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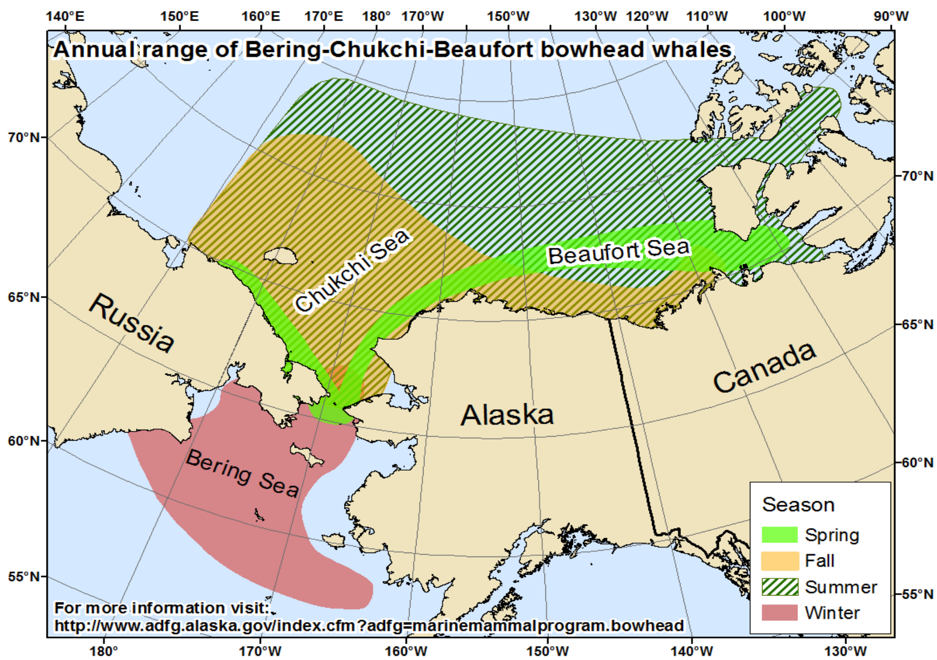
BOEM 2019-076

Satellite Tracking of Bowhead Whales

Habitat Use, Passive Acoustics and Environmental Monitoring
Final Report



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Prepared under BOEM Contract M12PC00005

Satellite Tracking of Bowhead Whales:

Habitat Use, Passive Acoustic, and Environmental Monitoring

Authors

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Prepared under BOEM Contract
M12PC00005
by
Alaska Department of Fish and Game
P.O. Box 25526
Juneau, Alaska 99802-5526

Published by
U.S. Department of the Interior
Bureau of Ocean Energy Management **Anchorage, Alaska**
Alaska Outer Continental Shelf Region **November 2019**

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CITATION

Quakenbush, L.T., and J.J. Citta. 2019. Satellite tracking of bowhead whales: habitat use, passive acoustic, and environmental monitoring. U.S. Dept. of the Interior, Bureau of Ocean Energy Management, Alaska Outer Continental Shelf Region, Anchorage, AK. OCS Study BOEM 2019-076. 60 pp + appendices.

Project Organization Page

Authors:
Lori Quakenbush is a Fish and 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, report writing, and manuscript preparation.

John J. Citta is a Biometrician II with the Arctic Marine Mammal Program within the Alaska Department of Fish and Game. His role in this project was data analysis, management, and archive, coordination and tagging, map production and distribution, presentations, and report, and manuscript preparation.

Key Project Personnel:
John "Craig" George is a Senior Wildlife Biologist for the North Slope Borough (NSB), Department of Wildlife Management. He is a bowhead whale expert and his role in this project was to coordinate project and tagging activities in the NSB, communicate with the Alaska Eskimo Whaling Commission and Whaling Captain's Associations, and review manuscripts.

Mads Peter Heide-Jørgensen is a Senior Scientist with the Greenland Institute of Natural Resources and is an expert in tagging large whales in Greenland, Canada, Russia, and South America. His group, which includes Mikkel and Anders Jensen, has developed and provided the tag attachment anchors and some of the tag deployment equipment. Mikkel and Anders Jensen also deployed tags and trained others in tag deployment.

Lois Harwood is a Wildlife Biologist with the Arctic Aquatic Research Division, Department of Fisheries and Oceans Canada. She provided coordination, contracting, permitting, personnel, and secured funding for tagging operations in Canada.

Ellen Lea is a Wildlife Biologist with the Department of Fisheries and Oceans Canada. She provided logistics, coordination, and permitting for tagging operations in Canada.

Harry Brower, Jr., Lewis Brower, Billy Adams, Tom Akeya, and Clarence Irrigoo are Alaskan Subsistence whalers who were key participants as taggers and boat drivers.

James Pokiak, Charles Pokiak, Gary Raddi, and Dennis Arey are Canadian hunters and trappers who were key participants as taggers and boat drivers.

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Executive Summary

The bowhead whale (*Balaena mysticetus*) is a highly valued subsistence species in Alaska due to its nutritional and cultural significance and importance to Beaufort, Chukchi, and Bering Sea communities. Summer habitats and the fall migration route of bowhead whales coincide with areas of interest for oil and gas development, and their spring and fall migration routes through Bering Strait overlap with shipping lanes, therefore information is needed to better understand bowhead migration routes and feeding areas to plan lease sales, permit development activities, design shipping lanes, and provide effective mitigation measures. A combination of satellite-linked tag technology and skilled tag deployment by Native subsistence whalers used in this study greatly increased our knowledge of bowhead whale movements and behavior. Objectives for this project period (September 2012–September 2019) included: a) improving and deploying tags that collect acoustic and environmental data; b) evaluating bowhead vocalization rates and assessing if all bowheads migrate to the Canadian Beaufort in spring; c and d) determine if bowheads observed in summer near Point Barrow are returning from the Canadian Beaufort or if they are late arrivals from the Chukchi Sea; e) determine if the tagged sample of whales is representative of the population; f) determine the residence time of whales near Point Barrow; g) estimate the rate and timing of travel of whales during migration across the Beaufort and Chukchi seas; determine the general pattern of movements and the variability in those movements; and i) tag other species of whales, if possible. All objectives were successfully met, except for deploying satellite-linked acoustic tags to determine bowhead vocalization rates in Alaskan waters. The satellite-linked acoustic tag was developed (but not deployed) and bowhead vocalization data were collected in Greenland and used for tag testing; hence this objective was partially accomplished.

During this project period, we tagged 28 bowhead whales. However, we used all available data from this and previous bowhead projects for our analyses. In all, 89 bowheads were tagged during 2006–2018, 77 of which provided sufficient location data for use in analyses. Note that different sample sizes occur across analyses, because analyses require differing amounts of information and tags provide differing amounts of data. For example, a tagged bowhead may leave the Bering Sea in spring and provide a reliable date of exit through Bering Strait, but may not transmit while rounding Point Barrow, resulting in data that are useful for determining the date of exit from the Bering Sea, but not the date of entry into the Chukchi Sea. This tag may begin transmitting again, providing sufficient data for other analyses. All tags collected dive data and temperature profiles (SPLASH10 and CTD tags); 10 tags also collected salinity profiles (CTD tags). The tagged sample was skewed toward immature males, possibly because females with calves were avoided during tagging, and although adding 10 adult females to the sample would make it more representative of the population, the addition would not substantially alter these results.

Bowhead whales typically begin migrating northwards from wintering grounds in the western Bering and southern Chukchi seas in mid-April before the Bering Sea is ice-free. Twelve tagged whales provided enough data to determine when they left the Bering Sea and passed Point Barrow, a journey that required approximately 12 days. For whales migrating to the Canadian Beaufort, which is something almost all whales do (76 of 77 tagged whales that provided location data during spring and summer or autumn), most of the migration through the Chukchi

Sea occurs within 50 km of the Alaskan coastline. Once past Point Barrow, migrating whales travel farther from shore, mostly between 80 and 250 km of the Alaskan coastline in the Beaufort Sea. Whales take a generally direct path from Point Barrow to the recurrent polynya at Cape Bathurst and tend to linger near the polynya until sea ice leaves Amundsen Gulf.

Almost all bowhead whales migrate to the Canadian Beaufort each spring. Only 1 of 26 (~4%) whales that provided location data during the spring migration did not migrate to Amundsen Gulf, Canada. This whale, B09-09, tagged near Point Barrow the prior autumn, did not leave the Bering Sea until 26 May, at which time it migrated up the coast of Chukotka Russia and spent the entire summer in the Chukchi Sea. This is consistent with spring surveys on the Russian coast, which indicate that perhaps 500 whales, out of a population of over 16,000 (~3%), may migrate up the Russian coast each spring and do not go to Canada.

Although most whales summer in the Canadian Beaufort Sea, some (n = 8) will leave there, in June and July, well before the usual autumn migration in late August and September. Five whales traveled west into the Alaskan Beaufort Sea, three of which passed west of Point Barrow, and then returned to the Canadian Beaufort prior to the autumn migration, thus adding an additional round trip to the spring and fall migrations. Two whales migrated to Russia in mid-summer. One whale left Amundsen Gulf and traveled north to the Northwest Passage (Viscount Melville Sound) where it remained until late August. Hence, the summer distribution of bowhead whales is much more dispersed with more complicated movements than originally thought.

The autumn migration is not as directed as the spring migration. For example, the average travel time in days between Point Barrow and Demarcation Point (at the boundary between U.S. and Canadian waters in the Beaufort Sea) averages 9 days in the spring and 19 days in the autumn. Likewise, the average travel time between Bering Strait and Point Barrow is 12 days in spring and 70 days in autumn. Residence times at Point Barrow range from 1–34 days; with longer periods of residence in the autumn ($\bar{x}$ = 8.4 d) than the spring ($\bar{x}$ = 2.8 d). On average, tagged whales passed west into Alaskan waters on 17 September, passed Point Barrow on 25 September, and entered the Bering Sea on 2 December.

The autumn migratory corridor in the Chukchi Sea between Point Barrow and Bering Strait, which includes the time bowheads spent in the Chukchi Lease Sale 193 area, was found to vary among years with an increase in use of the north-central Chukchi Sea and a decrease in use of the coast of Chukotka, Russia, during later years of the study. The shift towards more use of the north-central Chukchi Sea has implications for oil and gas development within the Chukchi Sea. This shift in autumn movements appears to be related to prey availability as determined by oceanographic factors that concentrate krill.

Six areas where whales spend time, and are likely feeding, were identified throughout their annual range; two in Canada (Cape Bathurst in spring, and the Tuktoyaktuk Shelf in summer); one in Alaska (Point Barrow in summer and autumn); and three in Russia (Northern Chukotka with Bering Strait in autumn, Anadyr Strait in winter, and the Gulf of Anadyr in winter). Oceanographic factors that concentrate krill were identified in each area and help explain conditions that drive bowhead movements. Diving data indicated that bowheads dove frequently to the bottom in winter and are likely feeding then, which was not previously known.

In addition to a shift away from the northern coast of Chukotka, Russia, towards the northcentral Chukchi in autumn, we also detected a northward shift in bowhead winter range related to declining sea ice. We suspect wintering farther north in the Chukchi Sea will occur more often with more years of light ice conditions.

In addition to the changes mentioned in this report, few bowheads passed near Point Barrow during September and October 2019 and only one whale was harvested at Utqiaġvik in November, which has never happened before. No satellite transmitters were active and aerial surveys saw too few bowheads to determine the migration route. Russians along the northern Chukotka coast, however, observed many bowheads there in mid- to late October indicating that most bowheads migrated well offshore in 2019.

Due to changes in bowhead movements documented by these studies during 2006–2018 we recommend that tagging studies be continued to monitor changes in movements if the climate continues to warm. Using tags that provide temperature and salinity data will also further our understanding of the oceanographic features that aggregate bowhead prey that appear to drive bowhead movements. In addition to tagging, we recommend local and traditional ecological knowledge be collected to document what whalers are observing now and how it compares to the past. Offshore industrial activity and shipping within the bowhead range creates noise that may negatively affect bowhead whale behavior. The acoustic tag (Acousonde 3S) developed during this study should be field tested and used to measure ambient noise relative to bowhead vocalization rates. As sea ice declines more gray whales and killer whales are likely to summer in the Bering, Chukchi, and Beaufort seas and stay longer. Future studies should include these little-known species that will be present during future oil and gas activities in the Alaska Region.

Introduction

The bowhead whale (*Balaena mysticetus*) is a highly valued subsistence species for its nutritional and cultural significance and is important for many Beaufort, Chukchi, and Bering Sea communities. Bowhead whale summer habitats and fall migration route coincide with areas of interest for oil and gas development, and spring and fall migration routes through Bering Strait overlap with shipping lanes. Therefore, information is needed to better understand bowhead migration routes and feeding areas to plan lease sales, permit development activities, design shipping lanes, and provide effective mitigation measures. A combination of satellite tag technology and skilled tag deployment by Native subsistence whalers used in this study greatly increased our knowledge of bowhead whale movements and behavior. Our previous BOEM studies (2006–2012) provided data on the movements and timing of spring migration, rate of travel, ice conditions along the spring migration route and at spring destinations. We documented interactions with seismic operations and summer movements beyond the known range of the western arctic stock of bowhead whales. We documented fall use of the Point

Barrow area, fall migration behavior through Chukchi Sea Lease Sale 193 area[1], and intensive use of the northern Chukotka coast as well as the timing and route into the Bering Sea for winter (Quakenbush et al. 2010a, b; Citta et al. 2012). We found that most tagged bowhead whales wintered in the western Bering Sea in heavy ice with little use of polynyas, the marginal ice zone, or near shore areas (Citta et al. 2012). Diving data indicated that bowheads dove frequently to the bottom and are likely feeding in winter (Citta et al. 2012, 2015). Cooperative efforts with local Alaska Native whalers, the Alaska Eskimo Whaling Commission, the North Slope Borough, the Greenland Institute of Natural Resources, the Department of Fisheries and Oceans Canada and the local Canadian Hunters and Trappers Associations used in previous studies were also effective in this study to further describe the year-round movements and behavior of the western Arctic stock of bowhead whales. Specifically, we expanded sample sizes to better address summer movements, fall migration in the Beaufort Sea and to further evaluate the inter-annual variability of feeding areas and migration routes.

This study was conducted during 2013–2019 (including a no cost extension) and is a continuation of the study that began in 2006. We have expanded on the movements and timing of movements during the fall migration across the Chukchi Sea and the amount of time whales spent in the Chukchi Lease Sale 193 area (Quakenbush et al. 2010a, b) by analyzing oceanographic processes that are likely to concentrate zooplankton (Citta et al. 2015, 2018a). Two bowheads traveled far to the north and entered the Northwest Passage; one used an area frequented by the eastern Arctic bowhead stock (Heide-Jørgensen et al. 2011). Another bowhead tagged whale, tagged near Point Barrow during the fall migration, did not pass Barrow into the Beaufort Sea the following spring but spent the summer in the Chukchi Sea (Citta et al. 2012; Quakenbush et al. 2012). We also identified six core-use areas we believe to be important for bowhead feeding; the suitability of these areas for feeding appears to be dependent upon oceanographic conditions, which may be ephemeral (Citta et al. 2015).

While most objectives of the current phase of the study are focused on continued documentation of year-round movements and the inter-annual variation of those movements and concentration areas using conventional satellite tags, one objective is to develop an acoustic tag that documents ambient environmental sound and sounds made by bowhead whales. An acoustic tag will allow bowhead vocalization rates to be monitored relative to ambient noise levels including those elevated by vessel traffic, seismic operations, drilling and construction. Although a few tags collect acoustic data, they have short deployment durations (days), they do not transmit those data to satellites and the tags must be retrieved to obtain the data. Retrieving tags deployed on the Bering-Chukchi-Beaufort stock of bowhead whales is extremely difficult. Acoustic information, however, is needed to interpret data collected by passive acoustic recorders and to better understand bowhead whale behavior relative to noise associated with oil and gas activities and shipping. Therefore, we developed a tag that summarizes acoustic data and transmit them to satellites so that the tag can provide data for a longer time (less battery requirements) and does not need to be retrieved.

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[1]All leases from Chukchi Lease Sale 193 have been relinquished.

Objectives
This study was designed to provide data to address the objectives listed below and for data to be integrated with concurrent research on oceanographic conditions relative to variability in bowhead whale feeding behavior and habitat use. Specific objectives include:

Objective a**:** Modify and improve, test, and deploy tags that collect acoustic and environmental data for use on bowhead and other large whales. Such tags may measure environmental conditions including ambient noise and physical ocean conditions.

Objective b**:** Evaluate bowhead whale vocalization rates related to various behaviors or potential disturbances with tagging representative of the demographic composition of the population. Test the general hypothesis that all bowhead whales in the western Arctic stock make seasonal migrations between the Bering Sea and the summer feeding grounds in western Canada.

Objective c: Test the related hypothesis that occasional concentrations of whales feeding in the nearshore waters of the Beaufort Sea, east of Barrow and in the Chukchi Sea, west of Barrow are a result of delays in migration by whales returning from summering in Canada.

Objective d: Test the alternate hypothesis that the above occasional concentrations of whales feeding in the Beaufort Sea east of Barrow and in the Chukchi Sea west of Barrow are composed of whales that generally summer in the eastern Chukchi Sea and only enter the southwestern Beaufort Sea periodically, and under certain oceanographic conditions.

Objective e**:** To the extent possible, test the hypothesis that the above concentrations of whales consist of representative proportions of demographic (sex and age, i.e., size) groups as observed in the western Arctic bowhead population.

Objective f**:** Test the hypothesis that the above concentrations of bowhead whales consist of individuals that are only present in the aggregations for hours to days as opposed to weeks to months.

Objective g: Estimate the rate and timing of travel of whales during migration across the Beaufort and Chukchi seas.

Objective h: To the extent possible, document and describe the general pattern and variability in inter-year year-round movements by bowhead whales, the degree to which migrating whales make use of specific polynyas or channels, and estimate for individual whales time budgets of time spent in specific geographic regions and/or functional habitat areas.

