally head); these tags fell off during the annual pelage molt in spring. Only seals captured after the molt will retain an epoxied tag. The third tag type, a SPOT tag (Wildlife Computers, Redmond, WA, USA) was attached to a hind flipper and provided location and haul-out data, but only when the seal was out of the water (Fig. 1). These tags were not affected by the molt and were programmed to conserve battery life and transmit data for up to two years. Most seals were tagged with a flipper-mounted SPOT tag but only seals that molted before capture were instrumented with a SPLASH tag or a CTD tag. SPOT tags were purchased by this BOEM project; MML provided an additional 16 SPOT tags and NSB provided 5 SPOT tags.

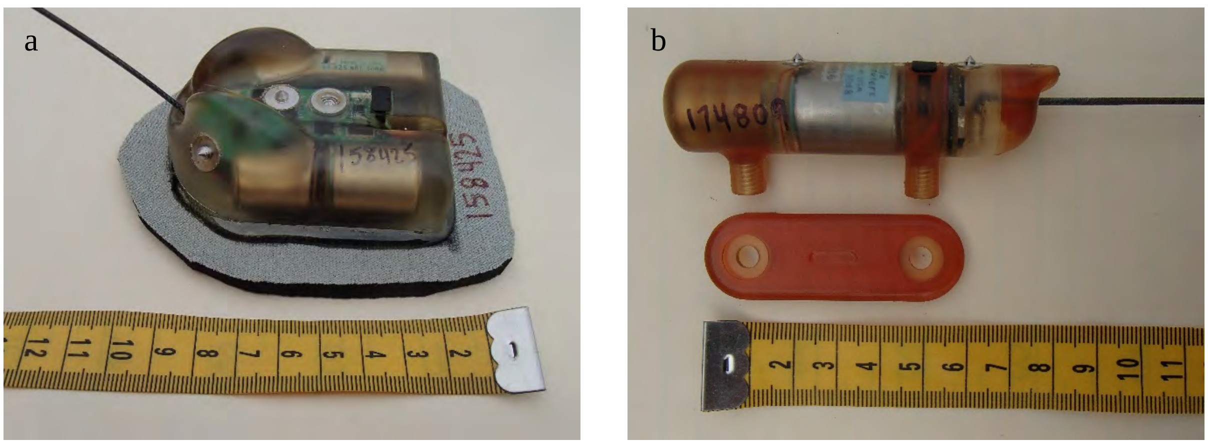


Figure 1. Satellite transmitters deployed on ice seals: a) SPLASH tags epoxied to the seal's back or head, and b) flipper-mounted SPOT6 tag. Both transmitters were manufactured by Wildlife Computers, Redmond, WA, USA. Ruler is in cm.

Typically, seals were captured in large mesh (~12–15-inch stretch) nylon or monofilament nets built with light lead lines that allowed captured seals to reach the surface to breathe. The nets were placed in areas known by subsistence hunters as traditional subsistence netting areas near shore, around pack ice, or in rivers, when seals were present.

Mapping

To keep all interested parties informed of the project and share the movements of tagged seals, we produced maps of seal tracks and sent them to an extensive mailing list that included many seal and other subsistence hunters as well as agency and oil company personnel at least every two weeks. ArcGIS version 10.3 (ESRI 2014) was used for mapping. The maps and information about the project were also posted at the Alaska Department of Fish and Game's (ADFG) webpage:
http://www.adfg.alaska.gov/index.cfm?adfg=marinemammalprogram.icesealmovements

Location Processing and Data Management

Locations and ancillary sensor data (i.e., dive, haul-out, temperature, and salinity) are transmitted to and processed by the Argos system of satellites (Harris et al. 1990). Raw transmitter locations are estimated based upon the Doppler Effect and the error associated with each location (quality) depends on the number of transmissions sent by tags, when the seal was at the surface, that were received by Argos satellites. Location quality was estimated by the Argos system and characterized by "location classes" (see the Argos User's Manual for a complete description; available online from argos-system.org/manual/).

We processed the raw location data depending upon how the data were to be used. We typically filtered raw location data prior to mapping and statistical modelling. The goal of a filter is to remove locations that are known to be unlikely or impossible. Filters calculate the distance between successive locations and use their timestamps to calculate velocity. If including the location results in a velocity that is physically impossible for the species, then that location is removed. Some filters also use an angular component to remove locations with a high degree of location error that fall far from the estimated line of travel, but still within the threshold velocity. These locations are essentially outliers and they create "spikes" or acute deviations in the line of travel (e.g., Freitas et al. 2008, Keating 1994). For location *i*, this deviation is measured as the angle between locations *i*-1, *i*, and *i*+1. We used a Speed-Distance-Angle (SDA) filter developed by Freitas et al. (2008) extensively. This filter has separate velocity and angular components and was fit with R software (available online from R-project.org). The filter removed seal locations that resulted in swim velocities of > 2.5 m/s, unless they were within 5 km of the previous location. The threshold velocity of 2.5 m/s was based on literature review indicating this velocity is the maximum observed speed of seals not fleeing vessels or assisted by currents (Williams and Kooyman 1985, Lowry et al. 1998). Otherwise, we used the default settings within the Freitas et al. (2008) filter; i.e., within 2.5 km of the track line, locations resulting in angles < 15° were removed and locations between 2.5 and 5 km of the track line were removed if they resulted in angles < 25° (see the manual for package 'argosfilter' for more detail, available online at cran.R-project.org). We used this filter for the regular maps we distributed and posted on our webpage and for analyses of seal locations in our published papers (Crawford et al. 2012, 2019).

To estimate daily locations, we modelled location data using the continuous-time Correlated Random Walk (CRW) model developed by Johnson et al. (2008). The model, which treats movement as a velocity process, is available in the R statistical package 'crawl'. We estimated two parameters, β, the autocorrelation in velocity and σ, the variation in velocity. Location error was assumed to be normally distributed with a mean of 0. Argos locations with quality scores 3, 2, and 1 have estimated standard deviations of 250 m, 500 m, and 1500 m, respectively, but standard deviations for poor quality location scores (0, A, and B) are not estimated (see the Argos user's manual: https://www.argos-system.org/manual/) (Fancy et al. 1988; Stewart et al. 1989; Harris et al. 1990). To incorporate location measurement error for poor quality locations into the seal movement model, we used the error distributions from Johnson et al. (2008), which are based upon the observations of Vincent et al. (2002).

More recently, we have explored an additional method for estimating daily locations that also infers one of two behavioral states for each location estimate: transiting or resident behavior. Joint-estimation state-space models (R package: ‘bsam’, Jonsen et al. 2005, Jonsen 2016) infer behavior based on movement parameters (velocity, turn angle and their autocorrelation), where transiting behavior is characterized by greater velocities and more correlated turning angles (moving in a straight line). Resident behavior is characterized by slower velocities and less correlated turning angles (milling or lingering). This method can be analyzed with dive data so we can better identify important habitats and how they associate with animal behavior.

A copy of the raw and decoded Argos data (with associated metadata) is archived at ADFG in Fairbanks and backed-up on State of Alaska servers in Juneau and Anchorage. The ‘raw data’ include location, dive, haul-out, and oceanographic data types. We worked with the Animal Telemetry Network (ATN) and the Alaska Ocean Observing System (AOOS) to better prepare them for archiving telemetry data with necessary metadata so that data could be used appropriately by third parties in the future.

Decoding, analyzing, and interpreting raw Argos data are not straightforward. Transmitters have complex settings, such as daily transmission limits or duty cycling, and dive data are often simplified for transmission into user-defined intervals. Even seemingly simple tasks, such as calculating correction factors for aerial surveys, require detailed knowledge of how tags were programmed to sample the environment, including how often they transmit (up-link) to satellites, sample water depth, determine if they are wet or dry, how they define the start and end of dives, and how they define a haul-out bout. Determining how to proceed with data management and analysis requires substantial time and expertise. Although we have the expertise to understand and manage the raw data we collected, we are concerned that future users may not, which could result in data that are unintentionally misused and misinterpreted. Because of this, we explored the level and complexity of metadata necessary for future users to adequately understand what can and should not be done with data we collect. We also suggested to ATN and AOOS that archiving data products that are processed for end-users may be useful, thereby removing the responsibility from naïve users to appropriately decode, analyze, and interpret raw data.

Movement, Dive, and Haul-out Analyses

Seal movement, dive, and haul-out data were examined in relation to bathymetry, distance from land, and sea ice cover. Most analyses were conducted with R statistical software using a model selection framework to compare habitat use and movements by species, age class, sex, time of day, and month. A typical analysis consisted of building linear or linear mixed-effects models using the ‘lm’, ‘lmer’ (package: ‘lme4’), or ‘lme’ (package: ‘nlme’) functions in R and comparing various models via Akaike’s Information Criterion (AIC) to select the best fitting model. Significant parameters (i.e. age class or month) within the final model were then used to identify and describe important patterns. When necessary, random effects (such as year or individual seal) were included.

For analyses of sea ice habitat, we defined ice conditions as ‘water’ (0% ice concentration), ‘marginal ice zone’ (15–80% ice concentration), and ‘heavy ice’ (> 80% ice concentration). We defined the ice edge as 15% ice concentration, delineating open water from pack ice (> 15% ice concentration). Sea ice data were daily Sea Ice Concentrations from Nimbus-7 SMMR and

DMSP SSM/I-SSMIS Passive Microwave Data at 25 km resolution, projected using NSIDC's polar stereographic projection. (Data obtained from: ftp://sidads.colorado.edu/pub/DATASETS/nsidc0051_gsfc_nasateam_seaice/final-gsfc/).

Methods used to determine high-use areas for seals was based on the movement behavior of each species. Bearded seals are primarily benthic foragers; therefore, we used a state-space model to infer foraging locations (lingering or resident behavioral state) from traveling locations (transiting behavioral state). For ringed and spotted seals, high-use areas were identified by assessing location densities by season. We identified high-use (core) areas based on the density of daily estimated locations (CRW model) within 50 x 50 km square cells across our study area. We considered the volume of locations in each cell the utilization distribution (UD) and high-use areas to be cells with UDs of < 50% volume. UDs are akin to density, a 95% UD contains 95% of all locations, essentially all areas an animal used. Lower percentages identify areas with higher densities (more animals in a smaller area or volume of locations). Designations of seasons were different for ringed and spotted seals because we based them on species-specific seasonal movements.

Analysis of Time Spent Within Areas of Petroleum Interest

We used all telemetry data collected between 2014 and 2019 to quantify when tagged seals were present within areas of petroleum interest. Transmitter locations were filtered as described above. When calculating the number of calendar days that seals were located within various oil and gas exploration/lease areas we pooled data from all study years (2014–2019). Although pooling across years provides a more general understanding of when seals might be located within a petroleum area, it removes the ability to detect annual variability. Tags were deployed from June through October and, on average, transmitted data for 4.5–7 months. As such, tags provided locations until mid-February through May of the year after they were deployed, a period that generally includes their migration north through the Chukchi Sea. Therefore, documenting the range of days that seals were present within an area will be a minimum estimate because some tags likely went off the air while seals were still in those areas.

We examined seal use of the Alaskan Chukchi and Beaufort Sea oil and gas program areas (Fig. 2):

1. Alaskan Chukchi Sea: All of Lease Sale 193 area.
2. General activity when near leased blocks in the Alaskan Beaufort Sea.

Analysis of Ship Traffic

We used Automatic Identification System (AIS) data collected from maritime ships to identify highly used shipping areas and those areas that overlapped with seal locations. AIS data were compiled by ExactEarth (Cambridge, Ontario, Canada) and made available to us by the Wildlife Conservation Society. AIS data included areas used by seals in the Bering and Chukchi seas during 2013–2015. AIS data extended to the northern Chukchi Sea (72°N), south of St. Lawrence Island (62.5°N), east to Point Barrow (156.5°W), and west to Anadyr Gulf and Chaunskaya Bay, Russia (172.5 °E). Monthly density rasters of maritime shipping traffic were made using a kernel utilization volume distribution of the AIS data and grid sizes < 2 km. The input AIS data for each month was cleaned by removing the points that had incomplete Maritime Mobile Service Identity numbers, fewer than 10 points for that vessel, or the reported speed was less than 2 knots or greater than 30 knots. Rasters were generated with R statistical software using the 'kernelUD' and 'getvolumeUD' functions from the package 'adehabitatHR'. Monthly rasters of densities were then averaged across month to match seasons with open-water that we report (Spring: April–June, Summer: July–September, and Fall: October–December). January–March had few ship locations within the study area after data cleaning so no rasters were generated. We then overlaid daily estimated locations (CRW model) of bearded, ringed, and spotted seals to determine areas of overlap with maritime shipping traffic. We further identified the seasonal proportion of each seal species locations that were generally within shipping areas, 95% density volume, and highly used shipping areas, 50% density volume.

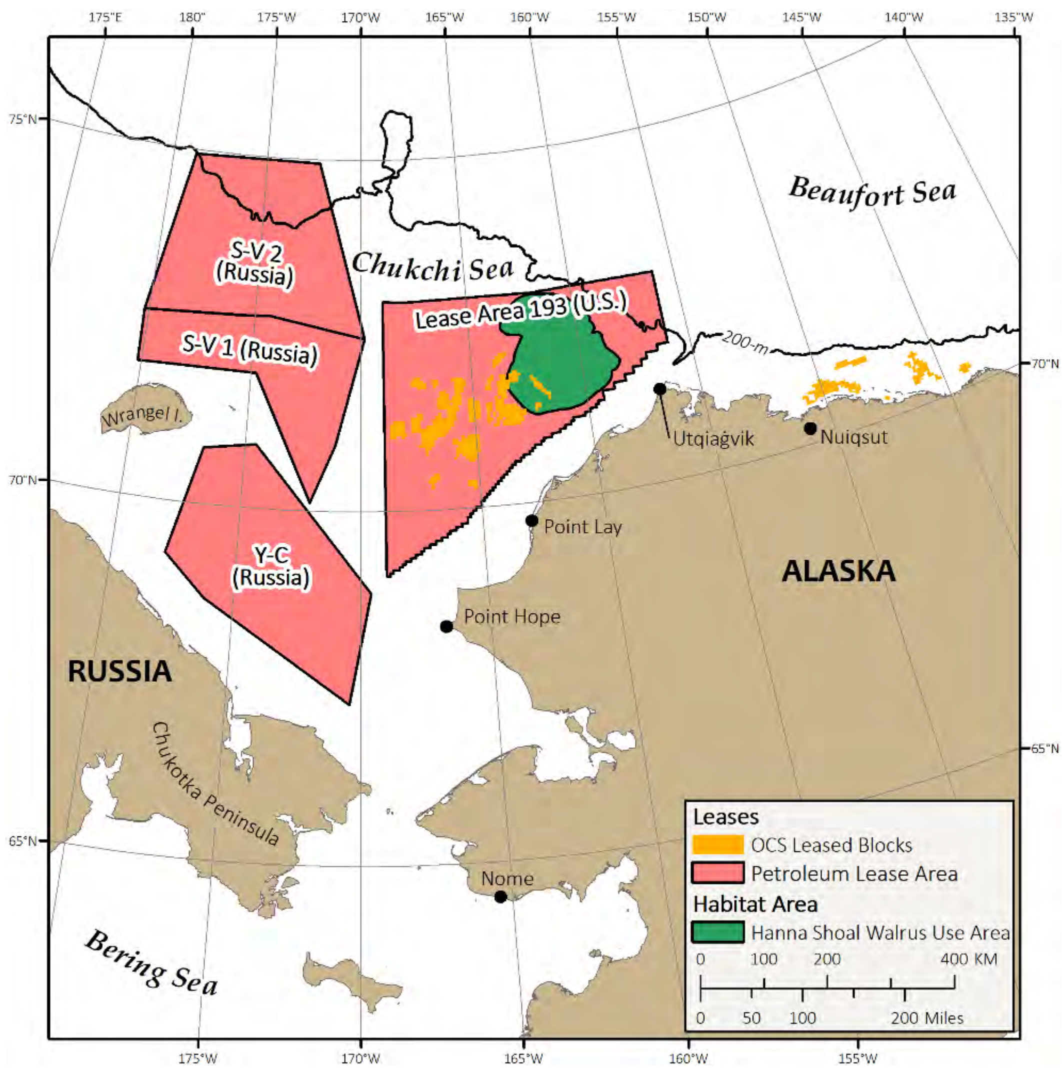


Figure 2. Map of the Chukchi and Beaufort seas with U.S. and proposed Russian petroleum exploration/development lease areas (red), and U.S. Outer Continental Shelf (OCS) historically leased blocks (orange). Proposed Russian petroleum areas include: Severo-Vrangelevskiy 1 (S-V 1), Severo-Vrangelevskiy 2 (S-V 2), and Yuzhno-Chukotsky (Y-C). The Hanna Shoal Walrus Use Area, recognized as an important foraging area for walruses was delineated by Jay et al. (2012) using utilization distributions of tagged walruses from June through September, is also shown (green). Note that OCS Leased Blocks associated with the Chukchi Sea Lease Sale 193 area were active during the study period, however, all were relinquished by 2017.

Safety
Safety plans were specific for each area and tagging effort. We purchased safety equipment and trained participants in its use. Safety equipment included Mustang floatation suits, waterproof handheld radios, satellite phones and other emergency communication devices, personal satellite-linked locator beacons and GPS units. Communication with a shore-base was coordinated prior to each trip.

Traditional Ecological Knowledge
A valuable component of this study was the collection of traditional ecological knowledge (TEK) regarding seal movements, timing of migration, and hauling out behavior provided by seal hunters. TEK was collected by organizing a formal interview or interviews with hunters and elders in a community. The interview process followed a semi-directive interview described by Huntington (1998) in which researchers initiated a discussion around various topics of interest, but allowed the person or group being interviewed to determine the order in which topics are discussed and to make connections among various topics the researchers might not have anticipated. The people interviewed were recommended by each community's Tribal Council and by other seal hunters.

We also collected TEK when we worked with hunters to catch seals for satellite tag deployments. To catch ringed, bearded, and spotted seals safely and effectively requires knowledge of local currents, tides, weather patterns, sea ice, seal behavior, and seal availability. TEK gained using both methods was then incorporated into a traditional knowledge report (e.g., Huntington and Quakenbush 2009, 2013; Huntington et al. 2012) and included in project annual and final reports.

Results

Coordination
We worked with the ISC, NSB, and local seal hunters. A chronology of the project history and accomplishments are included in Table 1. We also sent maps to an extensive list of interested entities (~185) including individual subsistence hunters, tribal council offices, ISC, NSB, BOEM, ONR, NOAA, University of Alaska, United States Coast Guard (USCG), and oil and gas industry personnel. We maintained a webpage on ADFG's website that explained the project, provided annual updates of seals tagged and the communities and hunter-taggers we worked with, and was updated bi-weekly with the maps of seal movements:
http://www.adfg.alaska.gov/index.cfm?adfg=marinemammalprogram.icesealmovements.

Table 1. Project history from September 2013 through September 2019. Appendices are referenced here in chronological order.

Month	Year	Event
September	2013	Received contract from BOEM.
January	2014	Project update to ISC, discussed locations for tagging and TEK. Met with collaborators, a capture-net maker, and BOEM COR at the Alaska Marine Science Symposium (AMSS).
February		Teleconference with NMFS, MML regarding seal tagging in Kotzebue.
March		Trained hunters from Hooper Bay, Elim, Koyuk, Unalakleet, and St. Michael to safely capture and tag seals.
April		Coordinated with Native Village of Kotzebue (NVOK) for seal tagging.
June		Tagged one young bearded and four ringed seals near Kotzebue.
September		Tagged three young bearded seals near Koyuk.
January	2015	Poster "*Hunter-assisted study on ringed and bearded seal movements, habitat use and traditional knowledge*" at AMSS, Anchorage (Appendix A). Traveled to Barrow to collect TEK. Submitted annual report to BOEM.
February		Traveled to Elim, St. Michael, and Stebbins to collect TEK.
March		Presented project update at the ISC annual meeting. Conducted a hunter-tagger training workshop for hunters from the North Slope (Kaktovik, Barrow, and Wainwright), Maniilaq (Kotzebue), Kawerak (Nome, Elim, and St. Michael), Yukon-Kuskokwim Delta (Scammon Bay and Hooper Bay), and Bristol Bay (Togiak).
April–May		Coordinated with NVOK for seal tagging in June. Received updated Animal Care and Use protocol (ADFG ACUC #2015-25).
May		Tagged one ringed seal near Hooper Bay.
June		Attempted to catch adult bearded seals near Kotzebue; poor ice, none caught.
August		Tagged four young bearded and one ringed seal near St. Michael and four bearded seals near Koyuk.
December		Oral presentation at Polar Seal Tagging Workshop in San Francisco at Biennial Marine Mammal Conference. Poster "*Effects of changing sea ice on marine mammals and subsistence hunters in northern Alaska*" in San Francisco at the American Geophysical Union Conference (Appendix B). Worked with Shishmaref, Kivalina, and Kotzebue IRA's, hunters, and ISC to organize a TEK gathering trip in January 2016. Final Barrow, Elim, St. Michael, Stebbins TEK reports (Appendices C–E).
January	2016	Posters "*Hunter-assisted study on ringed and bearded seal movements, habitat use and traditional knowledge*" (Appendix F) and "*Effects of changing sea ice on marine mammals and subsistence hunters in northern Alaska*" (Appendix G) at AMMS, Anchorage. Traveled to Shishmaref, Kivalina, and Kotzebue to collect TEK. Submitted annual permit report to NMFS for research permit #15324. Submitted annual report to BOEM.
January–March		Sent draft TEK reports to interviewees for review, comment, and approval.
April		Received Animal Care and Use Committee Assurance of Animal Care protocol (ADFG ACUC #2016-23). Submitted application to NMFS for new seal research permit.

April–July		Final Shishmaref, Kivalina, and Kotzebue TEK reports (Appendices H–J). Drafted manuscript combining TEK data for submission to Biology Letters.
June		Update to ISC on seal tagging and TEK. Tagged one ringed seal near St. Michael.
July		Tagged four young bearded seals near St. Michael.
August		"*Effects of changing sea ice on marine mammals and subsistence hunters in northern Alaska from traditional knowledge interviews"* published Biology Letters (Huntington et al. 2016). Tagged one young bearded seal near Utqiaġvik (Barrow).
September		Tagged two bearded seals near Koyuk. Traveled to St. Michael to catch seals but weather conditions were poor. Applied for an extension of our current research permit (NMFS#15324) while our new permit is being processed.
January	2017	Poster "*Update of hunter-assisted seal tagging and traditional knowledge studies of Pacific Arctic seals, 2016 and beyond*" at AMSS, Anchorage (Appendix K). TEK interviews conducted in Hooper Bay, Scammon Bay, and Mekoryuk.
January–December		Prepared and contributed seal location data to the BOEM-funded synthesis of Arctic Research (SOAR II) analysis of marine mammal distributions.
January–March		Sent draft TEK reports to the interviewees for review and approval.
March		Submitted 2016 annual permit report to NMFS for research permit #15324.
April		Received Animal Care and Use Committee Assurance of Animal Care protocol (ADFG ACUC #0027-2017-27).
May		Provided maps to NMFS, Alaska Region, of bearded and ringed seals and bowhead whales by month (July–November) relative to Quintillion laying fiber optic cable for preparation of a biological opinion (Appendix L).
June		ISC update on seal tagging and TEK. Finalized TEK reports for Hooper Bay, Mekoryuk, and Scammon Bay (Appendices M–O). Tagged two ringed seals and one spotted seal near Buckland.
July		Tagged three spotted seals near Scammon Bay. Worked with the NSB to tag seals near Utqiaġvik (Barrow), but poor ice conditions and weather limited capture opportunities to two days.
August		Tagged one spotted seal near Utqiaġvik. Tagged one young bearded seal and three spotted seals near Nuiqsut. Traveled to St. Michael to catch seals but weather conditions were poor and limited capture opportunities to two days. Received and commented on new draft research permit from NMFS.
September		Tagged three young bearded seals near Koyuk. "*Evaluating the effects of climate change on indigenous marine mammal hunting in northern and western Alaska using traditional* knowledge" published in Frontiers in Marine Science (Huntington et al. 2017). Received final NMFS research permit #20466.
October		Oral presentation for Canada-U.S. Oil and Gas Research Forum, Anchorage. Posters "*Seasonal movements, habitat use, and dive behavior of pup and yearling bearded seals in the Pacific Arctic*" (Appendix P) and "*Evaluating impacts of climate change on indigenous marine mammal hunting in northern and western Alaska using traditional knowledge"* (Appendix Q) at Society for Marine Mammalogy Conf. in Halifax, Nova Scotia, Canada. Tagged one bearded seal near Nome.

November		Provided haul-out data for ringed seals to NOAA Fisheries, Marine Mammal Lab, for correction factor to aid aerial survey data for population estimate. Provided maps of seal use areas to USGS for Chukchi Sea polar bear studies.
December		Prepared annual report to BOEM. Presented project at the Animal Telemetry Network Workshop in Anchorage. Provided ringed seal movements between the Chukchi and Bering seas for a CAFF project on ringed seal ecotypes circumpolar-wide.
January	2018	Posters "*Seasonal movements, habitat use, and dive behavior of pup and yearling bearded seals in the Pacific Arctic*" and "*Climate change, marine mammals, and indigenous hunting in northern Alaska: insights from a decade of traditional knowledge interviews*" at AMSS (Appendix R and S).
January–December	2018	Provided daily estimated locations of tagged seals to BOEM (Warren Horowitz, Physical Oceanographer) for use in planning and permitting.
February		"*A multi-species synthesis of satellite telemetry data in the Pacific Arctic (1987–2015): Overlap of marine mammal distributions and core use areas*" was published in Deep-Sea Research Part II (Citta et al. 2018), includes seal location data from this project.
March		Submitted 2017 annual permit report to NMFS for research permit #20466.
April		Received Animal Care and Use Committee Assurance of Animal Care protocol (ADFG ACUC #0027-2018-29).
June		ISC update on seal tagging and TEK.
July		Tagged two spotted seals near Scammon Bay. Worked with the NSB near Utqiaġvik, but poor ice conditions and weather limited capture opportunities to one day; tagged one spotted seal. St. Michael taggers searched for seals on two occasions but did not find any.
August		St. Michael taggers searched for seals on four occasions but did not find any.
September		Tagged two spotted seals on the Colville River near Nuiqsut. Tagged one young bearded seal near Koyuk. Tagged three spotted seals in Dease Inlet near Utqiaġvik.
December		Prepared annual report to BOEM. Analyzed location and haul-out data for spotted seal poster at AMSS.
January	2019	Poster "*Seasonal movements and high-use areas of spotted seals (*Phoca largha*) in the Pacific Arctic*" at AMSS (Appendix T). Submitted annual report to BOEM.
February–May		Prepared bearded seal movement and dive behavior manuscript.
April		Submitted abstract "*Oceanographic characteristics associated with movements and high-use areas of spotted seals (*Phoca largha*) in the Chukchi and Bering seas*" (Appendix U) to be presented at the Society for Marine Mammalogy Conference in December 2019 in Barcelona, Spain.
May		Attended ISC meeting and presented an update on seal tagging.
June		Tagged five ringed seals near Utqiaġvik. Submitted manuscript "*Movement, diving, and haul-out behaviors of juvenile bearded seals in the Bering, Chukchi and Beaufort Seas, 2014–2018*" to Polar Biology.
September		Final report to BOEM.

Tagged Seals

During 2014–2019, we deployed 122 satellite-linked transmitters on 67 seals (26 bearded, 16 ringed, and 25 spotted seals) (Table 2). We deployed 59 primary tags attached with epoxy (24 SPLASH tags and 35 CTD tags), and most seals (63 of 67) also received a secondary flipper-mounted SPOT tag.

Table 2. Bearded, ringed, and spotted seals tagged with satellite-linked transmitters during 2014–2019. Primary tags (SPLASH or CTD) were attached with epoxy and fell off during the annual pelage molt in spring. Secondary tags (SPOT) were attached to inter-digital webbing of a hind flipper and could transmit for multiple years. Seal ages were determined by counting foreflipper claw annuli. Durations of tag transmissions (Dur., # days) do not include tags deployed on seals that were harvested while the tag was still active or those deployed in 2019 that were active as of the drafting of this report. Five SPOT and one CTD tags did not transmit data or locations. Seal ID: BS = bearded, RS = ringed, SS = spotted.

				Date				
Seal ID	Species	Sex	Age (Yrs)	Deployed	Most Recent Location	Capture Location	Primary Tag Type[a] (Dur.)	SPOT Flipper-Tag (Dur.)
BS14-01-M	Bearded	M	0	18 Jun 2014	22 May 2015	Kotzebue Sound	SPLASH (257)	Yes[b] (338)
RS14-01-M	Ringed	M	7	18 Jun 2014	12 May 2016	Kotzebue Sound	SPLASH (173)	Yes[b] (694)
RS14-02-F	Ringed	F	6	18 Jun 2014	11 Jun 2015	Kotzebue Sound	SPLASH (213)	Yes[b] (357)
RS14-03-M	Ringed	M	6	19 Jun 2014	15 Jun 2015	Kotzebue Sound	SPLASH (213)	Yes[b] (361)
RS14-04-F	Ringed	F	6	19 Jun 2014	06 Jul 2015	Kotzebue Sound	None	Yes[b] (382)
BS14-02-M	Bearded	M	0	26 Sep 2014	31 Dec 2015	Koyuk River	SPLASH (127)	Yes[b] (461)
BS14-03-M	Bearded	M	0	26 Sep 2014	17 Nov 2014	Koyuk River	SPLASH (52)	Yes[b] (0)
BS14-04-M	Bearded	M	0	30 Sep 2014	18 Jul 2015	Koyuk River	SPLASH (89)	Yes[b] (291)
RS15-01-M	Ringed	M	1	14 May 2015	05 Aug 2015	Hooper Bay	None	Yes[b] (83)
BS15-01-M	Bearded	M	0	18 Aug 2015	09 Oct 2015	Koyuk River	SPLASH (53)	Yes[b] (0)
BS15-02-M	Bearded	M	0	18 Aug 2015	20 Oct 2015	Koyuk River	SPLASH (64)	Yes[b] (0)
BS15-03-F	Bearded	F	0	19 Aug 2015	19 Jan 2016	Koyuk River	SPLASH (153)	Yes[b] (119)
BS15-04-F	Bearded	F	0	20 Aug 2015	04 Jan 2016	Koyuk River	SPLASH (135)	Yes[b] (138)

BS15-05-M[e]	Bearded	M	0	22 Aug 2015	31 Aug 2015	St. Michael Canal	SPLASH (9)	Yes[b] (10)
BS15-06-F	Bearded	F	1	22 Aug 2015	01 Sep 2015	St. Michael Canal	SPLASH (10)	Yes[b] (10)
BS15-07-M	Bearded	M	1	23 Aug 2015	10 Sep 2016	St. Michael Canal	SPLASH (193)	Yes[b] (384)
BS15-08-F	Bearded	F	1	23 Aug 2015	11 Dec 2015	St. Michael Canal	SPLASH (91)	Yes[b] (110)
RS15-02-F	Ringed	F	0	23 Aug 2015	15 Dec 2015	St. Michael Canal	None	Yes[b] (115)
RS16-01-M	Ringed	M	0	10 Jun 2016	16 Sep 2016	St. Michael Canal	None	Yes[b] (98)
RS16-02-M	Ringed	M	8	01 Jul 2016	18 Apr 2017	Utqiaġvik	CTD (291)	Yes[c] (193)
RS16-07-M	Ringed	M	7	01 Jul 2016	31 Jan 2017	Utqiaġvik	CTD (110)	Yes[c] (214)
BS16-01-M	Bearded	M	0	03 Jul 2016	16 Jun 2017	St. Michael Canal	SPLASH (33)	Yes[b] (348)
BS16-02-M	Bearded	M	0	04 Jul 2016	17 Jul 2016	St. Michael Canal	None	Yes[b] (13)
BS16-03-F	Bearded	F	0	17 Jul 2016	25 Mar 2017	St. Michael Canal	None	Yes[b] (251)
BS16-04-F[e]	Bearded	F	0	23 Jul 2016	06 Aug 2016	St. Michael Canal	CTD (14)	Yes[b] (14)
SS16-01-F	Spotted	F	3	27 Jul 2016	08 Jun 2017	Dease Inlet (Utqiaġvik)	CTD (229)	Yes[c] (316)
SS16-03-M	Spotted	M	4	03 Aug 2016	10 Feb 2017	Dease Inlet (Utqiaġvik)	CTD (191)	Yes[c] (0)
SS16-05-M	Spotted	M	1	14 Aug 2016	01 Feb 2017	Dease Inlet (Utqiaġvik)	CTD (171)	Yes[d] (126)
BS16-05-F	Bearded	F	1	15 Aug 2016	13 Aug 2017	Utqiaġvik	None	Yes[b] (363)
SS16-06-F	Spotted	F	5	17 Aug 2016	29 Jul 2017	Dease Inlet (Utqiaġvik)	CTD (169)	Yes[d] (346)
SS16-07-M	Spotted	M	6	17 Aug 2016	19 Jul 2017	Dease Inlet (Utqiaġvik)	CTD (153)	Yes[d] (336)
SS16-08-M	Spotted	M	1	25 Aug 2016	07 Apr 2017	Dease Inlet (Utqiaġvik)	CTD (225)	No
SS16-09-F	Spotted	F	5	25 Aug 2016	05 Apr 2017	Dease Inlet (Utqiaġvik)	CTD (223)	No
BS16-06-M	Bearded	M	0	20 Sep 2016	11 Jun 2017	Koyuk River	CTD (158)	Yes[b] (264)

BS16-07-F	Bearded	F	0	20 Sep 2016	25 Sep 2017	Koyuk River	SPLASH (224)	Yes[b] (370)
SS16-10-F	Spotted	F	1	18 Oct 2016	04 Mar 2017	Scammon Bay	CTD (137)	No
SS16-11-F	Spotted	F	1	18 Oct 2016	05 May 2017	Scammon Bay	CTD (199)	No
BS16-08-M	Bearded	M	1	10 Nov 2016	11 Mar 2017	Cape Nome	CTD (84)	Yes[b] (121)
RS17-01-M	Ringed	M	7	20 Jun 2017	15 May 2018	Kotzebue Sound	SPLASH (266)	Yes[b] (329)
RS17-02-M	Ringed	M	5	22 Jun 2017	23 Feb 2018	Kotzebue Sound	CTD (149)	Yes[b] (246)
SS17-01-M	Spotted	M	0	22 Jun 2017	23 Jun 2017	Kotzebue Sound	None	Yes[b] (1)
SS17-02-M	Spotted	M	5	10 Jul 2017	27 Apr 2019	Scammon Bay	CTD (289)	Yes[b] (657)
SS17-03-F	Spotted	F	0	11 Jul 2017	31 Jan 2018	Scammon Bay	SPLASH (147)	Yes[b] (204)
SS17-04-M	Spotted	M	0	11 Jul 2017	28 Feb 2018	Scammon Bay	SPLASH (184)	Yes[b] (232)
SS17-05-M	Spotted	M	3	25 Jul 2017	13 Jan 2018	Dease Inlet (Utqiaġvik)	CTD (172)	Yes[c] (0)
SS17-06-F	Spotted	F	0	09 Aug 2017	07 Jun 2018	Colville River (Nuiqsut)	CTD (140)	Yes[d] (302)
BS17-01-F	Bearded	F	0	10 Aug 2017	19 Apr 2019	Colville River (Nuiqsut)	CTD (221)	Yes[b] (591)
SS17-07-M	Spotted	M	2	16 Aug 2017	11 Jan 2018	Fish Creek (Nuiqsut)	CTD (148)	Yes[d] (96)
SS17-08-F	Spotted	F	1	16 Aug 2017	26 Feb 2018	Fish Creek (Nuiqsut)	CTD (194)	Yes[d] (100)
BS17-02-F	Bearded	F	0	20 Sep 2017	03 Jul 2019	Koyuk River	CTD (147)	Yes[b] (652)
BS17-03-M	Bearded	M	0	21 Sep 2017	06 Nov 2017	Koyuk River	CTD (45)	Yes[b] (45)
BS17-04-F	Bearded	F	0	22 Sep 2017	26 Jul 2018	Koyuk River	CTD (164)	Yes[b] (307)
BS17-05-F[e]	Bearded	F	0	20 Oct 2017	21 May 2018	Cape Nome	CTD (135)	Yes[b] (213)
SS18-01-M	Spotted	M	3	03 Jul 2018	04 Feb 2019	Scammon Bay	CTD (216)	Yes[b] (55)
SS18-02-M	Spotted	M	3	05 Jul 2018	Active	Scammon Bay	SPLASH (102)	Yes[b] (*A*)

SS18-03-F	Spotted	F	5	26 Jul 2018	19 Jun 2019	Dease Inlet (Utqiaġvik)	CTD (117)	Yes[b] (329)
SS18-04-F	Spotted	F	0	07 Sep 2018	03 Nov 2018	Fish Creek (Nuiqsut)	SPLASH (57)	Yes[d] (52)
SS18-05-F	Spotted	F	5	09 Sep 2018	09 Jan 2019	Fish Creek (Nuiqsut)	CTD (122)	Yes[d] (48)
SS18-06-M	Spotted	M	0	20 Sep 2018	30 May 2019	Dease Inlet (Utqiaġvik)	CTD (252)	Yes[b] (58)
SS18-07-F	Spotted	F	1	20 Sep 2018	22 May 2019	Dease Inlet (Utqiaġvik)	CTD (244)	Yes[b] (80)
BS18-01-F	Bearded	F	0	24 Sep 2018	16 Jul 2019	Koyuk River	CTD (152)	Yes[b] (296)
SS18-08-F	Spotted	F	1	27 Sep 2018	26 Apr 2019	Dease Inlet (Utqiaġvik)	CTD (0)	Yes[b] (212)
RS19-01-M	Ringed	M	6	22 Jun 2019	Active	Utqiaġvik	CTD (*A*)	Yes[b] (*A*)
RS19-02-M	Ringed	M	6	22 Jun 2019	Active	Utqiaġvik	CTD (*A*)	Yes[b] (*A*)
RS19-03-M	Ringed	M	10	23 Jun 2019	Active	Utqiaġvik	SPLASH (*A*)	Yes[b] (*A*)
RS19-04-M	Ringed	M	7	23 Jun 2019	Active	Utqiaġvik	CTD (*A*)	Yes[b] (*A*)
RS19-05-M	Ringed	M	6	24 Jun 2019	Active	Utqiaġvik	SPLASH (*A*)	Yes[d] (*A*)

[a] SPLASH tags were funded by BOEM (this project), CTD tags were funded by Office of Naval Research (concurrent project)
[b] SPOT tags funded by BOEM (this project); [c] SPOT tags provided by the North Slope Borough
[d] SPOT tags provided by NOAA Fisheries, Marine Mammal Lab; *A* = tag transmitting as of 30 September 2019
[e] Harvested or found dead

Bearded seals. We tagged 26 young bearded seals (ages 0 and 1 year old) in the Bering, Chukchi, and Beaufort seas near the communities of St. Michael, Koyuk, Nome, Buckland, Utqiaġvik, and Nuiqsut during 2014–2018 (Table 2 and Fig. 3). Captures occurred between June and November, with most in August (38%, 10 of 26; Fig. 4). During TEK interviews and public meetings held in seal hunting communities we learned that young bearded seals follow migrating fish into river systems to feed and then rest on the riverbanks (see Appendices C–E, H, M, O). Indeed, most bearded seals (85%, 22 of 26) were captured in, or near, river systems (St. Michael Canal, Koyuk River, and Colville River). Without this information and the experience of local hunters, very few bearded seals would have been tagged. The remaining four young bearded seals were captured in coastal areas, including two captured in subsistence nets used to harvest beluga whales near Nome.

Ringed seals. We tagged 16 ringed seals near the communities of Hooper Bay, St. Michael, Buckland, and Utqiaġvik during 2014–2017 and 2019 (Table 2, Fig. 3). Most (81%, 13 of 16) were adults (≥ 5 years old) captured between May and August, with most captured in June (75%, 12 of 16; Table 2, Fig. 4). Conditions reported by subsistence hunters that have shortened the hunting season (Huntington et al. 2016, 2017) have also shortened the tagging season. These conditions include earlier sea ice retreat in the spring and later formation in the fall and are associated with climate change. Areas where we found ringed seals in June in the early years of this study, had little to no ice, or ringed seals, in the later years. Because the molt occurs in May and early June, tagging earlier in the season, before molt, is not an option. In 2019, we tagged five adult ringed seals by working farther north, near Utqiaġvik, where sea ice was present in mid-June.

Spotted seals. We tagged 25 spotted seals near the communities of Scammon Bay, Buckland, Utqiaġvik (Dease Inlet), and Nuiqsut during 2016–2018 (Table 2, Fig. 3). Tagging of spotted seals was added to the objectives of this project in 2016 when we received a no cost extension. Almost half of the spotted seals tagged were subadults (1–3 years old; 48%, 12 of 25), seven were adults (≥ 4 years old; 28%) and six were pups (24%). We captured spotted seals between June and October, with most captured in August (36%, 9 of 25; Fig. 4). All spotted seals were captured by setting nets in the water at the edge of occupied haulouts on islands and river bars known to local hunters as haulout areas. Seals would get entangled in the net as they left the haulout.