Objective i: Instrument other species of baleen whales when encountered during bowhead tagging efforts when practical.

Methods

Coordination

Meetings, workshops, other communication. Meeting with the Alaska Eskimo Whaling Commission (AEWC), local Alaska whaling captains, the North Slope Borough (NSB), Tuktoyaktuk Hunters and Trappers Committee was fundamental to this tagging project. Meetings with Greeneridge Sciences, Inc. and Scripps Institution of Oceanography were important for acoustic tag development.

Acoustic Tag and Telemetry Development

One objective of this project was to develop an acoustic recording tag that could not only detect vocalizations of tagged bowhead whales, but also other sounds in their environment (e.g., seismic pulses and the ambient background) and transmit summarized acoustic data (or digests) of those data via satellite. These capabilities are needed to understand the acoustic exposure and potentially associated behavior of bowhead whales over time scales of several weeks to months without the extreme difficulty and logistical expense of tag retrieval in the Arctic.

Acoustic detection and digestion have historically required substantial software complexity and power, making them difficult to implement in the context of a miniature battery-operated tag. Our collaborator, Mads Peter Heide-Jørgensen of the Greenland Institute of Natural Resources (GINR), determined that the best chance of developing a satellite-linked acoustic recording tag was to use an existing acoustic recording tag design rather than starting from scratch. He explored two existing designs, and identified the Acousonde, a commercially available tag made by Bill Burgess at Greeneridge Sciences, Inc., as the most promising foundation for our application. We contracted Greeneridge to extend the Acousonde design to support acoustic detection and digestion as well as satellite telemetry. GINR contracted Aaron Thode of the Scripps Institution of Oceanography to write detection and digestion software specific to our scientific goals for use with the new Acousonde.

Satellite tags

For the deployment of satellite-linked tags, we relied on the deployment and attachment developed by GINR (i.e., Mads Peter Heide-Jørgensen and his assistant, Mikkel Jensen) that had been used successfully with bowhead whales in our previous studies in Alaska, and Canada, as well as in Greenland and with endangered northern right whales (*Eubalaena glacialis*) in the Bering Sea (Heide-Jørgensen et al. 2001, Heide-Jørgensen et al. 2003). Most of our tags were deployed from boats by subsistence whalers with a pole.

During the current project, we primarily deployed two types of satellite-linked tags, SPLASH10 tags and SMRU CTD tags. Both tags collect location data through the ARGOS satellite system; however, the two tag types collect different environmental variables and dive summaries. We detail the differences below.

SPLASH10 tags are manufactured by Wildlife Computers, Inc. (Redmond, WA, USA) and use the Argos system of satellites. SPLASH10 tags collect dive information in four formats:

1) *Dive histograms* are summaries for the number of dives falling into different depth bins (depth histograms), the proportion of times spent in each depth bin (time-at-depth

histograms), or the number of dives of different durations (dive duration histograms). The summary period was 6 hours. The upper threshold of histogram bins are user specified before the tag is deployed. Histogram threshold depths for depth and time-at-depth histograms were 2, 10, 20, 30, 40, 50, 75, 100, 150, 200, 250, 300, 350, and >350 m. The final bin included all data on dives deeper than 350 m. Histogram threshold times for dive duration histograms were 1, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60 and >60 minutes. The final bin included all data on dives longer than 60 minutes.

2) *Time series depth-temperature profiles* are messages with paired depth and temperature readings for the deepest dive in a 6-hr period. This setting collects paired depth and temperature readings in a time-series with 10 second spacing. These messages are sometimes very large if dives are very long.
3) *Depth-temperature profiles* record the minimum and maximum temperatures observed at 8 depths. The depths are chosen dynamically to include the minimum and maximum depths detected, and 6 other intermediate depths arranged equally between the minimum and maximum. Hence, they provide more detail than a dive histogram, which covers a 6-hr period, but not as much data as a true time-series.
4) *Dive behavior* records the maximum depth and duration of a dive, along with its general shape. Possible shapes include "square," "V," or "U" shapes. Additionally, "V" and "U" shapes can be skewed right or left. This setting also records how much time is spent at the surface.

Each setting requires a differing amount of battery resources and messages are of different length. The *time series depth-temperature profiles* are long messages that are difficult to transmit to a satellite. The *dive histograms*, *depth-temperature profiles*, and the *dive behavior* messages are compressed data that are easier to transmit. As such, we have programmed tags to collect dive histograms, d*epth-temperature profiles* and *dive behavior* data. Currently tags are programmed to send a maximum of 200 transmissions every other hour to maximize battery life and to provide even coverage throughout the day. These settings were selected after inspection of previously collected data and through trial-and-error. SPLASH10 tags are capable of collecting other types of dive data; however, after careful review we found that those data types listed above provided the best summaries of dive behavior. For example, SPLASH10 tags will record another type of dive profile (PAT-style profiles); however, these depth-temperature profiles are limited to temperature readings above 0° C because the settings were designed for dolphins in temperate and tropical waters. SPLASH10 transmitters measured 8.5 x 5 x 2.5 cm and weighed 300 grams with the tag anchor.

The other satellite-linked transmitter we deployed was the SMRU CTD transmitter. Currently, the Sea Mammal Research Unit of St. Andrews, Scotland, produces the only true Conductivity (i.e., salinity), Temperature, and Depth (CTD) transmitters. These tags transmit a sample of dive profiles that pair depth readings with salinity and temperature. This differs from the SPLASH10 tag in that the SPLASH10 tag only reports depth and temperature and does not have a salinity sensor (note that Wildlife Computers is experimenting with salinity sensors, however, these tags are not commercially available). As with the SPLASH10 tags, the CTD tags will also transmit the dive shape and dive duration for a sample of dives. The SMRU CTD tags measured 12 x 6.5 x 6.5 cm and weighed 685 grams with the tag anchor.

Both tags were mounted on a stainless-steel anchor plate that swivels around the tag anchor shaft, allowing the transmitter to move to the position of least hydrodynamic resistance. When deployed, the tags and their mounting plates sit on top of the whale's skin and the anchor shaft, with cutting head and flexible barbs, extend ≤ 21 cm into the skin and blubber (but not into a bowhead's muscle layer). Tags were deployed with a 2 or 4-m long fiberglass pole system (Heide-Jørgensen et al., 2003). The pole was used as a harpoon to tag whales at 2–4 m. The pole system included a biopsy tip (manufactured by CETA-DART, Denmark), a 4 cm-long, 6 mm wide (inside diameter), stainless steel hollow cylinder with internal barbs, designed to obtain a skin biopsy during tag deployment that could be analyzed to determine gender of tagged whales. Most tags were deployed from aluminum boats (~5.5–6.1 m long) with outboard motors.

During the project period, we deployed only one SPOT tag. SPOT tags provide location but no dive or environmental data. This tag type was commonly used prior to the current project period and was available for deployment, however, we found that the tag duration was equal to that of a SPLASH10, which also provides dive and environmental data. Therefore, we stopped using SPOT tags in 2013.

Genetic Analyses

Biopsy tips were mounted on the deployment poles so that a skin sample was collected as the tag was deployed (Heide-Jørgensen et al. 2003). DNA was extracted and analyzed to determine sex by genetics experts at the National Marine Fisheries Service, Southwest Fisheries Science Center and at Texas A&M University and then archived. Genetic material from this archive was also used to determine that the western Arctic population of bowhead whales is comprised of one stock; a conclusion accepted by the International Whaling Commission.

Mapping

To keep all interested parties informed of tagged whale movements, maps were made on a weekly basis and sent to a mailing list (~250 recipients) that included whalers, other subsistence hunters, as well as agency personnel. ArcGIS version 9.2 (ESRI 2006) was used for all mapping. These maps and information about the project are also posted at the Alaska Department of Fish and Game's (ADFG) website:
http://www.adfg.alaska.gov/index.cfm?adfg=marinemammalprogram.bowhead

Data Analyses

We provide many analyses using bowhead location and dive data. During this project period, we tagged 28 bowhead whales. However, we used all available data from this and previous bowhead projects for our analyses. In all, 89 bowheads were tagged during 2006–2018, 77 of which provided sufficient location data for use in analyses. Note that different sample sizes occur across analyses, because analyses require differing amounts of information and tags provide differing amounts of data. For example, a tagged bowhead may leave the Bering Sea in spring and provide a reliable date of exit through Bering Strait, but may not transmit while rounding Point Barrow, resulting in data that are useful for determining the date of exit from the Bering Sea, but not the date of entry into the Chukchi Sea. This tag may begin transmitting again, providing sufficient data for other analyses. Methods specific to each analysis are included in the documents provided in the Appendices and in our publications.

1. *Overlap of bowhead winter range with pot fisheries:* Eskimo whalers were concerned with how the winter distribution of bowhead whales may overlap with the Bering Sea pot fisheries. We accessed pot fishery data from NOAA and ADFG and overlaid this information with bowhead whale location data (Citta et al. 2014).

2. *Bowhead distribution for oil-spill response mapping:* At BOEM's request we produced bi-weekly density maps of bowhead whale locations for use in oil-spill response planning (Appendix D).

3. *Oceanographic characteristics of bowhead whale hotspots:* As part of the BOEM-funded SOAR initiative, we collaborated with oceanographers (Drs. Stephen Okkonen and Weislaw Maslowski), a zooplankton scientist (Dr. Carin Ashjian), and a sea ice specialist (Dr. Matthew Druckenmiller) to examine the physical environment within areas where bowhead whales aggregate (Citta et al. 2015). This analysis used bowhead whale location and dive data. This was part of the BOEM-funded SOAR (Synthesis of Arctic Research) initiative.

4. *Analysis for NOAA's biological opinion on the Quintillion Subsea Operations, LCC, proposal to lay subsea cable in the Bering, Chukchi, and Beaufort Seas:* NOAA requested that we provide distribution data for bowhead whales, ringed seals, and bearded seals in order to write a biological opinion on a proposal by Quintillion's proposal to lay a subsea cable in the Bering, Chukchi, and Beaufort Seas. We overlaid the map of cable-laying operations with location data for bowhead whales (Appendix O).

5. *Movements and inferred foraging of whales in the Canadian Beaufort in August and September:* We collaborated with Lois Harwood (Department of Fisheries and Oceans Canada) to describe movements and residence times of bowhead whales on their autumn feeding grounds in the Canadian Beaufort (Harwood et al. 2017).

6. *Analysis for NOAA's biological opinion on the Liberty Development and Production Project:* At the request of NOAA, we provided distribution information for bowhead whales (using data collected during this project period), ringed seals, and bearded seals (Appendix U).

7. *Oceanographic characteristics associated with autumn movements of bowhead whales in the Chukchi Sea:* We collaborated with oceanographers (Drs. Stephen Okkonen and Weislaw Maslowski) to model how oceanographic features determined where bowhead whales stop to feed within the Chukchi Sea (Citta et al. 2018a). This analysis was part of the BOEM-funded SOAR II initiative.

8. *Trends in sea ice and bowhead distribution within the Alaskan Beaufort Sea:* We collaborated with Dr. Matthew Druckenmiller at the National Snow and Ice Data Center to analyze trends in sea ice within bowhead whale use areas as defined by aerial survey

data from the BOEM-funded ASAMM project and satellite telemetry data (this BOEM-funded study). The goal of this analysis was to better understand bowhead whale movements relative to decreased ice in the Beaufort Sea (Druckenmiller et al. 2018). This analysis was part of the BOEM-funded SOAR II initiative.

9. *Multi-species overlap within the Pacific Arctic:* We summarized satellite tagging studies of most species of marine mammals in the Bering, Chukchi, and Beaufort seas and then examined the spatial and temporal overlap among species (Citta et al. 2018b). For this project, we collected all the satellite telemetry data available for bowhead, gray, and beluga whales, ringed, spotted, and bearded seals, and walruses. We calculated utilization distributions (i.e., the spatial density of satellite telemetry locations) for each species and then overlapped all the distributions to identify winter (December-April) and summer (May-November) multi-species hotspots. In effect, we identified areas important for multiple species. This analysis was part of the BOEM-funded SOAR II initiative and included both bowhead and gray whale location data collected during this project.

10. *Camden Bay Collaborative Study:* The Camden Bay Collaborative Study is a partnership between the Alaska Eskimo Whaling Commission, the North Slope Borough, and Shell Offshore, Inc. The goal of the collaborative study is to integrate what is known about Camden Bay, including bowhead whale use of the area, for the development of improved mitigation measures to protect the availability of bowhead whales for subsistence hunters in Kaktovik and Nuiqsut while allowing industry to explore and potentially develop oil and gas resources in the area. The collaborative study requested that we summarize bowhead movements in Camden Bay (Appendix T).

11. *Bowhead movements and dive behavior in the Alaskan Beaufort Sea:* We analyzed movements and dive behavior of bowhead whales within the Alaskan Beaufort Sea (Olnes et al. *In review*). The goal of this analysis is to address how important the Alaskan Beaufort Sea is for whale foraging (See Results).

12. *Shifts in the winter distribution of bowhead whales:* In recent years, bowhead whales have shifted their winter distribution northwards. We are currently working on an analysis aimed at understanding how and why bowhead whales have shifted their winter distribution in the Bering Sea (See Results) (Citta et al. *In prep*).

13. *Bowhead book chapter:* For an upcoming book on bowhead whale biology, we prepared a chapter that summarized what we have learned about the distribution and behavior of bowhead whales via satellite telemetry (Citta et al. *In press*). The book editors are Drs. Hans Thiewessien and John Craighead George and the publisher is Elsevier.

Data Management

A copy of the raw Argos data (with associated metadata) is archived at ADFG in Fairbanks and backed-up on State of Alaska servers in Fairbanks and Juneau. The ‘raw data’ include location, dive, and oceanographic data types. We also archived a decoded copy of the data. We worked with the Animal Telemetry Network (ATN) and the Alaska Ocean Observing System to fulfill their goal to receive and view telemetry data in almost real time and for providing necessary metadata so that archived data can be used appropriately in the future. Since 2018, location data from bowhead tags has been sent directly to the ATN. Although ATN is also interested in archiving bowhead data collected prior to 2018 they do not currently have the capacity.

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 into histogram categories. Even seemingly simple tasks, such as calculating correction factors for aerial surveys, require detailed knowledge of how tags were programed to sample their environment, such as how often they turn on or how “dry” conditions are sensed. Determining how to proceed with data management and analysis requires substantial time and expertise. Although we have the expertise to manipulate the raw data, we are concerned that future users may face difficulties doing so. Because of this, we are exploring what level and complexity of metadata are necessary for future users to adequately understand what can and should not be done with the data we collected. We are also looking into archiving data products that end-users may wish, thereby removing the responsibility of decoding, analyzing, and interpreting raw data.

Results

Coordination

We worked with the AEWC, local whaling captain’s associations, the North Slope Borough (NSB), Greeneridge Sciences, Inc., the Greenland Institute of Natural Resources (GINR), the Department of Fisheries and Oceans (DFO) Canada and the Tuktoyaktuk Hunters and Trappers Committee, and BOEM. See Table 1 for project history by month and year. We maintained a webpage on the ADFG website updated weekly with whale movements and information (http://www. adfg.alaska.gov/index.cfm?adfg=marinemammalprogram.bowhead). We sent maps to an extensive list of interested entities including individual whalers and whaling captains, oil and gas industry personnel, NOAA, NSB, DFO, and BOEM.

Table 1. Project history from September 2012 through September 2019. Appendices are referenced here in chronological order.

Month	Year	Event
September	2012	BOEM contract to ADFG signed, project begins. Two bowheads tagged near Barrow (first CTD tag and first advanced SPLASH tag deployed).
October		Update on project presented to AEWC.
November		Oral presentation *Industrial activities and western Arctic bowhead whales: what we have learned from satellite telemetry* at U.S.-Canada Oil and Gas Conference in Anchorage (Appendix A).
December		Shared data for use in planning shipping lanes through Bering Strait.
January	2013	Presented poster “*Industrial activities and western Arctic bowhead whales: what have we learned from satellite telemetry*” at AMMS in Anchorage (Appendix B).
February		Met with crews in Gambell and Savoonga to prepare for spring tagging.

May		Met with taggers in Barrow.
June		Manuscript "*Interactions of bowhead whales and winter pot fisheries in the Bering Sea*" published Marine Mammal Science (Citta et al. 2013).
July		Update to AEWC (Appendix C).
August		Gray whale tagging near Gambell cancelled due to strong winds. Submitted Technical Report: "*Kernel densities of locations from satellite-tracked bowhead whales, 2006–2012, for oil spill response analysis"* to BOEM (Appendix D).
September		Presented at the 40th Anniversary of the Environmental Studies Program. Manuscript "*Presence and behavior of bowhead whales (*Balaena mysticetus*) in the Alaskan Beaufort Sea in July 2011*" published Polar Biology (Christman et al. 2013).
October		Update to AEWC in Anchorage (Appendix E).
December		Poster "*Ecological characteristics of core areas used by western arctic bowhead whales, 2006–2012*" at Marine Mammal Conference in New Zealand (Appendix F).
January	2014	Poster "*Ecological characteristics of core areas used by western arctic bowhead whales, 2006–2012*" at AMSS in Anchorage (Appendix F).
February		Met with crews in Gambell and Savoonga to prepare for spring tagging.
March		Reviewed maps for Oceana Marine Subsistence Use Data Synthesis. Participated in International Whaling Commission Workshop on Impacts of Increased Marine Activities on Cetaceans in the Arctic.
May		Submitted renewal application for Cetacean Research Permit to NMFS.
June		Provided boat safety training classes in Tuktoyaktuk required by Canada for local tagging crew.
July		Presentation to NSB/Shell Baseline Studies Program and AEWC for Camden Bay Collaborative Study. Consulted with BOEM to determine an appropriate response to many requests by prospective contractors applying to the MARES request for proposals.
August		Tagged two bowheads near Tuktoyaktuk, Canada. Gray whale photo-ID attempted near Gambell, weather too windy.
September		SOAR manuscript "*Ecological characteristics of core areas used by western Arctic bowhead whales, 2006–2012*" published online by Progress in Oceanography (Citta et al. 2015).
November		Presentation to NMFS MMPA Arctic Monitoring Strategy Meeting on how bowhead satellite telemetry results may be useful for developing monitoring for oil and gas mitigation.
January	2015	Met with Tuktoyaktuk Hunters and Trappers in Tuktoyaktuk, Canada, to coordinate 2015 tagging efforts. Poster "*Inter-annual variability in the fall movements of bowhead whales in the Chukchi Sea*" at AMSS in Anchorage (Appendix G).
February		Met with crews in Gambell and Savoonga to prepare for spring tagging. Guest Lecture on bowhead tracking project highlights to Marine Mammal Class at the University of Alaska.

March		Bowhead tracking project highlights to University of Alaska, School of Fisheries and Ocean Sciences seminar and at the Indigenous People's Council of Marine Mammals annual meeting. Gambell and Savoonga crews begin spring tagging efforts.
July		Project update to AEWC in Fairbanks.
August		SOAR I manuscript "*Ecological characteristics of core-use areas used by Bering-Chukchi-Beaufort (BCB) bowhead whales, 2006–2012*" published in Progress in Oceanography (Citta et al. 2015).
December		Presentations at the Biennial Conference on Marine Mammals in San Francisco; 1) *Why bowheads migrate* (Appendix H), 2) *Short-term effects of tagging on West Greenland bowhead whales* (Appendix I), 3) *Late summer aggregations of bowhead wales in the Canadian Beaufort Sea region, 2006–2012* (Appendix J), and 4) *Inter-annual variability and oceanographic correlates of bowhead whale movements in the Chukchi Sea* (Appendix K).
January	2016	Oral presentation "*Oceanographic characteristics associated with bowhead behaviors in the Chukchi Sea*" at AMSS in Anchorage (Appendix L).
April		Acoustic tags deployed in Greenland for a total of ~34 hrs of recordings (Appendix M).
June		Received new Cetacean Research Permit from NMFS.
August		Shore-based and offshore tagging crews began working near Tuktoyaktuk. TEK manuscript "*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). Few whales seen near Tuktoyaktuk, none tagged possibly due to dominant west winds impeding upwelling for good feeding conditions.
September		Few whales seen near Tuktoyaktuk.
December		Requested and received no cost extension to new end date of 2019.
January	2017	Poster "*Dive behavior of bowhead whales within the Cape Bathurst polynya*" at AMSS (Appendix N).
May		Aerial Surveys of Arctic Marine Mammals (ASAMM) requested an analysis of telemetry data to estimate a correction factor to provide a minimum bowhead population estimate from large numbers of bowheads observed during aerial surveys in the western Beaufort in August 2016 to present to the International Whaling Commission. We provided maps on bowhead whale and ice seal presence relative to fiber optic cable work by Quintillion to NMFS (Appendix O).
June		Manuscript "*Movements and inferred foraging by bowhead whales in the Canadian Beaufort Sea during August and September, 2006–2012*" (Harwood et al. 2017) published in Arctic.
July		Presented analysis of bowhead and crab fisheries overlap to AEWC to address recent bowheads entangled in pot gear.

August		Tagged seven bowheads near Tuktoyaktuk, Canada.
September		Presented project update and request for tagging to Barrow Whaling Captains meeting in Utqiaġvik (Appendix P). They approved tagging after fall whaling. Manuscript "*Evaluating the effects of climate change on Indigenous marine mammal hunting in northern and western Alaska using traditional knowledge*" published Frontiers in Marine Science (Huntington et al. 2017).
October		Oral presentation titled "*Dive behavior of bowhead whales within Cape Bathurst polynya*" at Society for Marine Mammalogy Conference, Halifax, Nova Scotia, Canada (Appendix Q). Met with Greeneridge Sciences and Scripps Institute of Oceanography in Halifax to discuss acoustic tag details for interfacing the software to summarize the acoustic data for transmission to satellites.
December		Presented a project summary and data issues to consider at the AOOS Animal Telemetry Network Workshop in Anchorage. Update to AEWC in Anchorage.
January	2018	Poster "*Summer movements of western Arctic bowhead whales outside of the Canadian Beaufort Sea*" at AMSS (Appendix R).
March		Submitted paper "*Bering-Chukchi-Beaufort stock of bowhead whales: 2006–2017 satellite telemetry results with some observations of stock sub-structure*" to International Whaling Commission (Appendix S).
April		Prepared 2017 maps of whale movements for Tuktoyaktuk HTC. Presented bowhead movements and behavior for the Camden Bay/Central Alaskan Beaufort Sea Collaborative Initiative meeting in Anchorage (Appendix T). Provided tagged bowhead movements, behavior, and timing near the Liberty prospect for preparation of the biological opinion at the request of NOAA (Appendix U).
May		Coordinated with DFO Canada and Tuk HTC to obtain Canadian permits for tagging at Tuktoyaktuk.
July		Provided locations of bowheads in Canadian waters to Department of Fisheries and Oceans Canada for maps to be used in the creation of a Marine Protected Area Network in the Western Arctic. Update to AEWC of whale locations by month (Appendix V).
August		Tagging in Tuktoyaktuk cancelled due to ice in Beaufort Sea preventing travel from Alaska by boat. Requested permission to tag near Utqiaġvik.
September		Ten bowheads tagged near Utqiaġvik.
October		Update to AEWC included 2018 tagging, bowhead overlap with crabbing (Appendix W). Manuscripts "*Oceanographic characteristics associated with autumn movements of bowhead whales in the Chukchi Sea"* (Citta et al. 2018a), "*A multi-species synthesis of satellite telemetry data in the Pacific Arctic (1987–2015)"* (Citta et al. 2018b), and "*Trends in sea ice cover within bowhead whale habitats in the Pacific Arctic*" (Druckenmiller et al 2018) published in SOAR special issue in Deep Sea Research II.

November		Meeting between Greeneridge Sciences and Scripps at Greeneridge for work with demo code and Acousonde operating system.
December		Greeneridge Sciences working on satellite link for acoustic tag.
January	2019	Oral presentation "*Declining winter sea ice is associated with a northward shift of bowhead whale winter range"* at AMSS in Anchorage (Appendix X).
February		Camden Bay working group teleconference.
April		Provided dataset for circumpolar Arctic multi-species distribution effort for CAFF project.
May		Prepared dataset for shipping analysis in Canadian waters.
June		Drafting chapter for new bowhead book on distribution and movements.
July		Update to AEWC Whaling Captain's Convention in Utqiaġvik. Submitted manuscript "*Use of the Alaskan Beaufort Sea by bowhead whales tagged with satellite transmitters, 2006–2018*" to Arctic.
September		Final report to BOEM.

Tag Development

Acoustic monitoring and telemetry tag development. Greeneridge rewrote its Acousonde Operating System (AcOS) in two ways. First, it added flexibility for the Acousonde to run third-party detection/digestion software "modules" written and compiled separately from AcOS; this allowed a team approach to development and offered a broader opportunity for future applications than "hard-coding" a particular detection and classification scheme into the operating system. Second, it expanded the AcOS to feed data to a provider's "platform transmitter terminal" (PTT) hardware. These two tasks involved substantial new software and updates to existing software. Specific tasks included: 1) rewrote key portions of the operating system to load, monitor, and run externally written and compiled third-party programs; 2) reorganized the existing operating system to simplify requirements for third-party modules as much as possible; 3) created an Application Programming Interface (API) with many new functions to support common module needs, including alerts when specific conditions are satisfied, access to file-writing and error logging, and mathematical functions (e.g. FFT) to minimize the need for module writers to "reinvent the wheel"; 4) added the capability to read pre-recorded external test data for processing, instead of having to use live acoustics when evaluating detection accuracy; 5) developed a framework for commanding and feeding satellite telemetry hardware, including packet queueing, queue monitoring, and prioritization; 6) designed salt-water switch hardware and integrating its software support with the new telemetry framework; 7) coded a complete example module (Hilbert transform envelope detector) as a template for third-party developers; 8) prepared a Module Development Kit (MDK) for third-party module developers, including a written manual and support code; and 10) performed extensive testing. Greeneridge plans to provide these new capabilities in a commercially available acoustic monitoring and telemetry tag to be called the Acousonde 3S.

To support satellite telemetry, Greeneridge initially intended to rely on ARGOS satellites using compatible PTT hardware provided by Wildlife Computers. ARGOS, however, introduced its own PTT hardware for sale, then suspended sales due to technical problems. Meanwhile, due to ARGOS' entry into the PTT market, Wildlife Computers was reluctant to provide their PTT hardware. This development, along with other ARGOS system limitations, including very small data transmission packet size (32 bytes), lack of receipt confirmation, and difficult-to-correct framing and bit errors, led Greeneridge to seek alternatives in anticipation of rapid future developments in satellite transmission capabilities.

Greeneridge found a new satellite company, Swarm Technologies, that is based on a constellation of low earth orbiting microsatellites based on “CubeSat” technology. Swarm Technologies can handle substantially larger data transmission packets (220 bytes) than ARGOS (32 bytes) and provides receipt confirmation, so that a packet need not be transmitted repeatedly to improve chances of successful transmission. These qualities allow a tag to transmit more new data because it does not need to retransmit old data, which can lead either to longer deployment life or more data transferred. The use of CubeSat technology in animal telemetry is a new topic being explored by BOEM; to our knowledge this is the first wildlife tag designed to use this technology.

A bench prototype of the new tag, to be called the Acousonde 3S, has been constructed and successfully tested. Tests in water will require the construction of field prototypes, which was outside the scope of this effort. Also, as of this writing, Swarm Technologies is waiting on an FCC commercial operating license. Field testing of the satellite transmission capability will not be possible until Swarm receives its commercial license. The on-board real-time acoustic processing software, however, can be field-tested independently of the satellite transmission component.

Detection/digesting software module development. Aaron Thode of the Scripps Institution of Oceanography developed the first third-party acoustic processing module for the Acousonde in close consultation with Greeneridge Sciences. The module detects bowhead calls, seismic pulses, and average background noise levels (Fig. 1). The algorithm used is a variant of the “energy detector” that is a workhorse of existing bioacoustic software packages such as Ishmael and PAMGUARD. SIO and Greeneridge Sciences has used it extensively in the past to process acoustic data from fixed passive acoustic recorders in the Beaufort Sea. The module works by estimating a moving average of the background noise spectrum. It then compares an incoming spectrum with this average spectrum to detect the presence of a transient signal, such as a bowhead call or an airgun pulse. The module breaks this process down into overlapping frequency bands, so that the detector can estimate the minimum and maximum frequency (and thus bandwidth) of the detection, along with its duration. This information, along with periodic updates of the background noise spectrum, is then written into both the transmission queue and the internal log.
In April–May 2016, two Acousondes were deployed on, and recovered from, seven different bowhead whales in Disko Bay, Greenland (Appendix M). The seven deployments ranged in duration from 1 min to 18.5 hrs. Bowhead vocalizations from these Acousonde deployments and from passive acoustic recorders deployed in the Beaufort Sea were analyzed to develop and test the acoustic detection software for the new tag, using the external test feed described above (specific task #4). The algorithm is very fast, however its relative power consumption needs to be evaluated under more conditions. An airgun classifier has been developed and previously tested on years of passive acoustic data and could also be incorporated into the Acousonde 3S.

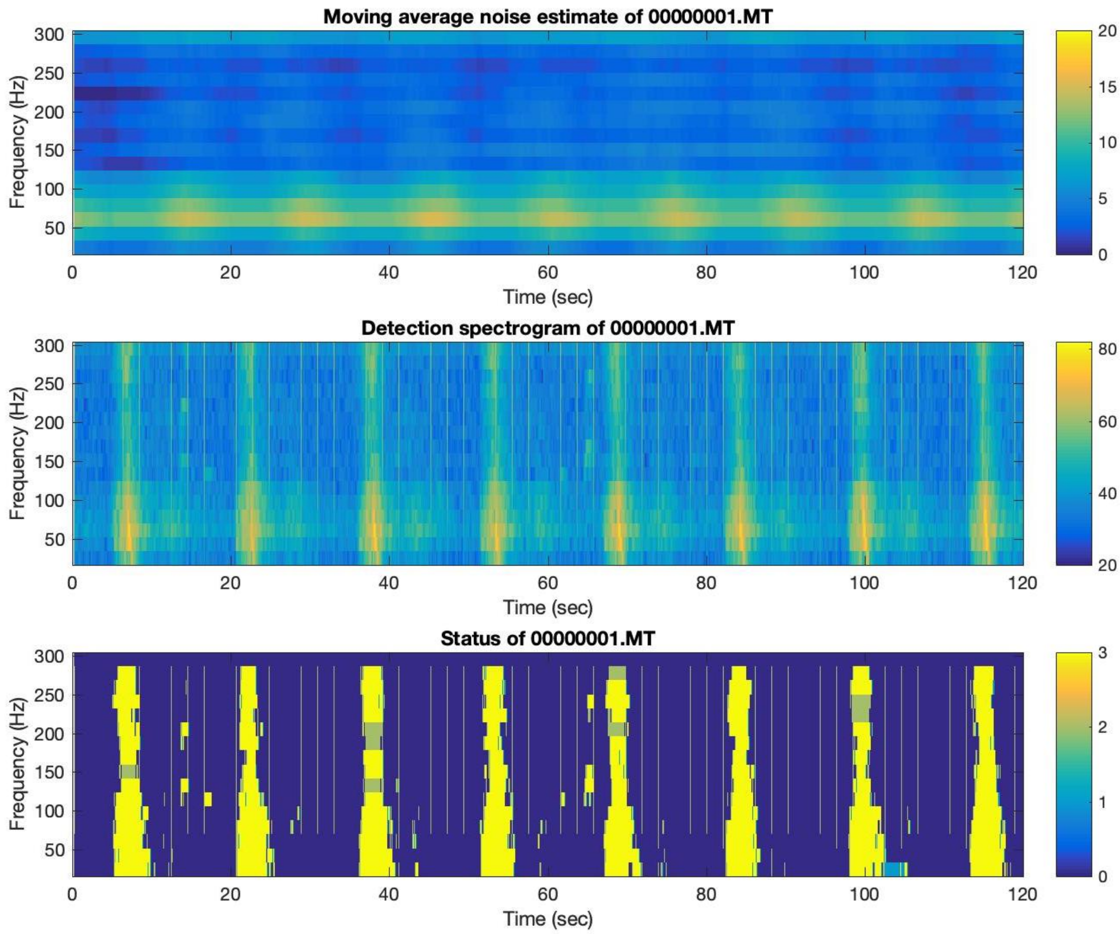

Figure 1. An example of the detector processing and output of the Acousonde 3S using two minutes of previously recorded data of a seismic survey and bowhead whale vocalizations in the Beaufort Sea. The first row displays the background noise level of the data, the second row shows the internal frequency- and time-averaged spectrogram, and the bottom shows the detector output, where '3' represents a detection and '0' represents no detection. The rhythmic sequence of airgun pulses is clearly visible, along with several detected whale calls (e.g., 15 and 68 seconds). These data are generated from a debugging file generated by the Acousonde 3S. The thin periodic yellow lines are artifacts in the debugging file that are not logged as detections internally to the tag.

Tagged Whales and Tag Performance

A total of 28 bowhead whales were tagged during September 2012–September 2019 (Table 2). Three were tagged in 2012, three in 2013, two in 2014, three in 2015, seven in 2017, and 10 in 2018 (Table 2). Sixteen were tagged near Utqiaġvik (formerly Barrow), Alaska, nine were tagged near the Tuktoyaktuk Peninsula, Canada, and three were tagged near St. Lawrence Island, Alaska. Sizes of tagged bowheads ranged from 7.6–15.2 m; the largest whale that provided data was tagged near Utqiaġvik. Of the 28 tagged whales, biopsies were collected from 20 for gender determination. No gray whales were tagged during this project, however one tagged in August 2012 provided data during this project period (Table 2).

Of the 28 tags deployed 16 were SPLASH10 tags, one was a SPOT tag, and 11 were CTD tags. All but one of the CTD tags were provided by an Office of Naval Research (ONR) funded project, but the movement and dive data from those tags are being included in these analyses. SPLASH10 tags lasted an average of 228 days (range = 0–710 days), the SPOT tag did not transmit, and the CTD tags lasted an average of 67 days (range = 4 to 203 days).

Table 2. Bowhead and gray whales tagged or tracked with satellite transmitters in Alaska between September 2012 and September 2019.