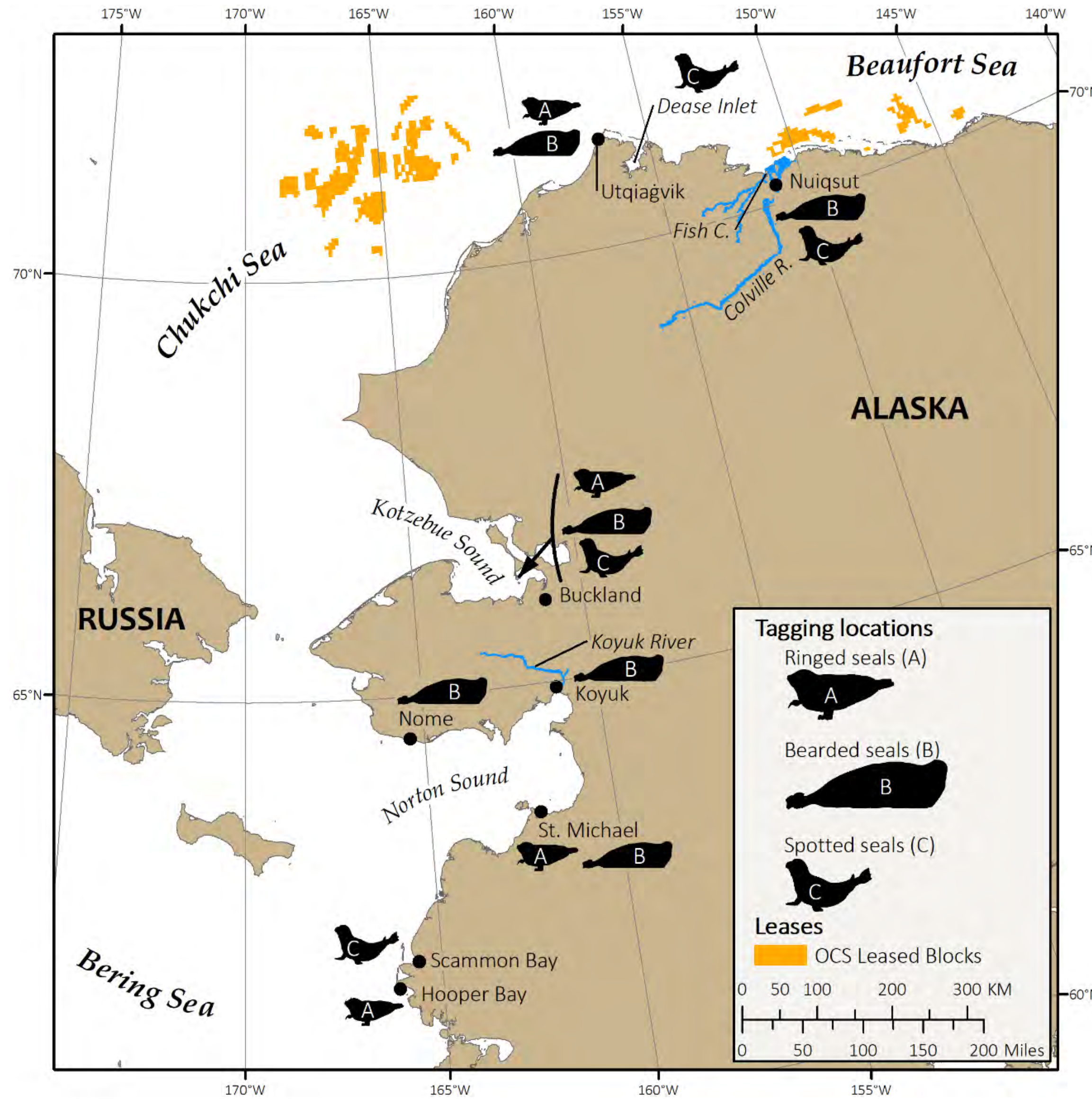


Figure 3. Locations where satellite-linked transmitters were deployed on bearded, ringed, and spotted seals during 2014–2018. OCS Leased Blocks associated with Chukchi Sea Lease Sale 193 area were active during 2013–2016; all were relinquished by 2017.

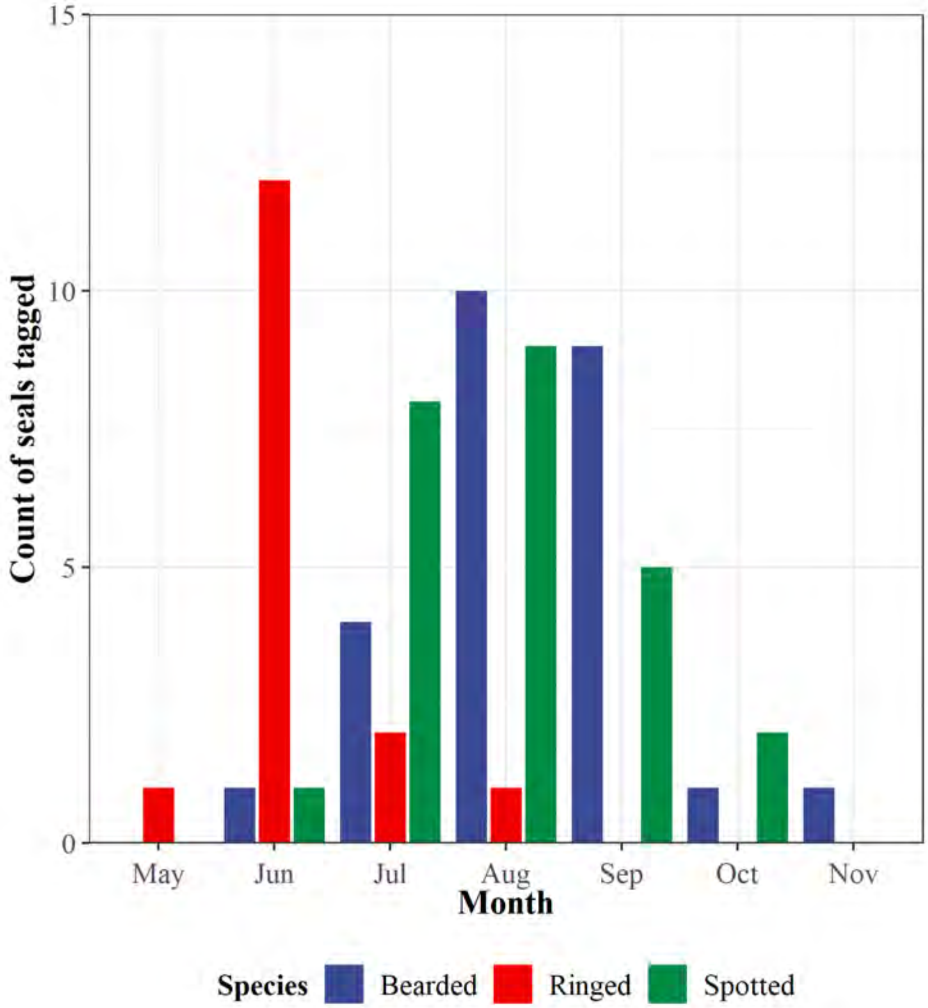


Figure 4. Count of bearded, ringed, and spotted seals tagged in the Bering, Chukchi, and Beaufort seas by month from 2014 to 2019.

Tag Performance

We primarily tagged seals between June and September (93%, 62 of 67; Fig. 4). The number of seals with active tags decline after deployment due to draining battery voltage, damage to the tag, and tag loss, including attachment wear and spring pelage molt. For bearded seals, more tags were active from September through January than February through August (Fig. 5a). For ringed seals, more tags were active in June and July than other months (Fig. 5b). For spotted seals, more tags were active in August through January than February through July (Fig. 5c).

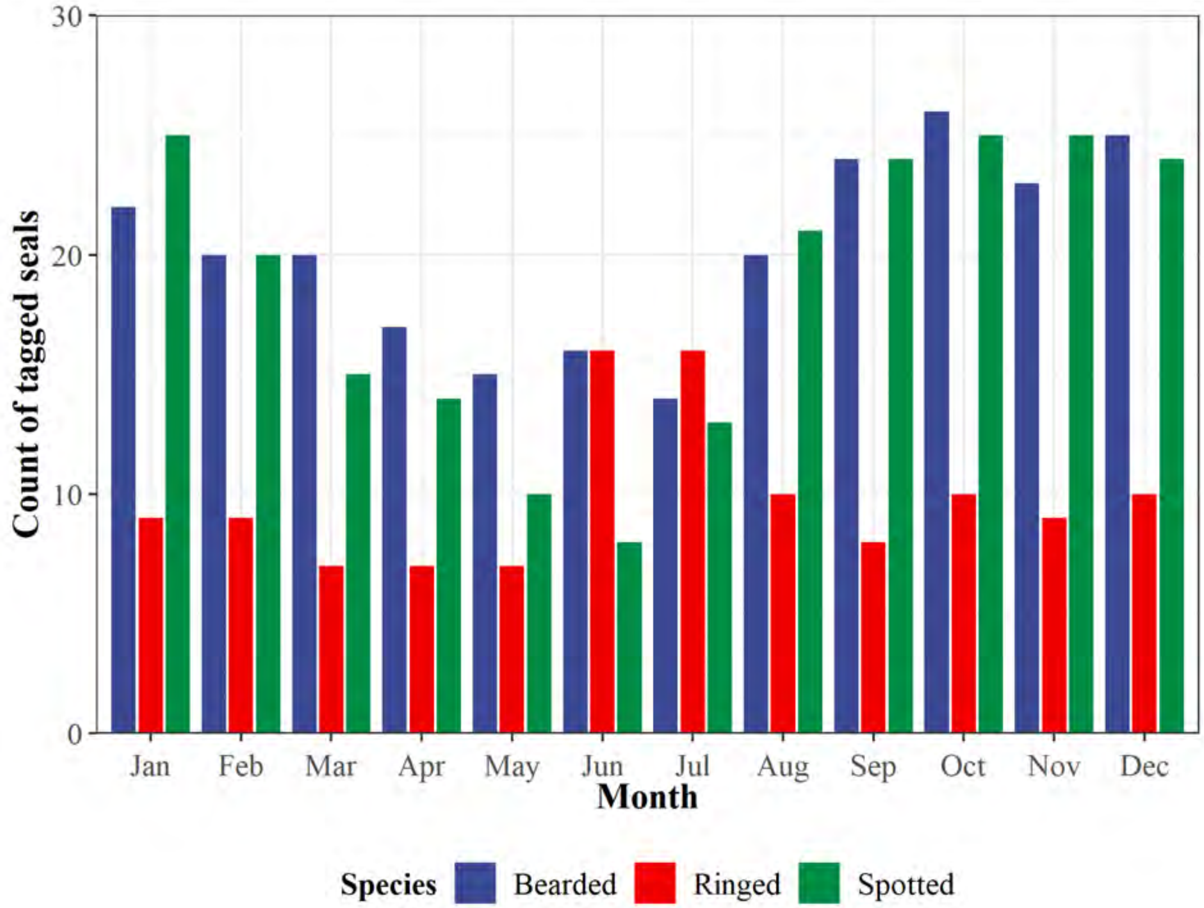


Figure 5. Number of bearded, ringed, and spotted seals with active tags by month, all years combined (2014–2019).

The number of days from deployment to last transmission (tag duration) did not differ among species, sex, age class, or deployment years ($P > 0.29$). Primary tags (SPLASH or CTD), epoxied to seals transmitted for similar durations (mean pooled duration 159 days, range 10–291 days, $P = 0.11$). Secondary tags (SPOT), attached to the hind flippers, transmitted an average of 72 days longer (mean duration 231 days, range 1–694 days) than primary tags ($P < 0.01$) (Table 2) and, for some seals, allowed us to assess seasonal site fidelity.

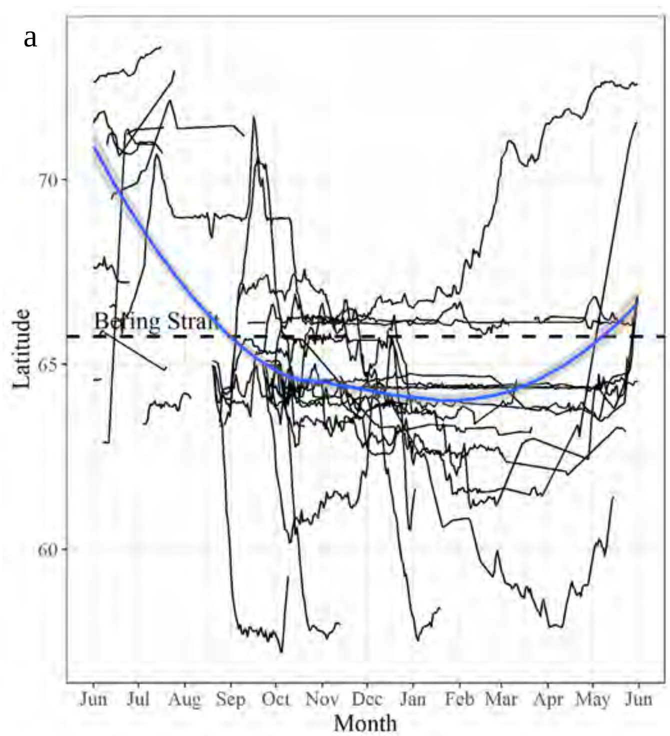
Seal Movements

We received locations from at least one of two tags deployed on all 67 seals instrumented during this project despite not receiving any locations from one CTD and five SPOT tags. Movements during the six years of this study were widespread from the eastern Beaufort Sea throughout the Chukchi Sea and the Bering Sea shelf. Seals moved north of the Chukchi Sea shelf break (200 m isobath), over the deep Arctic Basin and used shallow estuaries and river systems along the Chukotka Peninsula of Russia and the coast of Alaska. Between-year site fidelity (returning to the same area used in prior years during the same period) of foraging and resting sites was detected but varied considerably among individuals tracked for longer than one year. Although, individual movements were occasionally highly variable, we identified general trends in seasonal movements of each species of seal.

Bearded seals

The large-scale movements of bearded seals varied based on tagging location. Most bearded seals (*n* = 24) made broad latitudinal movements (Fig. 6a), however, those tagged in the Beaufort Sea (*n* = 2) did not travel south of ~70 °N (Fig. 6b).

a



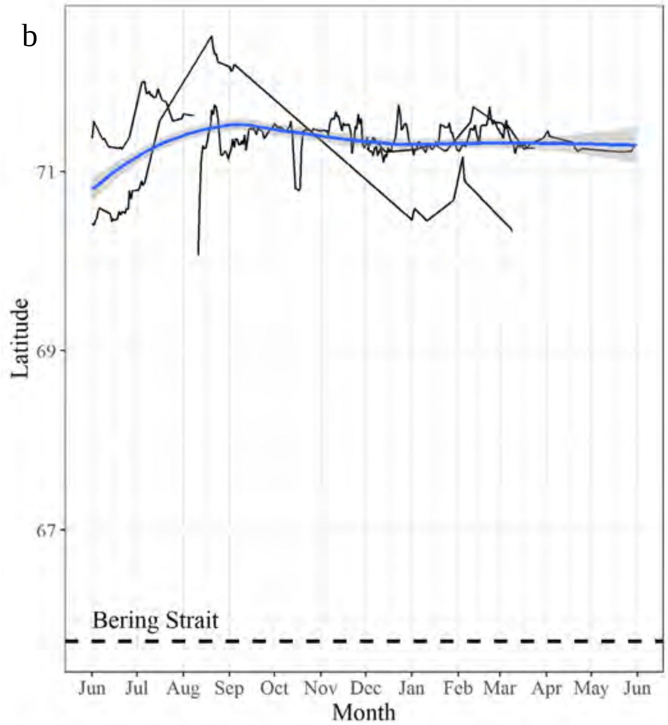


Figure 6. Latitudinal movements of bearded seals tagged in the a) Bering and Chukchi seas (n = 24) and b) Beaufort Sea (n = 2) by month during 2014–2019. Thin black lines are individual seals tracked by their primary tag. Dashed line delineates Bering Strait. June–October are generally ice-free months. November–May are generally characterized by ice formation, ice cover, and receding ice. Blue line and gray shaded region represent the smoothed conditional mean and standard error (SE) for latitudinal movements.

July–September. During this period of open water, bearded seals (*n* = 22) generally made localized movements near their tagging locations and stayed near shore, especially in Norton Sound (Fig. 7). A few bearded seals made long-distance movements soon after being tagged, including into the central Bering Sea and Mechigmenskaya Bay on the Chukotka Peninsula, Russia. Although most bearded seals were tagged in Norton Sound and stayed in that region during this period, beginning in September, some bearded seals moved north of the Bering Strait into the Chukchi Sea (Fig. 6a). During these northward movements, bearded seals generally stayed near shore, including entering Kotzebue Sound. Once in the northern Chukchi and Beaufort seas, bearded seals regularly moved along the 200-m isopleth, including near Barrow Canyon.

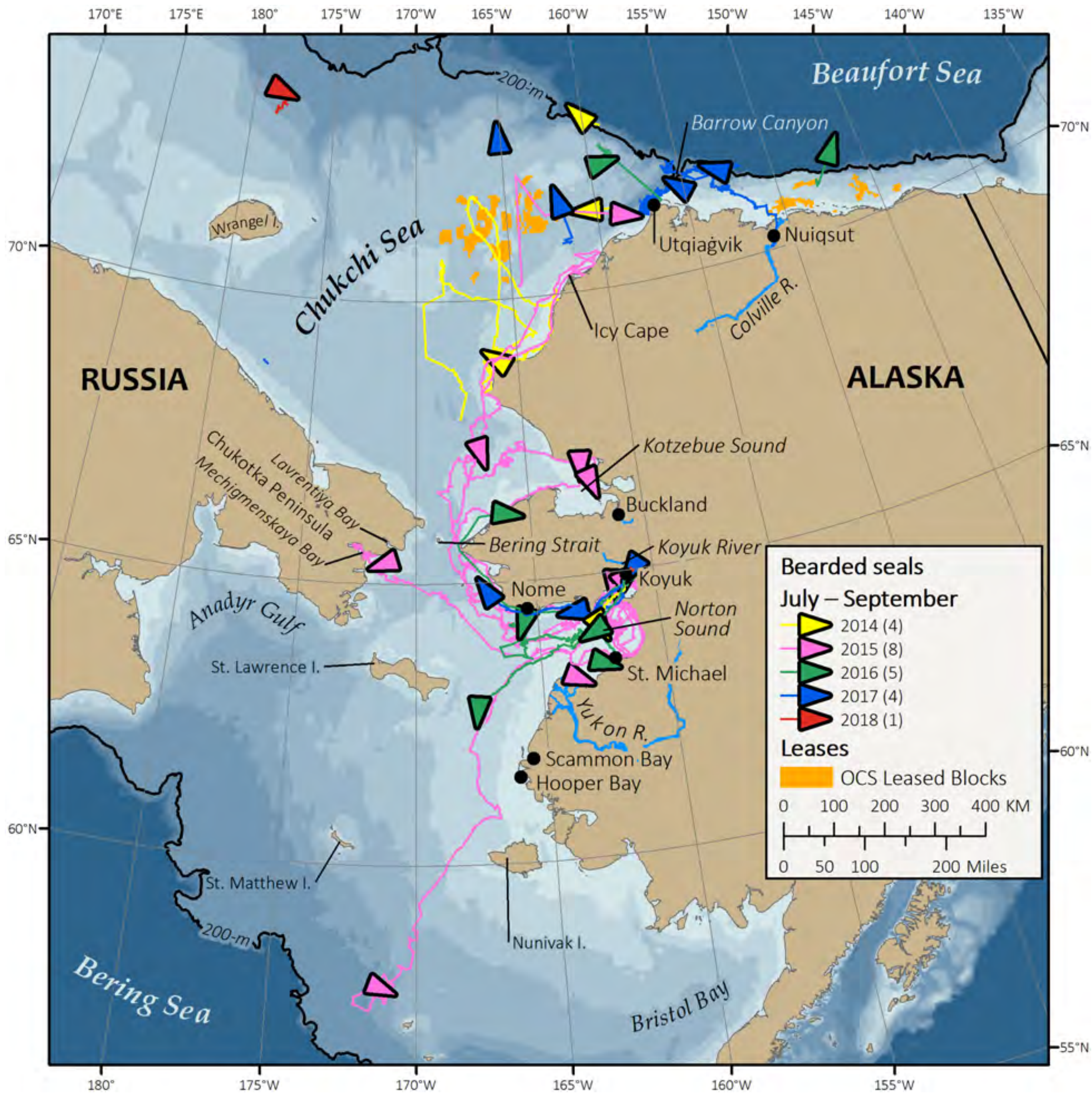


Figure 7. Movements of 22 bearded seals from July through September during 2014–2019. Movements are color-coded by the year seals were tagged. OCS Leased Blocks associated with Chukchi Sea Lease Sale 193 area were active during 2013–2016; all were relinquished by 2017.

October–December. During this period, most bearded seals (n = 23) stayed close to shore in Norton and Kotzebue sounds and when moving between them, but movements also varied by individual (Figs. 6 and 8). Four bearded seals spent time in the central Bering Sea, generally near the 100-m isopleth, well ahead of the advancing sea ice that could be used as a resting platform. Two bearded seals used coastal areas of the Chukotka Peninsula, entering Lavrentiya and Mechigmenskaya bays. One bearded seal (BS17-01-F) stayed in the northeast Chukchi Sea and made localized movements and foraging dives in and around Barrow Canyon.

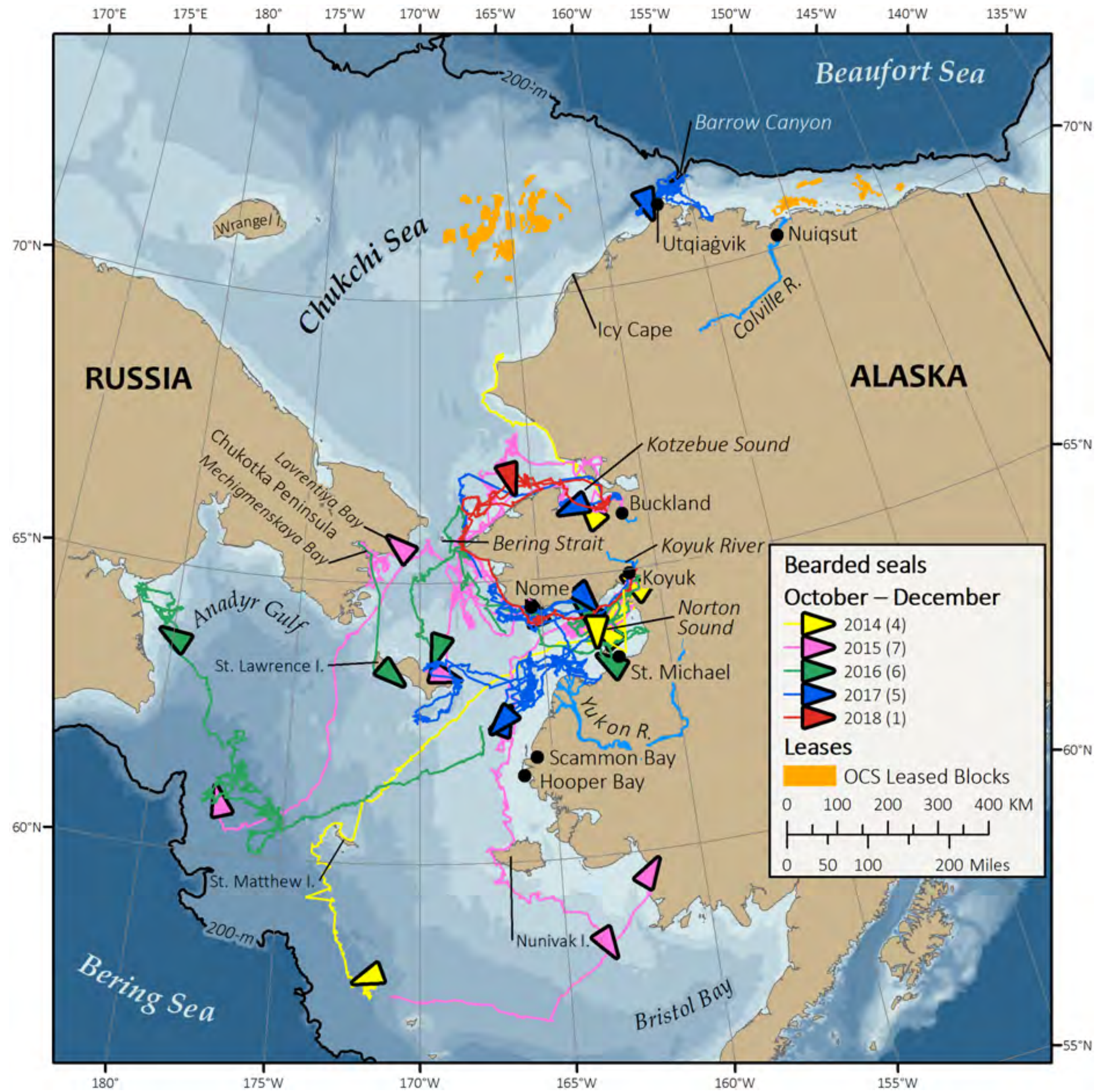


Figure 8. Movements of 23 bearded seals from October through December during 2014–2018. Movements are color-coded by the year seals were tagged. OCS Leased Blocks associated with Chukchi Sea Lease Sale 193 area were active during 2013–2016; all were relinquished by 2017.

January–March. During this period of ice cover, bearded seals (n = 18) exhibited two movement patterns; localized near shore and long-distance offshore (Fig. 9). Most bearded seals made localized movements that did not vary greatly by latitude (Fig. 6) and were near shore in highly consolidated ice, including near St. Lawrence Island, Bristol Bay, Norton Sound, Kotzebue Sound, Barrow Canyon, and the Beaufort Shelf. Three bearded seals made long-distance movements in less consolidated ice, two near the southern ice edge that were primarily offshore in the central and western Bering Sea (BS16-01-M and BS16-06-M) and one in the central Chukchi Sea (BS18-01-F).

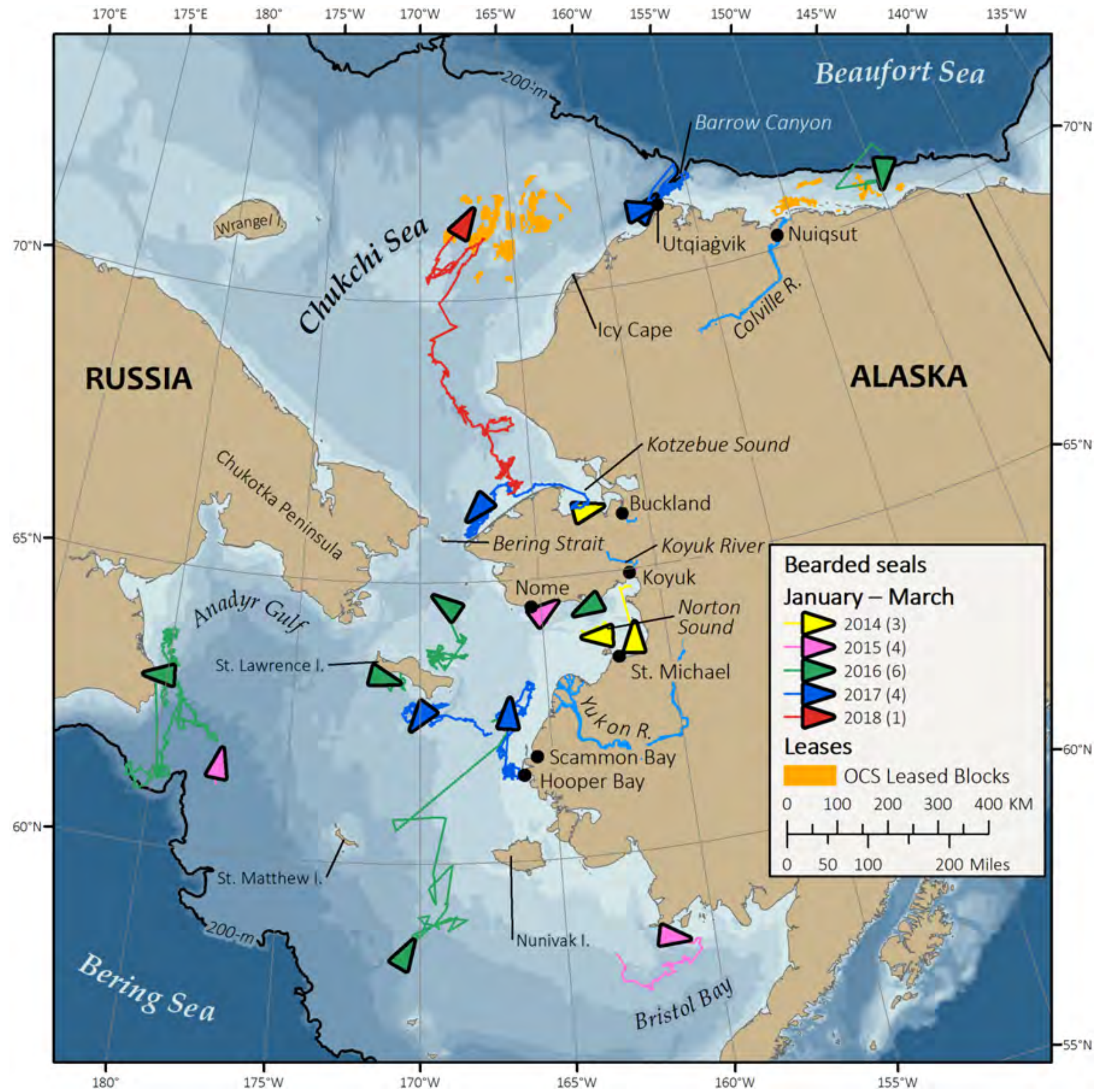


Figure 9. Movements of 18 bearded seals from January through March during 2015–2019. Movements are color-coded by the year seals were tagged. OCS Leased Blocks associated with Chukchi Sea Lease Sale 193 area were active during 2013–2016; all were relinquished by 2017.

April–June. We expected bearded seals to undergo their annual molt during this period; as such, we expected the primary tags epoxied to hair to fall off. We also expected the battery voltage of primary tags deployed the previous year to become too low to transmit locations. Therefore, most of the terminal locations plotted in Figure 10 represent the last locations from primary tags, which, unless we received locations from the flipper-mounted SPOT tags when the seal hauled out, likely were transmitted before the end of June. In other words, most seal tracks during this period represent less than three months of movements. In April, when sea ice had generally reached its southern-most extent, bearded seals (n = 16) were generally located near shore, from Anadyr Gulf and Norton Sound to the Beaufort Sea; however, most seals were either in Norton Sound, Kotzebue Sound, or areas between (Figs. 6 and 10). Two bearded seals, however, were located far from shore; BS16-01-M was in the central Bering Sea and BS18-01-F was in the northcentral Chukchi Sea. During this period, as ice began to retreat north, bearded seals generally moved north along the Alaskan coast, into the Chukchi Sea. Half of the seals (3 of 6) that started the period in the Bering Sea and migrated into the Chukchi Sea entered Kotzebue Sound. By the end of June, all but two bearded seals (BS16-06-M and BS17-03-M; 11 of 13) were in the Chukchi Sea (Fig. 6).

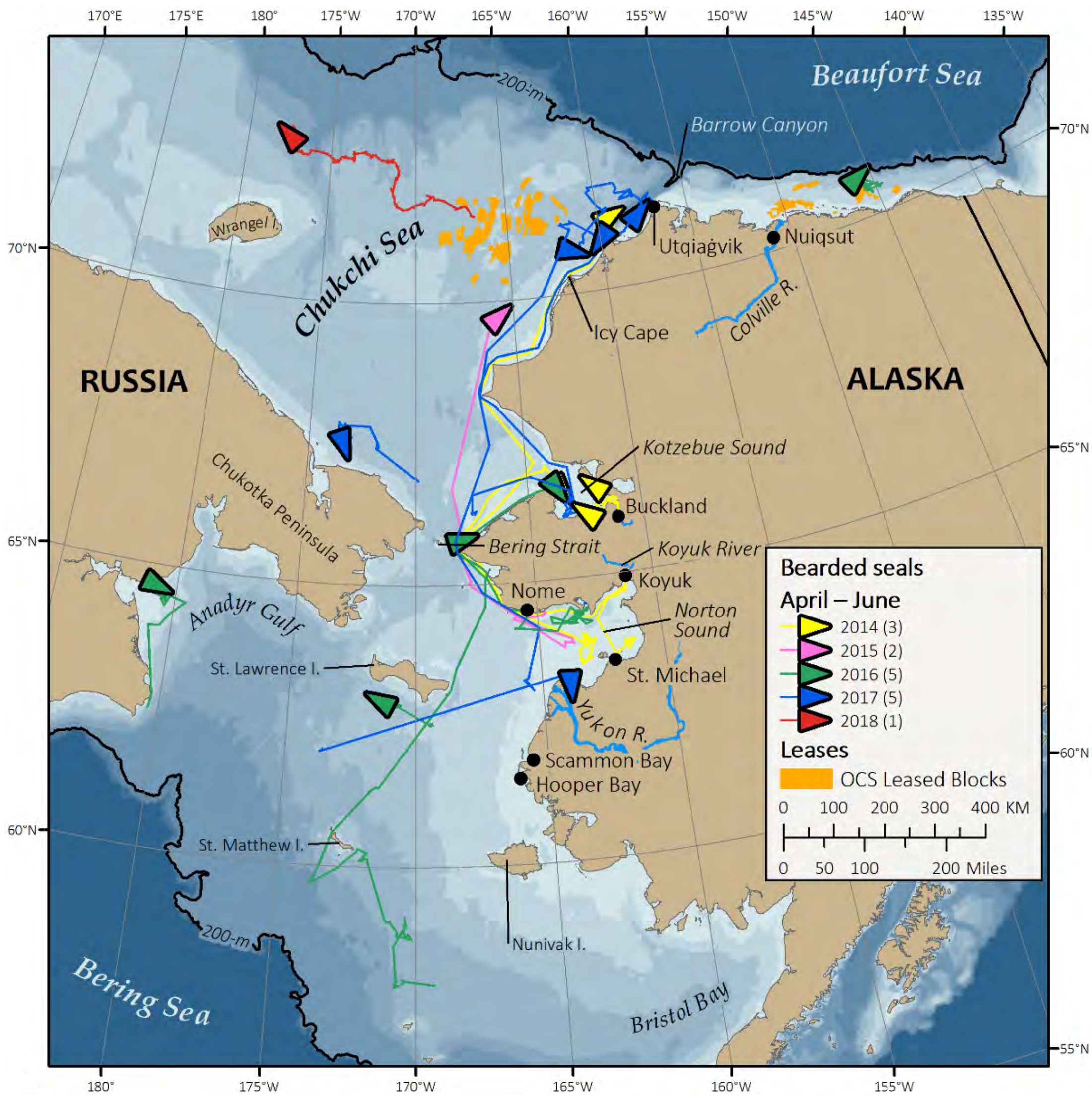


Figure 10. Movements of 16 bearded seals from April through June during 2014–2019. Movements are color-coded by the year seals were tagged. The terminal locations represent the last location received during this period, which were often before the end of June because primary tags fell off during molt. In some cases, however, the flipper-mounted SPOT tags provided additional locations during this period when the seal hauled out. OCS Leased Blocks associated with Chukchi Sea Lease Sale 193 area were active during 2013–2016; all were relinquished by 2017.

Site fidelity. Six bearded seals had tags that transmitted for 338 days or more (up to 651 days) (Table 2), and five of them exhibited fidelity to specific areas in consecutive years. Two seals tagged in September near Koyuk in northeastern Norton Sound (BS14-02-M, tracked for 461 days, and BS16-07-F, tracked for 370 days) returned to this area in the following year. BS14-02-M stayed in eastern Norton Sound from September 2014 to May 2015, then moved outside of Norton Sound, but returned in November and stayed until December 2015 when the tag stopped transmitting. BS16-07-F was tagged in the Inglutalik River, 16 km (10 miles) south of Koyuk, in September 2016 and returned to this river in July 2017.

BS17-01-F (tracked for 591 days) used the Barrow Canyon area during December to March for two consecutive years (Fig. 11). After being tagged in the Colville River in August 2017, this seal moved to and stayed near Barrow Canyon and nearshore areas southeast of Utqiaġvik from August 2017 to mid-July 2018, with the exception of a short trip to Smith Bay in October 2017, after which it returned to the Barrow Canyon area in December 2018 staying to March 2019.

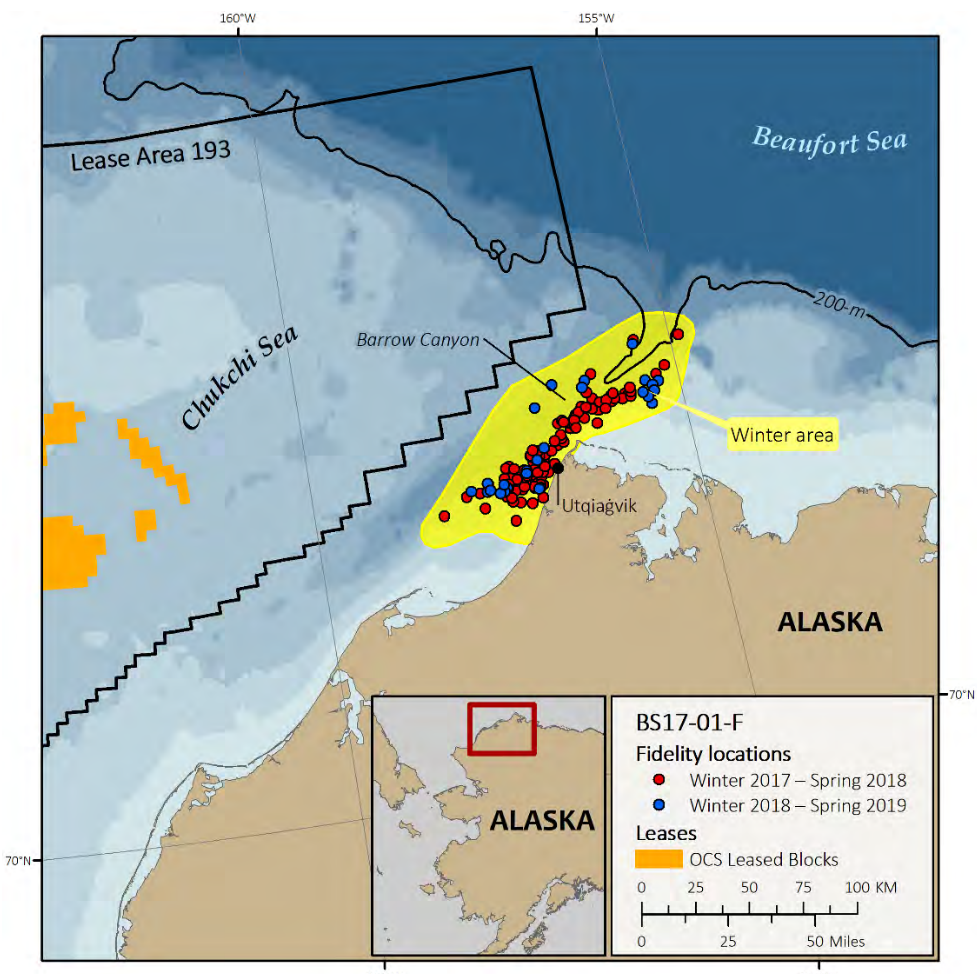


Figure 11. Locations of bearded seal BS17-01-F depicting site fidelity during winter (December–March) for two consecutive years. Red dots are locations during December 2017–March 2018; blue dots are locations during December 2018–March 2019. OCS Leased Blocks associated with Chukchi Sea Lease Sale 193 area *were active during 2013–2016; all were relinquished by 2017.*

One bearded seal (BS14-01-M, tracked for 338 days) used Kotzebue Sound during spring in two consecutive years. This seal was tagged in Kotzebue Sound in mid-June 2014 and left the Sound in late June but returned to southcentral Kotzebue Sound in mid-October where it remained until May 2015 when the tag stopped transmitting.

Bearded seal BS17-02-F, tracked for 651 days, used an area between the outlet of the Yukon River and Scammon Bay in the eastern Bering Sea in February of 2018 and 2019. Otherwise, despite being tracked for nearly two years, this seal did not exhibit fidelity to any other areas. Notably, during spring migration (May–July), this seal traveled along the Bering and Chukchi coast of Alaska in 2018, but along the northern coast of Chukotka, Russia, in 2019.

Bearded seal BS15-07-M, tracked for 384 days, did not exhibit fidelity to any specific areas. This seal was tagged in southern Norton Sound in late August 2015 and left the sound in mid-September, when it spent early October to mid-November in Kotzebue Sound and wintered in northern Norton Sound from late December 2015 to early May 2016. During July–September 2016, this seal was in the northeast Chukchi Sea.

Ringed seals

All ringed seals (n = 16) exhibited strong, seasonal, latitudinal patterns in movements throughout the year, using high-latitudes during the open-water season (July–November) and lower latitudes, near or south of the Bering Strait, when ice was present (December–June) (Fig. 12).