Whale Id	Date tagged	Location	Approx. length (m)	Sex	Tag type	Tag duration (days)
G12-01[1]	12-Aug-12	Gambell	9.1	unk	SPLASH10	65
B12-03	10-Sep-12	Barrow	13.7	M	SPLASH10[2]	113
B12-04	10-Sep-12	Barrow	15.2	M	SPLASH10	274
B12-05	21-Sep-12	Barrow	13.7	M	CTD[3]	33
B13-01	21-Apr-13	Pugughileq[4]	9.1	M	SPLASH10	225
B13-02	9-Apr-13	Pugughileq	8.2	unk	SPLASH10	0
B13-03	17-Dec-13	Savoonga	15.2	unk	SPOT[5]	0
B14-01	20-Aug-14	Tuktoyaktuk	9.4	unk	SPLASH10	196
B14-02	21-Aug-14	Tuktoyaktuk	13.7	unk	SPLASH10	0
B15-01	1-Oct-16	Barrow	13.7	M	SPLASH10	405
B15-02	19 Nov-15	Barrow	10.6	M	SPLASH10	78
B15-03	2-Sept-15	Barrow	10.6	F	SPLASH10	70
B17-01	23-Aug-17	Tuktoyaktuk	7.6	M	SPLASH10	437
B17-02	23-Aug-17	Tuktoyaktuk	7.6	F	SPLASH10	481
B17-03	28-Aug-17	Tuktoyaktuk	10.6	F	SPLASH10	716
B17-04	28-Aug-17	Tuktoyaktuk	9.1	unk	CTD	12
B17-05	28-Aug-17	Tuktoyaktuk	7.6	unk	CTD	44
B17-06	28-Aug-17	Tuktoyaktuk	10.6	unk	CTD	4
B17-07	28-Aug-17	Tuktoyaktuk	7.6	F	CTD	151
B18-01	2-Sep-18	Utqiaġvik[6]	13.7	M	SPLASH10	101
B18-02	20-Sep-18	Utqiaġvik	10.7	M	SPLASH10	126
B18-03	21-Sep-18	Utqiaġvik	7.6	M	SPLASH10	341
B18-04	21-Sep-18	Utqiaġvik	13.7	F	SPLASH10	307
B18-05	21-Sep-18	Utqiaġvik	9.1	M/F	CTD	102
B18-06	21-Sep-18	Utqiaġvik	7.6	M	CTD	22
B18-07	21-Sep-18	Utqiaġvik	10.7	unk	CTD	57
B18-08	25-Sep-18	Utqiaġvik	9.1	F	CTD	38
B18-09	25-Sep-18	Utqiaġvik	12.2	M	CTD	203
B18-10	25-Sep-18	Utqiaġvik	12.2	F	CTD	71

[1] Gray whale tagged during the previous study, but data provided during this study. [2] Tag that provides location, dive histograms, and other, more, specific dive records. [3] Conductivity, Temperature, and Depth tag that provides location and detailed depth profiles with information on water temperature and salinity. [4] St. Lawrence Island, Alaska. [5] Tag that provides locations only (see Methods). [6]Formerly Barrow.

Data analyses

Most of these analyses (numbers 1–10) have been finalized in report form or as published manuscripts. The actual abstracts, posters, and reports are provided as Appendices; for these analyses we provide a short summary of the main findings. Publications are listed in the List of Publications and Products. Analyses 11–13 are works in-progress and not provided in the Appendices; for these analyses, we provide more detail.

1. *Overlap of bowhead winter range with pot fisheries:* Eskimo whalers were concerned with how the winter distribution of bowhead whales may overlap with the Bering Sea pot fisheries (i.e., crab and cod). We accessed pot fishery data from NOAA and ADFG and overlayed this information with bowhead whale location data (Appendix P).

   Using data collected from 21 bowhead whales during 2008–2010, we found that bowhead whales did not enter active pot fisheries for cod, blue king crab, or snow crab. There was spatial overlap for cod and blue king crab pot fisheries, but those fisheries ended before whales arrived on the fishing grounds. The snow crab fishery was active while whales were in the area, but whales were typically under sea ice with > 90% concentration, which is too dense for pot fishing. As such, entanglements of bowhead whales in pot gear most likely occur due to lost pots (i.e., 'ghost' gear) and pots that are overrun by advancing sea ice. This analysis was published (Citta et al. 2014).

   At the request of Eskimo whalers, we re-examined this issue in 2018 when Bering Sea ice was at a historic low. We found that the pot fisheries have not moved northwards with declines in the extent of Bering Sea ice (Fig. 2, Appendix W). Hence, overlap of pot fisheries and bowhead whales has not increased, at least in U.S. waters (the situation in Russian waters is unknown).

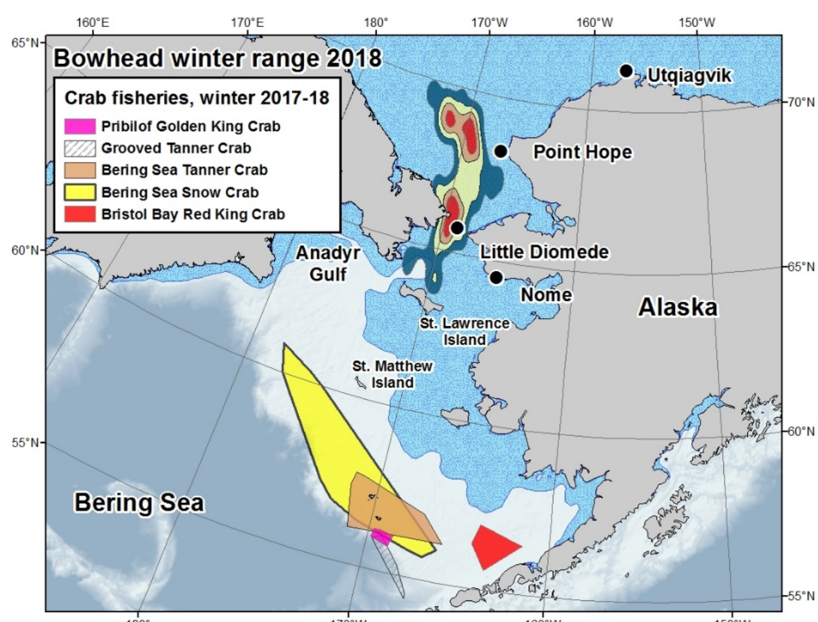

Figure 2. Bowhead range and range of crab fisheries in the Bering Sea in winter of 2017/18.

2. *Bowhead distribution for oil-spill response mapping:* At BOEM's request we produced bi-weekly density maps of bowhead whale locations for use in oil-spill response planning. After a review of different kernel density methods, we chose to use smoothed cross-validation (SCV, Duong and Hazelton 2005). We provided BOEM with bi-weekly kernel densities, the raw shapefiles for mapping in a GIS, metadata that included mapping projection information, and recommendations for interpretation and use. The full report is included in Appendix D.

3. *Oceanographic characteristics of bowhead whale hotspots:* As part of the BOEM-funded Synthesis of Arctic Research (SOAR) initiative, we collaborated with oceanographers (Drs. Stephen Okkonen and Weislaw Maslowski), a zooplankton scientist (Dr. Carin Ashjian), and a sea ice specialist (Dr. Matthew Druckenmiller) to examine the physical environment within areas where bowhead whales aggregate. This analysis used bowhead whale location and dive data.

   We used the lattice density model (Barry and McIntyre 2011) to identify six core use areas used by bowhead whales during 2006–2012 (Fig. 3). Within each core use area, we summarized residence times, ice conditions, and oceanographic characteristics. We found that each core use area has mechanisms for aggregating prey. In spring, most whales migrated from wintering grounds in the Bering Sea to the Cape Bathurst polynya, Canada (Area 1), and spent the most time in the vicinity of the halocline at depths < 75 m, which are within the euphotic zone, where calanoid copepods ascend following winter diapause. Peak use of the polynya occurred between 7 May and 5 July; whales generally left in July, when copepods are expected to descend to deeper depths. Between 12 July and 25 September, most tagged whales were in shallow shelf waters adjacent to the Tuktoyaktuk Peninsula, Canada (Area 2), where wind-driven upwelling promotes the concentration of calanoid copepods. Between 22 August and 2 November, whales also congregated near Point Barrow, Alaska (Area 3), where east winds promote upwelling that moves zooplankton onto the Beaufort shelf, and subsequent relaxation of these winds promoted zooplankton aggregations. Between 27 October and 8 January, whales congregated along the northern shore of Chukotka, Russia (Area 4), where zooplankton likely concentrated along a coastal front between the southeastward-flowing Siberian Coastal Current and northward-flowing Bering Sea waters. The two remaining core-use areas occurred in the Bering Sea: Anadyr Strait (Area 5), where peak use occurred between 29 November and 20 April, and the Gulf of Anadyr (Area 6), where peak use occurred between 4 December and 1 April; both areas exhibited highly fractured sea ice. Whales near the Gulf of Anadyr spent almost half of their time at depths between 75 and 100 m, usually near the seafloor, where a subsurface front between cold Anadyr Water and warmer Bering Shelf Water presumably aggregates zooplankton. The amount of time whales spent near the seafloor in the Gulf of Anadyr, where copepods (in diapause) and, possibly, euphausiids are expected to aggregate provides strong evidence that bowhead whales are feeding in winter. The timing of bowhead spring migration corresponds with when zooplankton are expected to begin their spring ascent in April. This work is published (Citta et al. 2015).

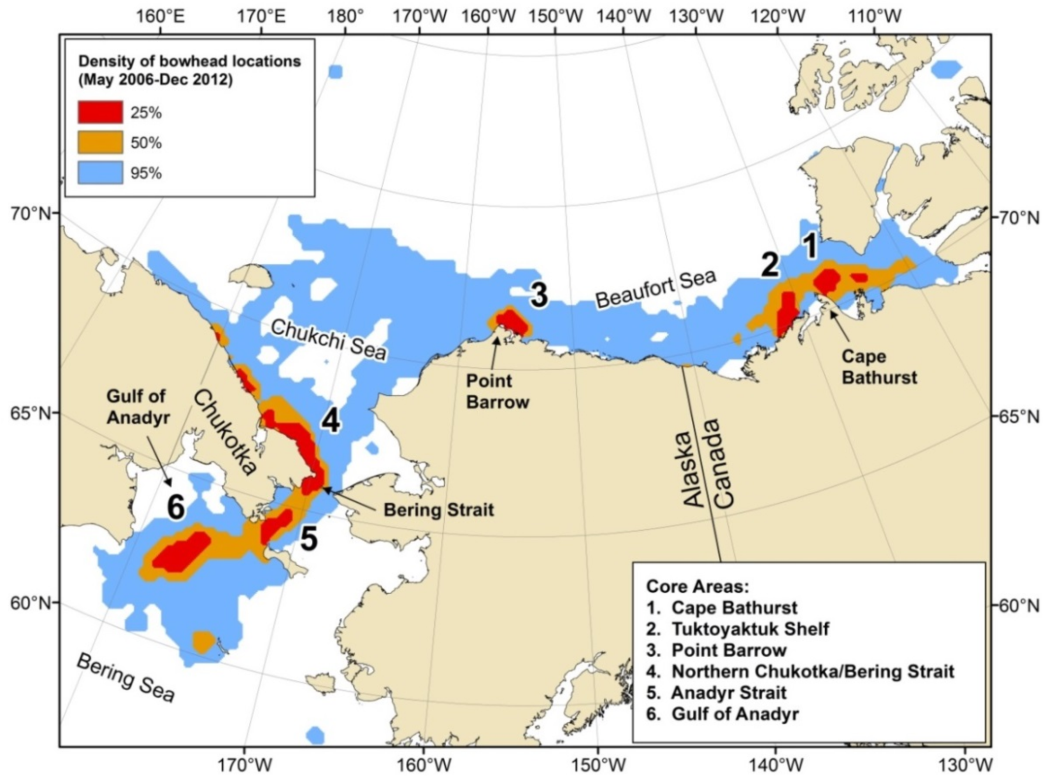

Figure 3. Utilization distribution for western Arctic bowhead whales with satellite tags, 2006–2011. Core-use areas, areas of high bowhead concentration, were defined as lying within the 25% density contours. Six primary core-use areas were identified. Figure from Citta et al. (2015).

4. *Analysis for NOAA's biological opinion on the Quintillion Subsea Operations, LCC, proposal to lay subsea cable in the Bering, Chukchi, and Beaufort Seas:* NOAA requested distribution data for bowhead whales, ringed seals, and bearded seals for a biological opinion on a proposal by Quintillion to lay a subsea fiber optics cable in the Bering, Chukchi, and Beaufort seas.

   We overlaid the map of cable-laying operations with location data for bowhead whales (using data from this project), ringed seals, and bearded seals. There was substantial potential for overlap in cable-laying operations and bowhead whales in the Beaufort Sea during July–October and in the Chukchi during August–November. This information was provided to NOAA; figures from this analysis are provided in Appendix O.

5. *Movements and inferred foraging of whales in the Canadian Beaufort Sea in August and September:* We collaborated with Lois Harwood (Department of Fisheries and Oceans Canada) to describe movements and residence times of bowhead whales on their autumn feeding grounds in the Canadian Beaufort (Harwood et al. 2017).

We used a behavioral switching state-space model (Jonsen et al. 2005) to statistically estimate where whales were located and to classify those locations as being associated with migratory behavior or lingering (presumed feeding) behavior. Kernel densities of whale locations were used to define five aggregation areas in the Canadian Beaufort Sea (Fig. 4). These areas are currently being used to help identify Marine Protected Areas in Canadian waters.

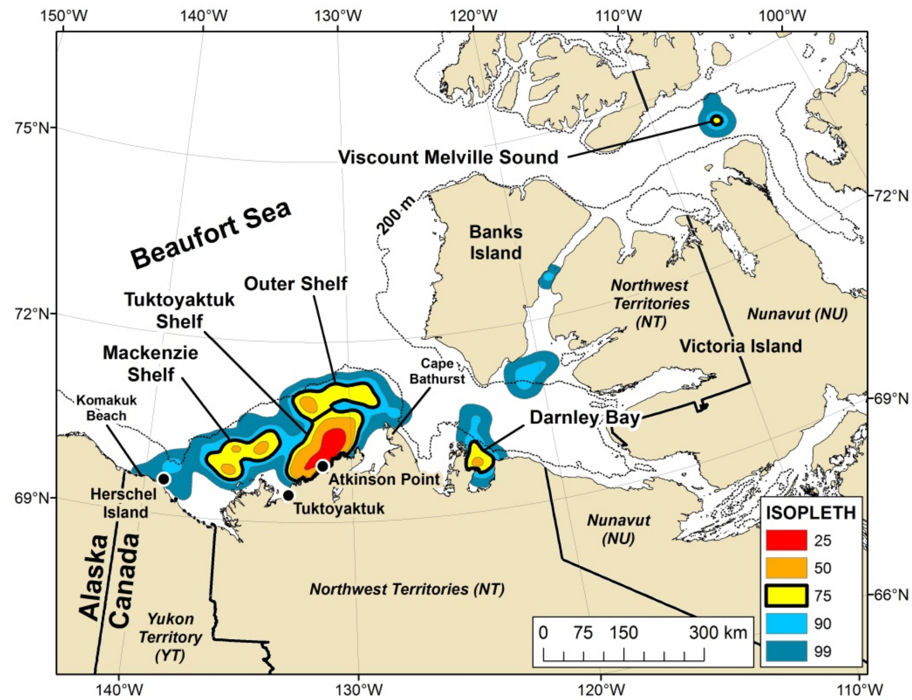

Figure 4. Use areas identified using the 75% contour of locations associated with lingering (i.e., feeding) behavior within the Canadian Beaufort Sea in August and September (Figure 3 from Harwood et al. 2017).

6. *Analysis for NOAA's biological opinion on the Liberty Development and Production Project:* At the request of NOAA, we provided distribution information for bowhead whales (using data collected during this project period), ringed seals, and bearded seals.

   Using bowhead location data from this project, we found little evidence that operations at Liberty Prospect would potentially influence bowhead whales in the spring, as the migration takes place north of the shelf break, which is approximately 70 km north of Liberty Prospect. Tagged whales first made inshore movements near Liberty Prospect in August and one whale passed within 16 km of Liberty Prospect. The main autumn migration occurs approximately 7 km north of Liberty Prospect and extends to approximately 40 km north of the barrier islands. No tagged whale lingered within 30 km of Liberty Prospect. This information was provided to NOAA and is included in Appendix U.

7. *Oceanographic characteristics associated with autumn movements of bowhead whales in the Chukchi Sea:* We collaborated with oceanographers (Drs. Stephen Okkonen and Weislaw Maslowski) to model how oceanographic features determined where bowhead whales stop to feed within the Chukchi Sea. This analysis was published (Citta et al. 2018a and was part of the BOEM-funded SOAR II initiative.

   We used a resource selection analysis, which compares locations that whales use with locations not used, to determine that bowhead whales followed Pacific Winter Water (PWW) and Bering Sea/Anadyr Water (BSAW) during their autumn migration across the Chukchi Sea (Fig. 5). The water mass that carries krill from the Bering Sea into the Chukchi Sea is BSAW; as this water cools over winter, it transforms into PWW. Krill overwinters in BSAW and PWW and we found that whales follow this water mass during their migration and avoid both Alaska Coastal Water (ACW) and Siberian Shelf Water (SSW), which are both mostly composed of river discharge. These water masses are known to be deficient in krill. It appears that SSW forms the western boundary of bowhead whale distribution in the Bering Sea.

8. *Trends in sea ice and bowhead distribution within the Alaskan Beaufort Sea:* We collaborated with Dr. Matthew Druckenmiller at the National Snow and Ice Data Center to analyze trends in sea ice within bowhead whale use areas as defined by aerial survey data from the BOEM-funded ASAMM project and satellite telemetry data (this BOEM-funded study). The goal of this analysis was to better understand bowhead whale movements relative to decreased ice in the Beaufort Sea. This analysis was published (Druckenmiller et al. 2018) and was part of the BOEM-funded SOAR II initiative.

   We examined changes in the number of open water days (OWD) between 1979 and 2014 within annual bowhead whale core-use areas as defined by the satellite tagging data generated during this project. We found that ice cover has decreased more in the core-use areas in the northern extent of the range than in core-use areas in the southern extent. The numbers of OWD within the core-use areas near Point Barrow and along the northern Chukotka Coast during peak use have increased by 13 days at Point Barrow and 10 days along the Chukotka Coast. The most dramatic reductions in sea-ice cover have taken place in the western Beaufort Sea where the number of OWD on the shelf and slope have increased by 20 and 25 days/decade, respectively. In contrast, sea-ice cover has not substantially changed within the winter core-use area near the Gulf of Anadyr. We predicted that bowheads would use the Chukchi and Beaufort Seas more in the fall as sea ice declined. This analysis was completed prior to the drastic loss of winter ice in the Bering Sea during the winter of 2016/17.