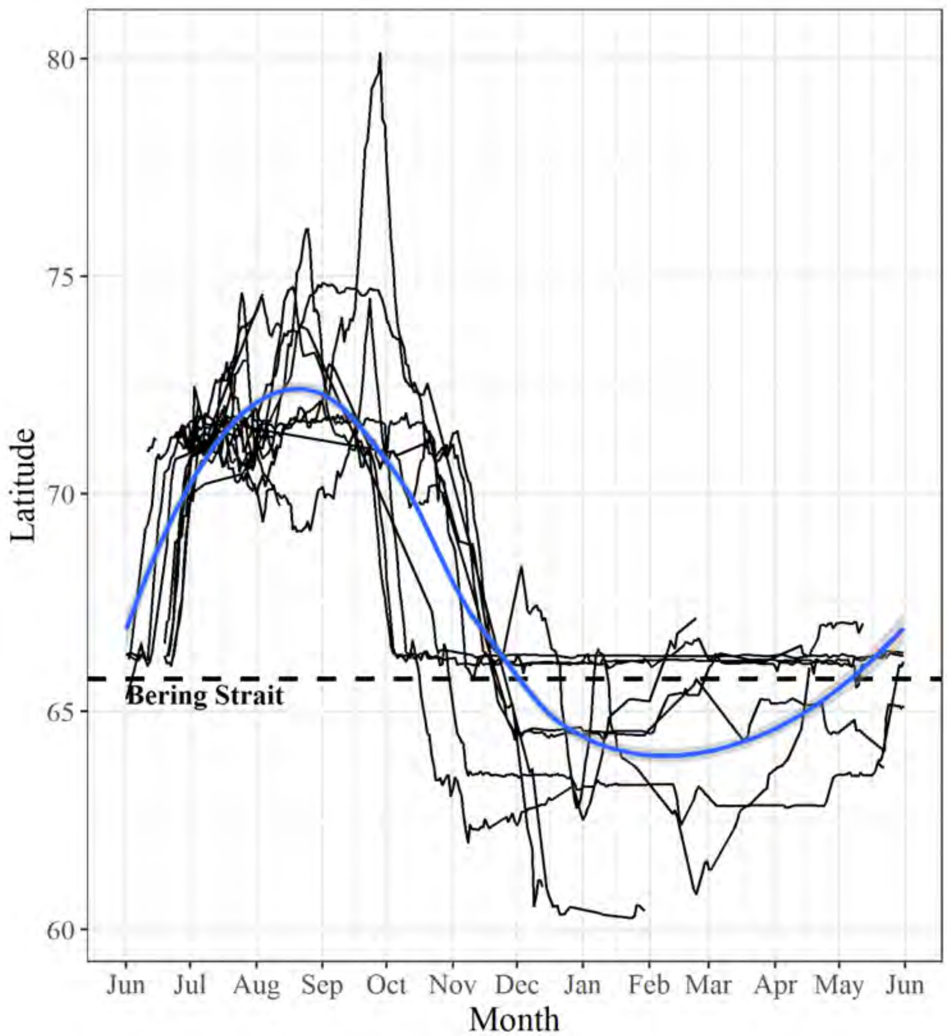


Figure 12. Latitudinal movements of ringed seals (n = 16) by month during 2014–2019. Thin black lines are individual seals tracked by their primary tag. Dashed line is Bering Strait. June–October are generally ice-free months. November–May are generally characterized by ice formation, ice cover, and receding ice. Blue line and gray shaded region represent the smoothed conditional mean and SE for latitudinal movements.

July–September. Ringed seals tracked during this period (*n* = 15) were primarily located in the northern Chukchi Sea, north of 70 °N (Figs. 12 and 13). Although movements of individuals varied, they primarily stayed on the intercontinental shelf in water < 200 m deep, between Utqiaġvik, Alaska, and Wrangel Island, Russia. Two ringed seals (RS14-02-F and RS16-02-M) moved along the Beaufort Shelf, east into the eastern Beaufort Sea, before returning along the shelf, into the eastern Chukchi Sea. Most seals spent some time near the 200-m isopleth during this period; however, two seals made distinct trips north into deeper water, one of which (RS17-01-M) made five trips north of the shelf break. By late September, only two ringed seals had moved south of 70 °N, ahead of the advancing sea ice (Fig. 12).

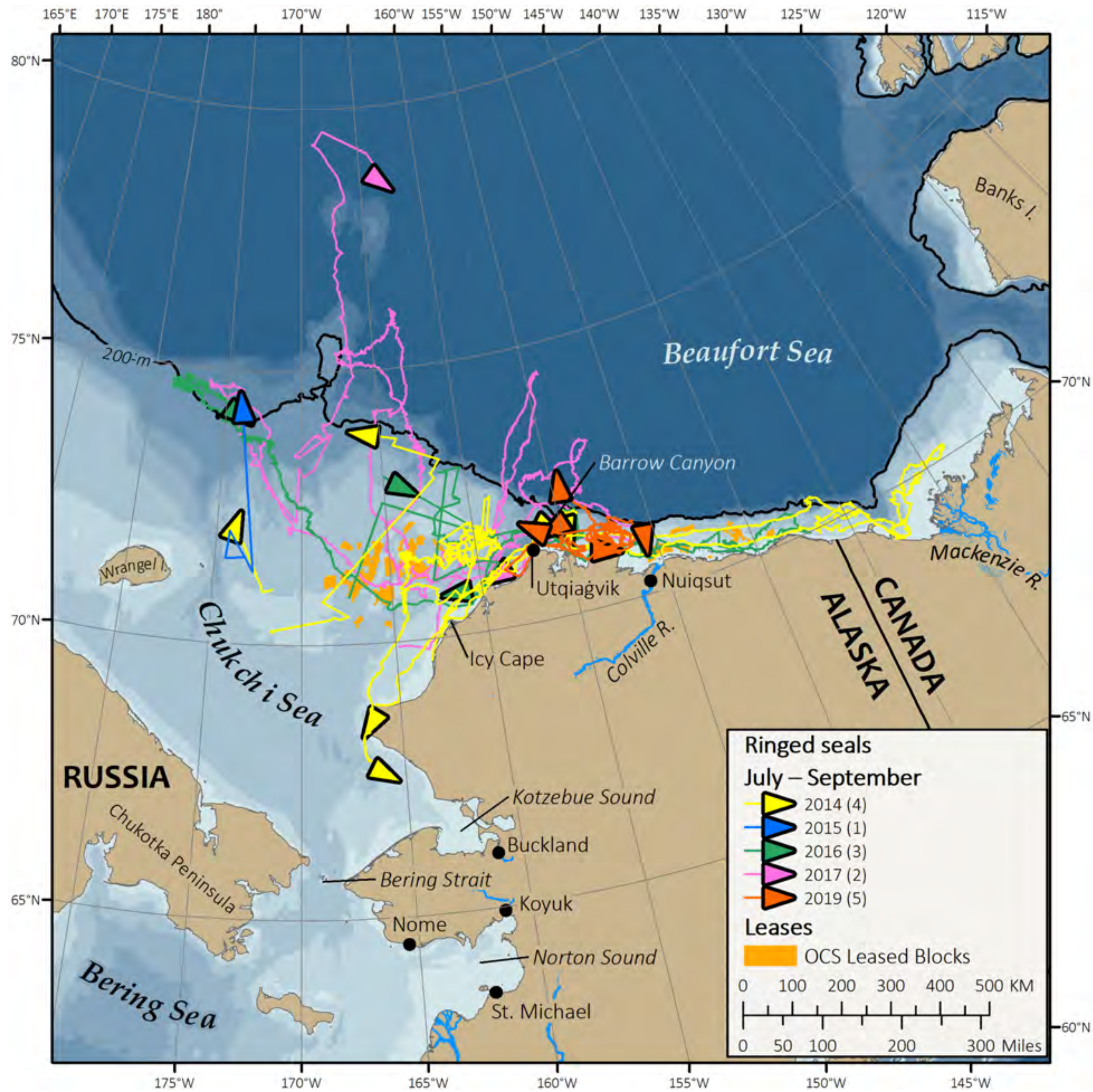


Figure 13. Movements of 15 ringed seals from July through September during 2014–2019. Movements are color-coded by the year seals were tagged. OCS Leased Blocks associated with Chukchi Sea Lease Sale 193 area were active during 2013–2016; all were relinquished by 2017.

October–December. In October, ringed seals (n = 9) were primarily in the northern Chukchi Sea, but moved south through December, ahead of the advancing sea ice (Figs. 12 and 14). During their migration, most ringed seals stayed near shore, using both the Alaskan and Russian coasts, and frequently entered coastal bays, inlets, and lagoons. For seals moving along the Alaskan coast, most entered Kotzebue Sound during their migration. Of note, before migrating south along the Alaskan coast, ringed seal RS17-01-M moved from the northcentral Chukchi Sea to the Beaufort coast of Alaska along the 200-m isopleth and made frequent foraging dives. By December, most ringed seals were south of Bering Strait (Fig. 12).

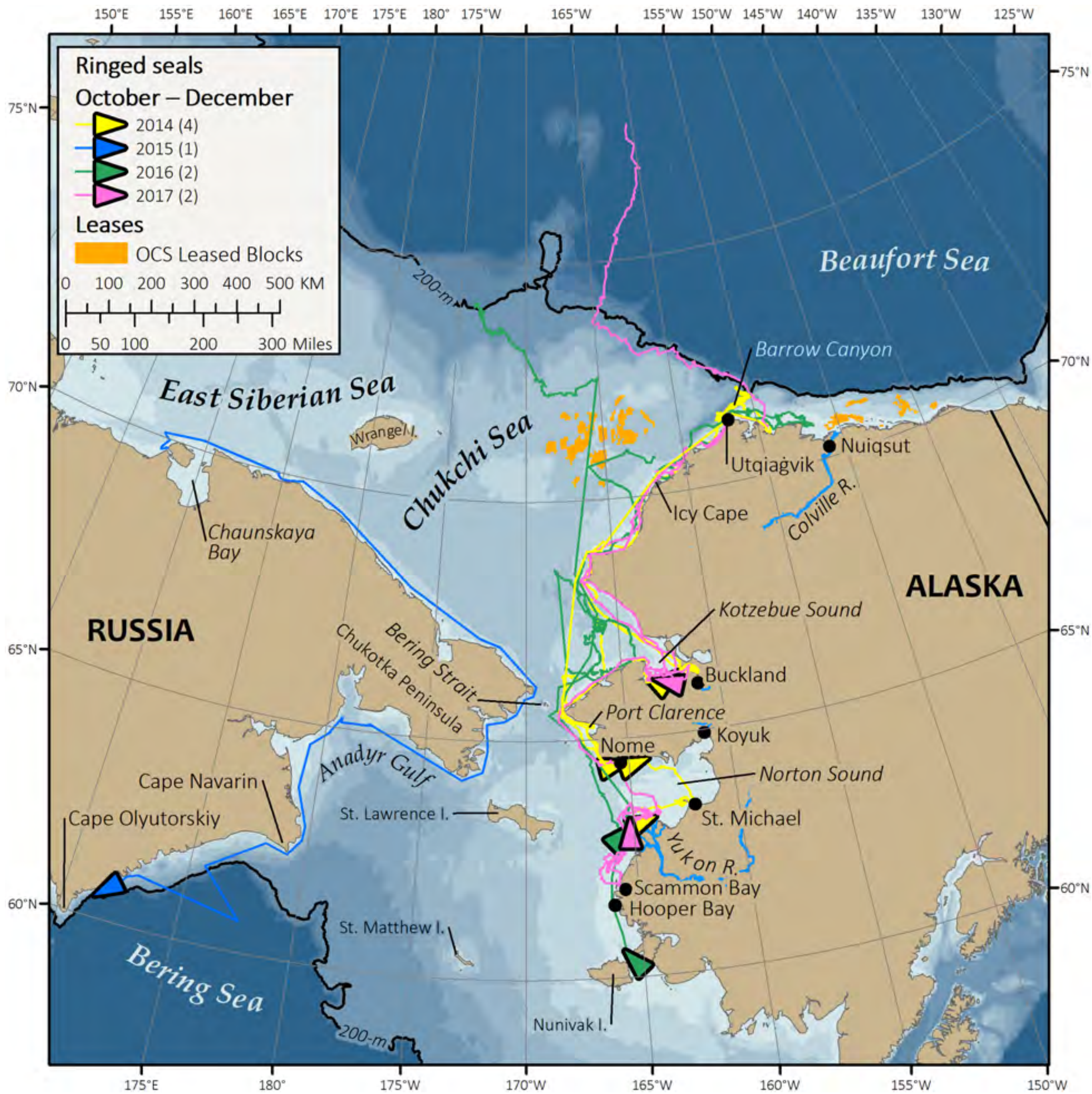


Figure 14. Movements of nine ringed seals from October through December during 2014–2018. Movements are color-coded by the year seals were tagged. OCS Leased Blocks associated with Chukchi Sea Lease Sale 193 area were active during 2013–2016; all were relinquished by 2017.

January–March. Ringed seals (n = 8) were primarily in Kotzebue Sound and the Bering Sea in early January (Figs. 12 and 15). During this period most ringed seals stayed near shore and in shorefast or dense pack ice. While most seals made localized movements in Kotzebue Sound or along the Bering Sea coast of Alaska, some seals made long-distance movements. Ringed seal RS14-01-M moved north along the coast from Nome into the southern Chukchi Sea; RS16-02-M moved between the Bering Strait, mouth of the Yukon River, Hooper Bay, and St. Lawrence Island; and RS17-02-M also moved north from the mouth of the Yukon River to Nome and into the southern Chukchi Sea along the north coast of the Chukotka Peninsula.

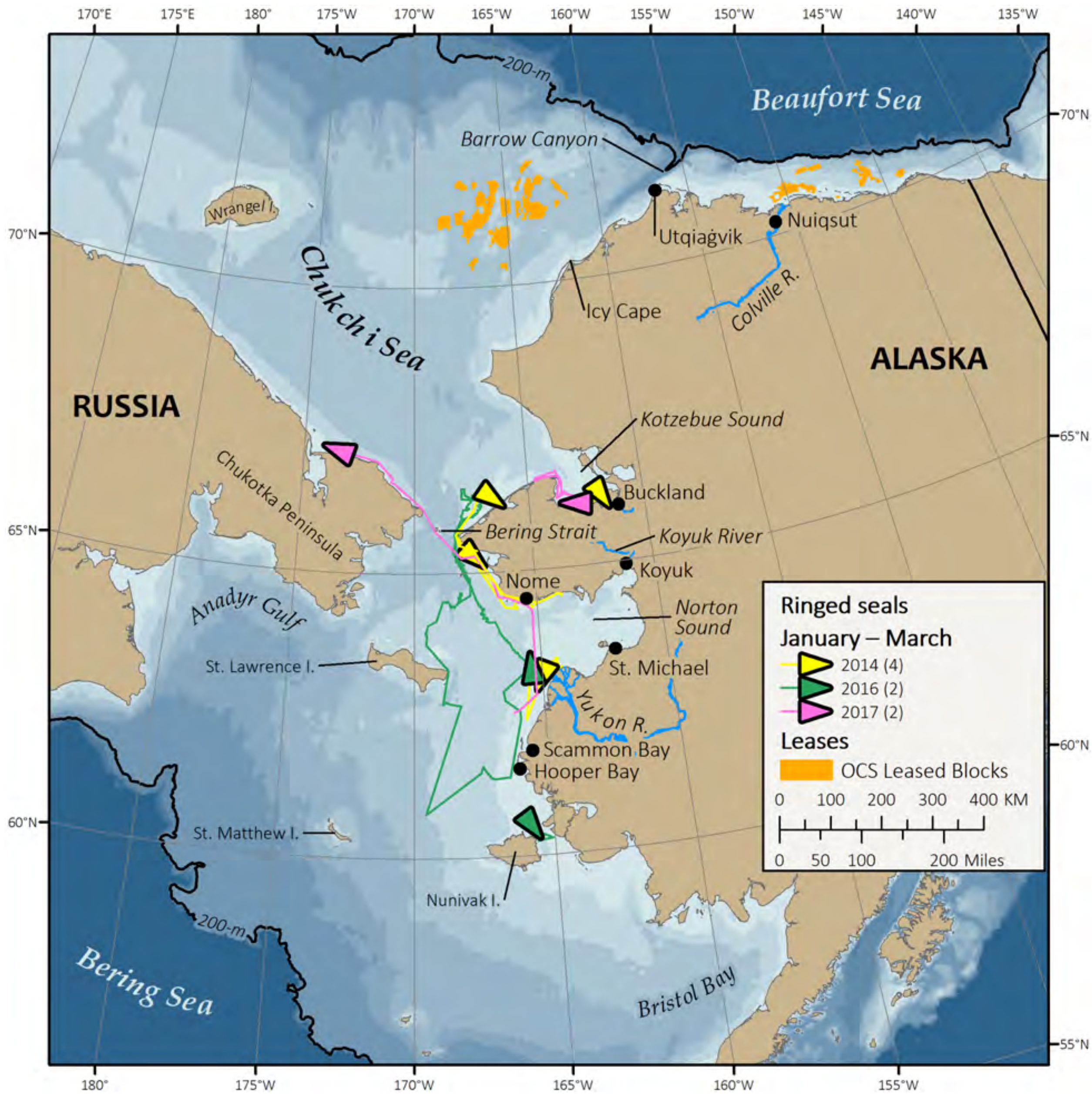


Figure 15. Movements of eight ringed seals from January through March during 2015–2018. Movements are color-coded by the year seals were tagged. OCS Leased Blocks associated with Chukchi Sea Lease Sale 193 area were active during 2013–2016; all were relinquished by 2017.

April–June. As stated above for bearded seals, most seal tracks during this period represent less than three months of movements because primary tags fell off or their battery drained before the end of June. The 13 ringed seals tracked during this time period were in the eastern Bering Sea, primarily in Norton Sound, or in the southern Chukchi Sea, primarily Kotzebue Sound, in early April (Figs. 12 and 16). During this period all ringed seals migrated north with the receding sea ice, most stayed near the ice edge as it moved into the central Chukchi Sea, but two seals tracked in April and May moved north along the northwestern Alaskan coast. Six seals tracked in April entered Kotzebue Sound (Fig. 16). By the end of June, most ringed seals were near, or north of, 70 °N, including the five ringed seals tagged near Utqiaġvik in mid-June 2019. (Figs. 12 and 16).

During this three-month period, four ringed seals were tracked during two consecutive years and one (RS14-01-M) for three consecutive years.

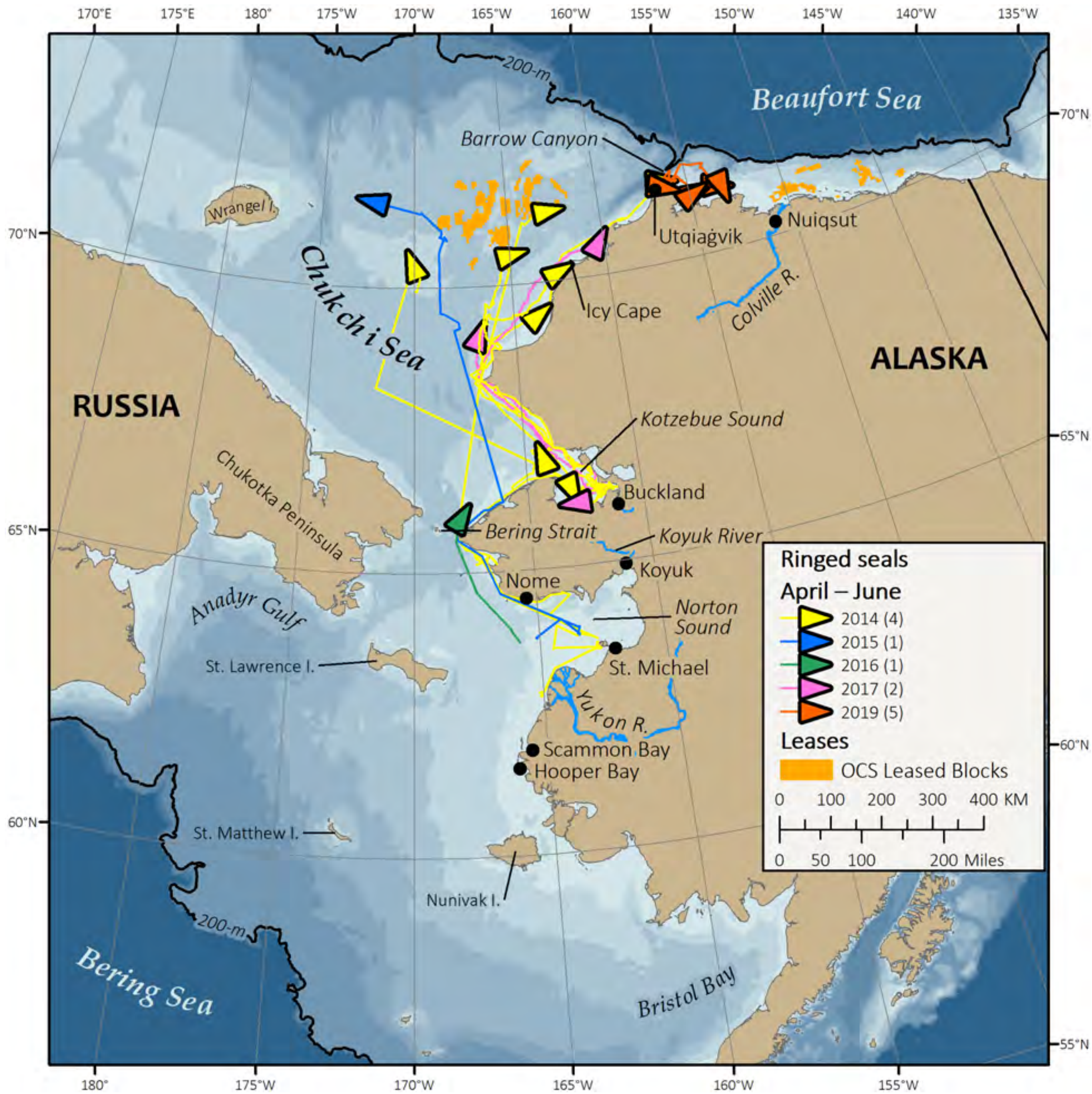


Figure 16. Movements of 13 ringed seals from April through June during 2014–2019. Movements are color-coded by the year seals were tagged. The terminal locations represent the last location received during this period, which were often before the end of June because primary tags fell off during molt. In some cases, however, the flipper-mounted SPOT tags provided additional locations during this period when the seal hauled out. OCS Leased Blocks associated with Chukchi Sea Lease Sale 193 area were active during 2013–2016; all were relinquished by 2017.

Site fidelity. Five ringed seals, all tagged in Kotzebue Sound in May or June, had tags that transmitted for 329 days or more (up to 694 days) (Table 2), and all five exhibited fidelity to areas or migration routes. In particular, ringed seal RS14-01-M (tracked for 694 days) used Barrow Canyon and Smith Bay (an area east of Dease Inlet in the Beaufort Sea) in the summer and fall of 2014 and 2015, then migrating south through the Chukchi Sea along the Alaskan Coast, entering Norton Sound in the Bering Sea in December of 2014 and 2015 (Fig. 17). RS14-01-M wintered in northern Norton Sound and along the western coast of Seward Peninsula in 2014 and 2015. This seal also used outer Kotzebue Sound during its northward migration in 2014, 2015, and 2016 and continued north of Kotzebue Sound, along the Alaskan coast to an area near Icy Cape in both 2014 and 2015.

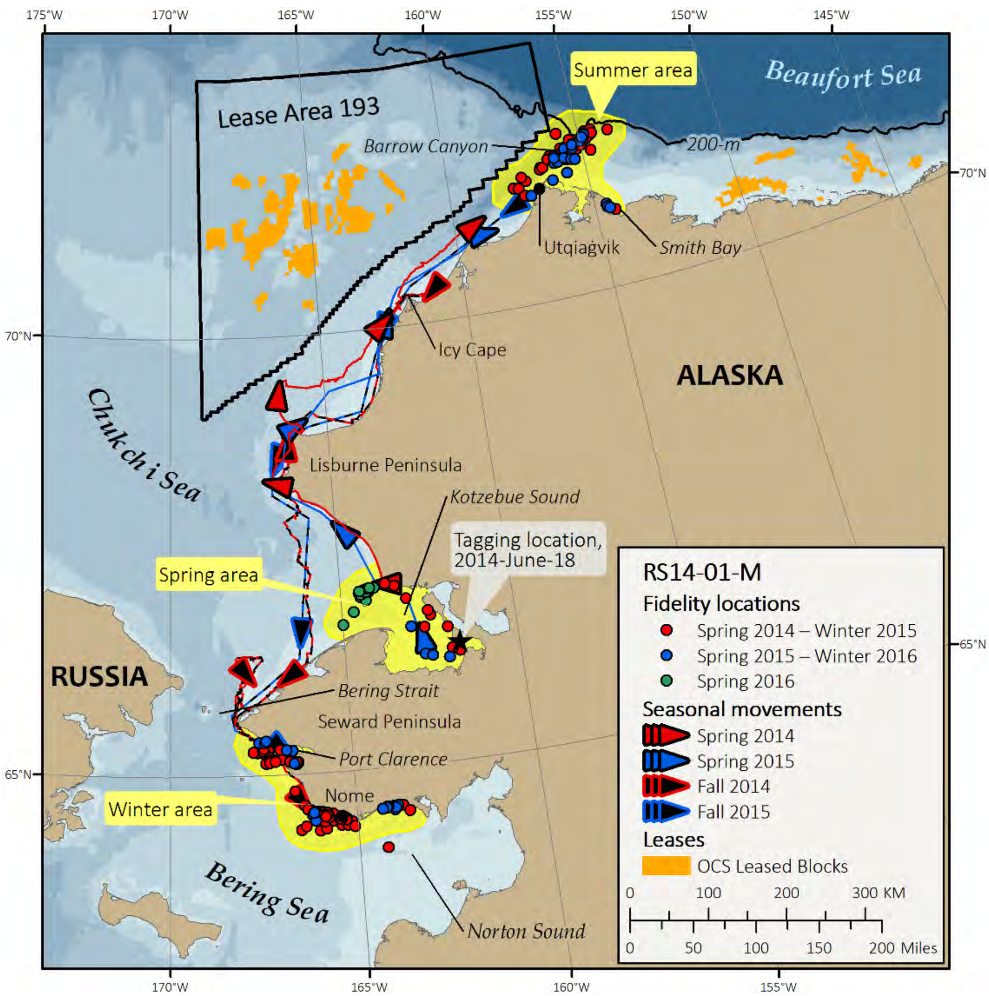


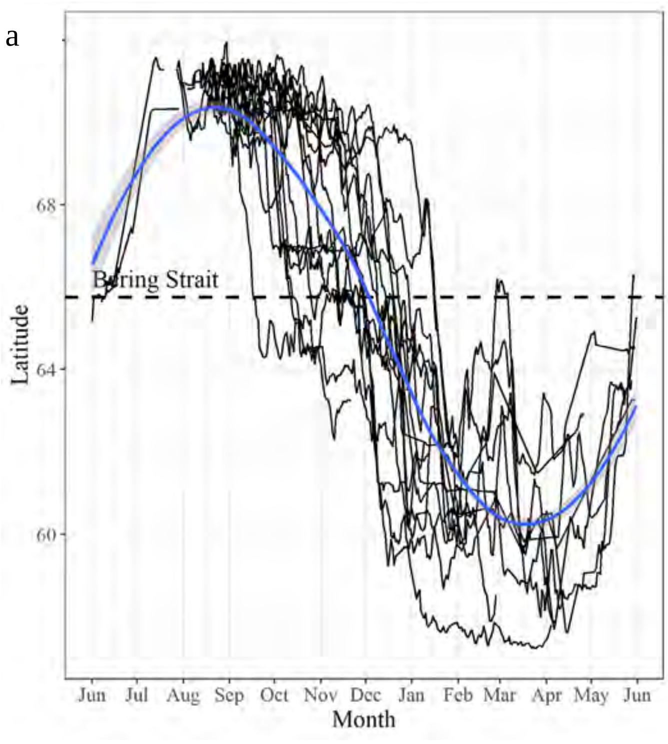
Figure 17. Locations and seasonal movements of ringed seal RS14-01-M (tagged in Kotzebue Sound) depicting site fidelity during summer (July–October) and winter (December–March) for two consecutive years and during spring (late-May–June) for three consecutive years. Red dots are locations during June 2014–March 2015; blue dots are locations during June 2015–March 2016; and yellow dots are locations during June 2016. Northward spring migrations are depicted by solid lines and colored arrows (2014 with red and 2015 with blue). Southward fall migrations are depicted by dashed lines and black arrows. OCS Leased Blocks associated with Chukchi Sea Lease Sale 193 area were active during 2013–2016; all were relinquished by 2017.

Ringed seal RS14-03-M (tracked for 361 days) used an area in the northeast Chukchi Sea, north and northwest of Icy Cape, in the late spring and early summer of 2014 and 2015. This seal left Kotzebue Sound in mid-June, soon after being tagged, and moved to this area in the northeast Chukchi Sea where it stayed from early July to mid-September 2014. It then wintered in Norton Sound and returned to this area in the northeast Chukchi Sea in mid-June 2015 when the tag stopped transmitting. RS14-04-F (tracked for 382 days) used southern Kotzebue Sound during the late spring of 2014 and 2015. This seal also left Kotzebue Sound in mid-June, soon after being tagged, and moved through the central and northern Chukchi Sea before returning to, and wintering in, Kotzebue Sound from late October 2014 to mid-June 2015.

Two other ringed seals (RS14-02-F, tracked for 357 days, and RS17-01-M, tracked for 329 days) also exhibited fidelity to Kotzebue Sound during their northward migration into the Chukchi Sea in two consecutive years in spring.

Spotted seals
Latitudinal movements of spotted seals varied by tagging location. Seals tagged in the Beaufort Sea (n = 17) made definitive, seasonal (south in fall and north in summer) movements between the Beaufort and Bering seas (Fig. 18a), but seals tagged in the Bering Sea (n = 7) tended to stay in the Bering Sea (Fig. 18b).

a



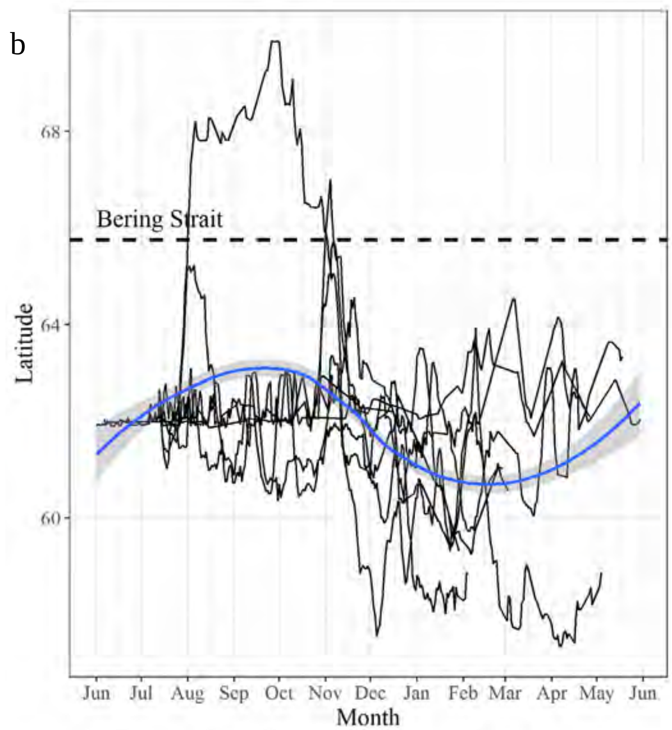


Figure 18. Latitudinal movements of spotted seals tagged in the a) Beaufort (n = 17) and b) Bering (n = 7) seas by month during 2016–2019. Thin black lines are individual seals tracked by their primary tag. Dashed line is Bering Strait. June–October are generally ice-free months. November–May are generally characterized by ice formation, ice cover, and receding ice. Blue line and gray shaded region represent the smoothed conditional mean and SE for latitudinal movements.

July–September. Spotted seals tagged in the Beaufort Sea (*n* = 15) made frequent west-east movements between foraging areas in the central Chukchi Sea and terrestrial resting areas on the Alaskan coast (Fig. 19). Between foraging trips, seals would generally make localized movements along the coastline of the northeast Chukchi Sea, including entering the Kugrua River, the Avak River, and Peard Bay, and rested on the barrier islands near Icy Cape. Seals also made long-distance movements back to the vicinity of their tagging locations in Dease Inlet, Fish Creek, and the Colville River. During these long-distance movements, seals would primarily stay near shore (Fig. 19). During this period, only one spotted seal tagged in the Beaufort Sea (SS16-08-M) moved south of 69 °N, ahead of the advancing sea ice. By the end of September, this seal left the Chukchi and entered the Bering Sea (Fig. 18a) along the east coast of the Chukotka Peninsula, including entering Lavrentiya Bay and Getlyanen Lagoon (Fig. 19).

Spotted seals tagged in the Bering Sea (*n* = 5) made similar frequent west-east movements between foraging areas in the eastern Bering Sea and coastal areas near the outlet of the Yukon River (Fig. 19). Between foraging trips these spotted seals would rest on barrier islands, including the islands where they were tagged in Scammon Bay, as well as islands south of Hooper Bay and on St. Lawrence Island. During this period, only one spotted seal tagged in the Bering Sea (SS18-01-M) moved north, through Bering Strait, into the Chukchi Sea (Fig. 18b). This seal moved west along the north coast of the Chukotka Peninsula where it entered the

Amguyema River twice; once on 5 August 2018 and again on 23 August 2018, each time staying in the river for 7–10 days where it likely foraged and was recorded hauling out a minimum of 72 straight hours both times (Fig. 19).

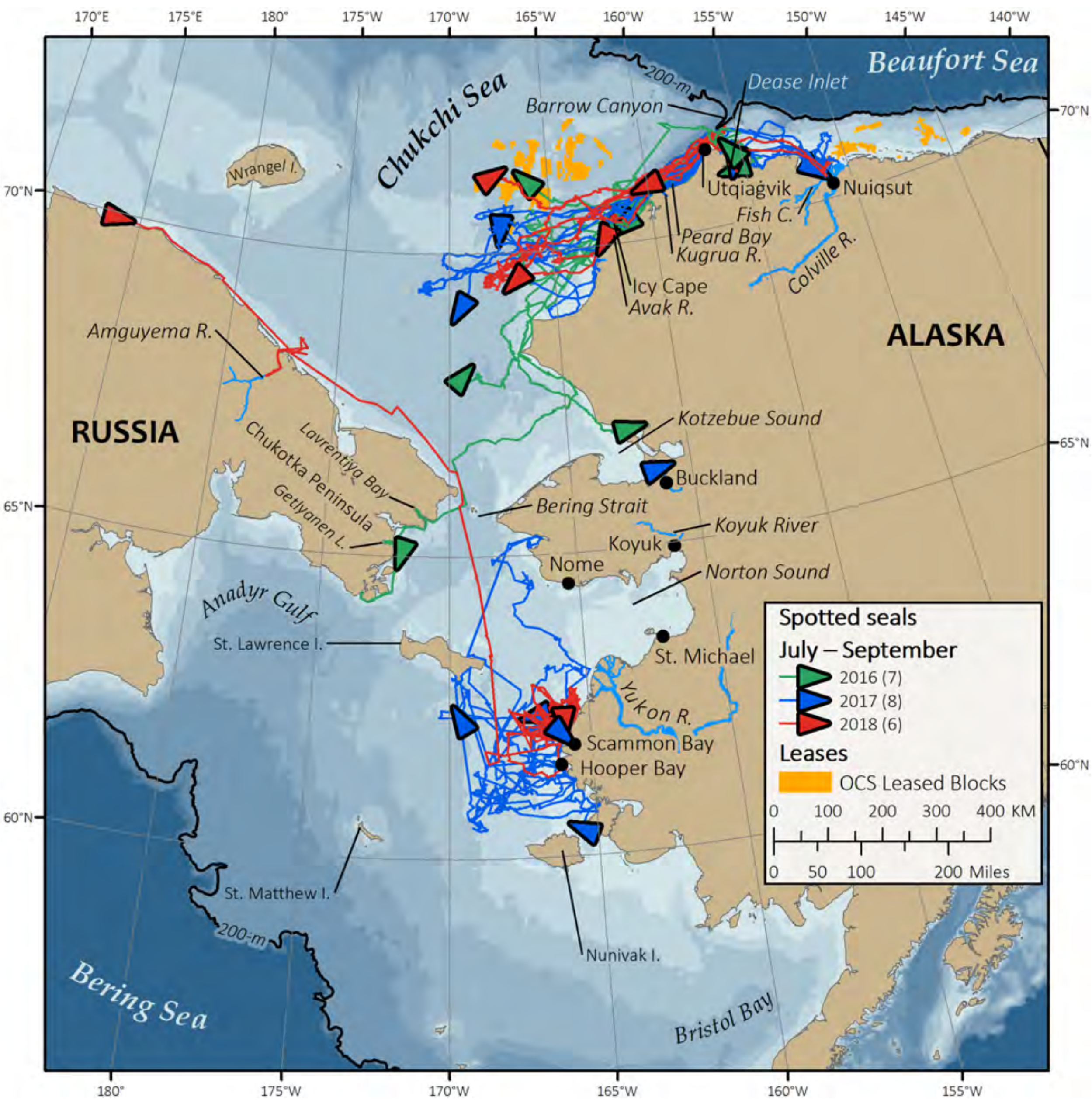


Figure 19. Movements of 21 spotted seals from July through September during 2016–2019. Movements are color-coded by the year seals were tagged. OCS Leased Blocks associated with Chukchi Sea Lease Sale 193 area were active during 2013–2016; all were relinquished by 2017.

October–December. Spotted seals tagged in the Beaufort Sea (*n* = 17) continued to make frequent west-east movements to forage in the central Chukchi Sea and haul out on land into mid-November (Fig. 20). As sea ice advanced south, seals migrated south, some near shore and others far from shore in open water. Seals that migrated along shore frequently entered coastal bays, inlets, and lagoons, including Kotzebue Sound, and used remote, coastal islands to haul out. Spotted seals tagged in the Bering Sea (*n* = 7) also continued to make frequent west-east movements to forage in the eastern Bering Sea and hauled out on barrier islands into mid-November (Fig. 20). By December, most spotted seals were south of Bering Strait (Fig. 18). When in the Bering Sea, movements of seals were similar, regardless of where they were tagged (Fig. 20).

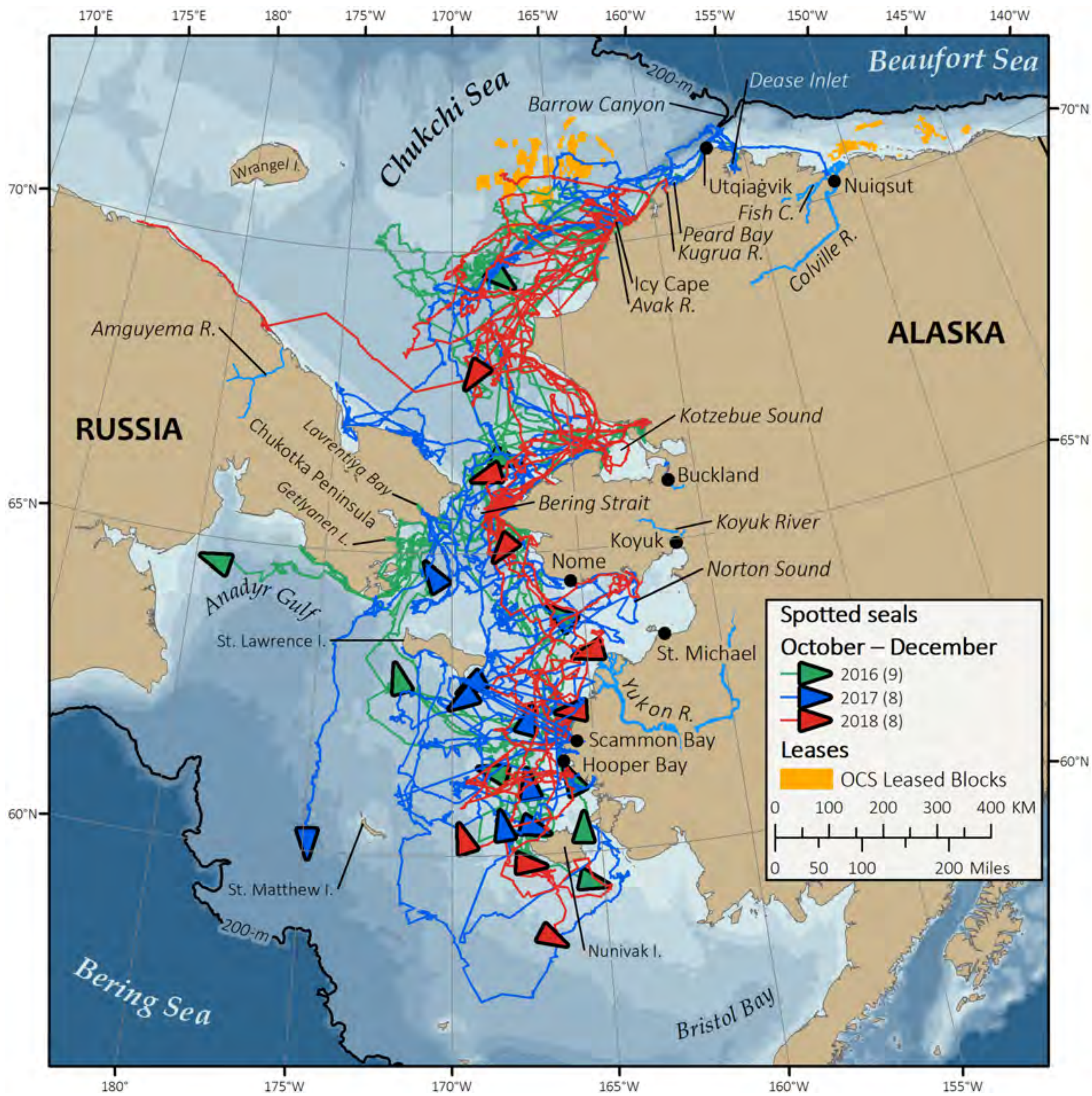


Figure 20. Movements of 25 spotted seals from October through December during 2016–2018. Movements are color-coded by the year seals were tagged. OCS Leased Blocks associated with Chukchi Sea Lease Sale 193 area were active during 2013–2016; all were relinquished by 2017.

January–March. By mid-January all spotted seals were in the Bering Sea (*n* = 23; Figs. 18 and 21). Throughout this period, all seals regardless of tagging location occupied pack ice and moved throughout the central Bering Sea. Spotted seals used the central Bering Sea regularly when ice was present. When ice was absent from the central Bering Sea and only located near shore, spotted seals generally restricted their movements closer to shore. By the end of March, all spotted seals were in the Central Bering Sea, generally near 61 °N, regardless of where they were tagged (Fig. 18).

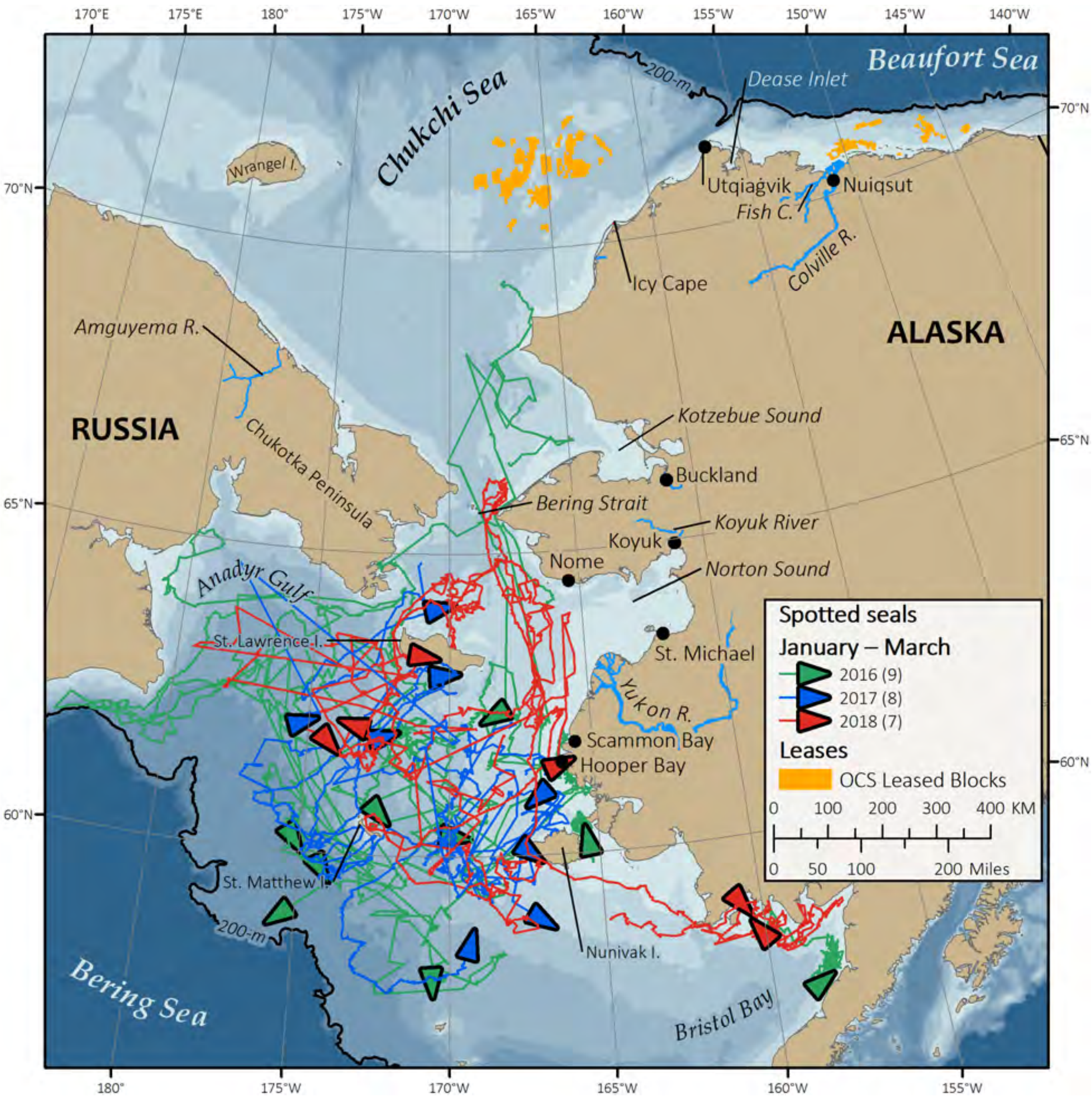


Figure 21. Movements of 24 spotted seals from January through March during 2017–2019. Movements are color-coded by the year seals were tagged. OCS Leased Blocks associated with Chukchi Sea Lease Sale 193 area were active during 2013–2016; all were relinquished by 2017.

April–June. Most seal tracks during this period represent less than three months of movements because primary tags fell off or their battery drained before the end of June. All spotted seals (*n* = 14) were in the Bering Sea in early April (Figs. 18 and 22). In April and May, all seals regardless of tagging location occupied pack ice and moved throughout the central and eastern Bering Sea. Spotted seals used the southern extent of the ice edge in the central Bering Sea regularly when ice was present. When ice was absent in the central Bering Sea and only located near the coast, spotted seals generally restricted their movements closer to the coast. One spotted seal (SS17-02-M) was located in two consecutive years during this three-month period; in 2018 this seal used areas near the mouth of the Yukon River, the barrier islands in Scammon Bay, and the central Bering Sea, south of St. Lawrence Island, but in 2019 it used areas in the central Bering Sea, west and southwest of St. Lawrence Island. By the end of June, two spotted seals, tagged in the Bering Sea, remained there (~62 °N) while three, tagged in the Chukchi Sea, moved north into the Chukchi Sea (~68 °N, Fig. 18).

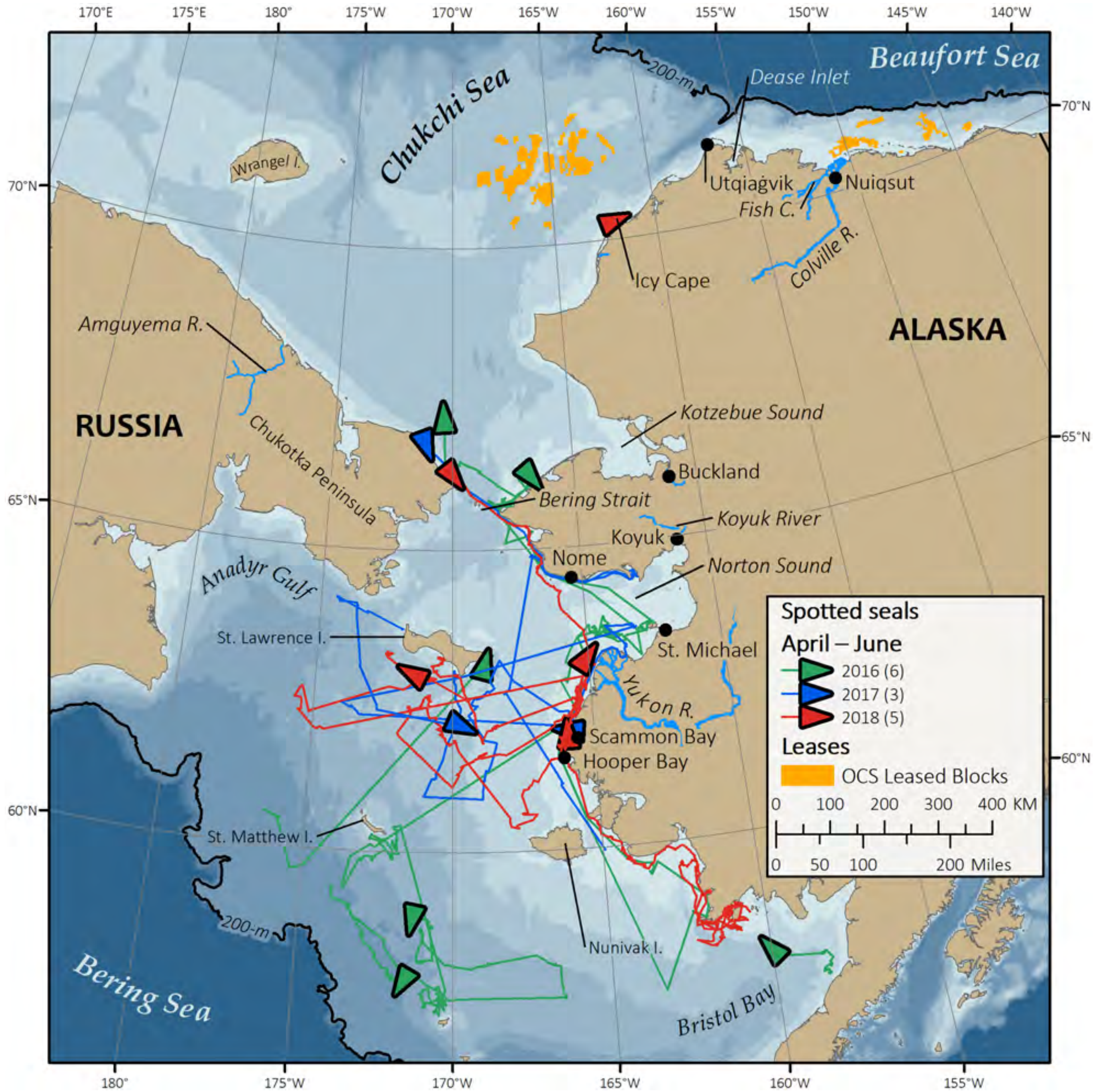


Figure 22. Movements of 14 spotted seals from April through June during 2016–2019. Movements are color-coded by the year seals were tagged. The terminal locations represent the last location received during this period, which were often before the end of June because primary tags fell off during molt. In some cases, however, the flipper-mounted SPOT tags provided additional locations during this period when the seal hauled out. OCS Leased Blocks associated with Chukchi Sea Lease Sale 193 area were active during 2013–2016; all were relinquished by 2017.

Site fidelity. Five spotted seals had tags that transmitted for more than 316 days (up to 647 days) and four of them exhibited fidelity to haulout sites or feeding areas in consecutive years. Two spotted seals, both tagged in August in the Beaufort Sea (Dease Inlet) exhibited fidelity to specific haulout sites in the summer of two consecutive years; SS16-06-F (tracked for 346 days) at Icy Cape and Peard Bay and SS16-07-M (tracked for 336 days) in Dease Inlet (Fig. 23).

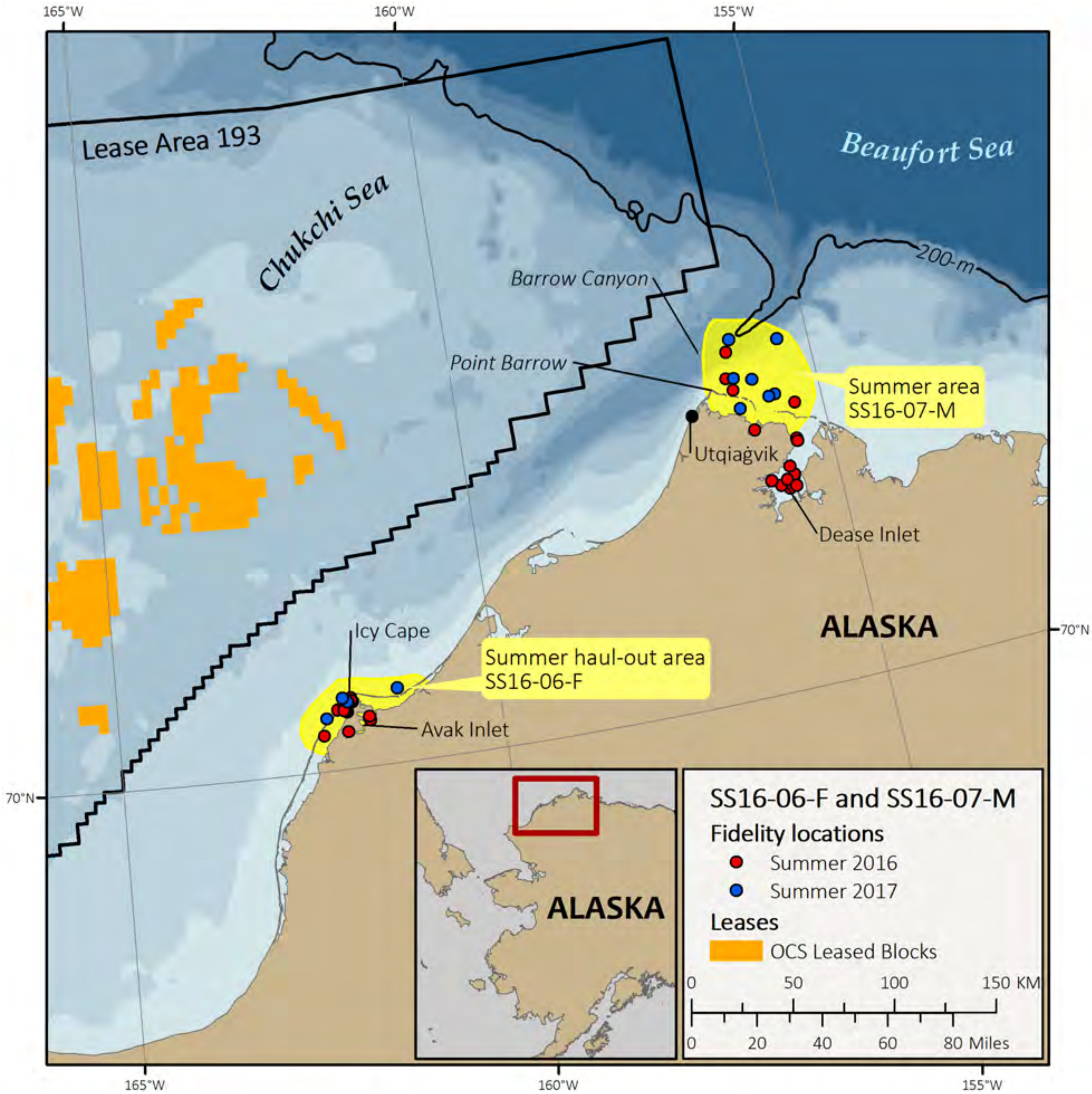


Figure 23. Locations of spotted seals SS16-06-F and SS16-07-M depicting site fidelity during summer (July–October) for two consecutive years. Red dots are locations during August–October 2016; blue dots are locations during July 2017. OCS Leased Blocks associated with Chukchi Sea Lease Sale 193 area were active during 2013–2016; all were relinquished by 2017.

Two spotted seals (SS17-02-M, tracked for 657 days and SS18-02-M, tracked for 452 days as of 30 September 2019), both tagged in the Bering Sea near Scammon Bay in July, also exhibited fidelity to specific haulout sites on barrier islands in Scammon Bay in the fall in two consecutive years. SS17-02-M also foraged between Scammon Bay and the mouth of the Yukon River in the fall and exhibited fidelity to the area between St. Lawrence and Nunivak islands in the Bering Sea in the winter of two consecutive years. One spotted seal, SS16-01-F (tracked for 316 days), was tagged in Dease Inlet in July, used the central and southern Chukchi Sea in the fall and wintered in the central Bering Sea but did not exhibit seasonal fidelity to haulout or feeding areas.

Distance Traveled

The average minimum total distance traveled for all seals combined was 8,347 km (Table 3). The overall shortest distance traveled was made by a bearded seal (1,282 km) and the longest distance traveled was made by a spotted seal (16,495 km). When the number of days tags provided locations for each seal was accounted for, spotted seals moved farther than bearded and ringed seals ($P < 0.01$) whose movements were not significantly different from each other ($P = 0.33$). Spotted seals tagged in the Beaufort Sea migrated south to winter in the Bering Sea, but spotted seals tagged in the Bering Sea rarely left there. Interestingly, despite moving farther from their tagging location, the total distances moved by spotted seals tagged in the Beaufort Sea did not differ from those tagged in the Bering Sea ($P = 0.22$).

Table 3. Distances traveled by tagged bearded, ringed, and spotted seals in the Bering, Chukchi, and Beaufort seas during 2014–2019.

	Bearded (*n* = 22)	**Ringed (*n* = 11)**	**Spotted (*n* = 24)**	**All seals (*n* = 57)**
Ave. min. distance (km)	6,166	8,076	10,470	8,347
Min. distance (km)	1,282	1,770	3,090	1,282
Max. distance (km)	15,480	16,374	16,495	16,495

Distance to Land

Seals of all three species used areas near land, including terrestrial haulouts and freshwater rivers, but also used areas 800 km from land. Distances to land, however, differed by seal species and months (all species, $P < 0.0001$), and were highly variable by individual. On average, the distances young bearded seals kept from land differed the least; they tended to remain closest to land (< 50 km) during November–January when ice was present, and farther from land (< 75 km) during April–September (Fig. 24). Ringed seals also were closer to land when ice was present (< 20 km) during November–May, and farther from land during the open-water season, June–October (> 45 km); they were farthest from land (~190 km) during September (Fig. 25). Spotted seals, however, tended to move farther from land when ice cover was maximal, January–April, and stayed closer to land during the open-water season, July–November (Fig. 26). On average, spotted seals were farthest from land during March (~140 km).

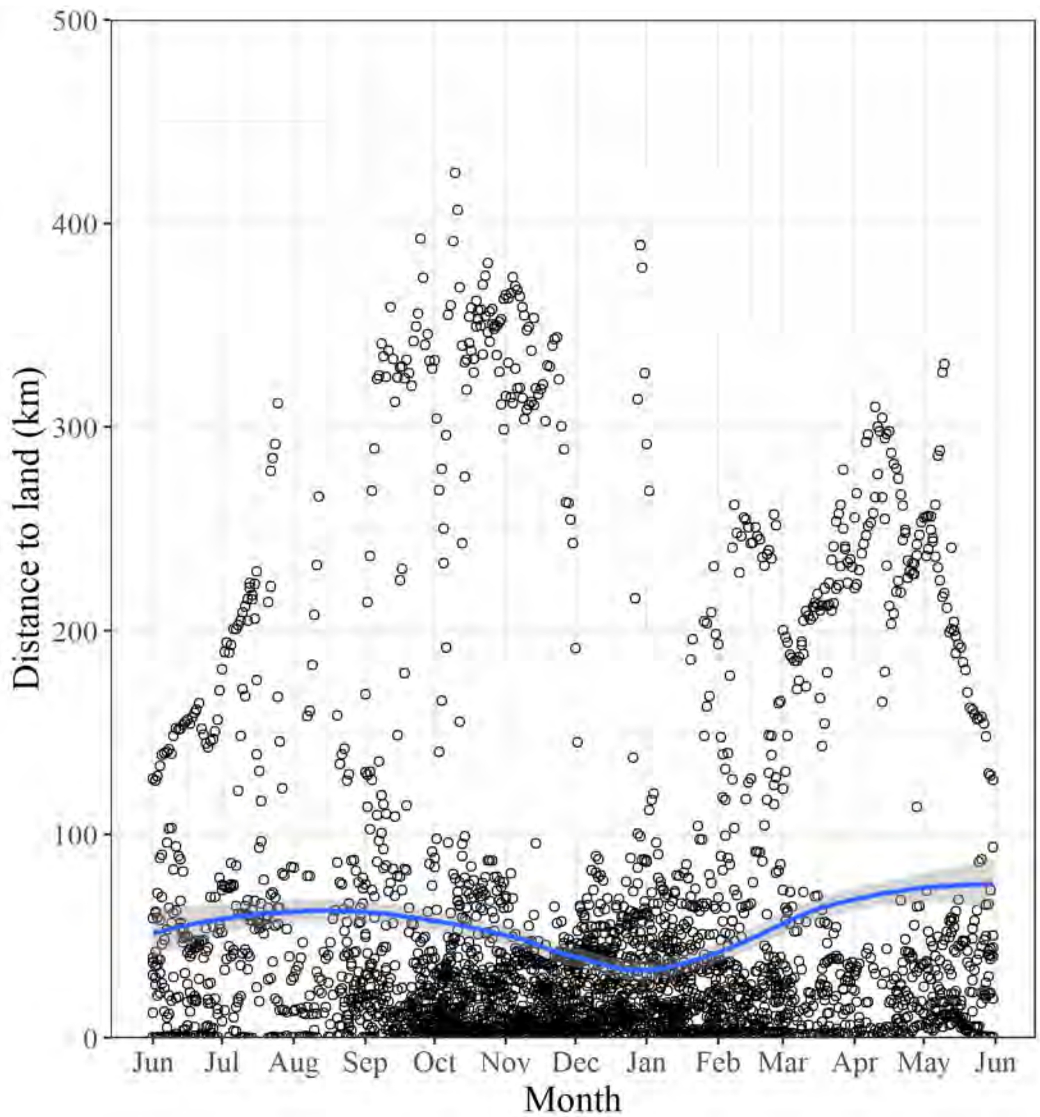


Figure 24. Distance to land (km) for daily estimated locations of 26 young bearded seals by month during 2014–2019. Blue line and gray shaded region represent the smoothed conditional mean and SE for distance to land.

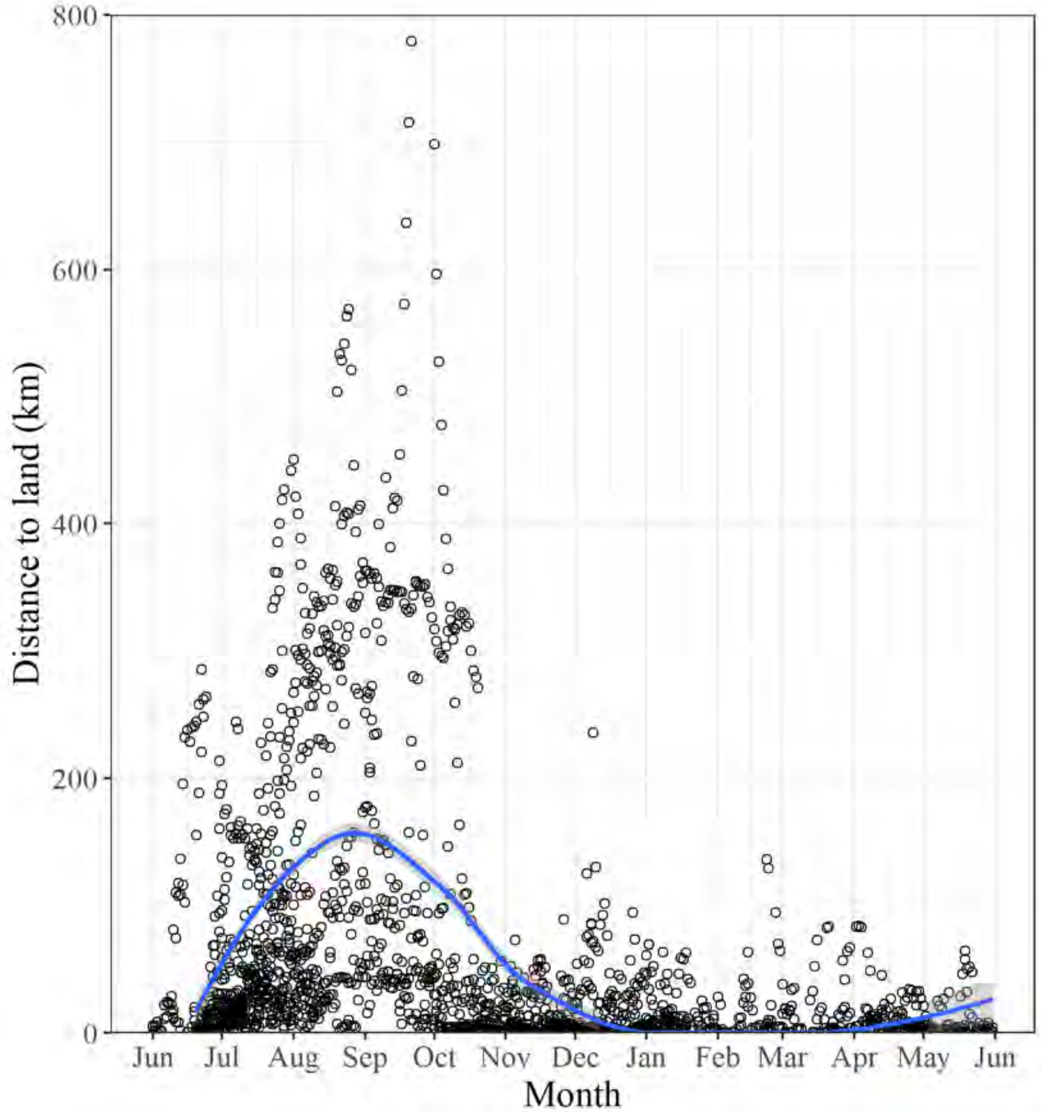


Figure 25. Distance to land (km) for daily estimated locations of 16 ringed seals (13 adults and 3 juveniles) by month during 2014–2019. Blue line and gray shaded region represent the smoothed conditional mean and SE for distance to land.

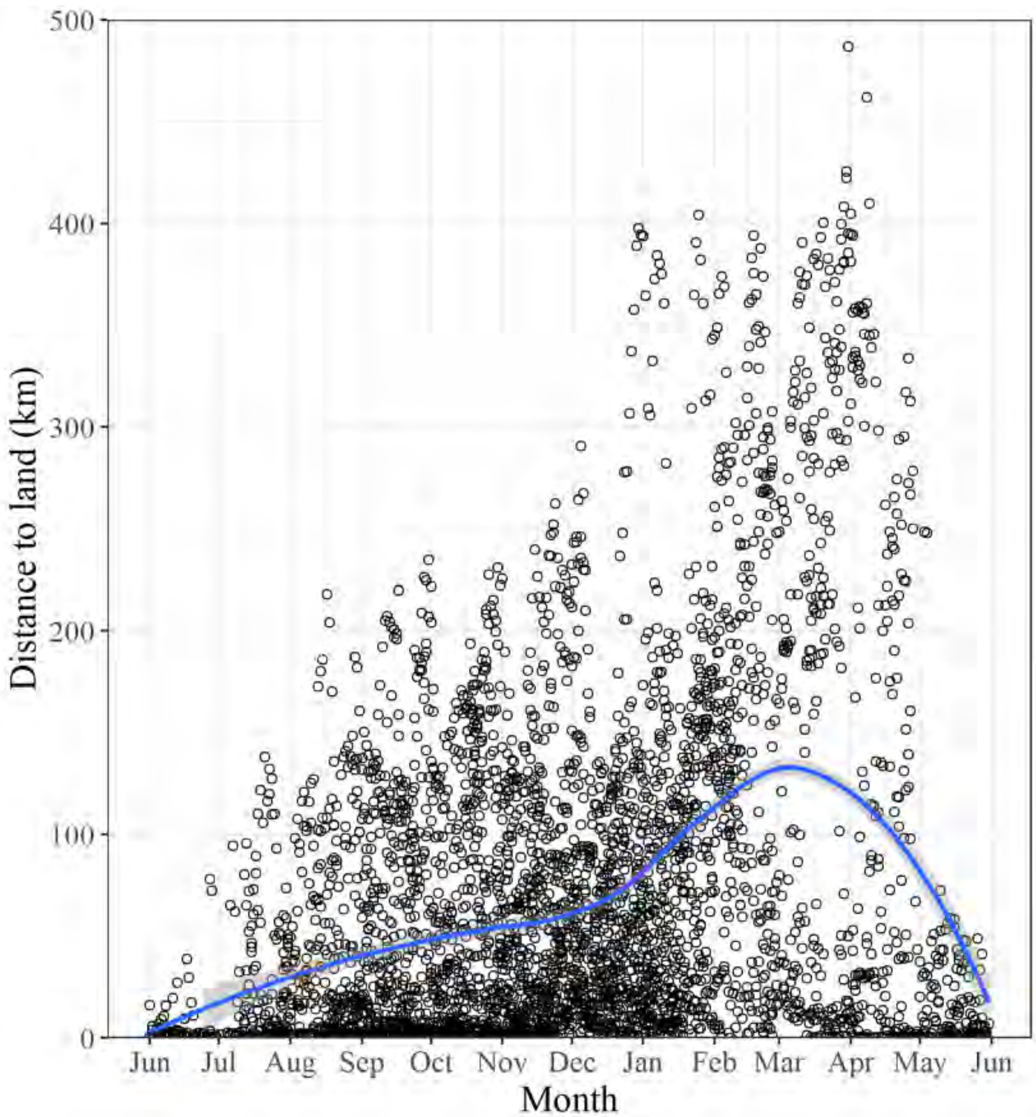


Figure 26. Distance to land (km) for daily estimated locations of 25 spotted seals by month during 2016–2019. Blue line and gray shaded region represent the smoothed conditional mean and SE for distance to land.

High-Use Areas Important for Foraging

Bearded seals. Bearded seals are primarily benthic foragers (85% of all dives are to the sea floor). To identify important foraging areas, we first explored how habitat covariates influence the time spent at the sea floor (i.e. feeding). We found they spent less time at the sea floor as sea ice concentration and water depth increased, and more time at the sea floor as distance from land increased, and these relationships varied seasonally (Fig. 27). Although these patterns were statistically significant, they only explained 10% of the variation in time spent at the sea floor. Rather, bearded seals appear to consistently dive to the sea floor throughout the year and in a variety of environmental conditions.

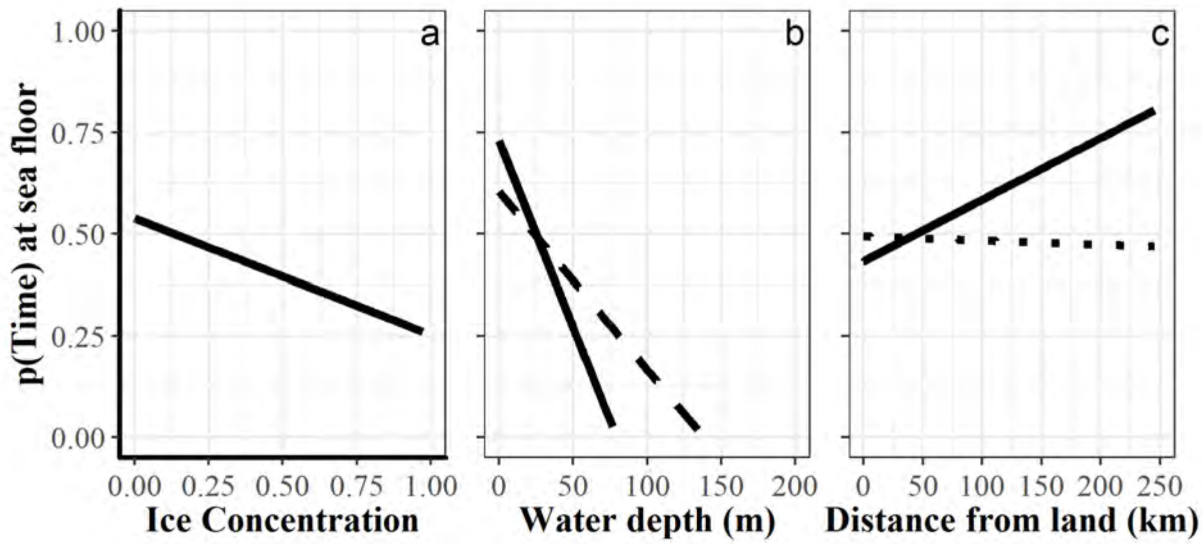


*Figure 27. The proportion of time bearded seals (n = 14) spent near the sea floor relative to the habitat variables (a) ice concentratoin, (b) water depth, and (c) distance from land. For ice concentration (a), solid line is the relationship during summer, fall and winter. For water depth (b), solid line depicts the proportion of time at the sea floor when seals are within the pack ice (> 15% ice concentration), and dashed line depicts this relationship when seals are in open water. For distance from land (c), the dotted line is the relationship during June–August and the solid line is the relationship during September–January. Figure reproduced from Olnes et al. (*In review*).*

Given their consistent dive pattern (it appears young bearded seals regularly dive to the sea floor looking for prey), we explored the use of a state-space model to infer foraging locations. If seals maintain a consistent dive pattern, then where they spend time in a resident behavioral state could indicate places where they have found prey. Our state-space model identified clear behavioral states for juvenile bearded seals (Figs. 28 and 29), however, where seals lingered in a resident state was highly individualistic, making the determination of high-use areas difficult to ascertain. Notable areas that are likely important for bearded seal foraging year-round are Barrow Canyon, southern Kotzebue Sound, Bering Strait, Norton Sound, and near St. Lawrence Island. During July–November, important areas also included Hope Basin, Mechigmenskaya Bay, Russia, and the ~100 m isopleth in the Bering Sea (Fig. 28); during December–June, important areas also included the mouth of the Yukon River and western Anadyr Gulf (Fig. 29). Much of the continental shelf, however, may also be important foraging habitat for bearded seals.

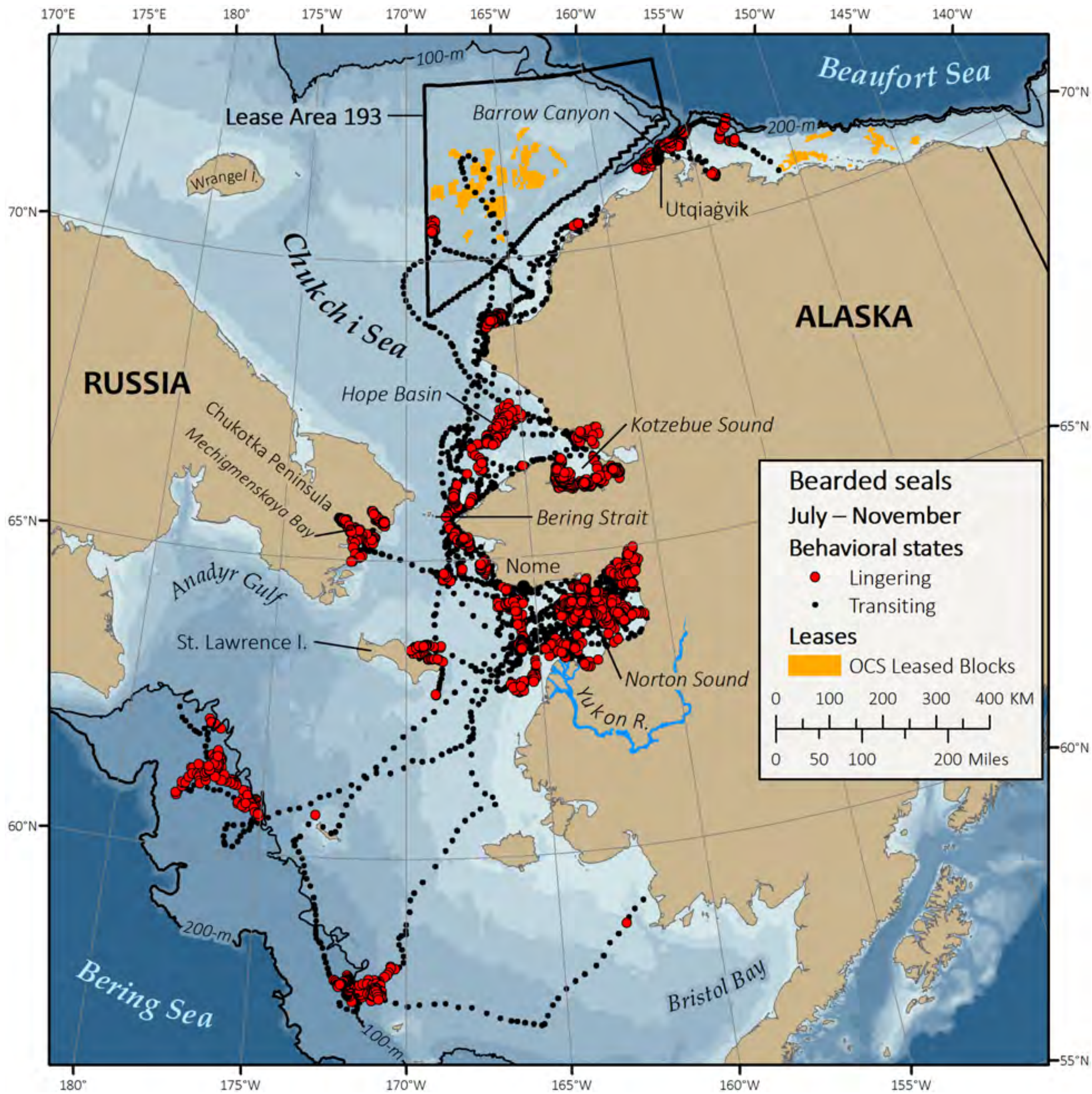


Figure 28. Juvenile bearded seal (n = 18) locations, as determined by a joint estimation state-space model, during July–November 2014–2017. Red dots are seal locations identified in lingering or resident behavioral state and small black dots are seal locations identified in transiting state.

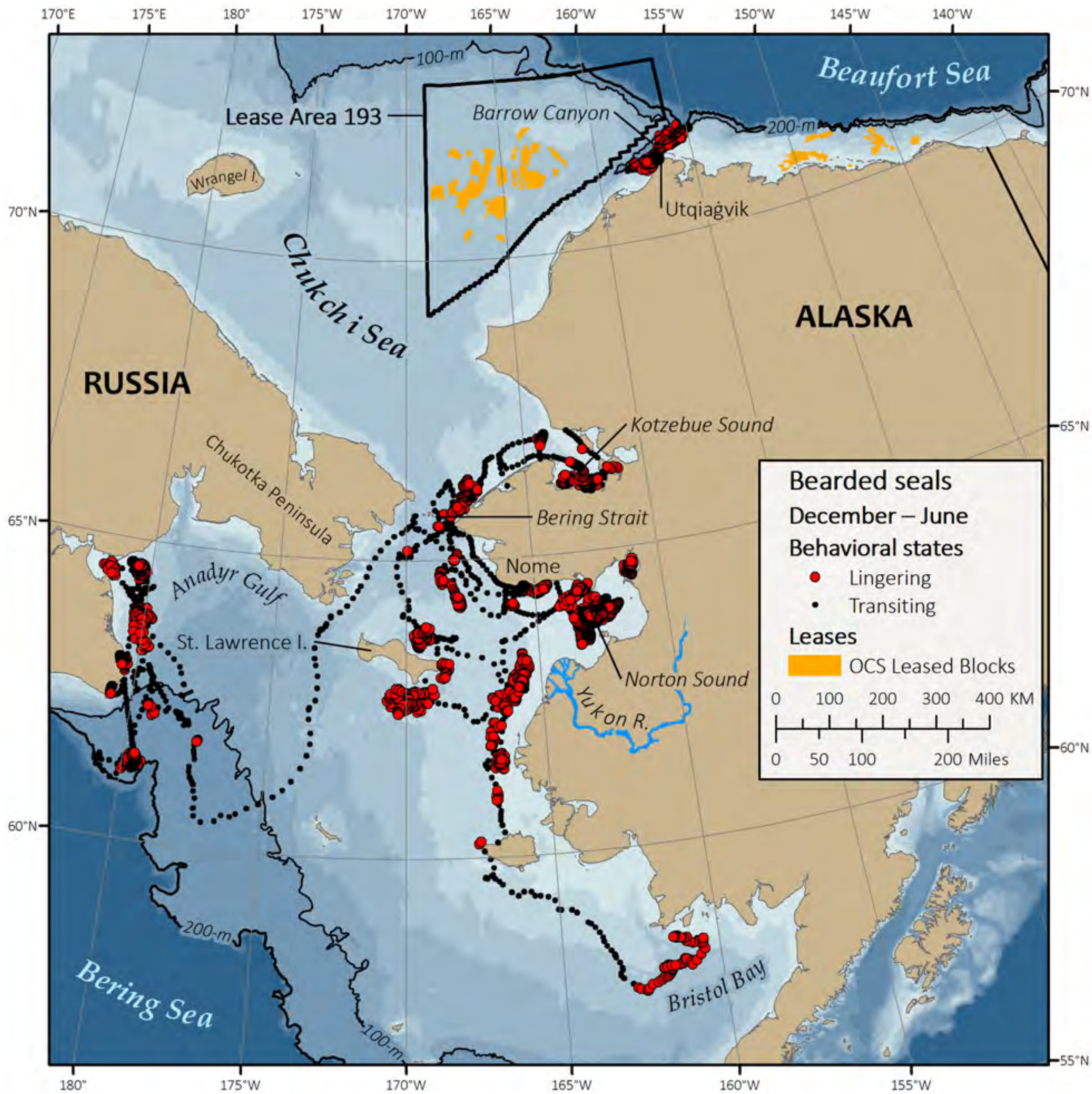


Figure 29. Juvenile bearded seal (n = 13) locations, as determined by a joint estimation state-space model, during December–June 2014–2018. Red dots are seal locations identified in lingering or resident behavioral state and small black dots are seal locations identified in transiting state.