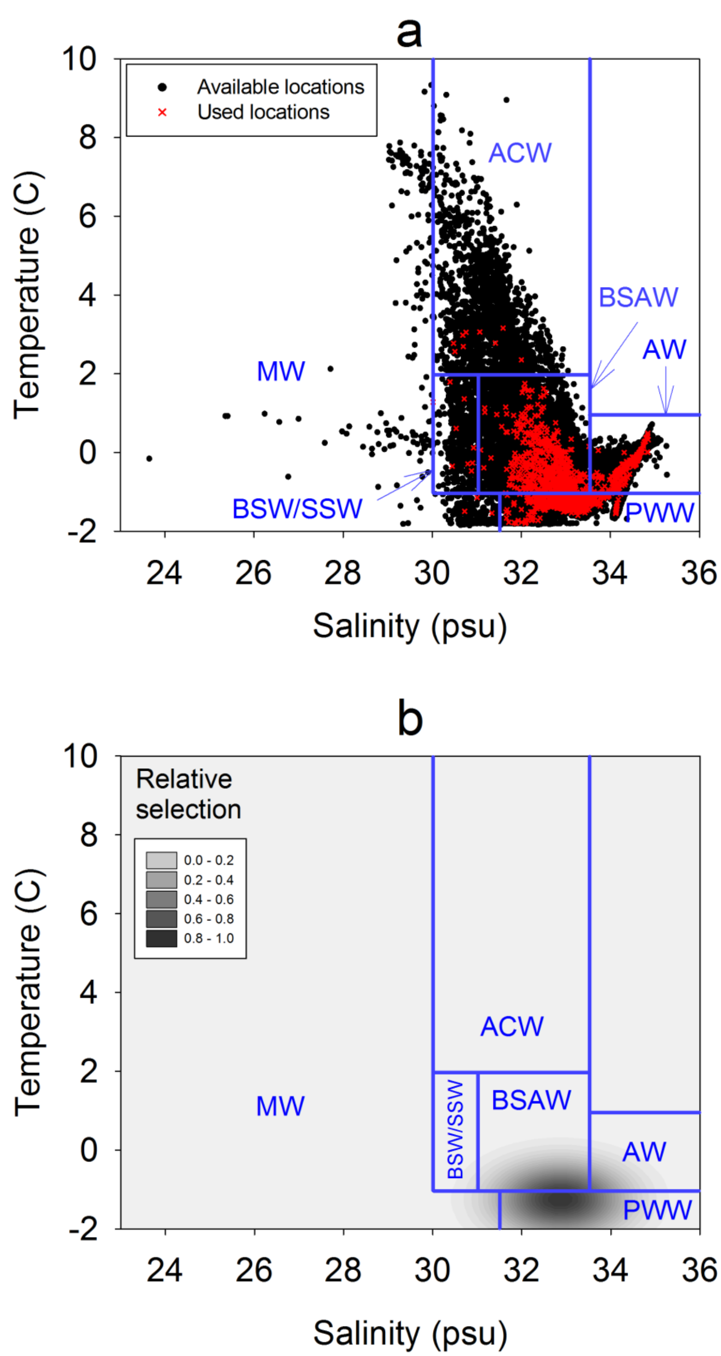

Figure 5. The distribution of bowhead whale locations in the Chukchi Sea in temperature-salinity space (a) and the fit models of bowhead whale habitat selection based upon temperature and salinity (b). Tagged whales were most likely to occur in water -1.2°C and 32.75 psu; selection for other temperatures and salinities are scaled relative to this maximum. Blue boxes denote the approximate temperature-salinity signatures of different water masses in the Chukchi Sea, including melt water (MW), Alaskan Coastal Water (ACW), Bering Summer Water (BSW), Siberian Shelf Water (SSW), Bering Shelf/Anadyr Water (BSAW), Atlantic Water (AW), and Pacific Winter Water (PWW). (Figure 6 from Citta et al. 2018).

9. *Multi-species overlap within the Pacific Arctic:* We summarized satellite telemetry data for most species of marine mammals in the Bering, Chukchi, and Beaufort seas and then examined the spatial and temporal overlap among species. For this project, we collected all the satellite telemetry data available for bowhead, gray, and beluga whales, ringed, spotted, and bearded seals, and walruses. We calculated utilization distributions (i.e., the spatial density of satellite telemetry locations) for each species and then overlapped all the distributions to identify winter (December–April) and summer (May–November) multi-species hotspots. In effect, we identified areas important for multiple species. This analysis was published (Citta et al. 2018b) and was part of the BOEM-funded SOAR II initiative and included both bowhead and gray whale location data collected during this project.

   Six multi-species core use areas were identified during the summer period: 1) Chukotka/Bering Strait; 2) Norton Sound; 3) Kotzebue Sound; 4) the northeastern Chukchi Sea; 5) Mackenzie River Delta/Amundsen Gulf; and 6) Viscount Melville Sound (Fig. 6a). During the winter period, we identified four multi-species core use areas: 1) Anadyr Gulf/Strait; 2) central Bering Sea; 3) Nunivak Island; and 4) Bristol Bay. During the summer period, four of the six areas were centered on the greater Bering Strait region and the northwestern coast of Alaska and included most of the species we examined. The two remaining summer areas were in the western Canadian Arctic and were largely defined by the seasonal presence of bowhead whales and Eastern Beaufort Sea stock beluga whales, whose distribution overlapped during both summer and winter periods. During the winter period, the main multi-species core use area was located near the Gulf of Anadyr and extended northwards through Anadyr and Bering Straits (Fig. 6b). This area is contained within the Bering Sea "green belt", an area of enhanced primary and secondary productivity in the Bering Sea (Springer et al. 1996). In addition to identifying the location of multi-species core use areas, a major contribution of this analysis was to identify what tagging has taken place in the Pacific Arctic and to give contact information for accessing that data.

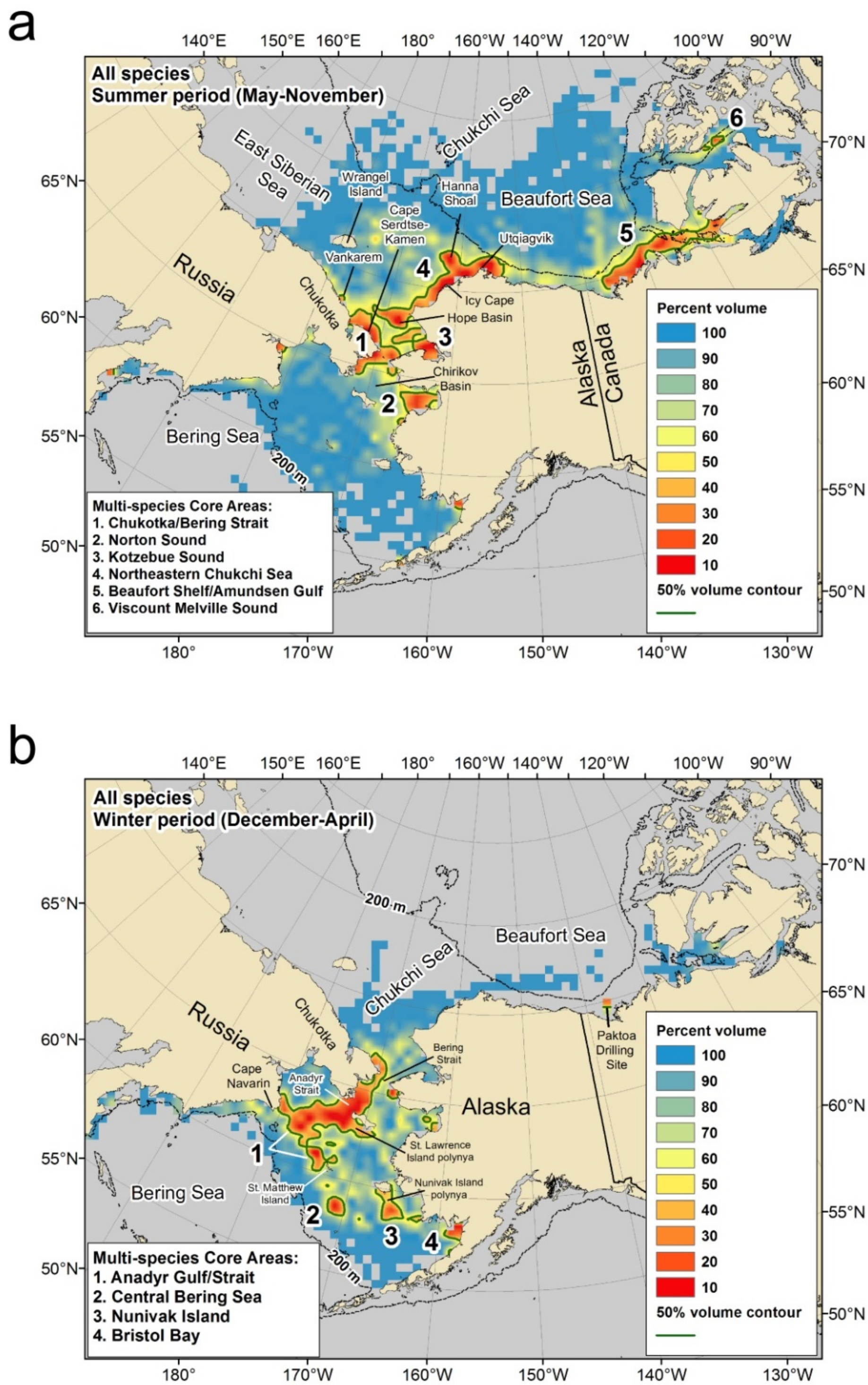

Figure 6. Multi-species core use areas during the (a) summer period (May–November) and (b) winter period (December–April). Contour lines contain 50% of the density of the multi-species distribution (Figure 13 in Citta et al. 2018b).

10. *Camden Bay Collaborative Study:* The Camden Bay Collaborative Study is a partnership between the Alaska Eskimo Whaling Commission, the North Slope Borough, and Shell Offshore, Inc. The goal of the collaborative study is to integrate what is known about Camden Bay, including bowhead whale use of the area, for the development of improved mitigation measures to protect the availability of bowhead whales for subsistence hunters in Kaktovik and Nuiqsut while allowing Shell to explore and potentially develop oil and gas resources in the area. The collaborative study group requested that we summarize bowhead movements in Camden Bay.

We analyzed movements of 41 tagged whales that traveled through the Alaskan Beaufort Sea during 2006–2017. Spring movements were direct, with little evidence of feeding. However, we found that sometimes whales paused their movements in Camden Bay likely to feed (Fig. 7). Three whales lingered in Camden Bay; B09-13 and B10-08 in September and B17-07 in October. Two other whales lingered off the shelf break in mid-summer (June and July). When compared to core use areas, such as Point Barrow and Tuktoyaktuk, use of Camden Bay is infrequent and ephemeral <10 days. We presented this information to the Camden Bay Collaborative Study in April 2018 (Appendix T).

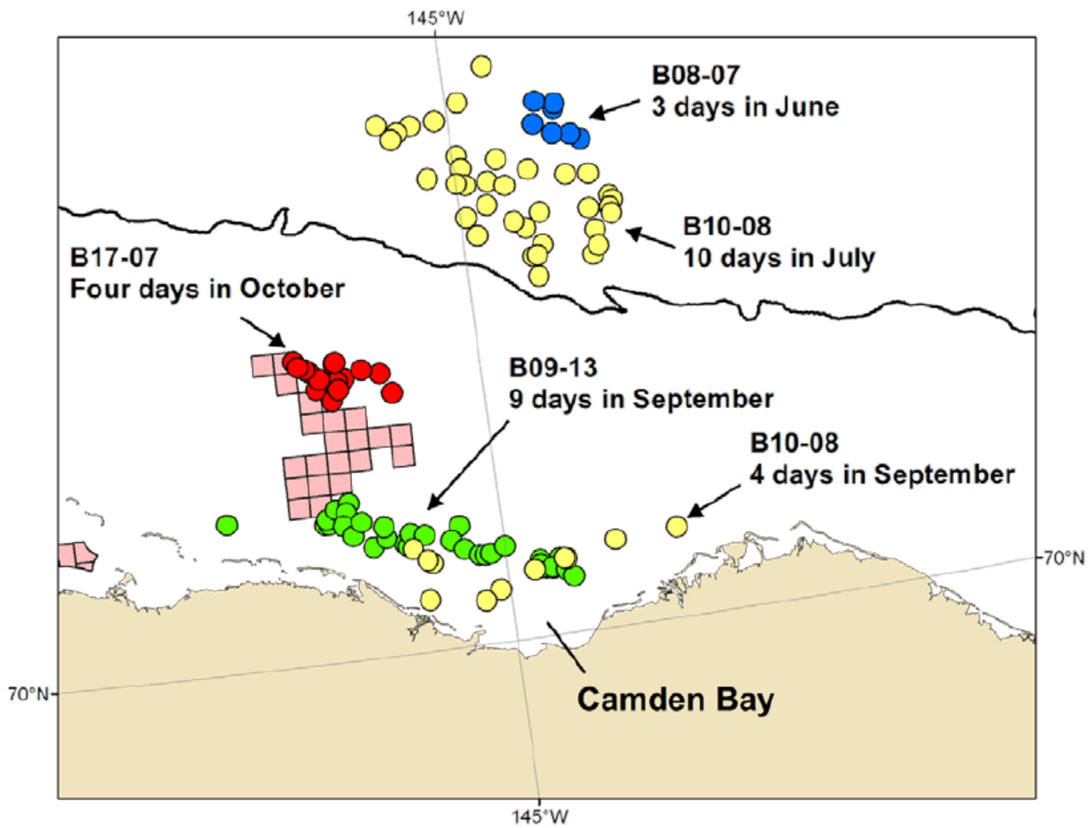

Figure 7. Behavioral state-space locations of lingering whales in Camden Bay, Alaska.

11. *Bowhead movements and dive behavior in the Alaskan Beaufort Sea:* We analyzed movements and dive behavior of bowhead whales within the Alaskan Beaufort Sea. The goal of this analysis is to address how important the Alaskan Beaufort Sea is for feeding.

    We examined bowhead whale movement behavior, residence times, and dive behavior in the Alaskan Beaufort Sea, 2006–2018. We explored the timing and duration of use of three subregions (western, central, eastern; Fig. 8) within the Alaskan Beaufort and used a two-state switching state-space model to infer bowhead whale behavior (transiting or lingering). In spring, whales migrated across the Alaskan Beaufort in 7.17 ± 0.41 days, primarily off the continental shelf in deep water. During the autumn migration, whales stayed in shallow shelf waters and crossed the Alaskan Beaufort in 18.66 ± 2.30 days, spending 10.05 ± 1.22 days in the western subregion near Point Barrow. Whales frequently dove to the sea floor during the autumn migration, where they spent 45% of their time, regardless of behavioral state. Consistent dive behavior in the autumn suggests that whales are looking for food while migrating, and the identification of lingering locations likely reflects feeding. Migrating bowheads engaged in longer dives to the sea floor could take advantage of infrequent and ephemeral prey concentrations in the eastern and central subregions. Prey is more frequently concentrated into dense aggregations in the western subregion, where whales often lingered. In agreement with our other analyses, this analysis indicated that while whales sometimes paused their migration near Camden Bay, such pauses were infrequent and of short duration. There were relatively few whale locations, lingering or transiting, near oil leases in Camden Bay (Fig. 9). This analysis is a draft manuscript currently in review by the journal.

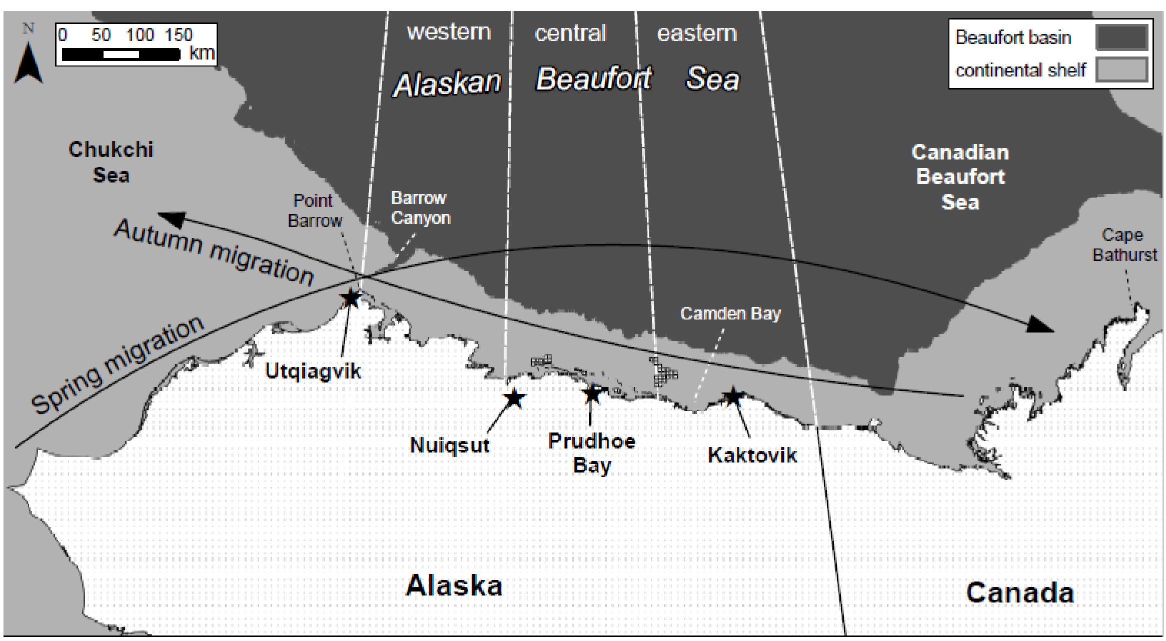

Figure 8. Map of the Alaskan Beaufort Sea divided into three subregions. Solid black lines with arrows show spring and autumn migration routes for the Bering-Chukchi-Beaufort stock of bowhead whales. Squares on the continental shelf are active oil lease blocks. Continental shelf waters are defined as waters < 200 m deep.