Ringed seals. We identified core-use areas for ringed seals as utilization distributions of < 50% volume (i.e., areas with the highest density of locations) during the summer (July–September) and winter (December–May) seasons. We defined seasons of use based on the seasonal movements of ringed seals (Fig. 12). Ringed seals are generally at their northern extent during summer when the Chukchi Sea is primarily free of sea ice and at their southern extent during winter when sea ice has advanced into the Chukchi and Bering seas. Ringed seals generally made long-distance movements during the rest of the year, migrating south with the advancing sea ice during fall (October and November) and migrating north with the receding sea ice during spring (June).

During July–September, seals were generally located along the intercontinental shelf break of the Chukchi and Beaufort seas (200 m isobath), but the core-use area was north and east of Utqiaġvik, including Barrow Canyon and the western Beaufort Sea (Fig. 30). Sea ice often stays until late July in the core-use area and seals were located and foraged near sea ice while in these areas. During December–May, seals used areas as far south as Nunivak Island, the mouth of the Yukon River, Stuart Island, Port Clarence, and Nome, but the core-use area was in southern Kotzebue Sound (Fig. 31). Sea ice is highly concentrated (> 80%) there during this period, and most (10 of 13) seals used to identify high-use areas during this period were adults. This pattern of use likely indicates these seals were establishing winter territories.

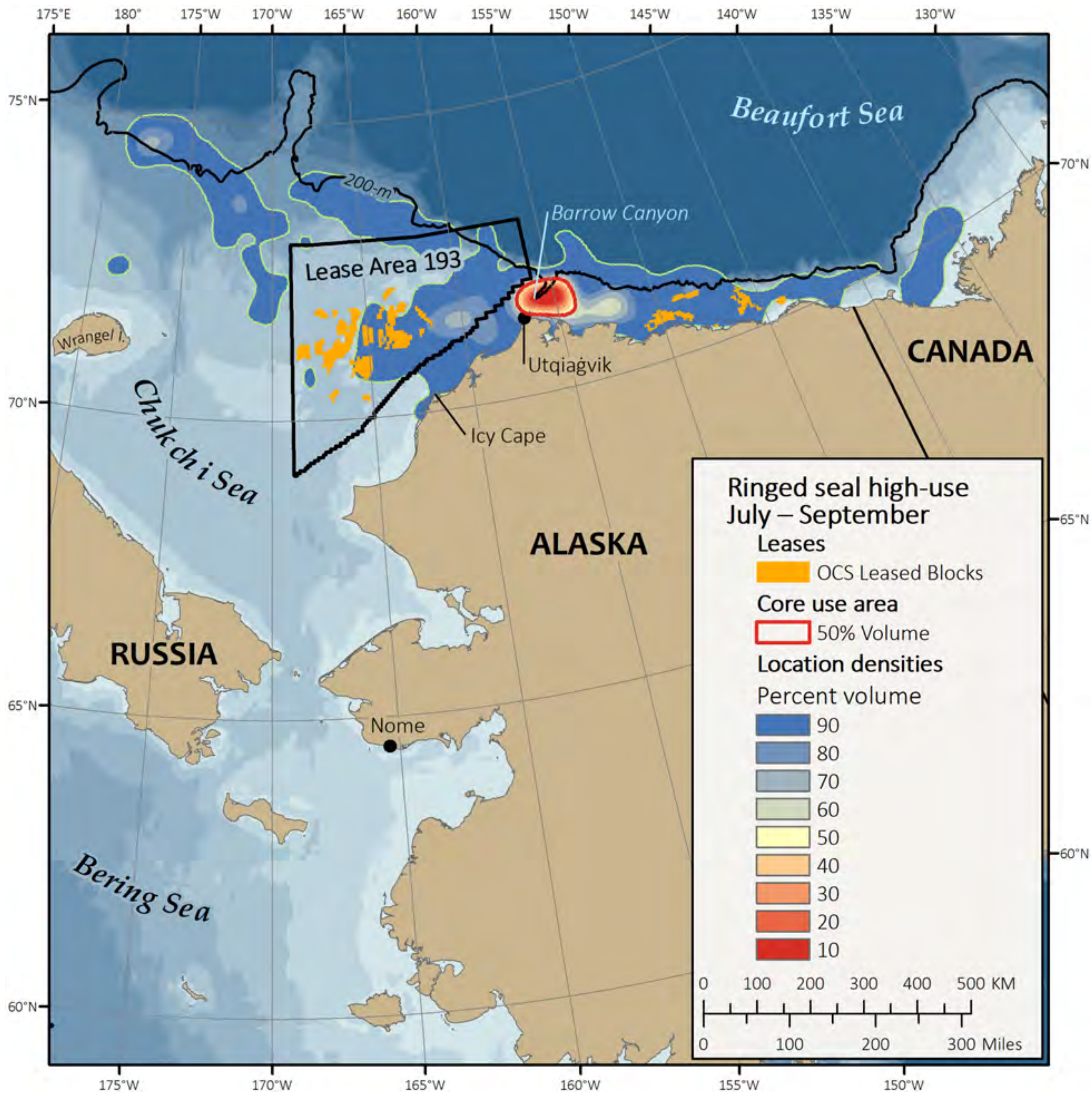


Figure 30. Distribution of ringed seals (n = 15) during July–September 2014–2019. Seals were tagged near Utqiaġvik (n = 7), Kotzebue Sound (n = 6), St. Michael (n = 1), and Hooper Bay (n = 1). Core-use areas (red circle) represent areas with utilization distributions < 50% volume (i.e., areas with the highest density of locations) within the season and delineate primary foraging areas. The lite-green line depicts the boundary of utilization distributions with < 90% volume and were used to differentiate location densities from areas with deep bathymetry.

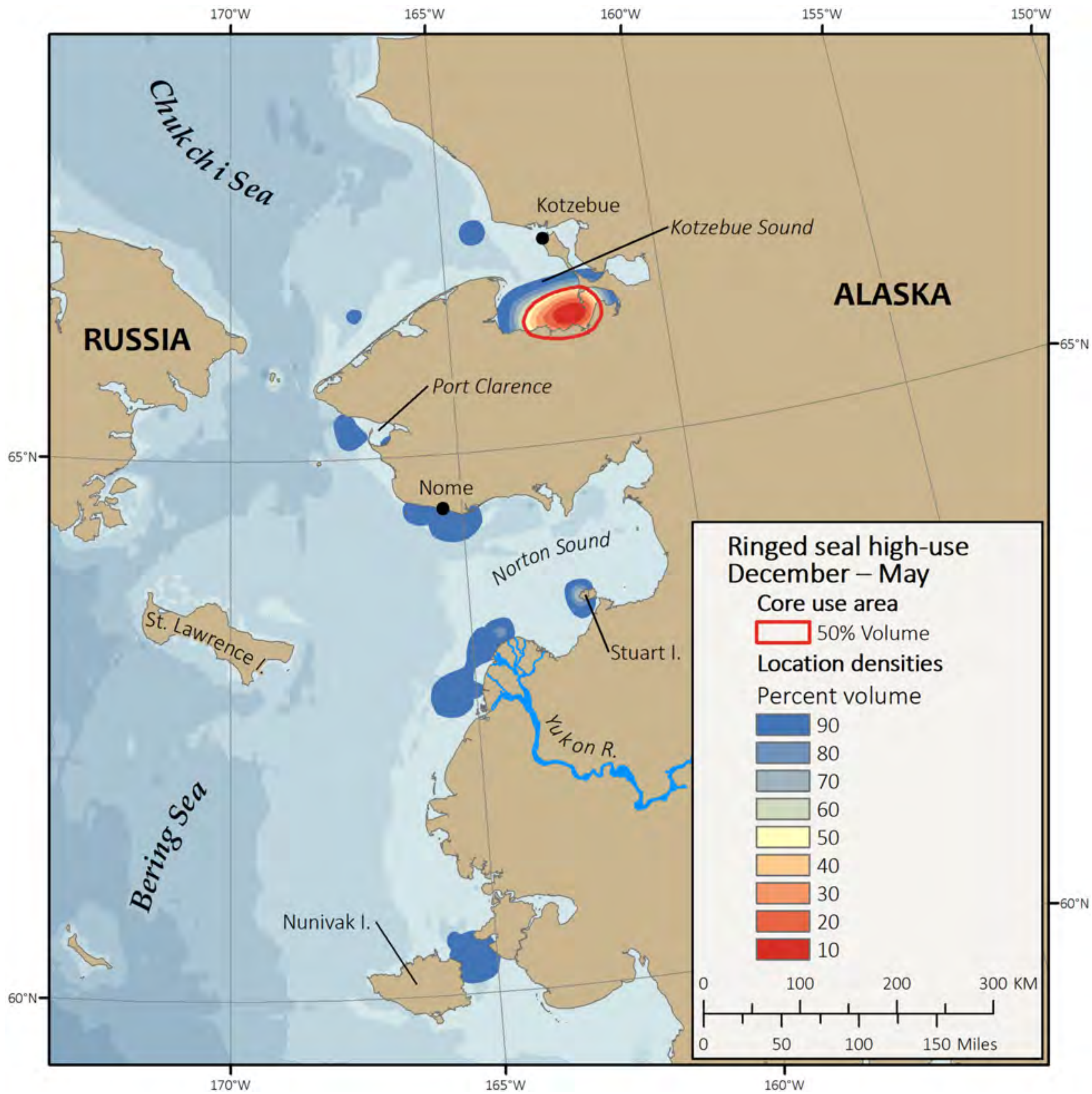


Figure 31. Distribution of ringed seals (n = 13) during December–May of 2014–2019. Seals were tagged near Utqiaġvik (n = 5), Kotzebue Sound (n = 6), St. Michael (n = 1), and Hooper Bay (n = 1). Core-use areas (red circle) represent areas with utilization distributions < 50% volume (i.e., areas with the highest density of locations) within the season and delineate primary foraging areas.

Spotted seals. We identified primary foraging and resting areas as core-use areas with utilization distributions < 50% volume (i.e., areas with the highest density of locations) within the open-water (May–November) and ice-covered (December–April) seasons. We used locations > 5 km from land to identify core-use areas important for foraging and locations < 5 km to identify core-use areas important for resting nearshore. While in resting areas spotted seals hauled out on land, often hauling out multiple times between foraging trips, but they also lingered in coastal waters and occasionally foraged there.

During the open-water season, spotted seals tagged in the Beaufort Sea moved between foraging areas in the Chukchi Sea and resting areas near the Alaskan coast (Fig. 32). The primary foraging area for spotted seals tagged in the Beaufort Sea was between Herald Shoal and the nearshore waters of the northeast Chukchi Sea (< 50 m deep; Fig. 33). On average, foraging trips in the Chukchi Sea lasted 9.7 days (range: 1–27 days) and seals traveled a total distance of 583 km (range: 83–1,610 km). Between foraging trips, resting areas primarily included islands near Icy Cape, Dease Inlet, and Kotzebue Sound (Fig. 34). Nearshore resting periods, associated with foraging trips in the Chukchi Sea, were on average 2.6 days (range: 0.5–8 days) and haul-outs (time out of the water) lasted 12.2 hrs (range: 0.5–106.0 hrs). For example, from 9 to 16 October 2016, SS16-06-F stayed within 5 km from shore of the barrier islands near Icy Cape, north of Point Lay, where it hauled out on land 10 times (mean duration = 9.3 hrs; range duration: 0.5–23.5 hrs; total duration = 92.6 hrs) and occasionally foraged. From 17–23 October 2016, this seal left Icy Cape to forage in the central Chukchi Sea, east of Herald Shoal, it then returned to Kasegaluk Lagoon and Icy Cape, from 23 to 28 October 2016, where it hauled out on land nine times (mean duration = 9.8 hrs; range duration: 1.0–37.7 hrs; total duration = 88.3 hrs) and occasionally foraged (Fig. 35).

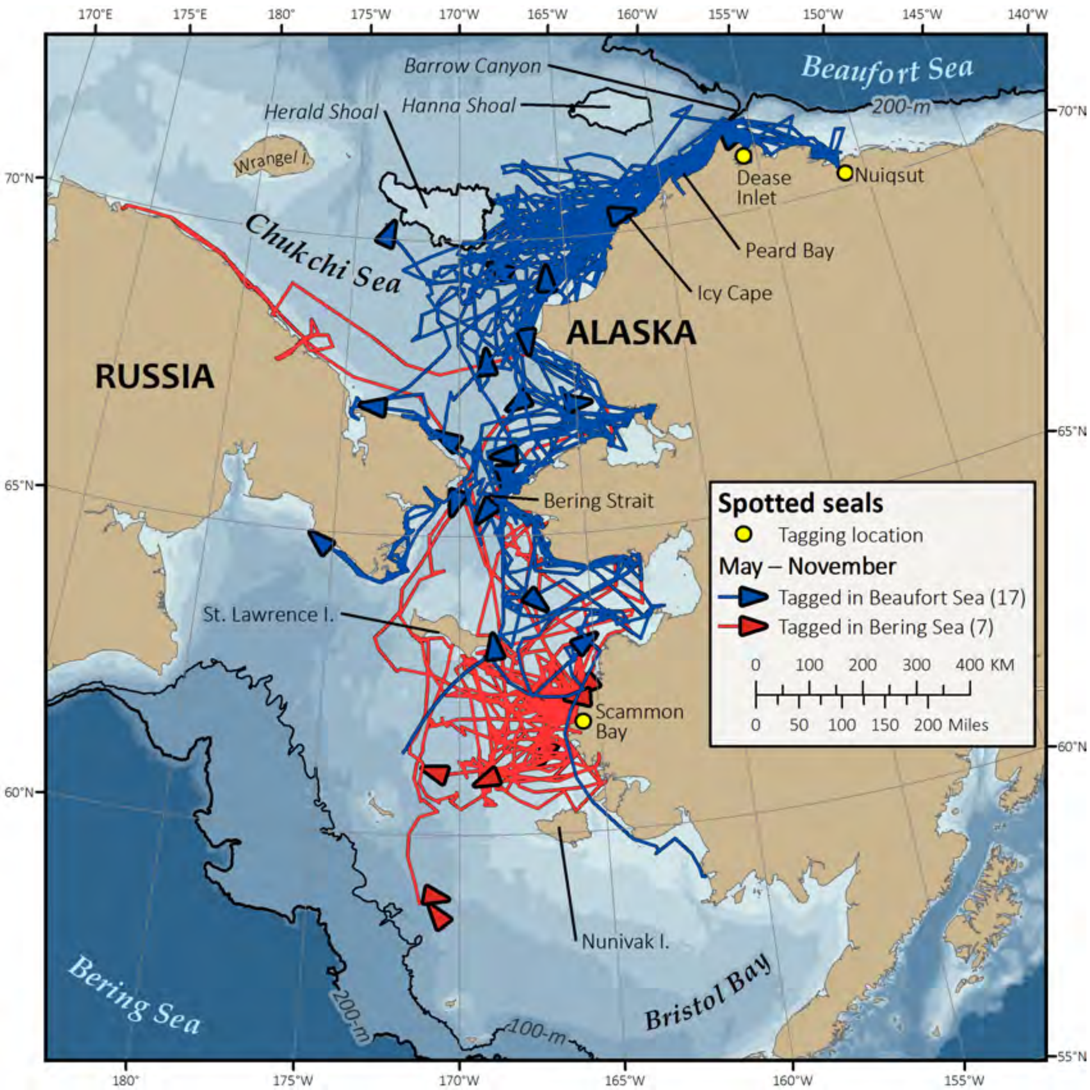


Figure 32. Movements of spotted seals in the Bering, Chukchi, and Beaufort seas during the open-water seasons (May–November) of 2016–2018. Spotted seals were tagged near Scammon Bay in the Bering Sea (n = 7; red lines) and Dease Inlet and the Colville River/Nuiqsut in the Beaufort Sea (n = 17; blue lines).

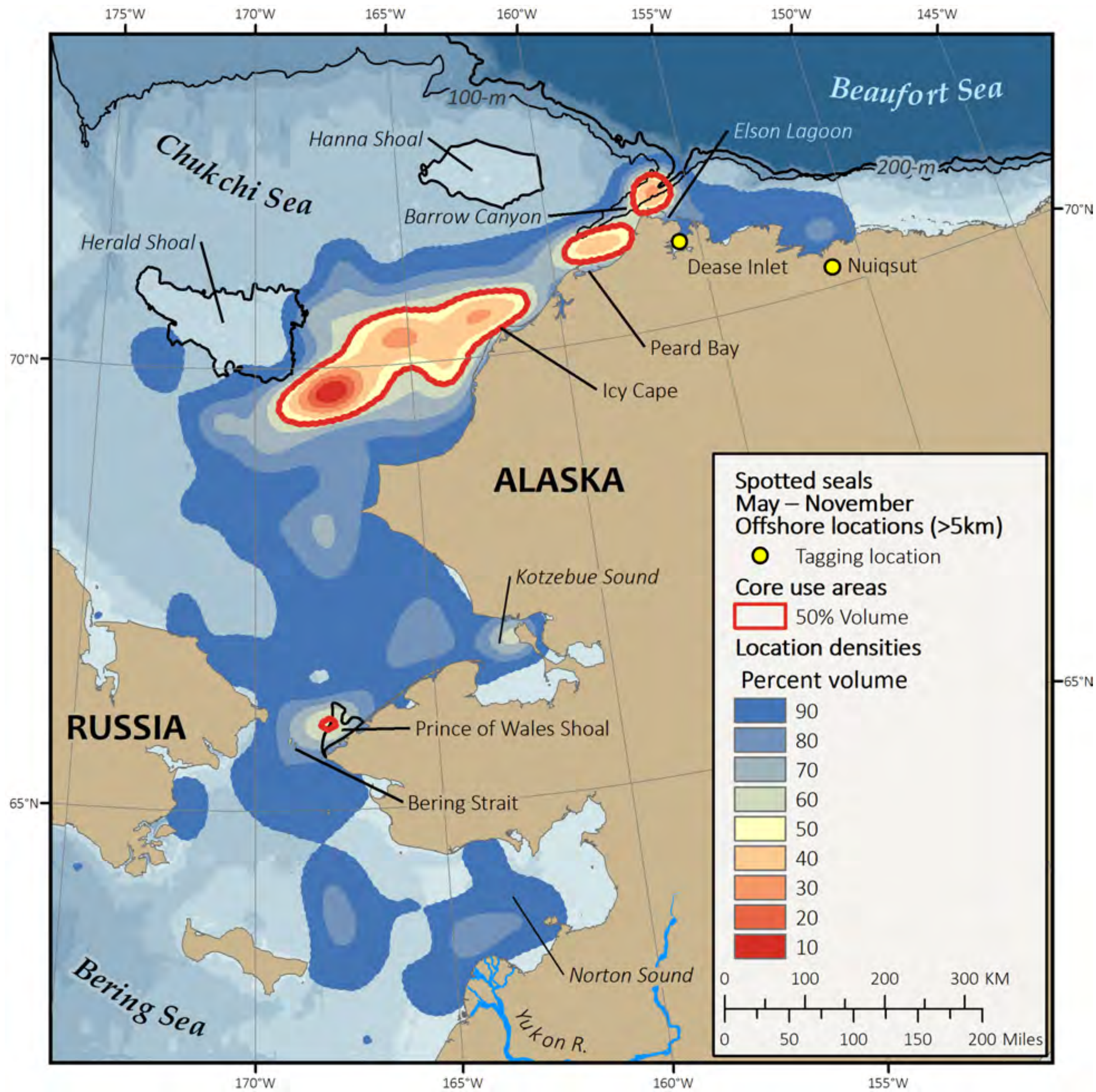


Figure 33. Offshore (>5 km) distribution of spotted seals during the open-water seasons (May–November) of 2016–2018. Seals were tagged in the Beaufort Sea (n = 17; Dease Inlet and Colville River/Nuiqsut). Core-use areas (red circles) represent areas with utilization distributions < 50% volume (i.e., areas with the highest density of locations) within the season and delineate primary foraging areas.

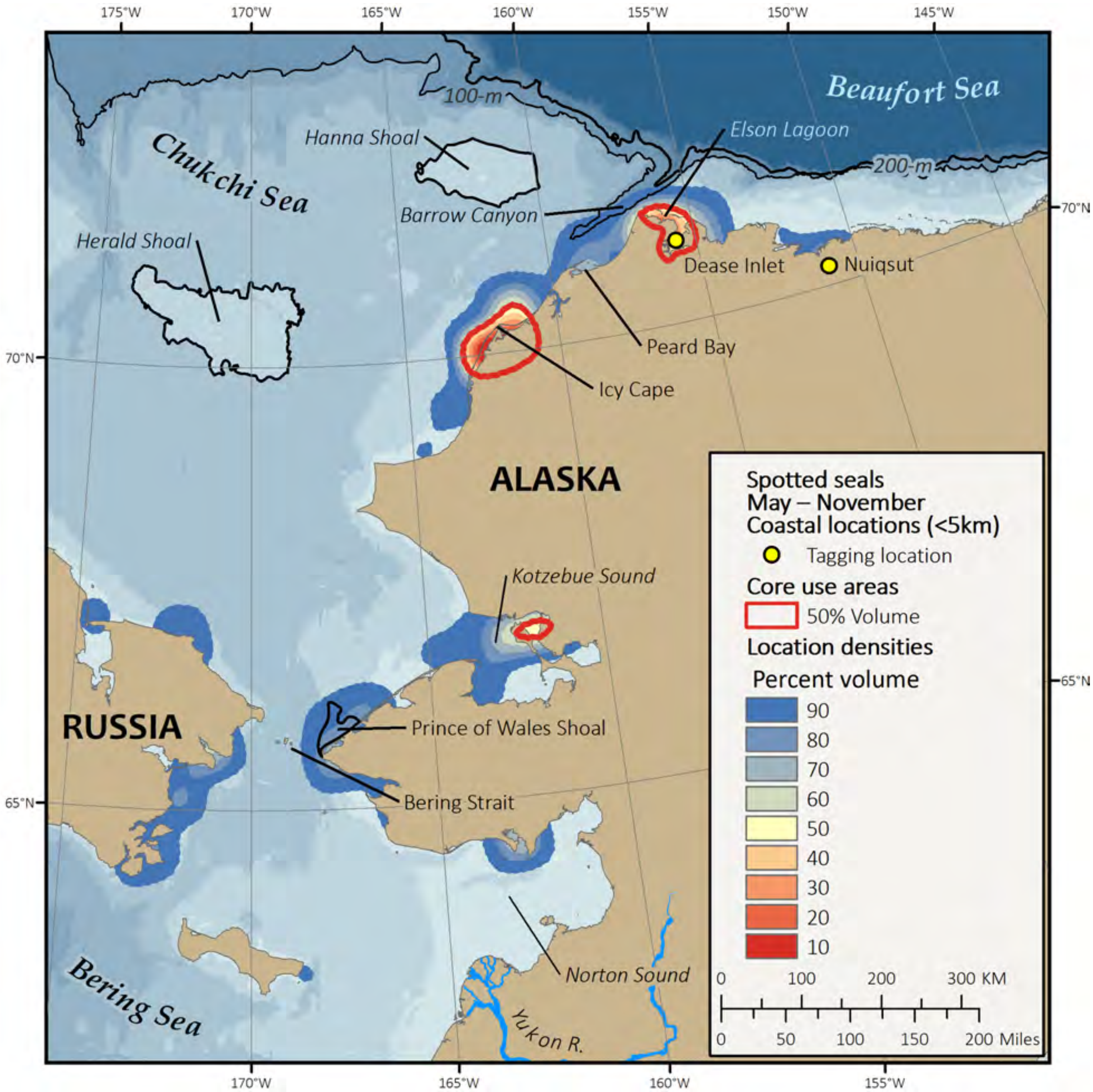


Figure 34. Nearshore (< 5 km) distribution (including terrestrial haulout locations) of spotted seals during the open-water seasons (May–November) of 2016–2018. Seals were tagged in the Beaufort Sea (n = 17; Dease Inlet and Colville River/Nuiqsut). Core-use areas (red circles) represent areas with utilization distributions < 50% volume (i.e., areas with the highest density of locations) within the season and delineate primary resting areas. Haul-out behavior data within these nearshore core-use areas further supported their identification as primary resting areas.

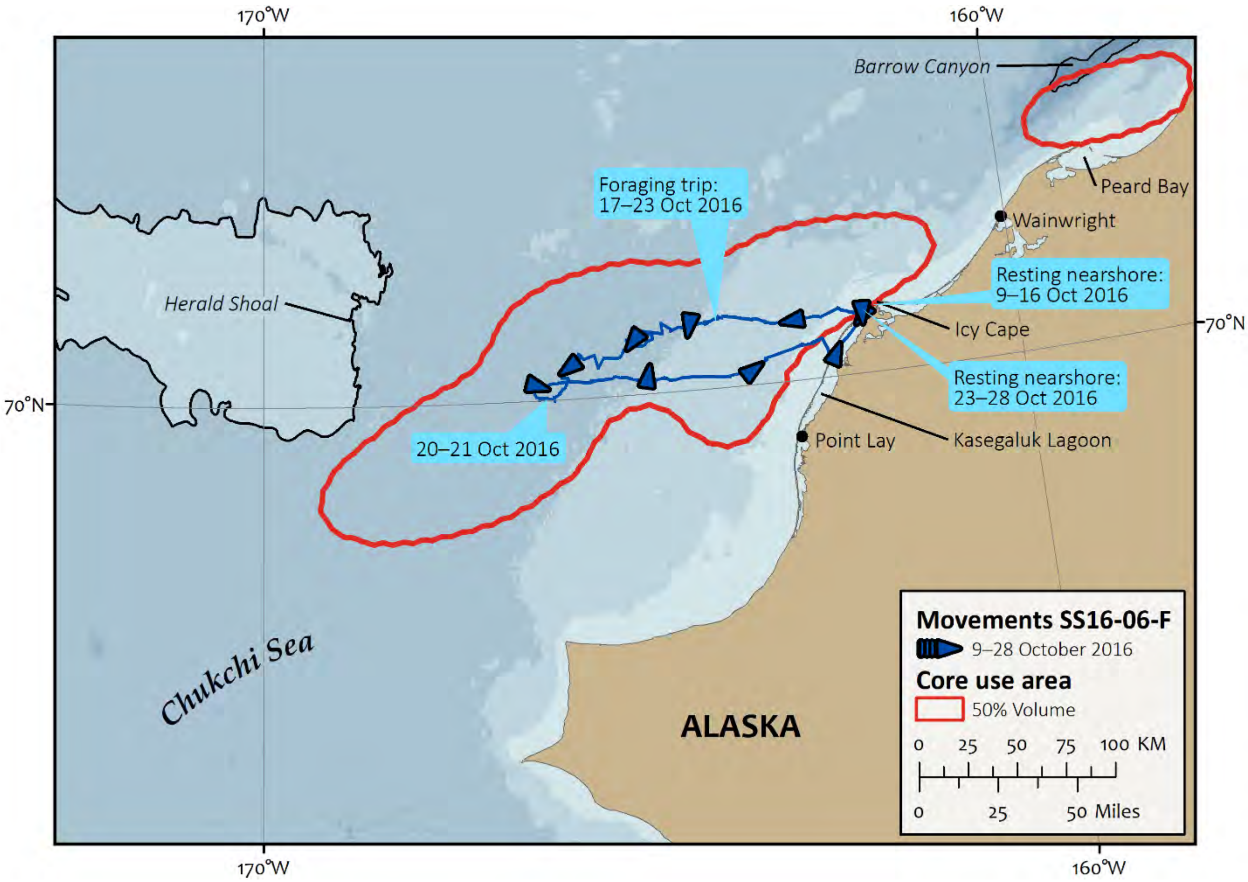


Figure 35. An example of movements and haulout behavior of one spotted seal (SS16-06-F) during October 2016. This seal was tagged in Dease Inlet on 17 August 2016. Core-use areas (red circles) represent areas with utilization distributions < 50% volume (i.e., areas with the highest density of locations) within the season and delineate primary foraging areas.

During the open-water season, spotted seals tagged in the Bering Sea moved between foraging areas in the central Bering Sea and the Alaskan coast (Fig. 32). On average, foraging trips in the Bering Sea lasted 5.9 days (range: 1–25 days) and seals traveled a total distance of 376 km (range: 86–1,293 km). Their primary foraging area was in the eastern Bering Sea, including Scammon Bay, where they were tagged (Fig. 36). Between foraging trips, resting areas primarily included islands near Scammon Bay (Fig. 37). Nearshore resting bouts, associated with foraging trips in the Bering Sea, were on average 2.8 days (range: 0.5–9 days) and individual haulouts lasted 9.6 hrs (range: 0.5–71.0 hrs).

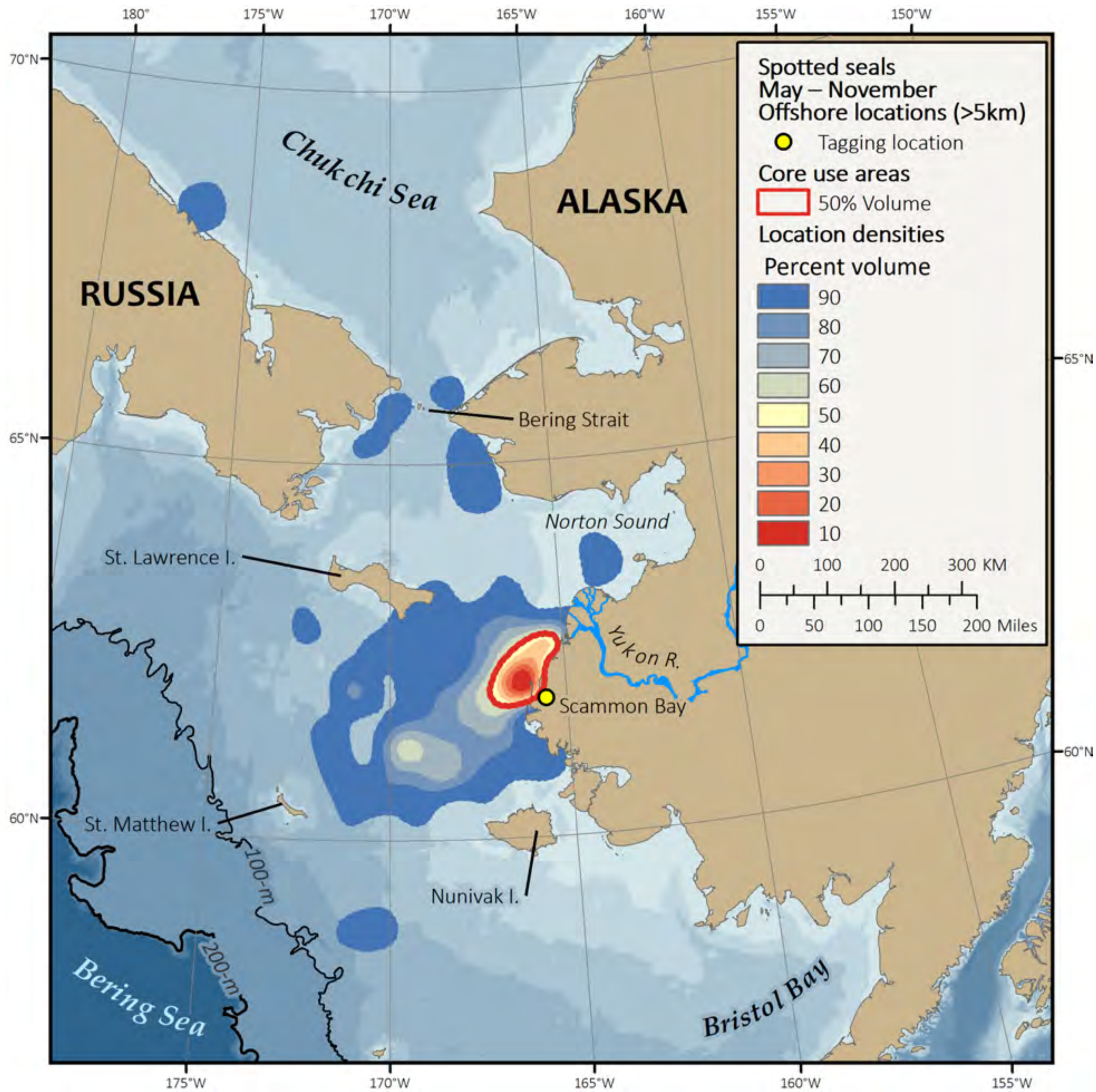


Figure 36. Offshore (> 5 km) distribution of spotted seals tagged in the Bering Sea (n = 7; Scammon Bay) during the open-water seasons (May–November) of 2016–2018. Core-use areas (red circle) represent areas with utilization distributions < 50% volume (i.e., areas with the highest density of locations) within the season and delineate primary foraging areas.

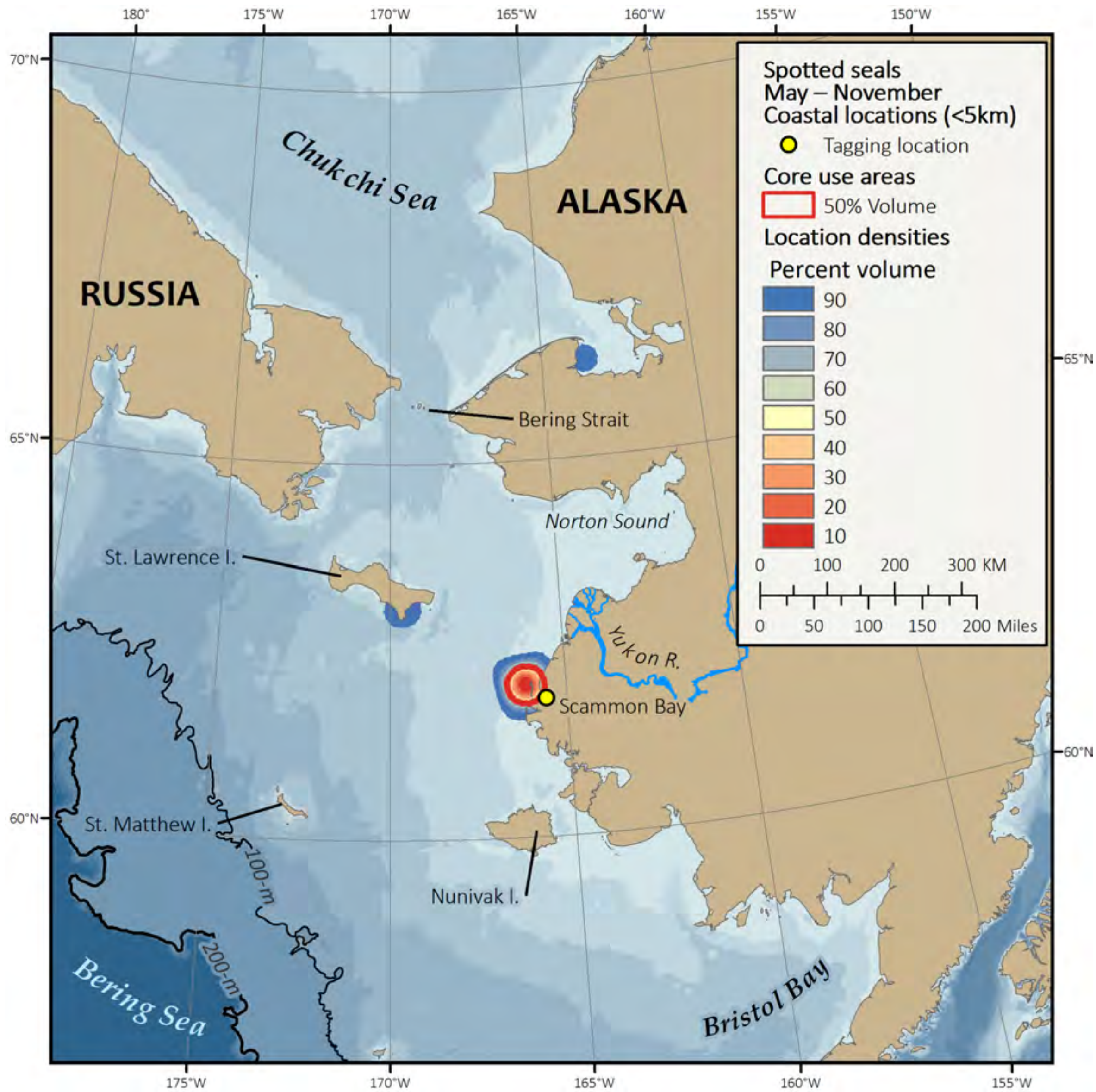


Figure 37. Nearshore (<5 km) distribution (including terrestrial haulout locations) of spotted seals tagged in the Bering Sea (n = 7; Scammon Bay) during the open-water seasons (May–November) of 2016–2018. Core-use areas (red circle) represent areas with utilization distributions < 50% volume (i.e., areas with the highest density of locations) within the season and delineate primary resting areas. Haul-out behavior data within these nearshore core-use areas further supported their identification as primary resting areas.

In December, spotted seals tagged in the Beaufort Sea moved south, ahead of the advancing pack ice (Fig. 38). By the end of December most spotted seals, regardless of tagging location, occupied pack ice, primarily in the marginal ice zone, and foraged in the central Bering Sea (Figs. 39, 40 and 41). Seals rested on sea ice between foraging bouts primarily near Nunivak Island and the Alaskan coast and Bristol Bay. Low sea ice in the Bering Sea in recent years may be limiting spotted seal use of the central Bering Sea, forcing spotted seals to restrict their movements to coastal areas where resting platforms, either shorefast ice or barrier islands, are available (Fig. 39).

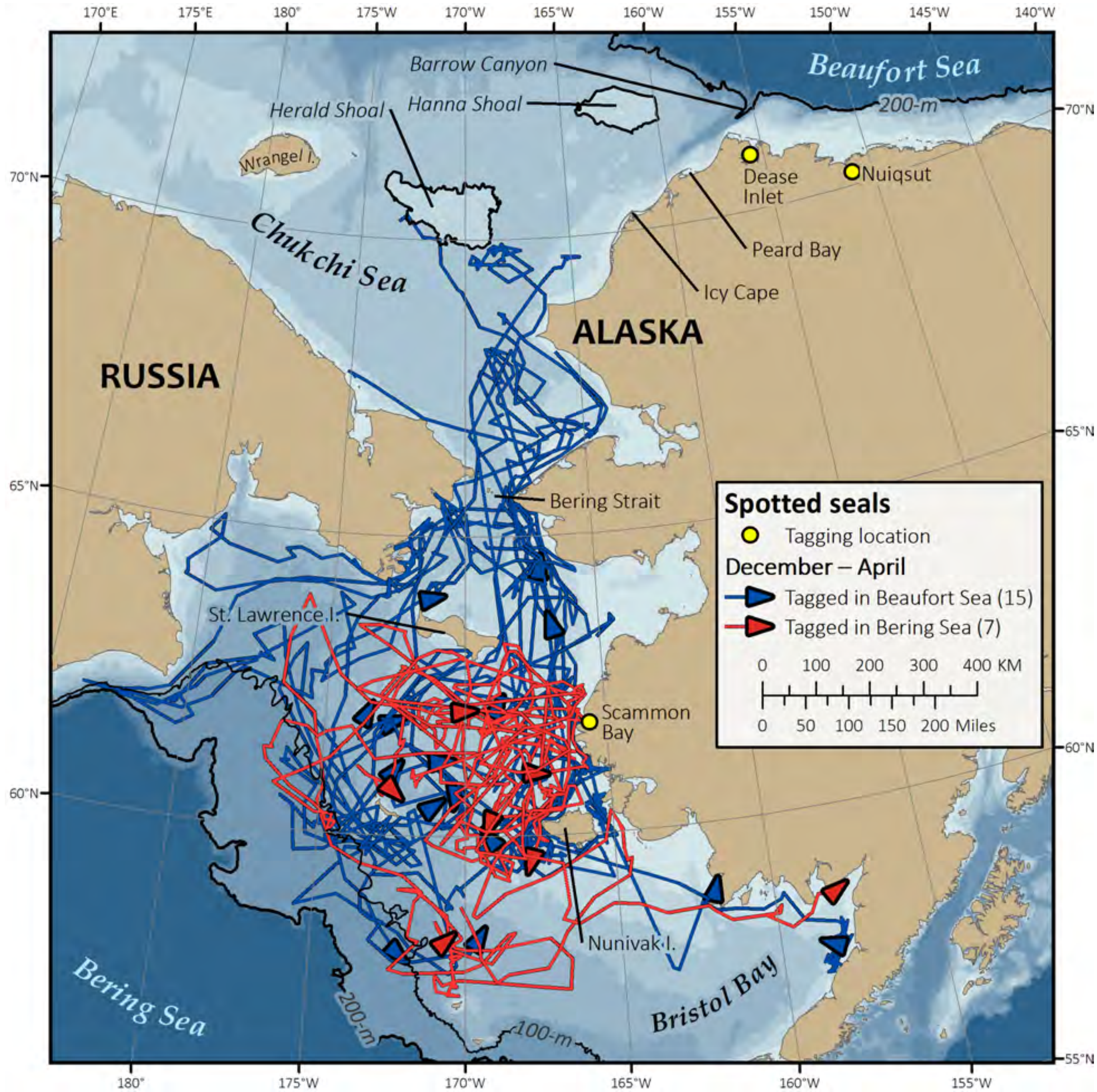


Figure 38. Movements of spotted seals in the Bering, Chukchi, and Beaufort seas during the ice-covered seasons (December–April), 2016–2018. Spotted seals were tagged near Dease Inlet and the Colville River/Nuiqsut in the Beaufort Sea (blue lines) and Scammon Bay in the Bering Sea (red lines).

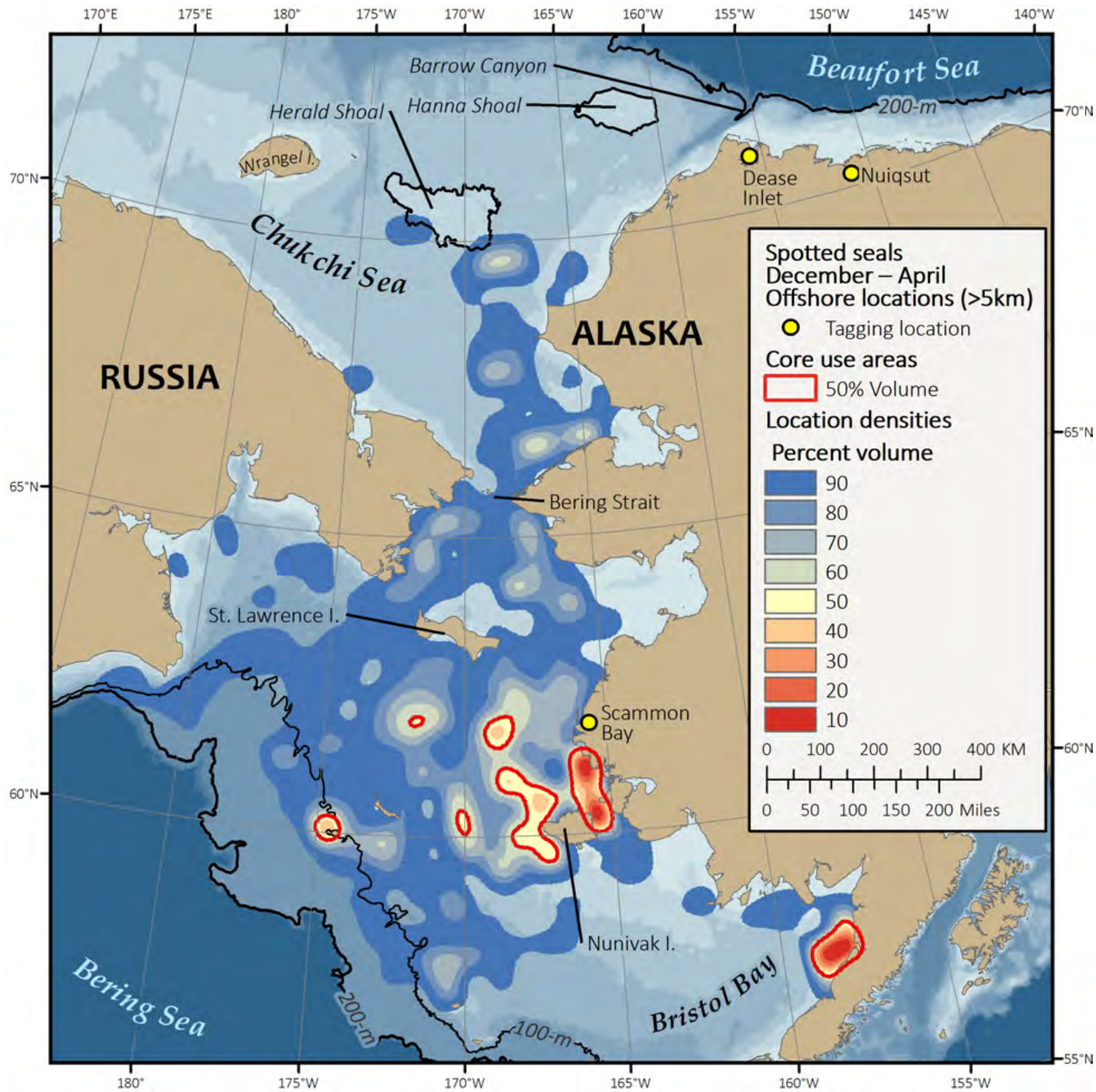


Figure 39. Offshore (> 5 km) distribution of all spotted seals during the ice-covered season (December–April) of 2016–2018. Seals were tagged in the Beaufort Sea (n = 17; Dease Inlet and Colville River/Nuiqsut) and Bering Sea (n = 7; Scammon Bay). Core-use areas (red circles) represent areas with utilization distributions < 50% volume (i.e., areas with the highest density of locations) within the season and delineate primary foraging and resting areas.

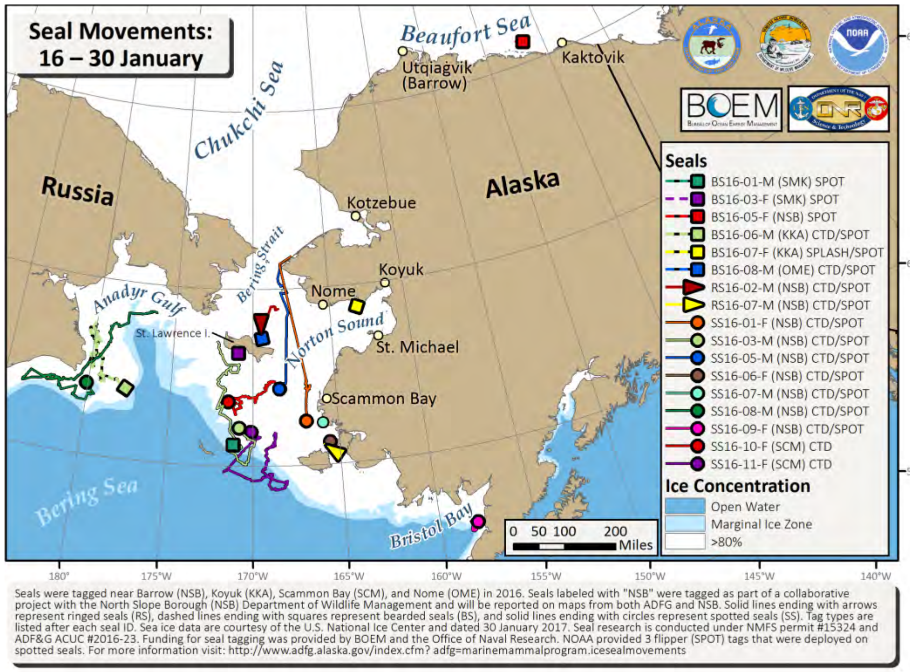


Figure 40. Movements of nine spotted seals, six bearded seals and two ringed seals in late January 2017 relative to sea ice. Seals were tagged with satellite transmitters during 2016. Sea ice data are courtesy of the U.S. National Ice Center and dated 30 January 2017.

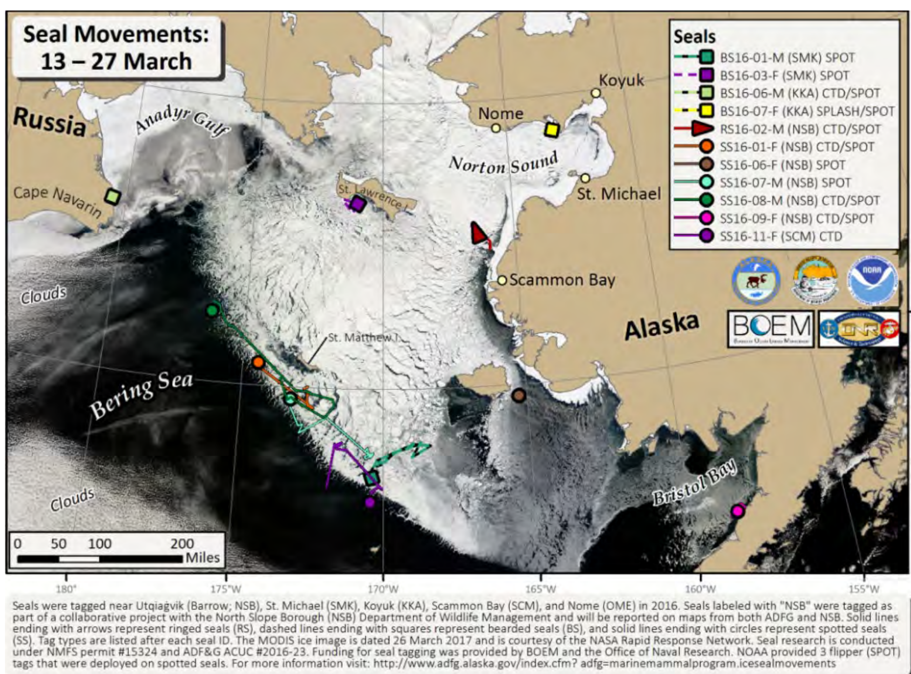


Figure 41. Movements of six spotted seals, four bearded seals, and one ringed seal in late March 2017 relative to sea ice. Seals were tagged with satellite transmitters during 2016. Sea ice data are from a 26 March 2017 MODIS ice image courtesy of the NASA Rapid Response Network.

The east-west movement patterns we observed of tagged spotted seals during the open-water period are likely associated with their use of land haulouts at fairly regular intervals between foraging trips. Indeed, during the winter months when ice is available for hauling out, spotted seals range far from shore along the ice edge into the central Bering Sea (Figs. 21, 22, and 38). In the winter, spotted seals used island haulouts at St. Lawrence, St. Matthew, and Nunivak islands in addition to a land haulout near Hooper Bay to access the central Bering Sea when little ice was present (Figs. 21 and 39).

Haul-out Behavior

Bearded Seals. During the open-water period (July–November), five young bearded seals spent 26–50 days in open water without hauling out (Fig. 42). One bearded seal spent 30 days in open-water without hauling out in the Beaufort and Chukchi seas in 2017, another spent 38 days in the Chukchi and Bering seas in 2015, and the other three stayed in the Bering Sea without hauling out for 26, 50, and 36 days, respectively in 2014, 2015, and 2016 (Fig. 42).

When bearded seals did haul out during the open-water period, they used both sea ice and land. We compared 34 haul-out bouts from six bearded seals on sea ice and 27 haul-out bouts from seven seals on land. The mean minimum haul-out duration for young bearded seals on ice (10.1 ± 1.4 hrs, mean ± standard error) was longer than when on land (5.0 ± 1.4 hrs; $P = 0.04$; Fig. 43). Bearded seals hauled out on land in Kotzebue Sound (Eschscholtz Bay and islands in the western Sound), and in Norton Sound (Norton Bay and near St. Michael). Seals hauled out on land may be disturbed more often, prematurely ending haul-out bouts.

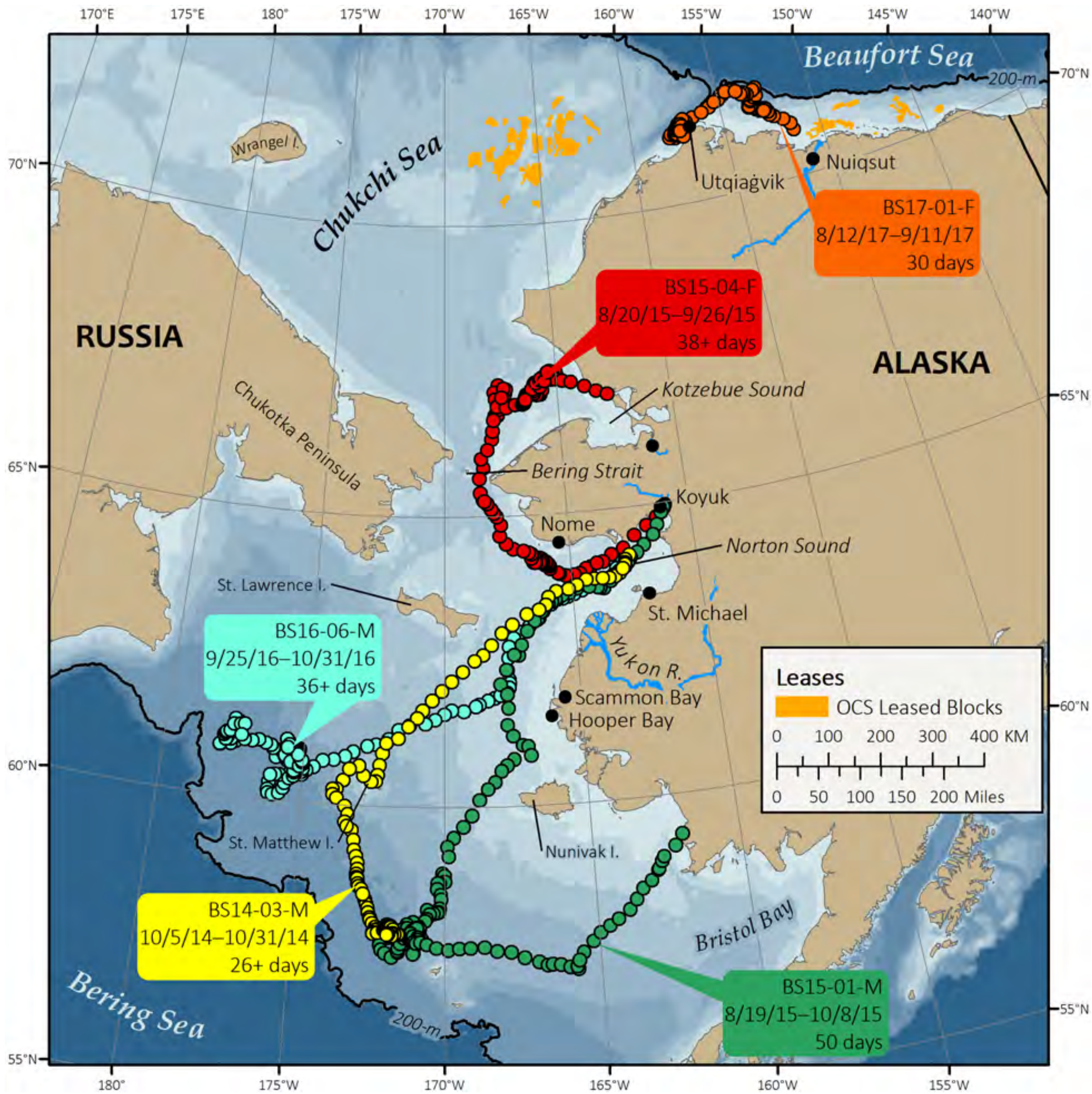


Figure 42. Tracks of five young bearded seals that remained in open water and produced no haul-out record for durations of ~1 month or longer during 2014–2018.

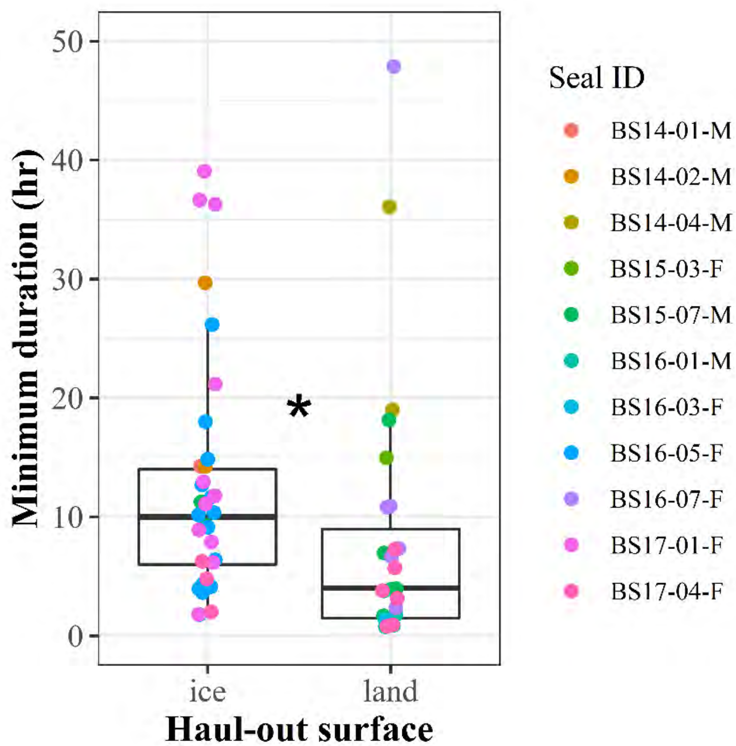


Figure 43. Boxplot of minimum haul-out durations (hrs) for juvenile bearded seals (n = 11) that hauled out on land versus on sea ice during the open-water period (July–October) during 2014–2018. Each point is the minimum duration of individual haul-out events, colored by individual seal. Asterisk denotes a significant difference between ice and land haulouts (P = 0.04).

Ringed Seal. Ringed seal haul-out behavior was seasonal and somewhat depended on the presence of ice. Eight of 11 tagged ringed seals were adults; therefore, we do not have the sample size to make comparisons between demographic classes regarding haul-out behavior. Ringed seals were more likely to haul out during the ice-covered season (daily haul-out probability = 57%) than the open-water season (48%; $P = 0.0162$) and haulout periods averaged 5 hrs. (Table 4). We identified four occasions when ringed seals hauled out on land, once near Icy Cape in July, once on the north shore of Russia in October, and twice on the north shore of the Seward Peninsula in November during their southward migration (Fig. 44). Two of these seals were males and two were females; the one that hauled out in Russia was a pup and the other three were adults at least 6 years old (Table 2).

Table 4. Haul-out duration and probability relative to seal species, season, and age class. The ice-covered season is December–April and the open-water season is May–November.

Species	Season	Age class (*n*)	Mean duration (hours)	Max duration (hours)	Daily haulout probability (%)
Bearded	Ice-covered	Young (19)	5.9	53	57.7
	Open-water	Young (24)	7.9	143	47.9
Ringed	Ice-covered	All ages (9)	4.8	23	56.9
	Open-water	All ages (11)	5.0	51	48.1
Spotted	Ice-covered	Non-pup (13)	9.2	54	41.3
	Ice-covered	Pup (9)	8.0	52	25.3
	Open-water	Non-pup (14)	8.3	146	43.9
	Open-water	Pup (10)	7.2	115	32.4

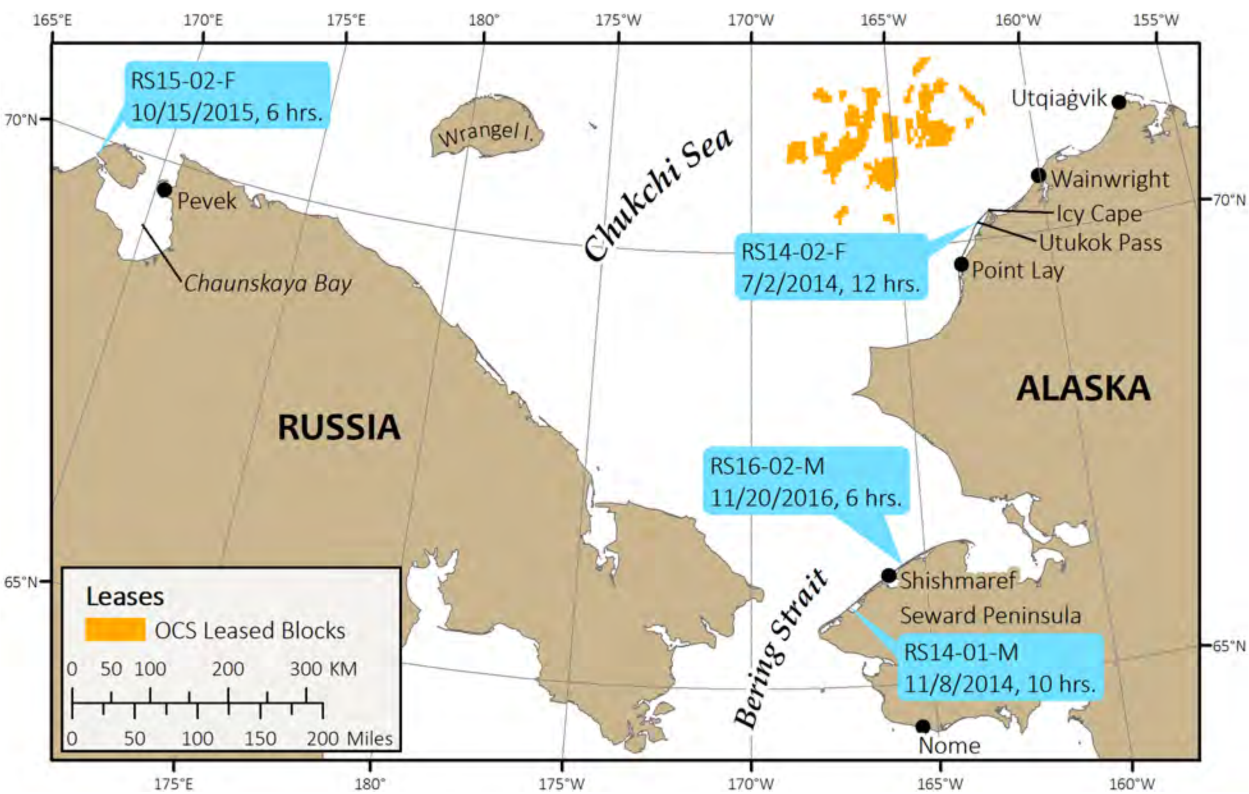


Figure 44. Locations where four ringed seals hauled out on land during 2014–2016. Seal ID and date and duration of haulout are listed in labels.

Spotted Seal. Spotted seals regularly hauled out on land and ice regardless of demographic class and our data identified four highly used land haulouts (Dease Inlet, Icy Cape, Kotzebue Sound, and Scammon Bay; Figs. 35 and 37) and at least 19 other sites. The seasonal pattern of haul-out durations among land sites was mostly similar between age classes; however, haul-out duration differed by age class. During the open-water season, spotted seals generally spent 1–21 days foraging before spending 1–6 days hauled out on land. Non-pup spotted seals were more likely to haul out (44%) than pups (32%) during the open-water season and during the ice-covered season (non-pups = 41%; pups = 25%; Table 4). Non-pups also hauled out longer than pups during the open-water (mean haul-out duration: non-pups =8.3 hrs, maximum = 146 hrs; pups = 7.2 hrs, maximum = 115 hrs) and during the ice-covered season (non-pups = 9.2 hrs, maximum = 54 hrs; pups = 8.0 hrs, maximum = 52 hrs). Although we have not formally analyzed the haul-out data for duration relative to other factors (e.g., weather, disturbance), it appears that spotted seals regularly travel to and from land haulouts between offshore feeding bouts, when ice is not available.

Use of Sea Ice

Bearded Seals. In general, the concentration of sea ice bearded seals used and their distance to the ice edge (15% ice concentration) differed by month ($P < 0.0001$), however their use of sea ice was highly variable. Despite variability in the timing and extent of sea ice during this study, the ice concentrations and distances to the ice edge used by bearded seals did not differ by year ($P > 0.19$). Bearded seals tended to use areas with the highest ice concentrations (> 50% mean ice concentration) from January through May (Fig. 45). Bearded seals tended to use pack ice (≥ 15% ice concentration) from December through the end of June and open water from July through November (Fig. 46).

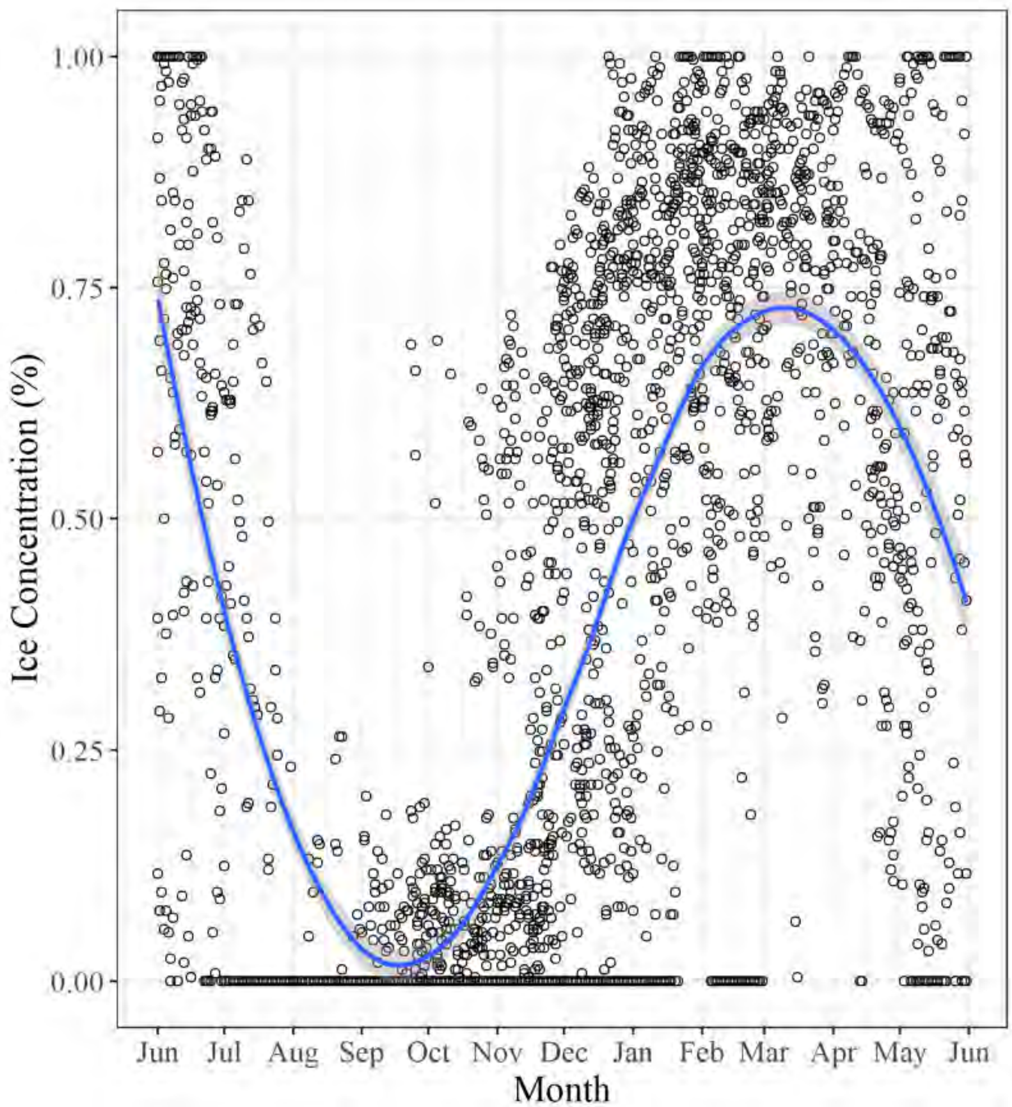


Figure 45. Sea ice concentration for daily estimated locations of 26 bearded seals by month during 2014–2019. Blue line and gray shaded region represent the smoothed conditional mean and SE of sea ice concentration for seal locations.

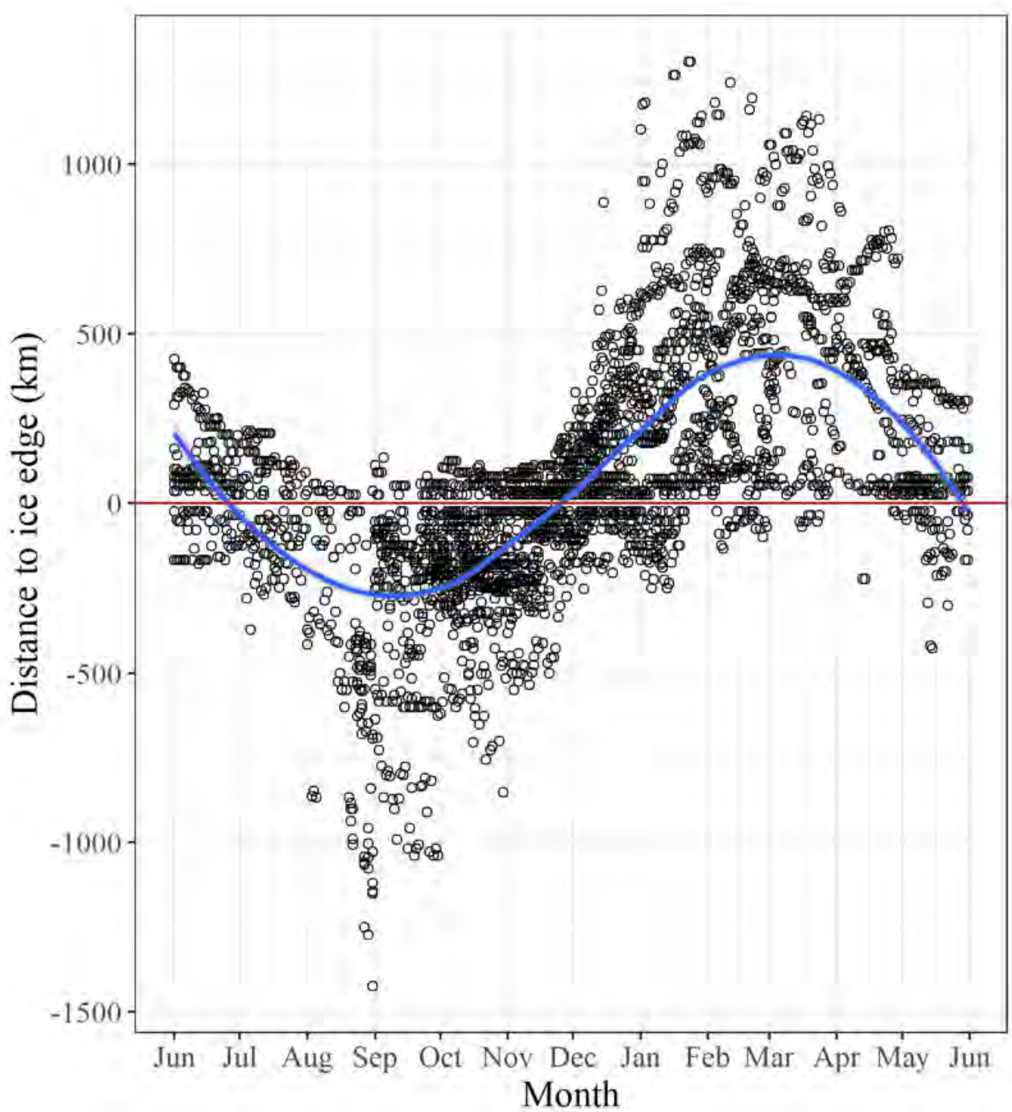


Figure 46. Mean distance (km) to the ice edge (15% ice concentration) from daily estimated locations of 26 bearded seals by month during 2014–2019. Red line represents the ice edge. Positive values represent a location that is within the ice edge (areas ≥ 15% ice concentration, i.e., pack ice). A negative value represents a location that is outside of the ice edge (areas < 15% ice concentration). Blue line and gray shaded region represent the smoothed conditional mean and SE of distance to the ice edge for seal locations.

We further examined sea ice habitat use by bearded seals during the open-water period, when sea ice is at its minimal extent, from July to October. A total of 3,119 6-hr location estimates were available for July to October 2014–2018 using the 'crawl' model in R. During this period, 72% (n = 2,255) of locations were in open water, 20% (642) were in 0 – 15% ice concentration, and 7% (222) were in pack ice. This pattern was consistent across all years, except for 2018 when less data were available from fewer tagged seals.

Ringed seals. In general, the concentration of sea ice ringed seals used and their distance to the ice edge (15% ice concentration) differed by month ($P < 0.0001$), however their use of sea ice was highly variable. Despite variability in the timing and extent of sea ice during this project period, ice concentrations and distances to the ice edge used by ringed seals did not differ by year ($P > 0.10$). Ringed seals tended to use areas with the highest concentrations (> 50% mean ice concentration) from January through June (Fig. 47). Similar to bearded seals, ringed seals tended to use pack ice (≥ 15% ice concentration) from December through the end of June and use areas of open water from July through November (Fig. 48).

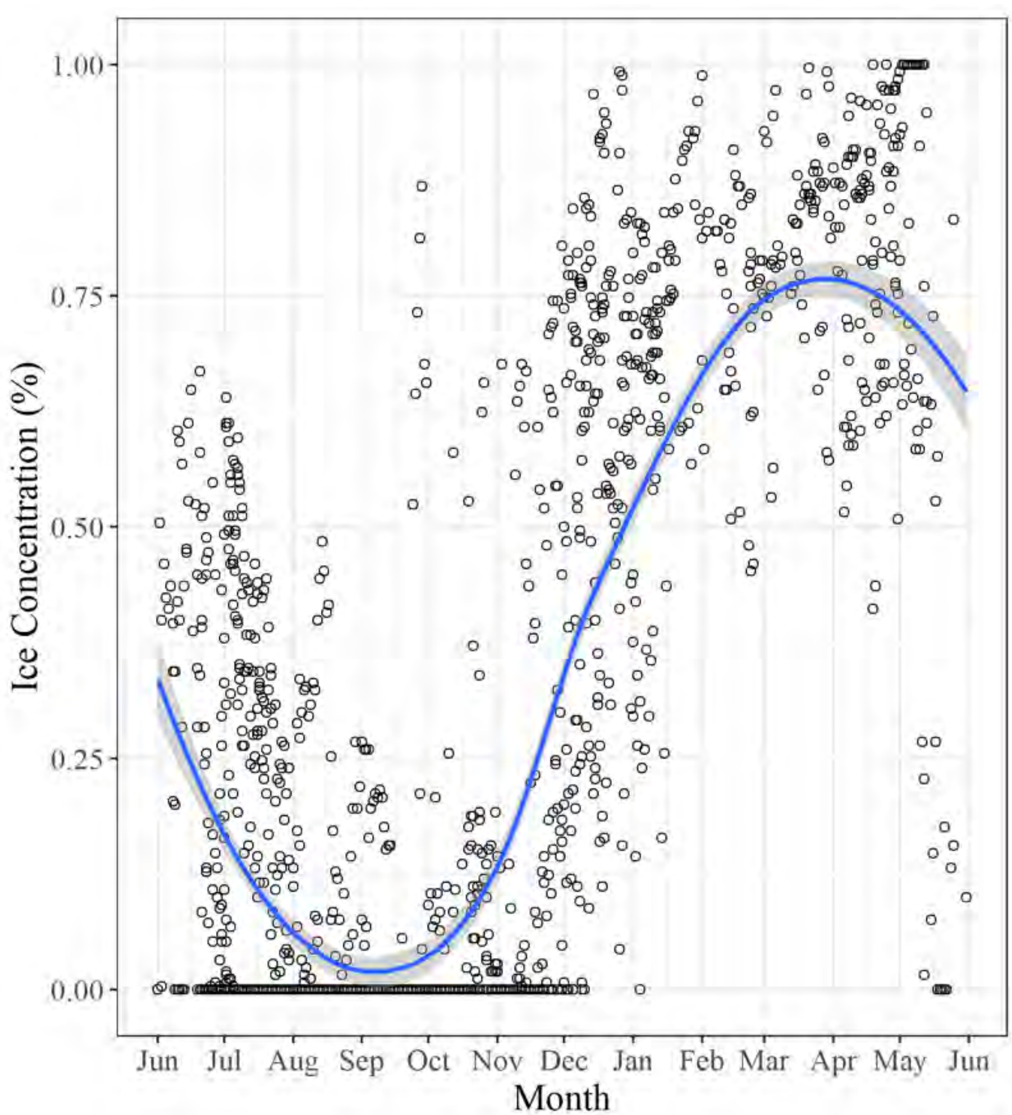


Figure 47. Sea ice concentration for daily estimated locations of 16 ringed seals by month during 2014–2019. Blue line and gray shaded region represent the smoothed conditional mean and SE of sea ice concentration for seal locations.

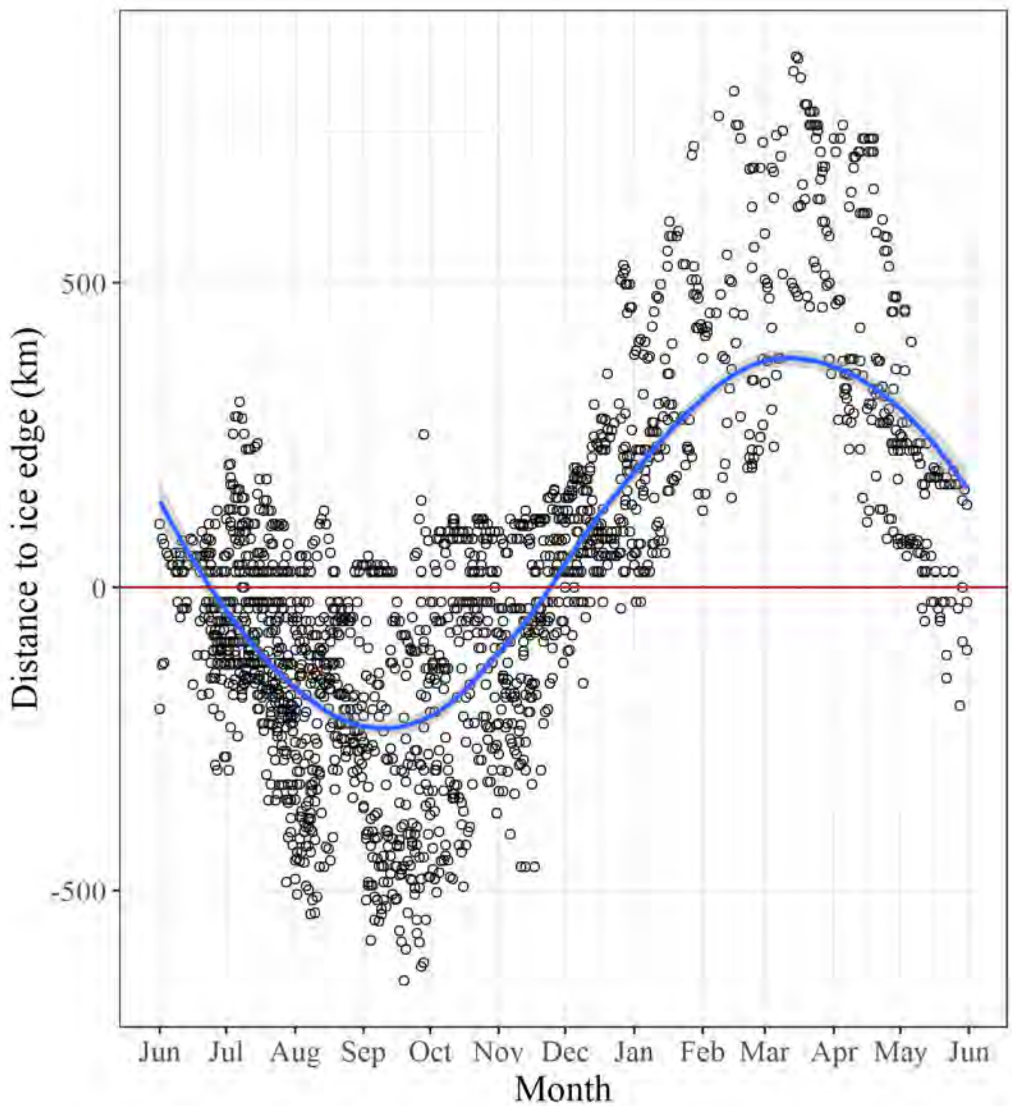


Figure 48. Mean distance (km) to the ice edge (15% ice concentration) from daily estimated locations of 16 ringed seals by month during 2014–2019. Red line represents the ice edge. Positive values represent a location that is within the ice edge (areas ≥ 15% ice concentration i.e., pack ice). A negative value represents a location that is outside of the ice edge (areas < 15% ice concentration). Blue line and gray shaded region represent the smoothed conditional mean and SE of distance to the ice edge for seal locations.

Spotted seals. In general, the concentration of sea ice spotted seals used and their distance to the ice edge (15% ice concentration) differed by month and year ($P < 0.0001$), however their use of sea ice was highly variable. All spotted seals tended to use areas with higher ice concentrations from January through March (Fig. 49). During the ice-covered seasons of 2016/17 (seals tagged in 2016) and 2018/19 (seals tagged in 2018), spotted seals used areas with higher ice concentrations then during the 2017/18 ice-covered season (seals tagged in 2017) (Fig. 49). During the ice-covered season of 2017/18, seals (tagged in 2017) rarely used pack ice (≥ 15% ice concentration; Fig. 49). However, unlike bearded and ringed seals, spotted seals tended to use pack ice for a shorter duration, from December through March, and used areas of open water the rest of the year (Fig. 50). Seals tagged in 2016 and 2018 used areas outside of the ice edge (i.e., in open water) from April through November, whereas seals tagged in 2017 used areas outside of the ice edge throughout the year.