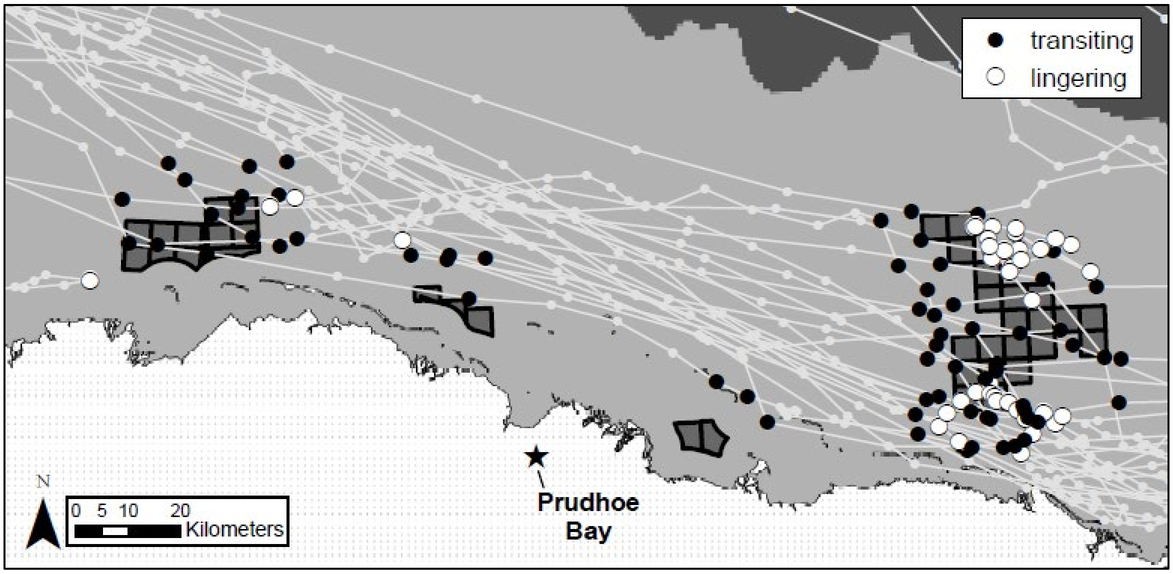

Figure 9. Bowhead whale locations (19 whales) within 10 km of oil lease blocks (dark grey squares) during the autumn migration in the Alaskan Beaufort Sea across all years (2006–2018).

12. *Recent northward shift in the winter distribution of bowhead whales:* During 2006–2016, the primary wintering (January–March) area was in the Bering Sea, under ice cover, east of Anadyr Gulf (Fig. 10). This primary wintering area was ice-free in 2017 and 2018 and it was unknown if whales would winter south of the ice margin to return to this area or if they would abandon it and shift their distribution north. No satellite tags were transmitting in 2017, however, four tags transmitted during the winter (January–March) of 2018, allowing us to compare the distribution and behavior of whales in two time periods, 2006–2016 and 2018. In neither time period did tagged whales venture south of the ice margin (Fig. 10). Consequently, the primary wintering area used during 2006–2016 was abandoned. During 2006–2016, less than 6% of all satellite locations (n = 4,793) were in the Chukchi Sea in winter. In contrast, 86% of all satellite locations (n = 576) were in the Chukchi Sea during 2018. Why bowhead whales do not venture south of the ice margin in winter, when they are often far from ice in summer, is unknown but may be related to the presence of killer whales, which are known to frequent the ice edge in winter but are rarely observed in bowhead summer ranges.

    We had four tags transmitting during the winter of 2019. Bowheads did not winter as far north in 2019 as they did in 2018. The extent of sea ice partially recovered late in the winter of 2019 and whales shifted southwards with the sea ice. Consequently, in 2019, the bowhead whale wintering area was centered north of Anadyr Strait, but south of Bering Strait. This analysis is a draft manuscript (Citta et al. *In prep*.).

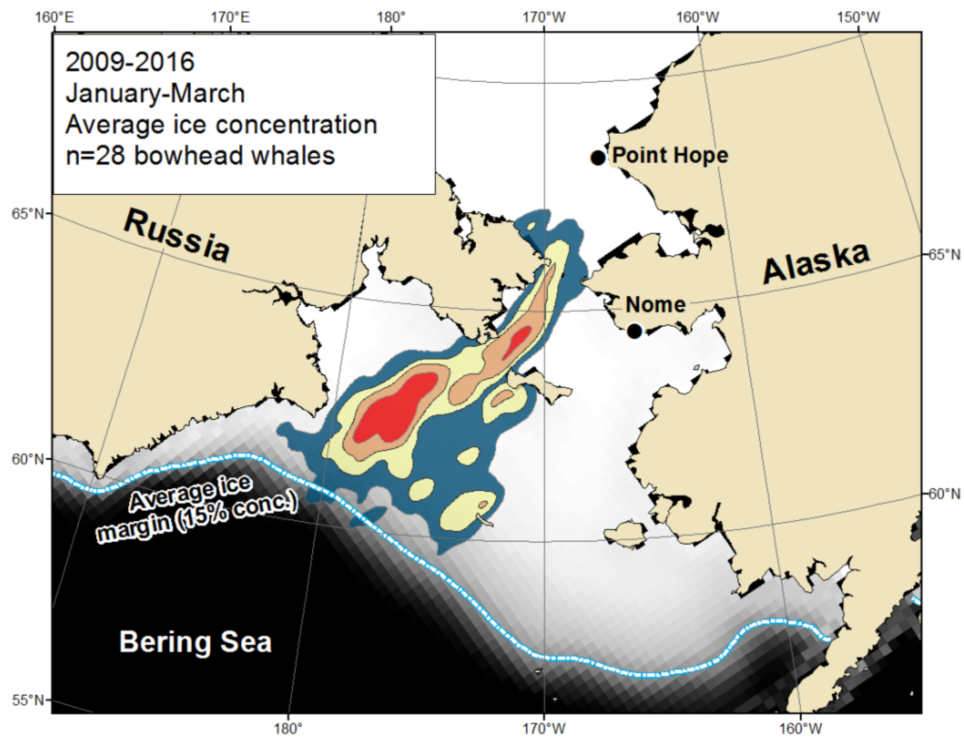

Figure 10. Bowhead winter (January–March) during 2009–2016.

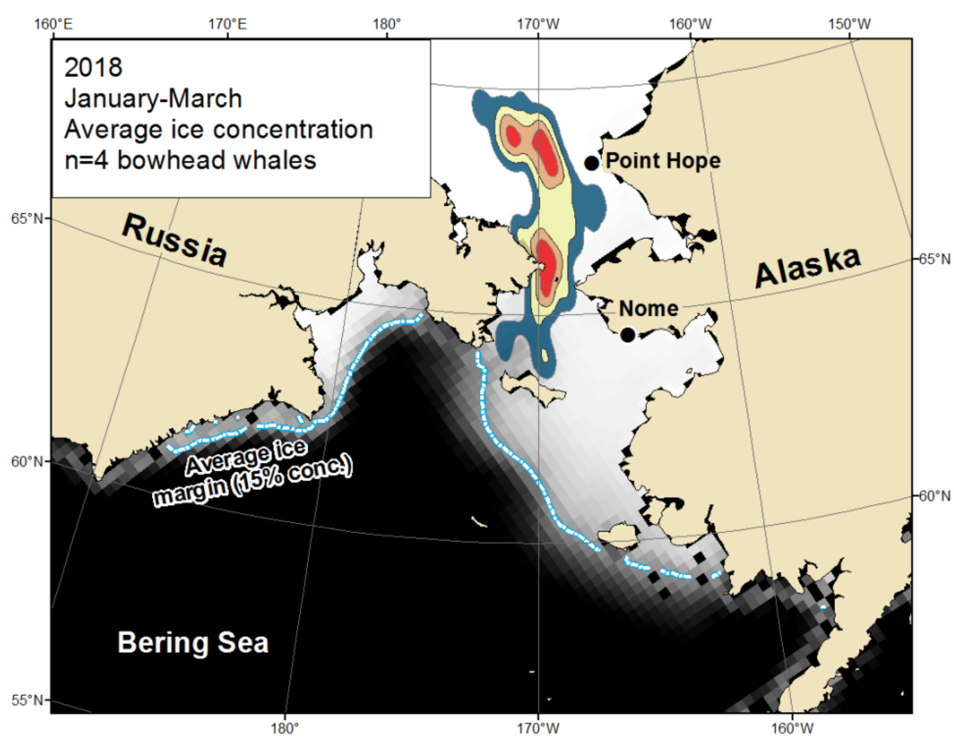

Figure 11. Bowhead winter range (January–March) during 2018.

13. *Bowhead book chapter:* For an upcoming book on bowhead whale biology, we contributed a chapter that summarized what we have learned about the distribution and behavior of bowhead whales via satellite telemetry (Citta et al. *In press*). The book chapter editors are Drs. Hans Thiewessien and John Craighead George and the publisher is Elsevier. For this chapter, we summarized the monthly distribution of bowhead whales (Figs. 12 and 13) and noting some of the more substantial movements and distribution shifts we have observed. Our findings include:

    a. Most whales migrate from the wintering grounds in the Bering and southern Chukchi Sea to Amundsen Gulf, Canada. Only 1 of 26 whales which provided location data during the spring migration did not migrate to Amundsen Gulf, Canada. This whale migrated to the coast of Chukotka, Russia, and spent the entire summer there.

    b. Most whales summer in Amundsen Gulf, Canada. However, in June and July, we observed eight whales leave the Canadian Beaufort prior to the fall migration in late August and September (Fig. 14). Five whales traveled west into the Alaskan Beaufort Sea, three of which passed west of Point Barrow, and then returned to the Canadian Beaufort prior to the fall migration. Two whales migrated to Russia in mid-summer. One whale left Amundsen Gulf and entered the Northwest Passage (Viscount Melville Sound) where it remained until late August. Hence, the summer distribution of bowhead whales is much more dispersed than originally thought.

    c. We also commented on the shift in the winter distribution of bowhead whales that has occurred since 2017 (Fig. 15).

    d. Bowhead whales sometimes shift their distribution in the fall away from the coast of Chukotka, Russia, and towards the north-central Chukchi Sea (Citta et al. 2018a; Fig. 16). Whales rarely lingered in the central Chukchi in 2006, 2007, 2008, or 2010; however, use of the north-central Chukchi was extensive in 2009, 2012, 2014, 2015, 2017, and 2018. Results were equivocal for 2011 and 2016; in those years few whales were transmitting in fall to determine if the north-central Chukchi was used extensively. In most of the early years of the study (4 of 5 years prior to 2011) whales did not linger in the north-central Chukchi. In contrast, the north-central Chukchi received extensive use in almost all years after 2011 (5 of 6). Hence, it appears that use of the north-central Chukchi as a fall feeding area is increasing. Preliminary analyses indicate that this is related to the prevalent wind patterns in the region; when east winds are weaker, there is more foraging in the north-central Chukchi and when east winds are stronger there is less foraging in the north-central Chukchi. Because west winds are becoming more common, bowheads may be shifting their fall distribution away from the Russian coast and into the central Chukchi Sea. The shift towards more use of the north-central Chukchi Sea will have implications for any oil and gas development within the Chukchi Sea.

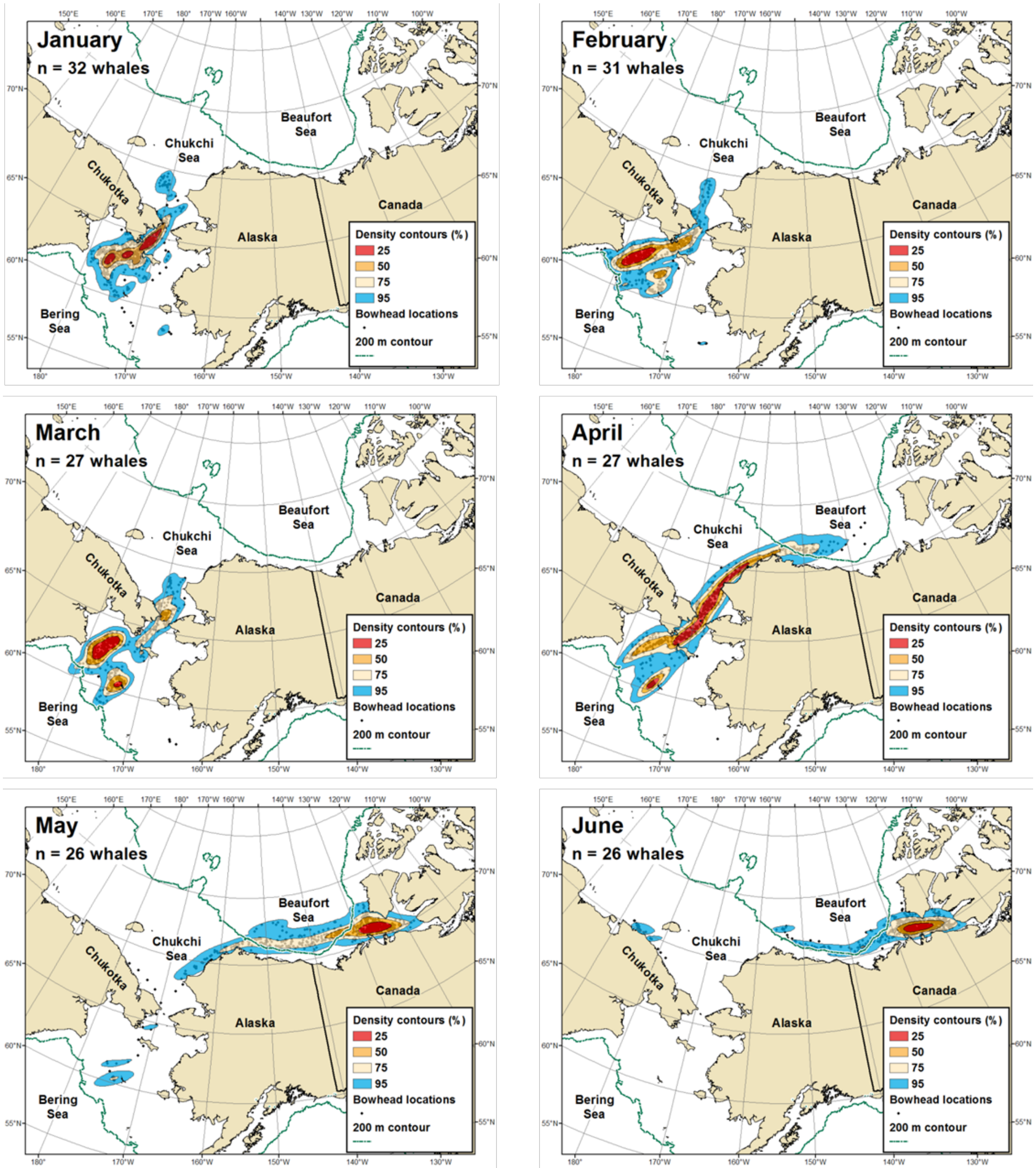

Figure 12. Kernel densities of bowhead whales January–June, using data collected from May 2006–April 2019.

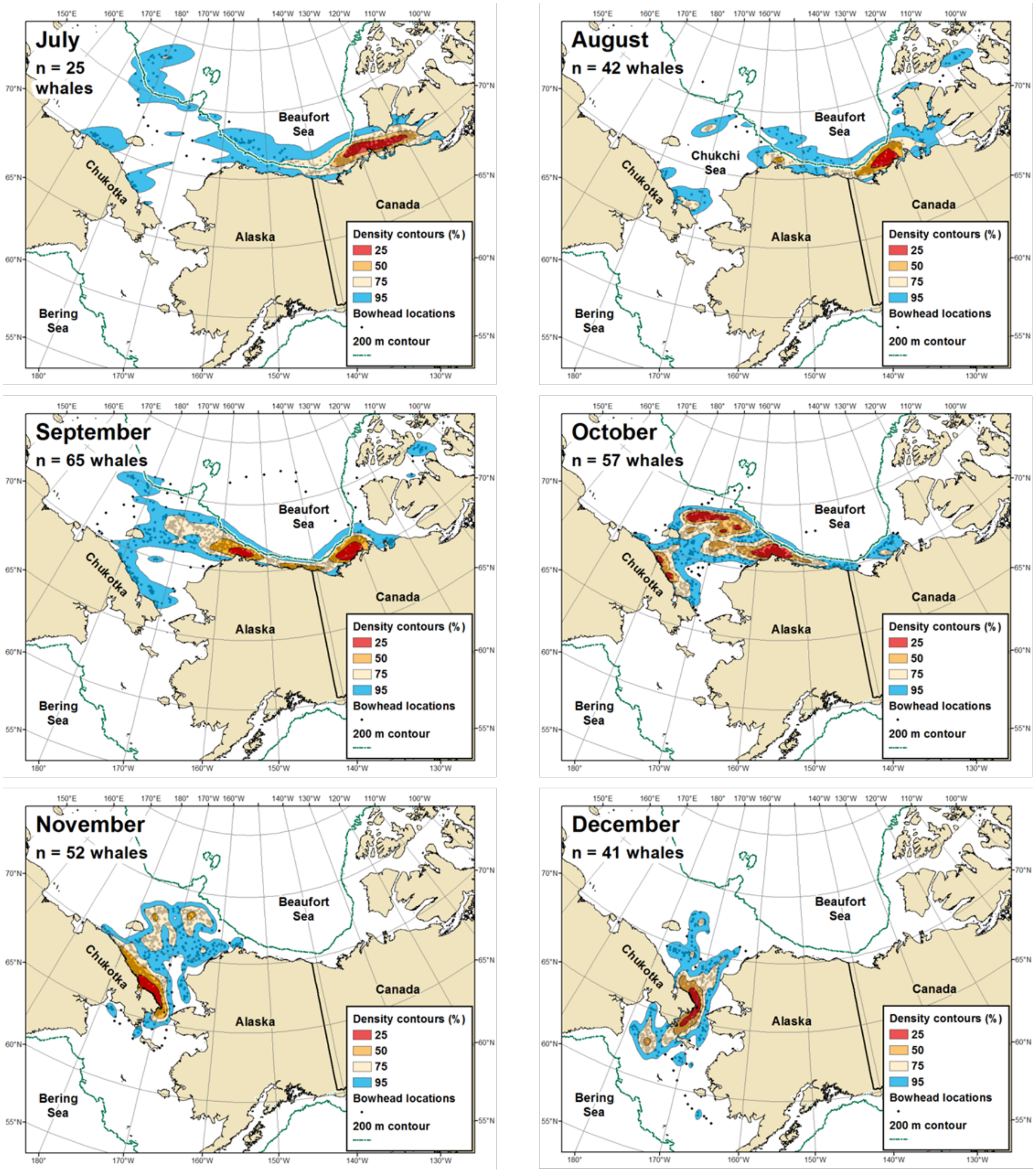

Figure 13. Kernel densities of bowhead whales July–December, using data collected from May 2006–April 2019.