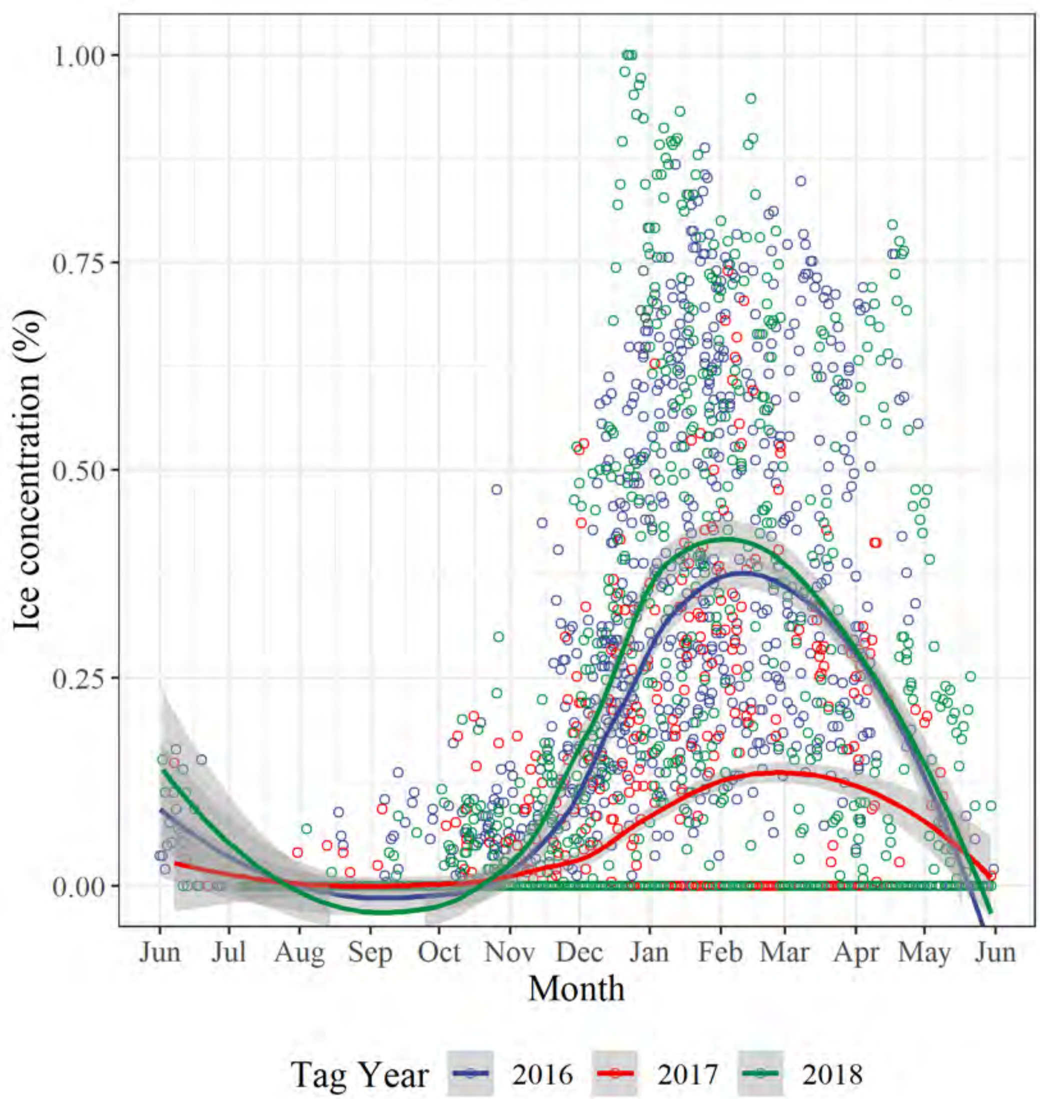


Figure 49. Sea ice concentration for daily estimated locations of 25 spotted seals by month during 2016–2019. Lines and gray shaded regions represent the smoothed conditional mean and SE of sea ice concentration for locations of seals tagged in 2016, 2017, and 2018.

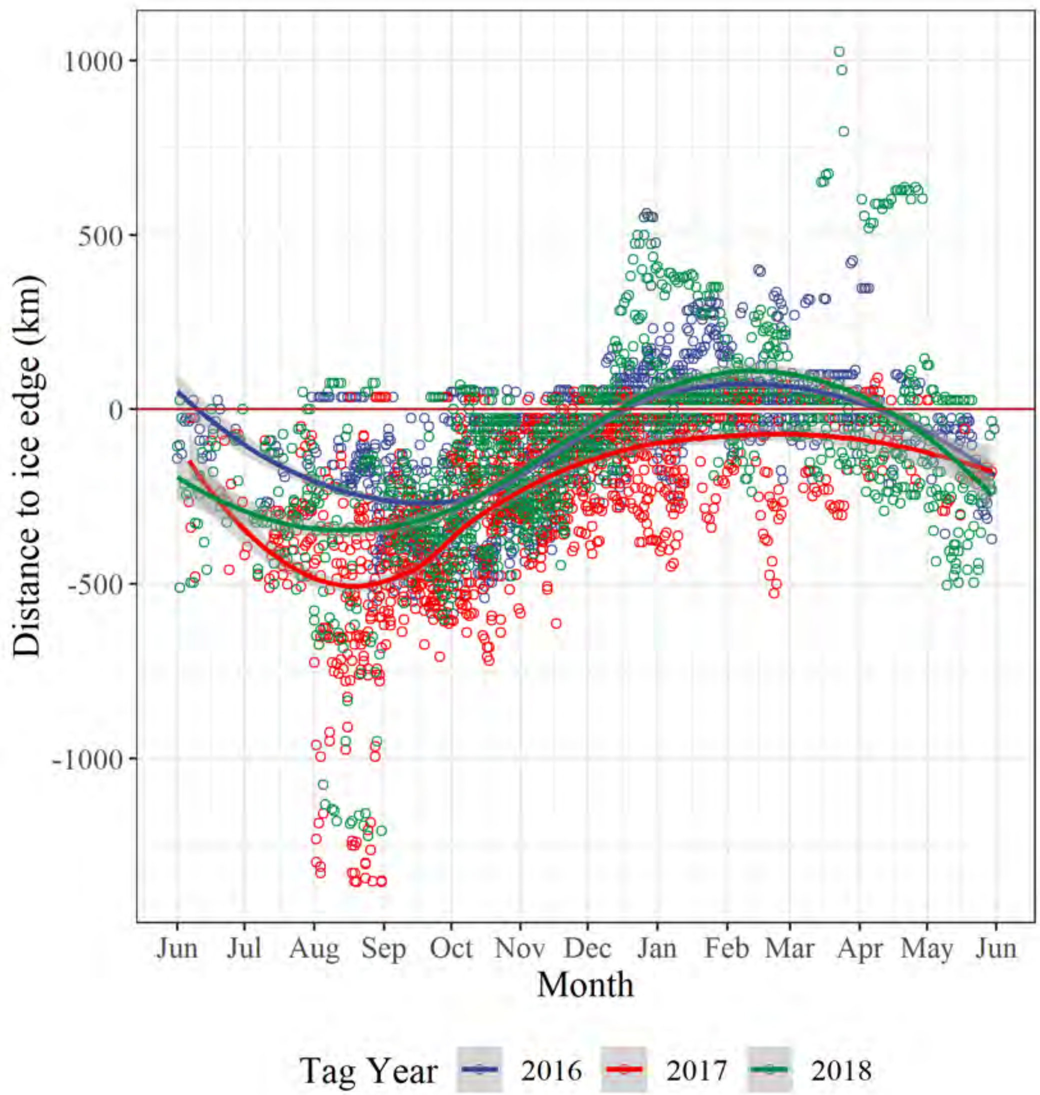


Figure 50. Mean distance (km) to the ice edge (15% ice concentration) from daily estimated locations of 25 spotted seals by month during 2016–2019. Red line represents the ice edge. Positive values represent a location that is within the ice edge (areas ≥ 15% ice concentration i.e., pack ice). A negative value represents a location that is outside of the ice edge (areas < 15% ice concentration). Lines and gray shaded regions represent the smoothed conditional mean and SE of distance to the ice edge for locations of seals tagged in 2016, 2017, and 2018.

Use of Oil and Gas Areas

Chukchi Sea. From 2015 to 2019, 32 of 67 (48%) tagged seals entered Chukchi Sea Lease Sale 193 area. On average, tagged seals were located within the 193 area for 5 days (range = 1–37 days; Table 5). One bearded seal, BS18-01-F wintered in the northern Chukchi Sea and used waters in the 193 area from 25 February to 12 April. Other bearded seals were located within the 193 area between 30 May and 31 December (Table 5; Fig. 51). The timing of entering the 193 area differed by species; bearded seals generally entered earliest, from 30 May to 19 September, and at most had two seals in the 193 area at the same time. Ringed seals used the 193 area later from 11 June to 19 October, and at most, five seals were in the 193 area at once in early July.

Spotted seals entered latest from 2 August to 31 December, and at most, nine seals were in the 193 area at one time in mid-September (Fig. 51). While in the 193 area, bearded and ringed seals ranged widely but were primarily located in the northeastern portion (in and near the Hanna Shoal Walrus Use Area) while spotted seals primarily used the southern portion, south of 71.2°N (Fig. 52).

Residence patterns within the leased blocks within the Lease Sale 193 area were similar to those within the larger 193 area (Fig. 51), except that the leased blocks represent a small area, thus fewer seals were located within the block boundaries and those that were in the leased blocks were there for a shorter period of time.

Beaufort Sea. Although relatively few tagged seals moved east of Dease Inlet, a few seals did enter, or move near, lease blocks in the Beaufort Sea. Two bearded seals entered lease blocks in the Beaufort Sea (Figs. 7, 9, and 10). Bearded seal BS16-05-F used areas near lease blocks in the Beaufort Sea from 1 January to 16 July and BS17-01-F, tagged on the Colville River, passed through the western most blocks on 11 August when it left the river after being tagged and moved into the western Beaufort Sea. Two ringed seals entered lease blocks in the Beaufort Sea (Fig. 13). Ringed seal RS14-02-F moved east across the Beaufort Sea Shelf and spent the late summer near the mouth of the Mackenzie River in the Canadian Beaufort Sea. This ringed seal entered the lease blocks in the Beaufort Sea during 24–30 July while traveling east and during 10–12 September while traveling west back to the western Beaufort Sea. During a similar movement pattern to the Alaska-Canada border, RS16-02-M entered the lease blocks of the Beaufort Sea from 15 to 30 July during its eastern migration and from 4 to 8 August during its western migration back to the western Beaufort Sea. Two other ringed seals (RS19-05-M and RS17-02-M) approached the western most edge of the blocks on 14 and 26 July, respectively, but did not enter the lease blocks. Spotted seals did not move east of the mouth of the Colville River, even though five seals were tagged near there (Fig. 19). Spotted seals SS17-06-F and SS17-08-F, both tagged in the Colville River Delta, briefly passed through the southwest portion of the western most lease block when they moved to the western Beaufort Sea.

Table 5. Summary of tagged bearded, ringed, and spotted seals entering the Chukchi Sea Lease Sale 193 area during 2014–2019.

	Bearded (*n* = 8)	**Ringed (*n* = 10)**	**Spotted (*n* = 14)**	**All seals (*n* = 32)**
Earliest date in Area	25 Feb	11 Jun	2 Aug	25 Feb
Average entry date in Area	9 Jul	10 Jul	9 Sep	2 Aug
Latest date in Area	19 Sep	19 Oct	31 Dec	31 Dec
Average last date in Area	15-Aug	20-Aug	23-Oct	12-Sep
Average duration in Area (days)	3.6	5.3	5.1	4.8
Minimum duration in Area (days)	1	1	1	1
Maximum duration in Area (days)	18	37	21	37
Total trips into Area	25	40	61	126
Max seals in Area during a week	2	5	9	13
Week of maximum seals in Area	multiple, primarily mid-July	5 Jul	17 Sep	17 Sep

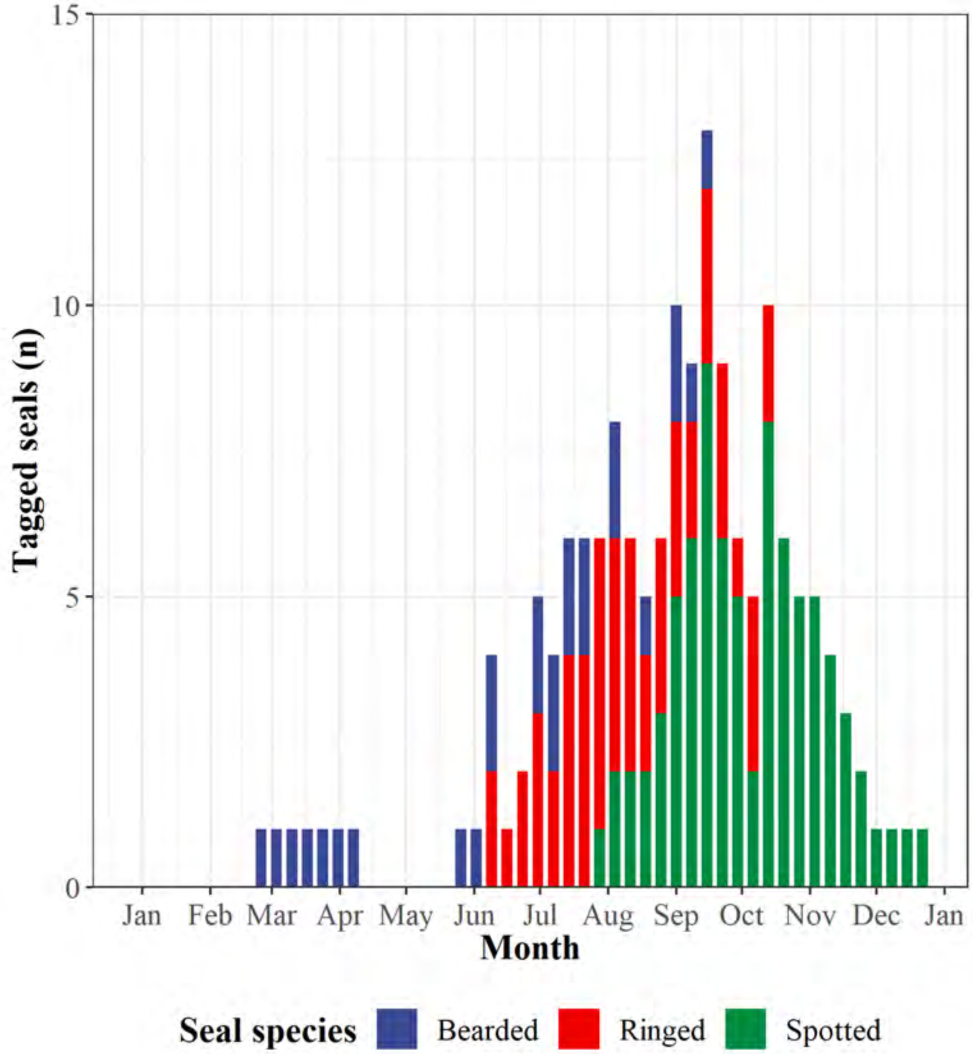


Figure 51. Number of tagged bearded, ringed, and spotted seals that were in the Lease Sale 193 area in Alaskan waters by week of the year, all years combined (2014–2019).

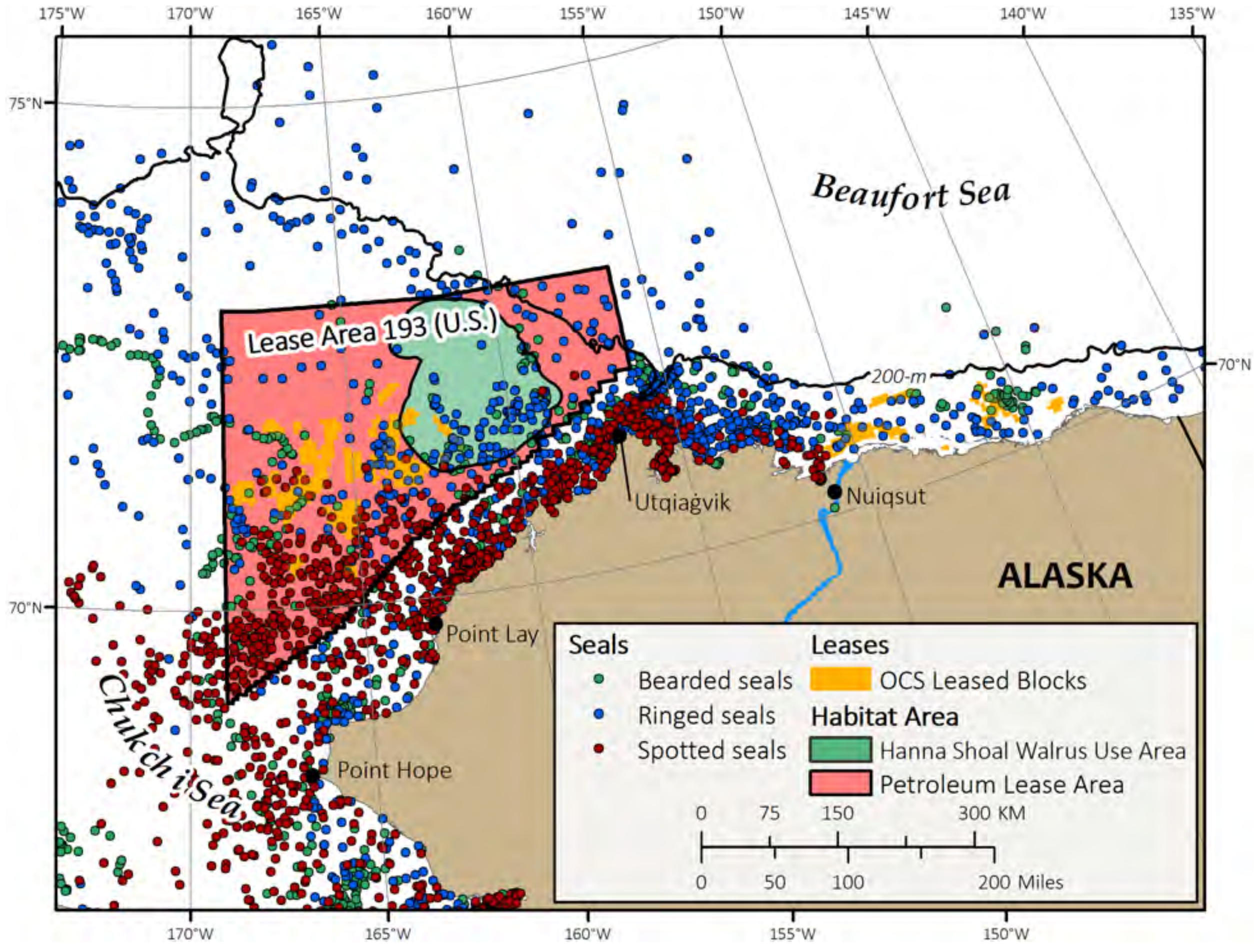


Figure 52. Locations of 57 tagged seals in all months 2014–2019 relative to OCS lease blocks in Chukchi Sea Lease Sale 193 area and in the Beaufort Sea. OCS lease blocks associated with Chukchi Sea Lease Sale 193 were active during the study period; all were relinquished by 2017.

Seismic Analyses

The activity associated with oil and gas exploration that has the greatest potential for harm in the Chukchi Sea is seismic testing due to the high noise levels associated with it. Many seismic arrays tow 36 airguns and noise levels can be as high as 210 dB depending on water depth, bottom substrate, and distance from the source. There is little information about how noise affects ice seal communication, navigation, and movements. Seals have good hearing and may be sensitive to noise. A study involving captive ringed and spotted seals showed limited sensitivity to seismic exposures, however, the authors stress that untrained, wild seals are likely to elicit a stronger response and emphasize that seismic surveys consist of continuous pulses over longer durations rather than a single pulse (Reichmuth et al. 2016).

One tagged ringed seal (RS14-02-F) may have been in the vicinity of an active seismic survey conducted between 1 June and 30 September 2014. The seismic survey was a 3D airgun array, however the dates within the time period the survey was conducted, and the location of the seismic lines are proprietary to the company that conducted it and are not available to the public. This ringed seal passed within 10 km of the seismic project location, near Prudhoe Bay, during late July while making a long-distance movement east towards Mackenzie Bay in Canadian water. Until details about seismic operations are available, we cannot acquire the information needed to overlay seal locations with the seismic operation before, during, and after the survey to analyze seal behavior.

Ship Traffic

During the shipping season, between April and December (all years combined), tagged seals were located within areas of ship traffic (< 95% traffic volume density) for 40% of days tracked, and they were in high traffic areas (< 50% traffic volume density) for 4% of those days. The proportion of seals located in traffic areas, however, differed somewhat by seal species and season.

During spring (April–June), bearded seals were in ship traffic areas more often (49% of days) than ringed and spotted seals (Fig. 53a), primarily in Norton Sound (Fig. 54), although all seals were in high traffic areas < 3% of days during spring (Fig. 53b).

During summer (July–September), all seals were in ship traffic areas more often than during spring (44% of days) and bearded seals were in these areas most often (69% of days) (Fig. 53a). Bearded seals again overlapped with traffic areas primarily in Norton Sound, while ringed and spotted seals overlapped primarily in the northeastern Chukchi Sea (Fig. 55). All seals were in high traffic areas 9% of days during summer (Fig. 53b), primarily in Norton Sound and the northeastern Chukchi Sea (Fig. 55).

During fall (October–December), all seals were in ship traffic areas for a similar percent of days (~39%; Fig. 53a) and were in traffic areas spread widely across the Bering and Chukchi seas (Fig. 56). All seals were in high traffic areas < 2% of days during fall (Fig. 53b).

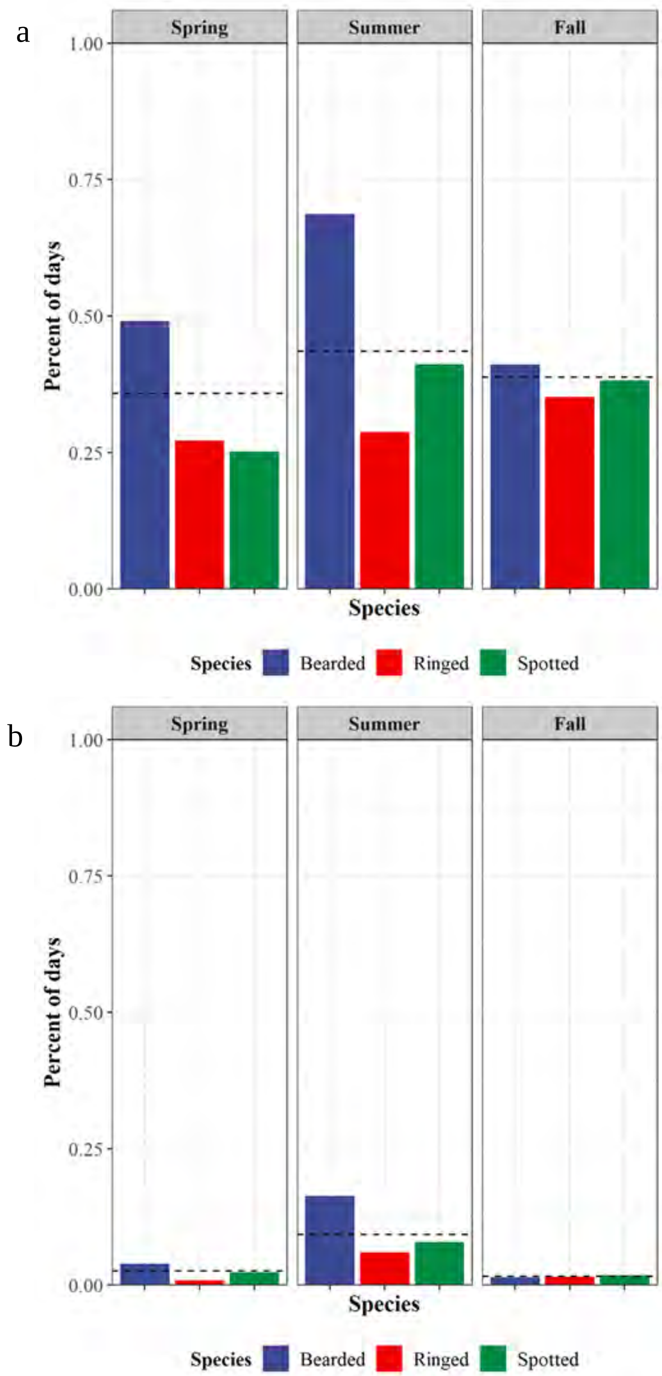


Figure 53. Percent of days tagged bearded, ringed, and spotted seals were within a) any, < 95% ship traffic volume densities and b) high, < 50% ship traffic volume densities in the Bering and Chukchi seas during the spring, summer and fall of 2014–2019. Dashed lines represent the mean percent of days all seals were within ship traffic areas during each season.

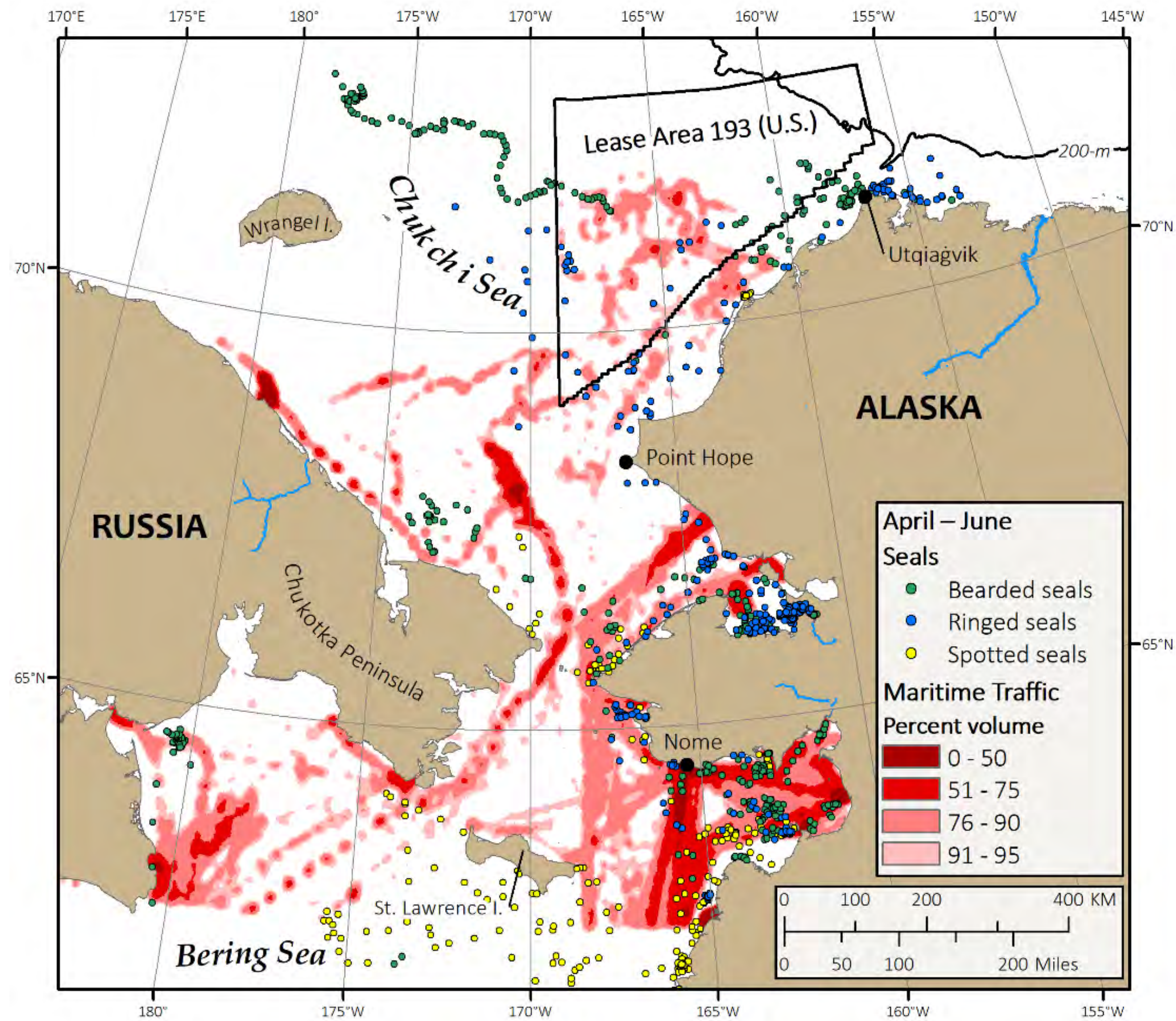


Figure 54. Locations of tagged bearded (n = 14), ringed (n = 13), and spotted seals (n = 13) and density estimates (red) for ship traffic derived from Automatic Identification System (AIS) data in the northern Bering and Chukchi seas from April to June during 2013–2015. Colored circles are daily seal locations estimated using the CRW model.

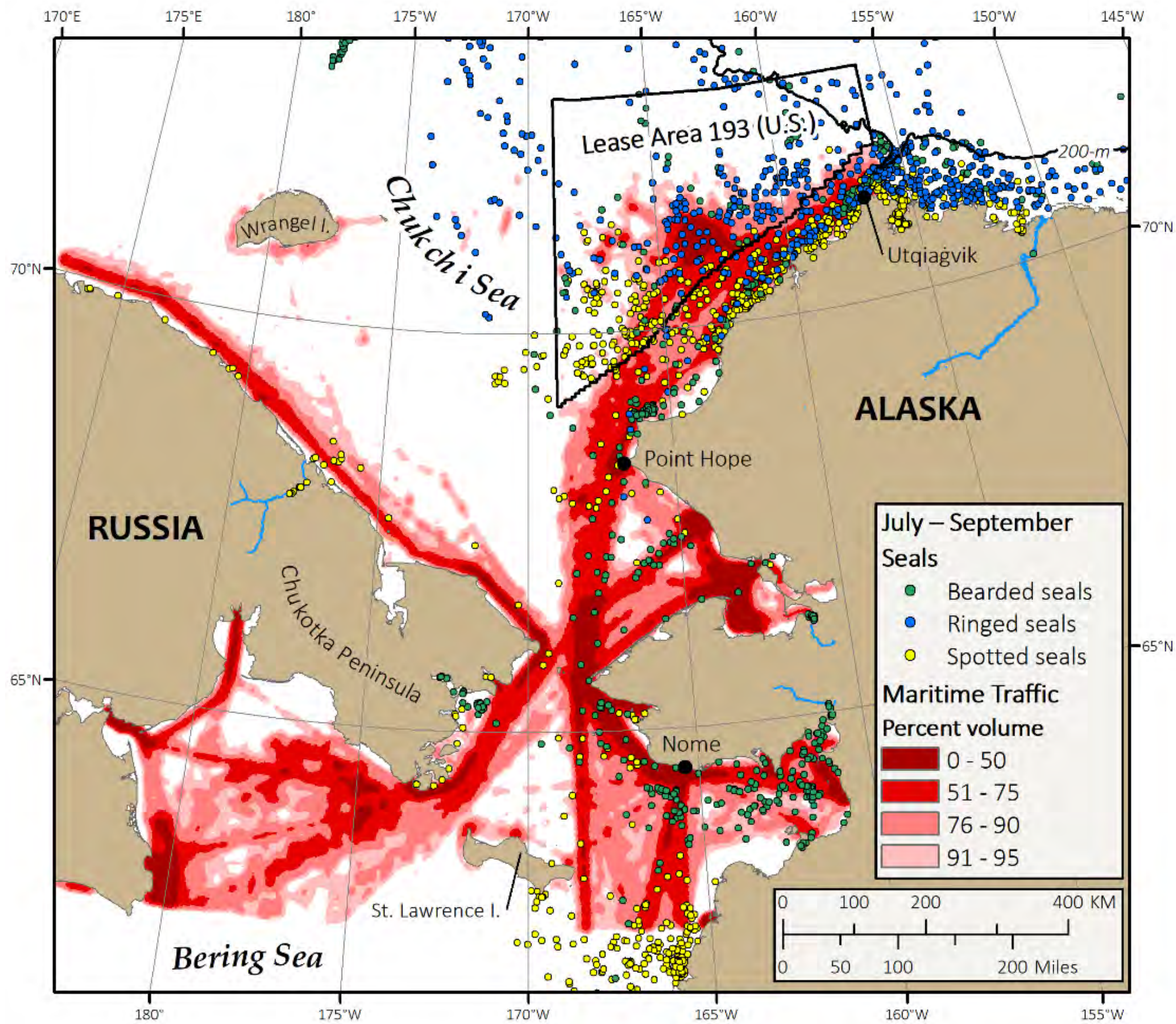


Figure 55. Locations of tagged bearded (n = 20), ringed (n = 15), and spotted seals (n = 20) and density estimates (red) for ship traffic derived from Automatic Identification System (AIS) data in the northern Bering and Chukchi seas from July to September during 2013–2015. Colored circles are daily seal locations estimated using the CRW model.

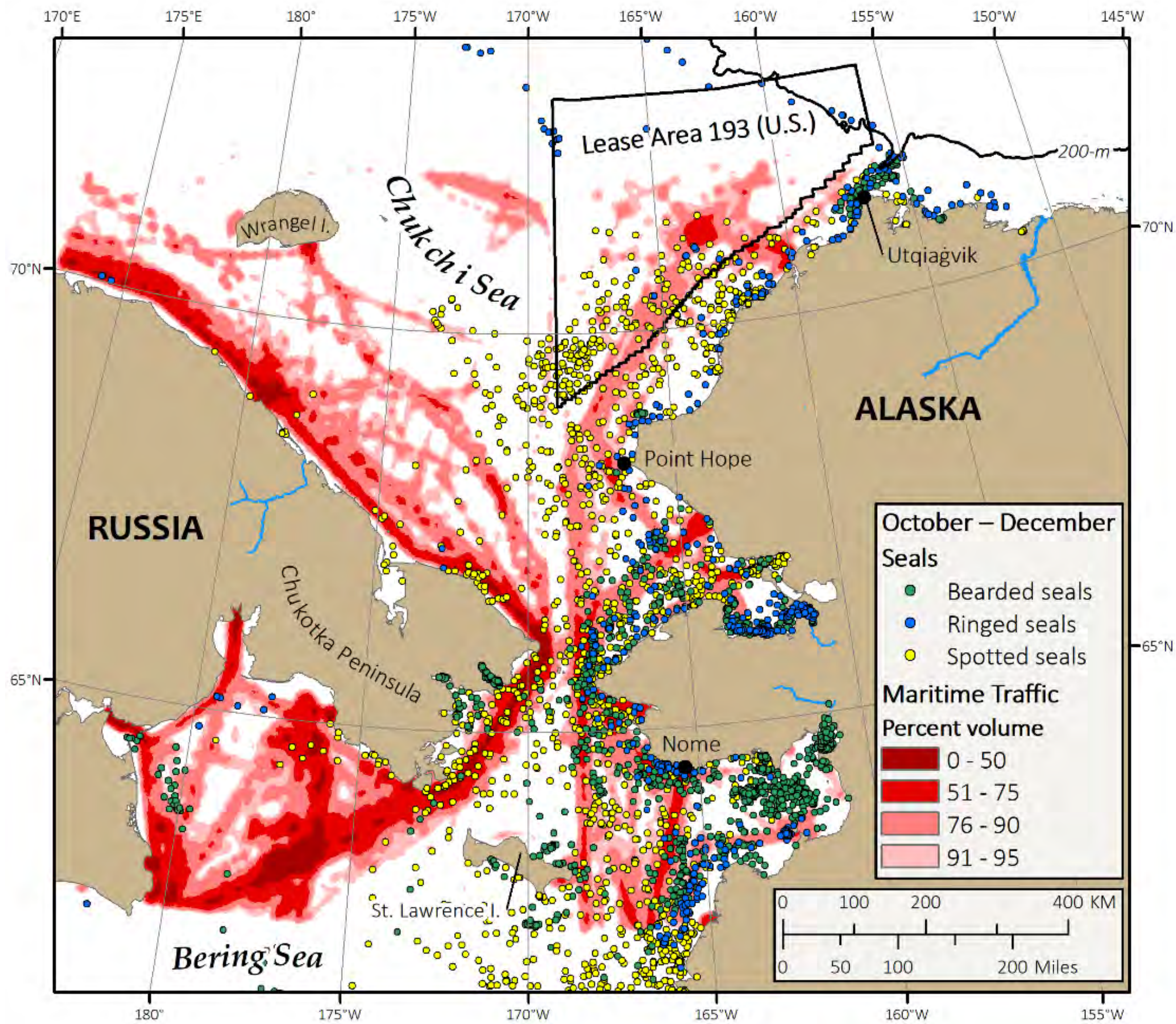


Figure 56. Locations of tagged bearded (n = 21), ringed (n = 9), and spotted seals (n = 24) and density estimates (red) for ship traffic derived from Automatic Identification System (AIS) data in the northern Bering and Chukchi seas from October to December during 2013–2015. Colored circles are daily seal locations estimated using the CRW model.

Local and Traditional Knowledge

In addition to greatly improving our ability to find, catch, and tag seals, Alaska Native seal hunters made many valuable contributions to this project regarding local and traditional knowledge of seal movements, timing of migration, and haul-out behavior. Information from interviews in Barrow (now Utqiaġvik), Shishmaref, Kivalina, Kotzebue, Elim, St. Michael, Stebbins, Scammon Bay, Hooper Bay, and Mekoryuk during this project (2015–2017) are contained in reports made for the communities, publications, and are incorporated into the results of this final report. Final reports are included here as Appendices C–E, H–J, M–O and are available at ADFG's webpage at
http://www.adfg.alaska.gov/index.cfm?adfg=marinemammalprogram.traditionalknowledgereports.

Traditional knowledge interviews conducted during our BOEM walrus study (OCS Study BOEM 2016-053) in Wainwright, Point Lay and Point Hope included information on seals and are also are referenced here (Table 6) and available at our webpage. Full references for publications (Huntington *et al.* 2016 and Huntington *et al.* 2017) are included in our List of Publications and Products. Details of the communities, topics, and numbers interviewed are presented in Table 6. Hunter experience relative to when and where to find seals and how to set nets to capture them was extremely important to this study. We worked with Tribal Councils to identify seal hunters that had extensive knowledge and were interested in participating in traditional knowledge interviews.

Table 6. Summary of traditional ecological knowledge interviews, final reports, and publications that include ice seals.

Community	Year	Species discussed	No. interviewed	Reference
Point Lay and Wainwright	2012	Seals, walrus	5 13	Huntington *et al.* 2012
Point Hope	2013	Seals, walrus, bowhead whale, beluga whale	8	Huntington and Quakenbush 2013
Barrow	2015	Seals, walrus, polar bear, bowhead whale, beluga whale	10	Appendix C
Elim	2015	Seals, walrus, beluga whale	8	Appendix D
St. Michael and Stebbins	2015	Seals, walrus	8 2	Appendix E
Kivalina	2016	Seals, walrus, bowhead whale	5	Appendix I
Kotzebue	2016	Seals, walrus	6	Appendix J
Shishmaref	2016	Seals, walrus	5	Appendix H
Scammon Bay	2017	Marine mammals	5	Appendix O
Hooper Bay	2017	Marine mammals	11	Appendix M
Mekoryuk	2017	Marine mammals	7	Appendix N
13 communities	**5 years**	**7 species**	**93 interviews**	**11 reports**

Traditional knowledge interviews provided information that generally supported the movements and behaviors we documented for tagged seals, but also added information that could not be obtained from telemetry. For example, interviews from Utqiaġvik (Barrow) confirmed that bearded seals are often seen where the Chukchi and Beaufort waters meet (i.e., Barrow Canyon) and one of the tagged bearded seals stayed there year-round (Figs.7–10). We learned from many of the seal hunters at different locations (e.g., Utqiaġvik, Kotzebue, Kivalina, Elim, Stebbins, St. Michael, Shishmaref, and Mekoryuk) that bearded seals, especially young bearded seals, swim up rivers in summer and fall. Using this information 22 of 26 bearded seals we tagged were caught up rivers. Without this information we would not have known to look for bearded seals up rivers and would have only caught a few in bays. We also learned in the Utqiaġvik interviews that bearded seals can sleep at the surface in open water potentially explaining the long periods (26–50 days) we documented between haul-outs (Fig. 42).

Utqiaġvik and Elim hunters mentioned that ringed seals haul out on land. Although it is more common for young ringed seals, adults are also observed hauling out on land. Utqiaġvik hunters mentioned seeing ringed seals hauled out on land near Peard Bay. Our data identified four instances of ringed seals hauled out on land, three of these were adults, including one near Peard Bay (Fig. 44).

Hunters say that many ringed and bearded seals winter in Norton Sound. Our analysis of high-use areas showed that ringed seals used Kotzebue Sound more than Norton Sound, but that bearded seals used both during the winter. This may indicate a bias in our sample of ringed seals, likely due to where seals were tagged, or that low concentrations of sea ice in Norton Sound limited ringed seal use.

Traditional knowledge interviews provided information about movements and behavior of adult bearded seals that we could not match with telemetry data because we did not catch any adults. Shishmaref hunters reported that young bearded seals migrate north with adults but migrate south before the adults. Nunivak hunters reported that most of the bearded seals seen on the south side of the Island in winter are yearlings and that older seals stay farther north. Bearded seals in Kotzebue Sound in fall are mostly juveniles, but adults are hunted there in spring.

Accomplishment of Objectives and Tasks

This study was designed to provide specific data and analyses to address the objectives listed below and integrate them with concurrent research on marine mammals in the Beaufort and Chukchi seas Lease Sale Areas. Specific objectives are as follows:

Objective 1: Estimate patterns of movement and behavior of bearded, spotted, and ringed seals, each with their own specific behavior, migrating to and moving about within the BOEM Beaufort and Chukchi Seas Planning Areas. Particular emphasis will be placed on estimating movements within ship traffic lanes and between haulout sites and feeding areas near potential oil and gas development sites.

Bearded Seals. Bearded seals made highly individualistic movements that covered much of the continental shelf in the Bering, Chukchi and Beaufort seas (Figs. 7–10). Thus, where seals hauled out (both on land and sea ice) and where they were likely feeding (i.e. exhibiting resident behavior, Fig. 28), demonstrated a broad use of the area, rather than concentrated areas or hotspots. Over the course of their movements, seals passed through lease areas in the Chukchi and Beaufort seas (Fig. 52), however their tendency to remain near the coast meant they used the Lease Sale 193 area less than ringed or spotted seals (Table 5). Bearded seals were most likely to encounter ship traffic in Norton Sound throughout the year (Figs. 54–56), and along Alaska's northwest coast in the summer (Fig. 55). Five of 6 bearded seals exhibited seasonal fidelity to specific areas, including near Barrow Canyon and the outlet of the Yukon River during winter and areas of Norton Sound during fall.

Ringed Seals. Ringed seals moved north in summer and made north-south movements often over deep water (north of the 200-m isobath; Fig. 13). Many of these movements occurred when the ice edge had receded north of the Chukchi-Beaufort shelf break and appeared to be trips to the ice edge and smaller patches of sea ice. For example, RS17-01-M made a long trip to the ice edge and RS17-02-M made three trips to the ice edge, north of the shelf break (Fig. 13). During these north-south trips, ringed seals hauled out on ice over deep water to the north but did not haul out when they returned to the shallow water shelf. During these trips north, over deep water and during the open-water season, ringed seals would generally not overlap with ship traffic located closer to the coast. High-use foraging areas were primarily near Utqiaġvik, Barrow Canyon, and the western Beaufort Sea during the open-water period (Fig. 30); during the ice-covered season they were primarily located in Kotzebue Sound (Fig. 31). Ringed seals were more likely to encounter ship traffic in Norton Sound in the spring (Fig. 54), in the northeastern Chukchi Sea in the summer (Fig. 55), and in Norton Sound and the Bering Strait region in the fall (Fig. 56). From June to October, ringed seals ranged widely throughout the Lease Sale 193 area (Fig. 52) and occasionally moved through the lease blocks in the Beaufort Sea. Five of 5 ringed seals exhibited seasonal fidelity to specific areas and migration routes, including Kotzebue Sound during spring, Barrow Canyon during the open-water period, northern Norton Sound and along the western coast of Seward Peninsula during winter, and moving through the Chukchi Sea along the Alaskan Coast during the fall migration south and spring migration north.

Spotted Seals. During the open-water season (May–November), spotted seals tended to repeat east-west movements between offshore foraging areas and the Alaskan coast, including returning to their tagging locations (Figs. 19 and 32). High-use foraging areas were between Herald Shoal and the nearshore waters of the northeast Chukchi Sea (< 50 m deep; Fig. 33) and included the southern portion of Lease Sale 193 area (Fig. 52). Spotted seals were more likely to encounter ship traffic in the northeastern Chukchi Sea and along Alaska's northwest coast in the summer (Fig. 55) and along the Russian coast and Bering Strait region in the fall (Fig. 56). Given their tendency to return to and forage near the Alaskan coast, spotted seals may overlap least with shipping on Northern Sea Route along the Russian coast but may overlap with ships hauling ore from Red Dog Mine or other traffic along the Alaskan coast. Spotted seals have the potential to overlap with oil and gas activities near Alaskan shores in the Beaufort, Chukchi, and Bering seas and land haulouts may be important habitats sensitive to disturbance. Four of 5 spotted seals exhibited seasonal fidelity to specific areas, including east of Point Barrow, in the Beaufort Sea, during the open water period and haulout sites on barrier islands near Icy Cape during summer and in Scammon Bay during fall.

We have accomplished Objective 1 by describing patterns of movement during ice-covered and open-water seasons relative to ice conditions, distance to shore, lease areas, and ship traffic for bearded, spotted, and ringed seals. We also identified haulout and feeding areas and described patterns of their use. In addition, we have described the degree to which seals show fidelity to some areas seasonally, and to migration routes.

Objective 2: Estimate and evaluate the effect of any changes in bearded, spotted, and ringed seal behavior related to changes in ice coverage and ice quality in the Beaufort and Chukchi Seas.

Although the duration of our study (2014–2019) was likely not long enough to fully evaluate the effects of changes in bearded seal behavior relative to changes in sea ice, there is some evidence that bearded seals may be responding to changing ice conditions. Young bearded seals generally make seasonal north-south movements in response to seasonal ice extent and have exhibited a preference for the ice edge (10–15% ice concentration) (Cameron et al. 2018, Breed et al. 2018) and the transitional ice between small and large ice floes (70–90% ice concentration; Simpkins et al. 2003, Cameron et al. 2018). Our data, however, suggest this relationship may be changing as bearded seals were often found far north of the ice edge, in less-consolidated pack ice, during maximum ice extent (50–75% ice concentration during January–April; Figs. 45 and 46), with some individuals wintering in the Chukchi and Beaufort seas (Figs. 9 and 10) (Olnes et al. *In prep*.). As ice becomes less extensive and more variable, young bearded seals may use a broader area of less-consolidated pack ice than in the past when ice was more densely concentrated and thus restricted seal movements.

For ringed seals, our data indicate an earlier migration north and delayed migration south mirroring changes in ice retreat and formation. We tagged ringed seals in Kotzebue Sound in June of 2014 and 2017, however after 2017, sea ice had retreated from the Sound during May. Ringed seals could however be found near Point Barrow in June 2019. Compared to ringed seals tagged in Kotzebue Sound (2007–2009) (Crawford et al. 2012, 2018), seals in this study tended to move farther north of the Chukchi Sea shelf break, likely to follow ice that had receded farther north than during the previous study.

We tracked spotted seals in the central Bering Sea in winter, including when very little ice was present. As mentioned above, spotted seals moved through open water that would have been ice covered in previous years and made trips back to land haulouts at St. Lawrence, St. Matthew, and Nunivak islands, and at the spit north of Hooper Bay. They used these terrestrial haulouts until ice formed. They also did not use areas in the western Bering Sea that were identified as high-use areas during previous winters and in years with more ice coverage (see Citta et al. 2018, Fig. 4b). These results suggest that spotted seals can continue to access open water areas south of the ice edge, as they do during the open-water season, by returning to haul out on islands and fast-ice until pack ice forms giving them greater access to the western Bering Sea.

We accomplished Objective 2 by analyzing data collected during this study that demonstrates changes in behavior relative to sea ice by all three ice seal species and by comparing our results to those in the published literature.

Objective 3: Estimate bearded, spotted, and ringed seal use of haulouts by demographic class and estimate the duration of occupancy as related to weather, disturbance, and other potential factors.

Bearded seals tagged were mostly pups (26) and a few yearlings (5); therefore, we could not evaluate haul-out behavior by age. Young bearded seals, however, were more likely to haul-out during the ice-covered season (December–April, daily haul-out probability = 58%) with an average haul-out duration of 5.9 hrs and maximum duration 53 hrs (Table 4). Although young bearded seals hauled out less during the open-water season (May–November, 48%) they hauled out longer (mean haul-out duration = 7.9 hrs, maximum duration = 143 hrs) when ice was at its minimum extent (July – October). During both periods, seals hauled out on both sea ice and land. Haul-out durations on land were half as long as that on ice (Fig. 43), likely because the incidence of disturbance was greater. Of greater interest than haul-out duration (hrs) perhaps, was the duration between haul-outs (weeks) while young bearded seals were in open water far from land. Five young bearded seals remained in open water for 26–50 days without hauling out at all (Fig. 42).

Most ringed seals tagged to date were adults (13 of 16); therefore, we do not have the sample size to make statistical comparisons between demographic classes. Ringed seals were more likely to haul out during the ice-covered season (daily haul-out probability = 57%) than the open-water season (48%); however, haul-out durations were similar between seasons, 4.8 and 5.0 hrs, respectively (Table 4). We found four instances where ringed seals hauled out on land, primarily during their fall migration south. Haulout durations while on land were from 6 to 12 hours.

Spotted seals regularly hauled out on land and ice regardless of demographic class. During the open-water season, spotted seals generally spent 1–21 days foraging before spending 1–6 days hauled out on land. Spotted seals older than pups (i.e., non-pups) were more likely to haul out (44%) than pups (32%) during the open-water season and during the ice-covered season (non-pups = 41%; pups = 25%; Table 4). Non-pups also hauled out roughly one hour longer than pups during the open-water (mean haul-out duration: non-pups =8.3 hrs, pups = 7.2 hrs) and during the ice-covered season (non-pups = 9.2 hrs, pups = 8.0 hrs). It appears that spotted seals regularly travel to and from land haulouts between offshore feeding bouts, when ice is not available. When available, spotted seals prefer to haul out on ice.

We accomplished Objective 3 in that we collected haul-out behavior on three species of ice seals, however, we could only compare demographic classes for spotted seals.

Objective 4: Create a database of traditional knowledge of bearded, spotted, and ringed seal behaviors including, but not necessarily limited to, movements, social behavior, and use of habitat including both feeding and pupping areas.

We conducted traditional knowledge interviews in 10 communities where ice seals were focal species and in three additional communities where other marine mammals (e.g., bowheads and walruses) were the focus, but information about ice seals was included. We finalized nine reports of traditional knowledge that included ice seals and published two peer-reviewed papers on traditional knowledge in science journals (Huntington et al. 2016, 2017).

We have listed all reports and publications in Table 6 and in the Publications and Products section of this report and made all the reports available on our ADFG webpage: (http://www.adfg.alaska.gov/index.cfm?adfg=marinemammalprogram.traditionalknowledgereports) and we added these reports as Supplementary Material to Huntington et al. (2016). Electronic supplementary material is available at http://dx.doi.org/10.1098/rsbl.2016.0198 or via http://rsbl.royalsocietypublishing.org. In addition, we have archived the reports on the Exchange for Local Observations and Knowledge of the Arctic (ELOKA) website https://eloka-arctic.org/websites

We did not create a database of seal behavior from traditional knowledge documents because such a database would distill the information and disassociate the behavior from the context which is fundamental to Traditional Ecological Knowledge.

We accomplished Objective 4 by collecting traditional knowledge across a large geographic area, representing the range of ice seals and ice seal hunters in Alaska, and made it available through publication and websites. We found, however, that creating a database would be counter to the principles of traditional knowledge and therefore did not accomplish that component of the objective.

TASK 1. DATA REVIEW AND HYPOTHESIS DEVELOPMENT

We used ADFG's extensive library of old and recent published and unpublished literature from the U.S., Russia, Norway, and Canada regarding ice seals. We reviewed available data on ice seals, advances in satellite telemetry, and modelling techniques for movement analysis and resource selection. In addition to our own data we peer reviewed manuscripts and read literature on ice seal movements and behavior from all species and collaborated with the NSB and MML on tagging projects. We also worked with the hunters to develop working hypotheses related to the objectives of this study.

TASK 2. EXPERIMENTAL DESIGN AND FIELD WORK

ADFG has worked with local Alaska Native seal hunters throughout this project to catch and tag ringed, bearded, and spotted seals where possible at multiple sites each year. Tagging sites have included the Colville River, Dease Inlet, Utqiaġvik, Buckland, Nome, Koyuk, St. Michael, Scammon Bay, and Hooper Bay. Alaska Native subsistence hunters and other community members participate in all aspects of the project development and information from the project is shared directly with participants on a regular basis, through the regular movement maps distributed by email, through meetings with the ISC, and on the ADFG webpage. Project activities did not interfere with subsistence activities as defined by each community where the activity occurred.

Seals were tagged with satellite transmitters capable of providing either long-term location data (flipper-mounted tags that provided data for up to 2 years), or short-term location data and dive information (head or back-mounted tags that provided data up to 8 months). Duty cycles and other battery saving options were determined based on the objectives and changed as data were collected and evaluated. Settings used in previous studies by us (Quakenbush et al. 2010a, Crawford et al. 2011) and others (NMFS) for duty cycles, dive behavior, and other parameters served as the standard until new information suggested other settings would provide better or more data.

We have had success with satellite tags manufactured by Wildlife Computers in our studies of bowhead, gray, and beluga whales, and walruses and seals. Newer versions of the SPOT and SPLASH (now Splash10) tags were available for this project and they had improved capabilities for collecting water temperature at depth and for more detailed dive profiles. We used these tags throughout the project.

In addition to deploying tags we also measured, weighed, sexed, counted claw annuli, collected the skin plug made to attach the flipper tag, and collected blood from each captured seal when possible. Claw annuli provided a minimum age, skin samples were archived for genetics studies, and blood serum was screened for disease exposure and archived for future studies.

We built upon the traditional knowledge (TEK) efforts conducted during the BOEM Walrus project *Pinniped Movements and Foraging: Walrus Habitat Use in the Potential Drilling Area* (AK-09-01) (Huntington et al. 2012). Our interview framework, where interviews were loosely structured around a series of questions, but participants could divert to other topics they felt were important, resulted in productive gathering of TEK.

TASK 3. DATA ANALYSIS AND REPORTING

We provided regular maps of tagged seals when they were on the air to our e-mail list (185 member) and we archived the maps at our webpage. Data analysis is described in detail in the Methods section of this report. We explored and implemented the most current methods for analyzing complex data collected during this study, such as modelling predicted locations and behavioral states. Given the variable behaviors of each species of ice seal, and thus the variable nature of the data for each species, we implemented multiple analytical approaches to best address our objectives. For example, we found that state-space models were best for addressing foraging areas of bearded seals, but that utilization distributions were more appropriate for identifying spotted seal foraging areas.

We reported results to the ISC at their annual meetings and at all Alaska Marine Science Symposia (Appendices A, F, G, I, K, O, P. R, S, and T), at the Society for Marine Mammalogy Biennial Conferences (Appendices P, Q, and U), at the American Geophysical Union (Appendix B).

TASK 4. INTEGRATION OF FINDINGS WITH OTHER RELATED TASKS

We provided maps and data to BOEM and others for integration into other projects, one paper was published in 2018 using data from this project for SOAR (Phase II) titled "*Multi-species marine mammal use of the Bering, Chukchi, and Beaufort seas*" (Citta et al. 2018, See List of Publications and Products).

We provided our tagged seal movement data to augment other projects and efforts:

1) We made our maps and other products available through our webpage http://www.adfg.alaska.gov/index.cfm?adfg=marinemammalprogram.icesealmovementsarchive
2) Many consulting companies, agencies, researchers, and other entities downloaded these maps for their needs.
3) We provided monthly maps (July–November) of tagged bearded and ringed seal locations relative to Quintillion's fiber optic cable route to NMFS, Alaska Region for preparation of a biological opinion (Appendix L).
4) We provided movements data for use in developing shipping lanes through Bering Strait.
5) We provided time at surface data to MML for use in aerial survey correction factors to estimate abundance.
6) We provided location, dive, and haul-out data to international collaborators for a Pan-Arctic study to identify important areas for marine mammals across the Arctic.
7) We combined location, dive, and haul-out data from our ONR project with the BOEM project to increase sample size for all species.

TASK 5. DATA MANAGEMENT AND ARCHIVAL

We ensured that all data were properly recorded, validated, backed up, and archived to be available to other investigators after the objectives and obligations of this project were met. Location data from Argos were downloaded weekly and complete files were received monthly. These data were archived on ADFG's servers and on CDs as unprocessed data files. Processed data are also archived on ADFG's servers and CDs. Processed locations were imported into ArcGIS software and maps were plotted using ArcMap. Maps were produced and e-mailed to interested parties regularly and then placed on the ADFG webpage.

ADFG maintains an archive of all data collected during this study. We worked with ATN and the Alaska Ocean Observing System to improve metadata requirements and presentation of data online. We presented at their workshop in Anchorage in 2017 and continue to participate in discussions for developing the ATN into a useful tool for federal agencies and researchers. Our current data archive and access policy is consistent with standards adopted by BOEM, the National Oceanographic Data Center, NOAA, and other federal agencies.

TASK 6. LOCAL COORDINATION, OUTREACH, AND PERMITTING

ADFG worked with the ISC and local communities to identify coastal communities with hunters interested in tagging seals. We worked cooperatively with the seal hunters to deploy the tags. We attended local tribal or city meetings prior to tagging to explain the project and hear local questions and concerns to determine if any changes should be made to the study plan. We received community approval prior to tagging. We worked with the hunters and the communities to determine their interest in TEK interviews prior to conducting interviews and reported results using their preferred media. Research results were shared with the participating communities by presentations at meetings, posters, flyers, or reports depending on the community preference; often we used more than one method (Table 1 and List of Publications and Products below). Updates to the ISC were co-presented by hunters and researchers whenever possible.

We presented results at the Alaska Marine Science Symposium and at the Society for Marine Mammalogy Biennial Conference (See Table 1 and List of Publications and Products below) and published papers for the peer-reviewed scientific literature. These presentations and papers include hunters as co-authors or presenters as appropriate. The seal movement maps we produced were our primary method of outreach with the most recent tagged seal locations and a description of any additional pertinent information. We often received responses and discussion among recipients in real time when the map was sent. The e-mail list included many subsistence hunters as well as agency personnel. The maps then went to our ADFG webpage http://www.adfg.alaska.gov/index.cfm?adfg=marinemammalprogram.icesealmovementsarchive where they are available along with animations of seal movements relative to sea ice and other information about the seal tagging project.

Marine mammal research permits required under the Marine Mammal Protection Act take more than 12 months to acquire and renew. Seal research was conducted under NMFS Permits #15324 and 20466 issued to ADFG as required under the Marine Mammal Protection Act. ADFG also requires an annual review by the Institutional Animal Care and Use Committee (IACUC) of projects that handle live animals for compliance under the Animal Welfare Act (IACUC Nos. 2013-020, 2014-03, 2015-25, 2016-23, 0027-2017-27, 0027-2018-29). We kept all research permits up to date and fulfilled all permit-related reporting requirements. We purchased land use permits when required by local communities for non-tribal members to use the beaches and other areas.

TASK 7. LOGISTICS/SAFETY PLAN

Our logistics plan included using local hunter's expertise to determine what capture method should be used, how nets should be set to catch seals for tagging, and where and when capture activities should occur to avoid any interference with subsistence hunting. In some cases, nets were set using local boats and in other cases set from shore. Appropriate floatation devices were worn, and some combination of hand-held marine VHF radios, Emergency Personal Locator Beacons, and satellite telephones were carried. A First Aid kit and GPS unit were also required equipment. An emergency plan was made for each location and included the local radio frequencies, an onshore contact, and procedures for an emergency.

Safety plans were developed specific to each tagging effort based on the local logistics, infrastructure, and measures already in place. Safety equipment was present and inspected to ensure it was in working order. Radio communication was established between boats and with a contact on shore. In addition to marine VHF radios, radio beacons, and satellite telephones were on board boats. In the Utqiaġvik area a "float plan" was filed with the NSB Search and Rescue office prior to departure.

Discussion

Coordination

The success of this project was largely due to our partnership with Alaska Native seal hunters and their interest in learning to capture and tag seals to support research that contributes to a better understanding of seals in general and how climate change may affect seal biology. The collaboration among hunter-taggers (in Nuiqsut, Kotzebue, Buckland, Nome, Koyuk, St. Michael, Scammon Bay, and Hooper Bay), NSB personnel, and ADFG biologists established an excellent framework for catching and tagging seals and for exchanging information. Seal hunters knew where to find seals and where to set nets to catch them. We worked with hunters, communities, and other researchers to learn about movements and habitat use of bearded, ringed, and spotted seals and how they are changing with decreasing sea ice and increasing human activities (e.g., oil and gas and shipping) in the Arctic. We made the results of this project available to communities where seals were tagged, to the ISC at their annual meeting, and to others interested in seal movements in the Arctic by e-mailing maps of recent movements, maintaining a webpage of project activities and movement updates, and presenting results in villages during tag trainings. We collaborated with MML by sharing seal tags and data. We presented results at the Alaska Marine Science Symposium annually (Appendices A, F, G, K, R, S, T). We also posted citations to publications, analyses, posters, and other products on our webpage. These products are used by many entities for environmental assessments, biological opinions, incidental harassment applications and authorizations in oil company reports and in species and habitat maps.

Tag Performance

Primary tags (SPLASH and CTD tags) provided locations and data for a mean duration of 159 days (5.3 months), range 10–291 days. Many factors affect tag performance, including low battery voltage, tag and antenna damage, and tag loss due to attachment wear and spring pelage molt. The expected battery life for these tags was 5–8 months depending on the number of daily transmissions attempted and the amount of data transmitted to satellites. The performance of these tags matched our expectations.

Flipper-mounted SPOT tags were programed to conserve battery life and to provide location data for 1–2 years, with the goal to assess seasonal fidelity over consecutive years. Identifying specific areas used over multiple years is valuable when assessing high-use areas and important seal habitat. SPOT tags provided locations and data for a mean duration of 231 days (7.7 months), range 1–694 days (maximum of almost 2 years). Flipper-mounted SPOT tags deployed on five bearded, two ringed, and two spotted seals provided data for longer than 1 year.

Seal Movements

During this project (2014–2019), we deployed transmitters on 67 seals (26 bearded, 16 ringed, and 25 spotted seals) at nine tagging locations in the Beaufort, Chukchi, and Bering seas (Table 2). This is the first study in Alaska to deploy satellite transmitters on three sympatric species at multiple locations within three seas (Beaufort, Chukchi, and Bering) in the same year to better understand ice seal movements, habitat use, ecology, and the effect of tagging location on observed movements. We identified similarities and differences in movements and areas used by species and by tagging location within species.

Overall distribution. Bearded and ringed seals moved farther north than spotted seals in spring when ice moved north of the continental shelf. Ringed seals used less of the central Bering Sea in fall and winter and more of coastal areas than either bearded or spotted seals. This apparent low use of the central Bering Sea in winter by ringed seals, however, may be because few subadult ringed seals were tagged during this study. In a previous study, subadult ringed seals wintered in the central Bering Sea near the southern ice extent, while adults wintered farther north and closer to shore (Crawford et al. 2012). Adult ringed seals establish breeding territories in winter and spring where they maintain breathing holes and build lairs for pupping on heavier, more stable ice (Smith and Stirling 1975), however, subadults may take advantage of the productive, less consolidated ice habitat in central Bering Sea, where they do not need to maintain breathing holes or avoid adult territories (Crawford et al. 2012).

All three species of ice seals made extensive use of the intercontinental shelf in the Bering, Chukchi, and western Beaufort seas. Documenting this broad use of the region is attributable to capturing and tagging seals in multiple locations throughout their range in Alaska. For example, if we relied solely on data from juvenile bearded seals tagged in Norton Sound, we would not have documented that some juveniles remain in the Beaufort Sea throughout winter, as this behavior was only exhibited by seals tagged in in the Beaufort Sea. Tagging seals at multiple locations within the same season is critical to understanding the true extent of each species' movements and use of the region.

Latitudinal. All species (although not all individuals) made latitudinal movements seasonally. For bearded and spotted seals, these movements differed by where they were tagged. Most bearded seals made large latitudinal movements seasonally, however two bearded seals tagged in the Beaufort Sea stayed north of 70 °N (Fig. 6). Spotted seals (14 of 15) tagged in the Beaufort Sea stayed north of 69 °N until they moved south with advancing sea ice. Spotted seals tagged in the Bering Sea (n = 7) tended to stay in the Bering Sea (Fig. 18). These results suggest that range-wide ice seal movements are more complicated than those found by telemetry studies that deployed tags from one location. Future telemetry studies should tag seals at multiple locations throughout their range.

It is likely that patterns of latitudinal movement will change with changes in sea ice. For example, less consolidated pack ice may reduce southward movements as seals are able to move in ice farther north, as appears to be the case with bearded seals. Conversely, as ice retreats farther north during the open-water season, seals may also move farther north as exhibited by two ringed seals in this study that traveled beyond the intercontinental shelf to reach ice.

Site fidelity. The minimum proportion of seals that exhibited seasonal fidelity to specific areas was similar among species (16–19%). However, only 16 tags (on 67 seals) provided data long enough to assess seasonal fidelity. Although the proportion is not overwhelming, some areas repeatedly used by individuals were remarkably specific (See Figs. 11, 17, and 23).

The ability to document site fidelity is dependent on the longevity of satellite tags, highlighting the value of deploying multiple tags on individuals. Although the SPLASH and CTD tags provided more detailed data, the SPOT flipper tags transmitted longer and were critical for documenting habitat use over multiple years.

Distance traveled. Overall, spotted seals traveled farther overall distances than bearded and ringed seals, likely due to their "central-place" foraging style (Orians and Pearson 1979, Sjøberg and Ball 2000). Spotted seals made many east-west movements during the open-water season, foraging in areas offshore and hauling out onshore during the open-water season. In contrast, bearded and ringed seals stayed in foraging areas longer or foraged near sea ice (especially ringed seals) where they hauled out near foraging areas.

All species moved extensively throughout the region, often crossing the Chukchi and Bering seas to use coastal areas in Russia. Our data show that all three seal species made use of the entire intercontinental shelf.

Distance to land. Bearded and ringed seals were closest to land during the ice-covered season and farther from land during the open-water season while spotted seals were farthest from land when ice was at its maximum. That ringed seals were closer to land when ice was present (Nov-May) could be explained by their choice of heavier (including landfast) ice as pupping habitat and most of the ringed seals in this study were adults (81%, 13 of 16). Bearded seals had the same tendency but presumably for a different reason because none of the tagged bearded seals in this study were of breeding age. Juvenile bearded seals may use nearshore areas in part because distance to land is correlated with water depth and, as benthic foragers, they may use areas with shallower water. We did not tag any adult bearded seals, therefore we cannot report on areas they used, although two adult bearded seals that were tagged in a prior study also primarily used areas near land (< 50 km; Boveng and Cameron 2013). Spotted seals winter along the southern ice edge, which generally reaches the central Bering Sea by March (See Fig. 41), and they pup there in April–May. The offshore areas spotted seals use when ice is present generally have less consolidated pack ice (< 50%; see Fig. 49); spotted seals use the central Bering Sea during years sea ice forms there, however in low ice years, when ice is restricted to the coastal areas of Alaska and Russia, spotted seal remain closer to land.

High-Use Areas

During the open-water season, bearded seals primarily used nearshore areas, but also used Hope Basin in the southern Chukchi Sea, Mechigmenskaya Bay, Russia, in the northern Bering Sea, and central and west central Bering Sea along the 100–200 m isobath (Fig. 28). Ringed seals used the northern continental shelf and were centered on Barrow Canyon and the northeastern Beaufort Sea (Fig. 30). High-use areas for spotted seals differed by where seals were tagged. Spotted seals tagged in the Beaufort Sea used Barrow Canyon, but in shallower waters and closer to shore than areas used by ringed seals (Fig. 33). These seals also used the area between Herald Shoal and nearshore areas of Peard Bay and Icy Cape. The southernmost area of use for spotted seals tagged in the Beaufort Sea was near Bering Strait (Fig. 33). Spotted seals tagged in the Bering Sea used areas near Scammon Bay, where they were tagged (Fig. 36).

During the ice-covered season, bearded seals used Barrow Canyon, southern Kotzebue Sound, Bering Strait, Norton Sound, and near St. Lawrence Island, the mouth of the Yukon River and southwestern Anadyr Gulf (Fig. 29). Ringed seals primarily used Kotzebue Sound but also other nearshore areas in the Chukchi and Bering seas (Fig. 31), while spotted seals used the central Bering Sea regardless of which sea they were tagged in (Fig. 39).

In addition to marine high-use areas, spotted seals also had coastal high-use areas (haulouts) in the Beaufort Sea (Dease Inlet), Chukchi Sea (Icy Cape, northern Kotzebue Sound) and Bering Sea (Scammon Bay) (Fig. 34 and 37). Although spotted seals were tagged at haulouts in the Colville River and nearby Fish Creek, they used these haulouts less often, possibly because those seals were tagged in late summer near the end of when spotted seals could haul out on land along the Beaufort Sea coast and most tags stopped transmitting before seals would return there the following year. In other words, spotted seals could use the Colville River more often, and possibly exhibit fidelity to the area, then our data were able to show.

High-use areas that overlapped among species included Barrow Canyon, Kotzebue Sound, Norton Sound, and the Bering Sea shelf break between the 100 and 200 m isobaths. Barrow Canyon was used by one bearded seal in all seasons and by ringed and spotted seals during the open-water period, although spotted seals used only the shallow zone close to shore. Kotzebue and Norton sounds were used by bearded seals in all seasons, ringed seals only during the ice-covered season, and spotted seals only in the open-water season. The Bering Sea shelf break was used by bearded seals in all seasons, but not by ringed seals during this study, although it was used by subadults during winter in a previous study (Crawford et al. 2012). Spotted seals used this area only during the ice-covered season.

Although we identified high-use areas for all three species, it is important to note that the identification of high-use areas is limited by the movements of the seals tagged, which likely only partially represent high-use areas used by the population as a whole. As more seals are tagged, our understanding of high-use areas may change. For example, we expect that data from more bearded seals will further emphasize the individualistic nature of their movements, but also reinforce the importance of high-use areas already identified, such as Barrow Canyon or Norton Sound. For spotted seals, it is likely that tagging more individuals will identify additional land-based haulouts.

Haulout Behavior

This study documented that young bearded seals spent 26–50 days between haul-out bouts during the open-water period demonstrating their ability to access habitats far from the mainland or islands (Fig. 42). It is likely that adults are at least as capable, if not more so. During the open-water period, ringed seals primarily used high-latitude areas near the shelf break in the Chukchi Sea, areas generally proximal to remnant sea ice, which they used to haul out. Therefore, ringed seals in our study did not spend long periods of time between haul-out bouts. During the open-water season, spotted seals in the Bering and Chukchi seas spent 1–25 days on foraging trips without hauling out. When sea ice was present, however, spotted seals behaved similarly to ringed seals and made shorter duration foraging trips near ice and hauled out more often.

These behaviors are noteworthy as they suggest bearded and spotted seals can remain at sea for extended durations without requiring a haul-out platform nearby. Durations at sea are less clear for ringed seals because they usually stay with the ice and have ready access to it for resting. We documented ringed seals moving far off the shelf to the north to access sea ice; however, we cannot assess whether the purpose was to haul out or to feed on their primary fish prey (Arctic cod), which are also associated with ice. Native Alaskan seal hunters have observed bearded seals sleeping in the water; this behavior may allow seals to stay in foraging areas longer because they do not need to leave these areas to find haul-out platforms to rest on when in open water.

We documented four instances of ringed seals hauled out on land (Fig. 44), which is considered rare in Alaskan waters (Kelly 1988), although common in other parts of their range, including the Sea of Okhotsk (Ognev 1935), White Sea (Lukin 2006), and has recently become common in Svalbard (Lydersen et al. 2017). Ringed seals that hauled out on land included two males and two females, of which one was a pup (female) and three were adults. The haul-out dates ranged from 2 July to 20 November and durations lasted 6–12 hours. We also documented bearded seals hauling out on land in Kotzebue and Norton sounds. We further documented the high-use of several common spotted seal haulouts on land, near Dease Inlet, Icy Cape, Kotzebue Sound, and Scammon Bay.

When bearded seals hauled out on land, the duration of their haul-outs were shorter than when on sea ice, presumably because they are more easily disturbed on land. Although hauling out on ice, when it is available, is likely preferred because predation risk is lower (i.e., land-based predators cannot access them on ice), all three species did haul out on land during this study.

Use of Sea Ice

Bearded and ringed seals used similar ice concentrations during the same months; low concentrations in September–October and an average of 75% concentration in February–April (Figs. 45 and 47). Spotted seals, on the other hand, used lower concentrations (average 0–40%) regardless of the time of year (Fig. 49).

During the open–water period all species were 250 km or more away from the ice edge (defined as < 15% ice concentration) (Figs. 46, 48, and 50). During the ice-covered season, bearded seals were farthest from the ice edge and into the ice (400 km; Fig. 45), followed by ringed seals (300 km; Fig. 48), and spotted seals (100 km; Fig. 50).

Use of Oil and Gas Areas

All three species used the Chukchi Sea Lease Sale 193 area during the open-water season when industrial activity would be highest. Although more spotted seals were located within the 193 area (n = 9) they used it over a shorter time by entering later in the season (2 August). Spotted seals use of land and their frequent offshore-nearshore movements suggest they could be affected by industry related traffic between the 193 area and shore facilities at Wainwright (between Peard Bay and Utqiaġvik). Spotted seal movements documented during this study began in 2016 and did not overlap with activity within the 193 area, which had ended. Thus, foraging trips from Icy Cape to Herald Shoal that appear to avoid some of the 193 area were not influenced by industrial activity but, instead represent normal movements to and time spent in areas spotted seals preferred to forage.

Ship Traffic
Bearded seals are most likely to be affected by ship traffic because their movements overlap with highly used shipping lanes more often than ringed and spotted seals, especially in Norton Sound in spring and summer and in the eastern Chukchi Sea in fall. Ringed and spotted seals overlap with ship traffic most in the Chukchi Sea in the fall. Inferences regarding overlap between seal movements and the ship traffic data presented here should be made with caution because ship data were collected during 2013–2015. Ship traffic in the northeastern Chukchi Sea likely diminished as the oil and gas activity in the 193 area ended in 2016. On the other hand, as the open-water period has lengthened, cargo traffic may have increased.

Traditional Knowledge
Traditional knowledge related to seals and other marine mammals was collected and reported for 13 communities (Table 6). We published two TEK papers in the peer-reviewed scientific literature based on these reports (Huntington et al. 2016, Huntington et al. 2017). All TEK reports are available at the ADFG webpage:
http://www.adfg.alaska.gov/index.cfm?adfg=marinemammalprogram.traditionalknowledgereports

These interviews contribute substantially to the body of information regarding seal movements and behavior and were extremely valuable to this study. In some cases, hunters provided information that supported telemetry results and in other cases provided information that suggests our telemetry data were biased. Furthermore, they provided additional information that could not be gained from telemetry. Hunters informed us about young bearded seals using the Koyuk River (Appendix D) and estuary near St. Michael (Appendix E). Without this information we would have tagged far fewer bearded seals. TEK regarding areas bearded seals use seasonally and their movements suggest that adult bearded seal behavior is likely different from that of young seals; at least for some areas and times of year.

Limitations of Data
We learned a great deal about three sympatric ice seal species during this study, however, we know some of our results are biased by sample size and by limitations of data collected by satellite-linked transmitters on marine mammals in the marine environment. For example, we know from a previous study that adult and subadult ringed seals behave differently in winter (Crawford et al 2012). Our sample of ringed seals included few subadults, therefore we did not document use of the Bering Sea shelf break in winter by ringed seals. It is likely that our sample of only young bearded seals (no adults) has similar repercussions.

Our data are also seasonally biased because we must wait until after seals molt to attach primary tags. Therefore, sample sizes of tagged seals are biased for the open-water period, during summer and fall, and slowly diminish during winter as battery power drains and tags drop off (Fig. 5). As such, haul-out data collected during the seals' annual molt that could be used to inform correction factors for aerial surveys is limited.

Conclusions

During this study we collected and analyzed extensive data regarding bearded, ringed, and spotted seals throughout their range in Alaskan, Russian, and Canadian waters. We worked with Alaska Native subsistence seal hunters to tag seals near Nuiqsut, Kotzebue, Buckland, Nome, Koyuk, St. Michael, Scammon Bay, and Hooper Bay, and with NSB personnel in Utqiaġvik and Nuiqsut to tag and to train interested hunters. We kept the ISC informed about this project at their annual meetings. We collaborated with MML and NSB by sharing seal tags and data. We made the results of this project available to the communities where seals were tagged and to others interested in seal movements in the Arctic by e-mailing maps, maintaining a webpage, and presenting results in villages during community meetings and tagger trainings. We worked with hunters, communities, and other researchers to learn about movements and habitat use of bearded, ringed, and spotted seals and how they are changing with decreasing sea ice and increasing human activities (e.g., oil and gas and shipping) in the Arctic. We published three papers in peer-reviewed journals containing data from this project: (1) *Effects of changing sea ice on marine mammals and subsistence hunters in northern Alaska from traditional knowledge interviews* (Huntington et al. 2016), (2) *Evaluating the effects of climate change on indigenous marine mammal hunting in northern and western Alaska using traditional knowledge* (Huntington et al. 2017), (3) *A multi-species synthesis of satellite telemetry data in the Pacific Arctic (1987–2015): overlap of marine mammal distributions and core use areas* (Citta et al. 2018). In addition, we have one paper in review, and another in preparation: (1) *Movement, diving, and haul-out behaviors of juvenile bearded seals in the Bering, Chukchi and Beaufort seas, 2014–2018* (Olnes et al. *In review*), (2) *Juvenile bearded seal responses to 10 years of sea ice change in the Bering, Chukchi and Beaufort Seas* (Olnes et al. *In prep.*). We made numerous oral and poster presentations at conferences, symposia, and meetings (See Appendices).

Results from this study contributed to understanding the distribution, movements, and overlap of bearded, ringed, and spotted seals. These include, but are not limited to:

Bearded, ringed, and spotted seals made extensive seasonal latitudinal movements. The extent of those movements, however, depended on where seals were tagged. Bearded seals tagged in the Beaufort Sea did not travel south of 70 °N, while bearded seals tagged in Norton Sound made more extensive movements. Spotted seals tagged in the Beaufort Sea stayed north of 69 °N until they accompanied the advancing sea ice south. Spotted seals tagged in the Bering Sea tended to stay in the Bering Sea. These results have large implications for the interpretation of movements in studies where all seals are tagged in the same location and indicate changes in the design of future telemetry studies are needed.

We summarized the movements of bearded, ringed, and spotted seals, walruses, bowhead whales, gray whales, and beluga whales in the Bering, Chukchi, and Beaufort seas through 2015 and then overlaid these data to identify multi-species core-use areas. In addition to overlapping with other seals, ringed seals overlapped with gray, bowhead, and Norton Sound beluga whales, and walruses in summer and with Eastern Beaufort and Norton Sound stock of beluga whales and walruses in winter. Bearded seals overlapped more with gray whales and Norton Sound belugas than other seals in summer and with Eastern Bering and Chukchi Sea belugas in winter than with other seals. Spotted seals overlapped more with bearded seals than ringed seals but also with walruses, gray, and beluga whales in summer and with all species in winter (Citta et al. 2018).

Recommendations

1. Additional satellite telemetry studies are needed to monitor seal movements and behavior as climate and ocean waters warm and the timing, extent, and availability of sea ice changes. As we demonstrated during this study, seal behavior has changed with changes in sea ice coverage and changes are likely to continue, though we cannot predict what those changes will be. To be effective, mitigation measures for oil and gas activities will likely require changes that can only be determined by continued monitoring of seal movements associated with sea ice through time.

2. There is a need to tag adult bearded seals because we expect their movements and high-use areas may be different from that of young bearded seals. We recommend further work on developing methods to catch adult bearded seals.

3. Seals have become more difficult to hunt, due to larger storms and less, more variable sea ice. We recommend that local and traditional ecological knowledge be updated as the climate continues to warm and sea ice continues to change to better understand how seal behavior changes.

4. A comprehensive analysis of seal interactions with seismic activities and other sources of industrial noise is needed. Seal tracks that spatially and temporally overlap with seismic operations need to be analyzed to learn about seal behavior near seismic activities. Oil and seismic companies need to be forthcoming with their program track lines (location and dates, number of guns used, and time on and off) for this analysis to occur. Removing the geo-reference to where the survey actually occurred could be done to maintain the proprietary nature of the seismic program and still allow the analysis to occur.

5. Offshore industrial activity creates noise that may negatively affect seal behavior. We recommend field testing the Acousonde 3S acoustic tag that combines satellite telemetry and acoustic technology to directly monitor noise levels that seals are exposed to. This tag could be deployed on bearded seals to document how bearded seal vocalizations (e.g., rate, loudness) change with noise level.

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List of Publications and Products

Publications are listed chronologically:

Huntington, H.P., L.T. Quakenbush, and M. Nelson. 2016. Effects of changing sea ice on marine mammals and subsistence hunters in northern Alaska from traditional knowledge interviews. Biology Letters, doi:10.1098/rsbl.2016.0198.

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Abstracts:

Crawford, J. A., M. A. Nelson, L. T. Quakenbush, A. L. Von Duyke, M. Henry, A. Niksik, A. Simon, J. Goodwin, A. Whiting, K. Frost, J. London, and P. Boveng. 2017. Update of hunter-assisted seal tagging and traditional knowledge studies of Pacific Arctic seals, 2016 and beyond. Alaska Marine Science Symposium, 23–27 January, Anchorage, AK. (abstract/poster)

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Other:
Seal and bowhead maps to National Marine Fisheries Service for use in Quintillion Project biological opinion

Ringed seal location and haul-out data were provided to MML to inform correction factors used with aerial surveys to make abundance estimates.

Seal location and haul-out data were provided to the CAFF (Conservation of Arctic Flora and Fauna) marine mammal network group to contribute to a circumpolar assessment of marine mammal hotspots.

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