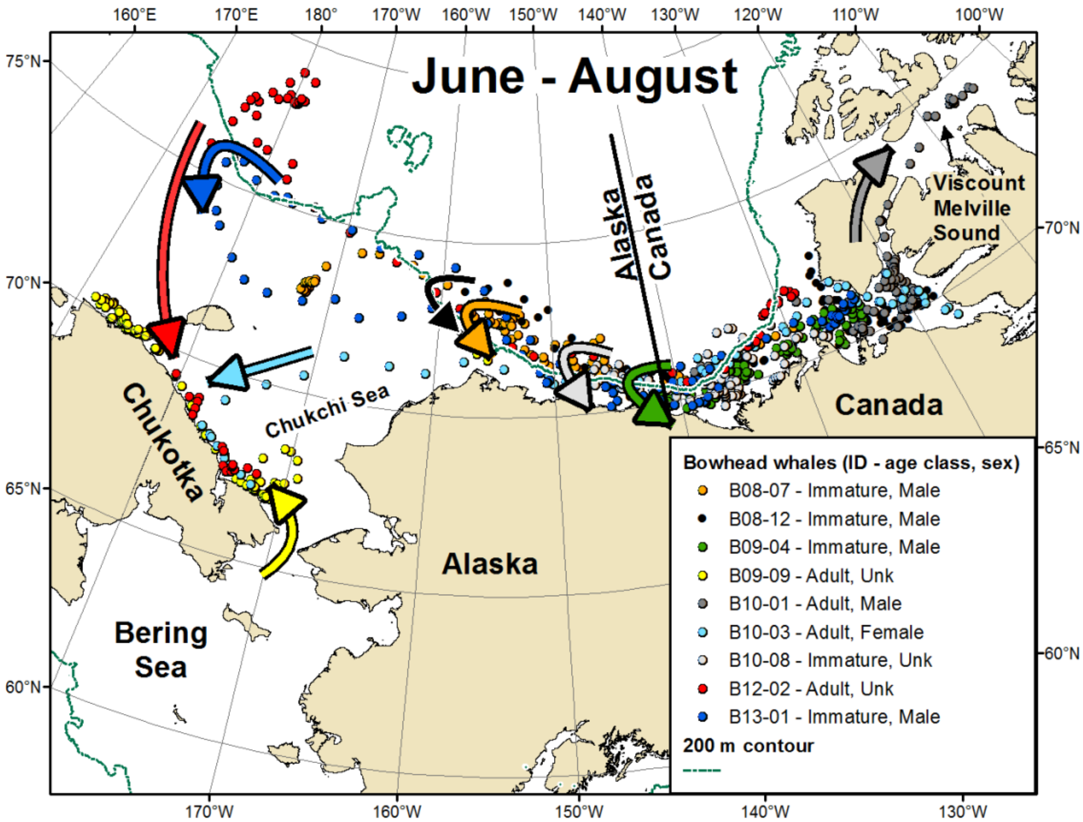

Figure 14. Anomalous movements of bowhead whales during summer (June–August).

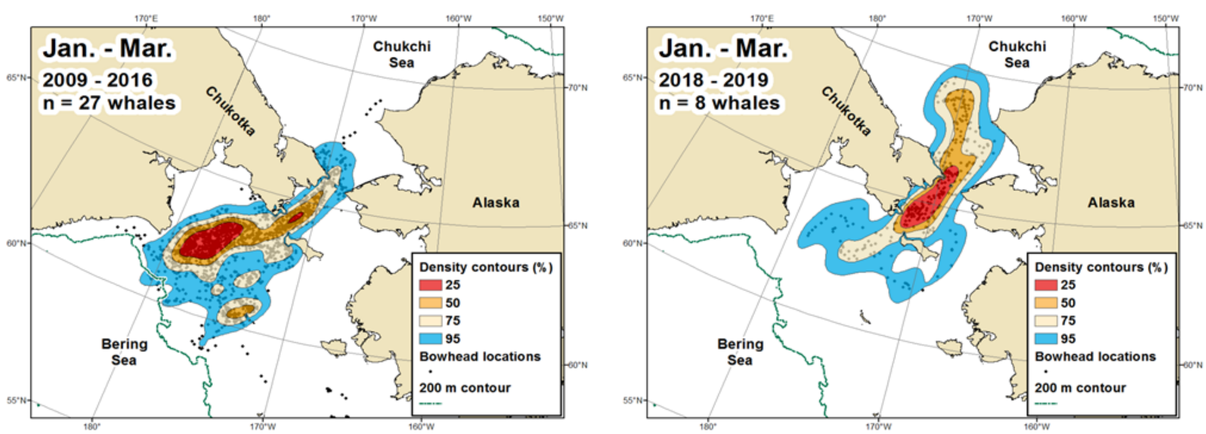

Figure 15. Northward shift of the winter (January–March) distribution of bowhead whales. Due to decreasing sea ice extent, the southern boundary of the winter distribution has shifted northwards and the southern core use area observed during 2009–2016 has largely been abandoned in 2018 and 2019 (here the two years are pooled).

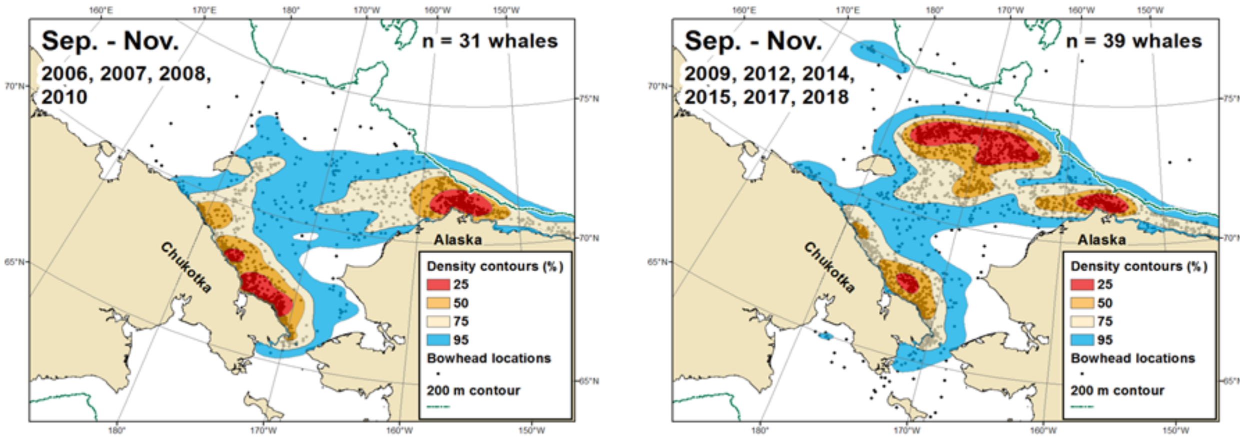

Figure 16. Interannual variability of the use of the north-central Chukchi Sea. During most of the initial years of the bowhead tagging study (2006, 2007, 2008, and 2010) there was little use of the north-central Chukchi Sea. However, in most recent years (2009, 2012, 2014, 2015, 2017, and 2018) there has been extensive use of the north-central Chukchi Sea. This will have implications for any future oil and gas development in the Chukchi Sea.

Accomplishment of Objectives and Tasks

Objectives. This study was designed to provide data to address the objectives listed below and for data to be integrated with concurrent research on oceanographic conditions relative to variability in bowhead whale feeding behavior and habitat use.

Objective a*: *Modify, improve, test, and deploy tags that collect acoustic and environmental data for use on bowhead and other large whales. Such tags may measure environmental conditions including ambient noise and physical ocean conditions.

We worked with Wildlife Computers to improve the data that their SPLASH10 tags collect. Current production tags are capable of sampling more detailed data on individual dives rather than simply collating data into histograms. New tags measure the depth of individual dives and pair those data with temperature measurements to generate temperature profiles of the water column. These depth-temperature profiles are included in our publications (Citta et al. 2015, 2018; Olnes et al. *In review*).

We also worked with Wildlife Computers to generate more detailed surface timelines. Surface timelines are the proportion of time spent at the surface within each hour of the day; these timelines were originally rounded to the nearest 10%. We were able to get Wildlife Computers to increase their sampling rate such that new timelines (called “high definition timelines”) are now rounded to the nearest 1%. These data, in addition to information on the duration of time spent on individual dives, were used in developing correction factors for the joint ASAMM, BOEM, NSB bowhead abundance survey completed in August 2019.

We began duty cycling tags in 2016 to transmit every other hour; this extended tag life and allowed for an even distribution of locations throughout the day while not sacrificing the amount of data received. Four tags duty cycled in this way lasted more than 400 days.

We also worked with SMRU to program CTD tags for deployment on bowhead whales. We deployed 11 CTD tags on bowhead whales. Most of the tags (10 of 11) were deployed in 2017 and 2018, so we are just beginning to analyze this data and appreciate their value in measuring physical ocean conditions to identify water masses used by bowheads.

We combined tag time and location with oceanographic models to better understand physical ocean conditions that were important for feeding bowhead whales. This work led to two publications, one describing high use areas used by bowheads range wide (Citta et al. 2015) and another describing the migration pattern across the Chukchi Sea in fall (Citta et al. 2018a), both behaviors are likely related to oceanographic conditions that concentrate prey. To more analyses are underway that combine oceanographic model data and bowhead movements; we will use oceanographic model data to explain the shift in the winter distribution of bowhead whales (Analysis #12, above) and another to describe bowhead dive behavior near Cape Bathurst (Appendices N, and Q).

Efforts to develop a tag that would transmit summarized acoustic data to satellites so that the tag would not need to be recovered were largely successful. The commercially available Acousonde acoustic recording tag (developed by Bill Burgess of Greeneridge Sciences, Inc.) was modified to support a software acoustic-analysis module that detects acoustic events of interest (i.e., bowhead calls and seismic pulses) and transmits the summarized data to satellites (See Tag Development in Results and Figure 1). The updated design called the Acousonde 3S will increase deployment duration by increasing battery capacity, and its use of satellite telemetry will allow researchers access to acoustic behavior and exposure data in near real-time without requiring tag retrieval, which is extremely difficult with large Arctic whales.

To accomplish the task of developing a satellite linked acoustic tag, the operating system of the Acousonde was modified to support acoustic-analysis modules written and compiled separately from the Acousonde. This strategy allows for third parties to write their own acoustic detection and digestion software modules for specific uses allowing greater flexibility than hard-coding one detection classification scheme into the Acousonde. A bench prototype of the new tag (to be called the Acousonde 3S) with a software module designed to detect seismic pulses, bowhead calls, and background noise level was constructed and successfully tested. New “CubeSat” style satellite technology appears promising for this acoustic tag. BOEM has identified this new technology as important for the future of animal and environmental instrument telemetry and has partnered with NASA to investigate its potential (https://www.boem.gov/CubeSat-video/). CubeSat has several advantages over Argos satellite technology. In addition to a substantial increase in the amount of data that can be sent per transmission (32 vs 220 bytes), CubeSat provides receipt conformation, so that a data packet need not be transmitted repeatedly (often more than necessary) to ensure receipt. This ability reduces transmissions per data packet and greatly increases the amount of data that can be transmitted, extending deployment life.

Hence, we have mostly achieved Objective a. We developed, modified, tested, and deployed tags that collect environmental data (SPLASH10, CTD, and Acousonde tags). We developed, modified, and tested a tag (but did not deploy) a tag that collects and transmits processed acoustic data to a satellite (i.e., modified the Acousonde to create the Acousonde 3S tag). This tag is ready for power consumption testing and field testing and has uplinked to the CubeSat test system but not to a satellite in orbit.

***Objective b*: Evaluate bowhead whale vocalization rates related to various behaviors or potential disturbances with tagging representative of the demographic composition of the population. Test the general hypothesis that all bowhead whales in the western Arctic stock make seasonal migrations between the Bering Sea and the summer feeding grounds in western Canada.**

We recorded bowhead whale vocalizations in Disko Bay, Greenland, during acoustic tag tests in 2013 and 2016 (Appendix M) and those data were analyzed to develop algorithms to 1) determine average background noise levels, 2) detect seismic (airgun) pulses, and 3) detect and differentiate calls made by bowheads from seismic pulses (Fig. 1). We reviewed the literature regarding bowhead vocalization rates in general, and in relation to industrial sounds from passive acoustic buoys (e.g., Blackwell et al. 2015; 2017) to inform module preparation, testing of the acoustic tag, and to determine general vocal behavior by time of year, bowhead activity, and noise. To further address this component of Objective b we will need to use data from deployments of the newly developed satellite-linked acoustic recording tag (the Acousonde 3S) developed during this project.

To address the hypothesis that all bowhead whales migrate to western Canada in spring we looked at all whales tagged whose tracks include a spring migration (n = 27). Only one bowhead (B09-09) did not migrate to the summer feeding grounds in western Canada. This whale stayed in the Chukchi Sea for the summer. Hence, it appears that most bowhead whales migrate to the Canadian Beaufort in spring. This agrees with the findings of Melnikov and Zeh (2007), which indicates that perhaps 500 whales (out of a population of over 15,000) may migrate up the Russian coast each spring and not go to Canada. It also agrees with Miller et al. (1986) who did not see any bowhead whales in the Chukchi Sea during shipboard surveys in July and August of 1982.

Hence, we have achieved Objective b to the extent possible with the technology that was available and have expanded the technology so that this objective could be achieved in a future study. We evaluated bowhead vocalizations to develop an acoustic recording tag (using test data from a retrievable acoustic tag; Acousonde) and we showed that most bowhead whales migrate to the Canadian Beaufort in spring.

Objective c: Test the related hypothesis that occasional concentrations of whales feeding in the nearshore waters of the Beaufort Sea, east of Point Barrow and in the Chukchi Sea, west of Point Barrow are a result of delays in migration by whales returning from summering in Canada.

Except whales tagged near Point Barrow in fall, all tagged whales observed in summer and fall near Point Barrow (both on the Beaufort side and on the Chukchi side) were known to have returned from Canada. Most tagged whales began to leave the Canadian Beaufort Sea in September and passed by Point Barrow in September and October. However, when tagged whales return to Alaskan waters is highly variable. Whales that traveled to the Canadian Beaufort Sea in spring returned to Alaskan waters (i.e., passed west of Demarcation Point) as early as 8 June and passed west of Point Barrow as early as 1 July. Hence, it appears that whales found near Point Barrow in summer are returning early from the Canadian Beaufort Sea.

Tagged whales that returned to Alaskan waters in summer did not remain there and either "looped" back into Canadian waters (n = 5) or continued into Russian waters (n = 2) (Fig. 14). Five tagged whales left the summering grounds in Canada and moved into Alaskan waters, but then returned to Canadian waters prior to the final fall migration. Three tagged whales did not travel as far west as Point Barrow before returning to the Canadian Beaufort Sea. Three whales traveled west to Point Barrow before they "looped" back to the Canadian Beaufort. Hence, some tagged whales traveled west past Point Barrow twice, once in mid-summer and once during the fall migration. For example, in 2009, B08-07 left the Canadian Beaufort on 8 June, passed west of Point Barrow on 8 July, returned to the Canadian Beaufort on 28 July, left the Canadian Beaufort again on 31 July, and passed Point Barrow a second time on 11 August. Of the whales that traveled to Russian waters in mid-summer, one whale passed Point Barrow on 1 July (B12-02) and the other on 22 July (B10-03). Neither of the whales that migrated to Russian waters returned to the Canadian Beaufort in the same season.

We also see whales return to Point Barrow after passing west during the fall migration. Quakenbush et al. (2010) reported on three whales that did this in 2008. In 2018, two whales that passed west of Point Barrow returned later. B17-03 passed Point Barrow on 16 October and returned on 10 November, after which it migrated west the same day. B18-07 was tagged on 21 September but did not transmit until 29 September, when it was located near Herald Canyon and Wrangel Island; this whale returned to Point Barrow on 5 October. Another whale (B18-01) tagged near Utqiaġvik on 2 September 2018 traveled east to Kaktovik and passed Point Barrow westbound on 7 October.

In summer 2016, an unusually high number of bowheads (> 1,200) were seen in the Alaskan Beaufort Sea in July and August, earlier than they have been seen before by the ASAMM aerial survey crew (Janet Clarke, pers. comm). This corresponded with our tagging crew finding very few bowheads on the Tuktoyaktuk Shelf in core Area 2 defined by Citta et al. (2015) and known to be the major summering area for the population. Only one tagged whale (B15-01) was on the air during this time; it arrived in Amundsen Gulf in early June 2016 and stayed until 2 August when it began to travel west. This whale crossed into Alaskan waters on 9 August and passed Point Barrow on 25 August. This is another example of a bowhead whale in the Chukchi Sea in late summer that came from spending spring and early summer in the Canadian Beaufort Sea.

Early movements of whales away from the primary summer feeding area in Canada, and concentrations of whales near Point Barrow and in the central Chukchi Sea, may be related to the distribution of summer feeding opportunities. Therefore the "occasional concentrations of whales feeding in the nearshore waters of the Beaufort Sea, east of Barrow and in the Chukchi Sea, west of Barrow" are not so much a result of delays in migration by whales returning from summering in Canada, but an example of more complicated summer movements than were known previously. These concentrations of bowheads near Point Barrow are related to feeding events and the timing of such events is related to the distribution of summer feeding opportunities. At times when prey are not sufficient in Canada due to lack of upwelling winds and other factors, bowheads travel elsewhere and may find better feeding opportunities in the central Beaufort, near Point Barrow, or in the central Chukchi Sea in in some years. If feeding is not better to the west bowheads return to Canada in summer prior to the fall migration.

Objective c has been fully achieved. Evidence indicates that whales seen near Point Barrow in summer are returning from the Canadian Beaufort. We identified much more summer movement of bowhead whales than was previously known (Figs. 13 and 14).

Objective d: Test the alternate hypothesis that the above occasional concentrations of whales feeding in the Beaufort Sea east of Barrow and in the Chukchi Sea west of Barrow are composed of whales that generally summer in the eastern Chukchi Sea and only enter the southwestern Beaufort Sea periodically, and under certain oceanographic conditions.

We found no evidence that concentrations of bowheads near Point Barrow in summer are whales that summer in the Chukchi Sea. There is only one example of a whale that did not pass Point Barrow and migrate to the Canadian Beaufort in spring (B09-09). B09-09 stayed in the western Chukchi Sea and did not come near Point Barrow in summer 2010; however, it was tagged near Point Barrow in August of 2009, suggesting that it may have returned from the Canadian Beaufort in that year. Tagged whales observed near Point Barrow in summer have migrated to the Canadian Beaufort in spring and then return to Barrow prior to the typical fall migration. Some of these whales go back to the Canadian Beaufort prior to the fall migration (Fig. 14). Hence, our data strongly support the hypothesis that whales observed near Point Barrow in summer are returning from the Canadian Beaufort Sea.

We have fully achieved Objective d. Whales observed feeding in the Beaufort Sea east of Barrow and in the Chukchi Sea west of Barrow are not whales that generally summer in the eastern Chukchi Sea.

Objective e*: *To the extent possible, test the hypothesis that the above concentrations of whales consist of representative proportions of demographic (sex and age, i.e., size) groups as observed in the western Arctic bowhead population.

The tagged sample is skewed toward immature males; however, this skew is unlikely to affect our results. Here, we limit the consideration of age and sex ratios to those whales that yielded enough location data to be used in analyses and were also able to be classified to sex and age (n = 40). Based upon the harvest at Utqiaġvik, the sex ratio should be approximately 50:50 (Suydam and George, 2018). Of 40 tagged whales of known sex, 26 (i.e., 65%) were male, possibly because females with calves were avoided during tagging (prior to 2016, our permits did not allow tagging females with calves). The sample is also skewed towards immature whales, defined as those with estimated lengths < 13 m. Koski et al. (2006) used photogrammetry to estimate the length distribution of bowhead whales near Point Barrow; we re-calculated this length distribution, removing calves, which we did not sample. Our recalculation of Koski et al. (2006) results in 58.9% immature whales and the tagged sample consisted of 65% immature whales. To achieve an equal sex ratio and a representative age ratio, we would have to tag approximately 10 more adult (≥ 13 m length) female bowhead whales. Adding 10 more adult females to the sample would not significantly alter our results regarding the distribution or behavior of bowhead whales.

We have met Objective e to the extent that was possible, however our current permit allows tagging females with calves so more adult females could be tagged in a future study.

***Objective f*: Test the hypothesis that the above concentrations of bowhead whales consist of individuals that are only present in the aggregations for hours to days as opposed to weeks to months.**

We defined residence time as the sum of days individual whales were within 100 km of Point Barrow during spring and fall, 2006–2019 (Table 3). Bowheads tagged near Point Barrow likely have residence times that are biased low because they were present for an unknown length of time before being tagged. However, some of the longest residence times were for whales in the year in which they were tagged. This preliminary analysis suggests that spring residence time near Point Barrow is on the order of days, while fall residence time is on the order of days to weeks. Spring durations are generally short because whales are migrating past Point Barrow and generally not stopping to feed. In the summer and fall, whales may stop for longer durations if feeding conditions are favorable, such as when the "krill trap" is operating (Ashjian et al. 2010).

Table 3. Residence time of tagged bowhead whales within 100 km of Point Barrow during spring, summer, and fall 2006–2019. A whale may spend time in the Barrow area in different seasons; hence, whales that return in different seasons are treated as different samples.

Season	Months	Number of tagged whales	Average (d)	Range (d)
Spring	Apr–May	24	2.8	1–5
Summer	Jul–Aug	11	5.1	1–10
Fall	Sep–Nov	51	8.4	1–34

Hence, we have achieved Objective f. Not only did we determine the length of time individual whales spent in aggregations near Point Barrow, we detected a difference in duration between spring (days) and fall (weeks).

Objective g: Estimate the rate and timing of travel of whales during migration across the Beaufort and Chukchi seas.

Travel times for individual whales

After leaving the Bering Sea in spring, whales travel an average of 12 days to Point Barrow (range = 8–16 days) and cross the Alaskan Beaufort in an average of 8.5 days (range = 5–22 days) (Table 4). The return trip across the Alaskan Beaufort is typically slower ($\bar{x}$ = 19 days, range = 5–54) and from Point Barrow to the coast of Chukotka may take anywhere from 6 to 82 days ($\bar{x}$ = 32.6 days). The high degree of variability in how much time is necessary to cross the Chukchi Sea is because whales sometimes stop to feed in the north-central Chukchi Sea.

Table 4. Travel times in days for individual bowhead whales. Demarcation Point marks the boundary between the Alaskan and Canadian Beaufort Seas.

Season	**Route**	**Average # days**	**Minimum # days**	**Maximum # days**	**# whales**
Spring	Bering Sea to Pt. Barrow	12	8	16	12
	Pt. Barrow to Demarcation Pt.	8.5	5	22	13
	Demarcation Pt. to Cape Bathurst	5.8	3	13	14
Fall	Demarcation Pt. to Pt. Barrow	19	5	54	21
	Pt. Barrow to Chukotka Coast	32.6	6	82	39
	Pt. Barrow to Bering Sea	69.6	32	94	21

Average dates of arrival and departure

In spring, the average date at which whales depart the Bering Sea is 17 April (range = 1 April–26 May; Table 5). However, these statistics are only for whales that entered the Bering Sea. Two whales tagged in 2017 wintered in the southern Chukchi Sea and did not enter the Bering Sea during winter. Another two whales tagged in 2018 had not entered the Bering Sea as late as 25 December, when the tags went off the air. After leaving the Bering Sea, the average date of arrival at Point Barrow is 29 April (range = 16 April–25 May). The average date of passing Demarcation Point, into the Canadian Beaufort, is 12 may (range = 26 April–26 May).

When returning in the fall, the average date that whales cross into the Alaskan Beaufort from the Canadian Beaufort is 17 September (range = 13 July–26 October). On average, whales reach Point Barrow on 25 September (range = 21 July–2 November), the coast of Chukotka Russia on 27 October (range = 28 July–21 December), and the Bering Sea on 2 December (range = 5 November–29 December).

Table 5. Dates at which bowhead whales arrive at different boundaries and geographic features. Demarcation Point marks the boundary between the Alaskan and Canadian Beaufort Seas.

Season	Event	Average date	Minimum date	Maximum date	# whales
Spring	Leave Bering Sea	17-Apr	1-Apr	26-May	15
	Pass Pt. Barrow	29-Apr	16-Apr	25-May	17
	Pass Demarcation Pt.	10-May	26-Apr	30-May	17
	Arrive Cape Bathurst	12-May	2-May	26-May	14
Fall	Pass Demarcation Pt.	17-Sep	13-Jul	26-Oct	24
	Pass Pt. Barrow	25-Sep	21-Jul	2-Nov	53
	Arrive at Chukotka Coast	27-Oct	28-Jul	21-Dec	40
	Arrive in Bering Sea	2-Dec	5-Nov	29-Dec	24

We have fully achieved Objective g. We have described the timing and duration of travel between wintering grounds, summering grounds, and passage across the Alaskan Beaufort Sea and Chukchi Sea.

Objective h: To the extent possible, document and describe the general pattern and variability in inter-year and year-round movements by bowhead whales, the degree to which migrating whales make use of specific polynyas or channels, and estimate for individual whales time budgets of time spent in specific geographic regions and/or functional habitat areas.

In our previous project, we found that bowhead whales rarely used polynyas and leads while wintering in the Bering Sea (Citta et al. 2012) and have shown in annual reports that bowheads often do not follow lead systems during the spring migration in the Beaufort Sea (Fig. 17).

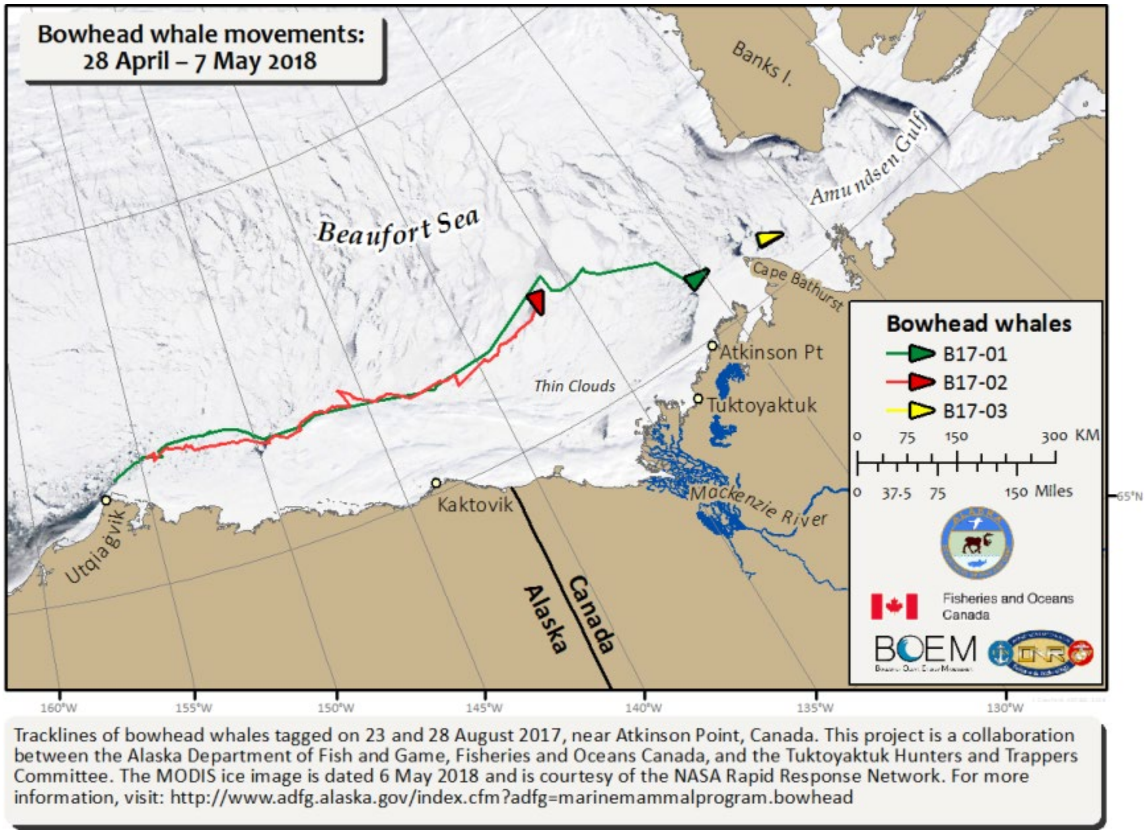

Figure 17. Tracks of bowhead whales through >98% ice concentration in spring 2018.

Our SOAR I manuscript titled "*Ecological characteristics of core-use areas used by Bering-Chukchi-Beaufort (BCB) bowhead whales, 2006–2012*" (Citta et al. 2015) also addressed parts of this objective. In this publication we identified the geographic regions in which bowheads spent time and explored the physical oceanography before, during, and after bowheads were present to better understand what features may provide concentrated zooplankton for feeding. We documented the residence times of bowheads in each core use area.

Our first SOAR II manuscript titled "*Oceanographic characteristics associated with autumn movements of bowhead whales in the Chukchi Sea*" (Citta et al. 2018a) also addresses this objective. We examined the variability of inter-annual use in the Chukchi Sea in the fall relative to oceanographic variables. We found that bowheads followed cold (< 0 ºC) water of Pacific origin with salinities between 31.5 and 34.25 psu. Bowheads were more likely to linger in areas with stronger gradients in bottom salinity, which likely contain higher densities of zooplankton. Bowheads avoided warmer and fresher Alaskan Coastal Water and Siberian Shelf Water, which are less likely to contain zooplankton.

The SOAR II manuscript titled "*Trends in sea ice cover within bowhead whale use areas in the Pacific Arctic*" (Druckenmiller et al. 2018) also addressed this objective. In this publication, we showed how ice cover has decreased more in the core-use areas, as defined by Citta et al. (2015), in the northern extent of the range than in core-use areas in the southern extent. The number of open water days within the bowhead core-use areas near Point Barrow and along the northern Chukotka Coast during peak use has increased by 13 and 10 days/decade, respectively. The most dramatic reductions in sea-ice cover have taken place in the Alaskan Beaufort Sea where the number of open water days on the shelf and slope has increased by 20 and 25 days/decade, respectively. Using aerial survey data, we found that in the fall bowheads migrate closer to shore when there is less sea ice and farther from shore when there is more sea ice. We speculate that this might be because there are increased feeding opportunities closer to shore as a result of greater upwelling along the shelf break when the ice cover is farther from shore. Furthermore, the aerial survey data also revealed that high use areas within the Alaskan Beaufort Sea have shifted westward, toward Point Barrow, during fall in the period 1997–2014 compared to 1982–1996. We anticipate that bowheads will spend increasingly more time within summer and fall feeding areas, delaying their migration to the Bering Sea. Reduced ice coverage and thickness in the southern Chukchi Sea may make wintering there more common in the future. Indeed, whales tagged in 2017 did not move into the Bering Sea until late January 2018.

Data from this project were used in a manuscript titled "*Movements and inferred foraging by bowhead whales in the Canadian Beaufort Sea during August and September, 2006–12*" (Harwood et al. 2017). This publication identified core use areas in the Canadian Beaufort Sea and documented residence times in each area.

Hence, we have fully achieved Objective h by describing general patterns and variability in inter-year and year-round movements of bowhead whales, the degree to which migrating whales make use of specific polynyas or channels, and estimating time spent in specific geographic regions and habitat areas. We published our findings in four peer-reviewed scientific papers and included results in our annual and final reports.

Objective i: Instrument other species of baleen whales when encountered during bowhead tagging efforts when practical.

The only other baleen whales encountered during our bowhead tagging efforts were gray whales. We tagged eight gray whales during previous phases of this study: one gray whale near Tuktoyaktuk, Canada in 2009, six near Point Barrow in 2011, and one near Gambell in 2012. Four of these were females, three where males, and one was undetermined. Of the eight tags seven were SPOTs and one was a SPLASH tag. Tag durations were shorter for grays than bowheads averaging 36 days (range = 0–100 days). To contribute to photo-identification efforts we took photos of six gray whales near Gambell in 2012. All six had right and left side photos and two also included ventral fluke photos. A ventral fluke photo was also taken of the gray whale tagged in Canada in 2009 (G09-01). The photos were submitted to various catalogs for matching. No matches were found in the Western North Pacific Sakhalin catalog. Much more could be done with a dedicated gray whale effort. Our priority, however, was bowhead whales and there was not enough time or money to do both.

Tasks

Task 1 – Data Review and Hypothesis Development.

Throughout this project, we reviewed available data on bowhead whales. In addition to analyzing our own data we peer reviewed manuscripts and read literature on bowhead whale movements and behavior from all stocks. During our interdisciplinary work on the SOAR I paper titled "*Ecological characteristics of core-use areas used by Bering-Chukchi-Beaufort (BCB) bowhead whales, 2006–2012*" (Citta et al. 2015) we were struck by how well pairing the hotspot locations of tagged whales with the oceanographic model explained how zooplankton might concentrate in those locations and how well bowhead movements away from those locations fit with changes in the oceanography that discouraged zooplankton concentration. We then used the same oceanographic model to explore inter-annual variation in bowhead movements through the Chukchi Sea (Citta et al. 2018a). We developed a hypothesis regarding specific core use areas by analyzing dive data in the spring at Cape Bathurst in Amundsen Gulf and compared it to the oceanography to further explore the dynamics there that are conducive to the concentration of zooplankton (Citta et al. *In prep*).

Task 2 – Experimental Design and Field Work.

We worked with Greenland Institute of Natural Resources, Greeneridge Sciences, and Scripps Institute of Oceanography to develop a satellite-linked acoustic recording tag (Acousonde 3S) that will provide average background noise level and detect bowhead vocalizations and seismic events and transmit data to a satellite for download. We collected acoustic data from retrievable acoustic tags to develop algorithms to summarize the data for transmission to satellites. The Acousonde 3S uses the available Acousonde acoustic retrievable tag developed by engineer Bill Burgess (Greeneridge Sciences, Inc.) and adds software designed by Aaron Thode (Scripps) to process acoustic data for detections of bowhead calls and seismic pulses into packets of data small enough to be transmitted to satellites. This onboard processing also extends battery life so that the tag will function on the animal for weeks instead of hours or days.

Field work ended in fall of 2018. The success of this project was due to our partnership with the Alaska Native subsistence whalers and the Canadian hunters and trappers. Their knowledge of bowheads, skill on the water, and interest in the project was key to our success.

Task 3 – Data Analysis and Reporting.

We have analyzed satellite telemetry data to address many objectives. Some of which were original objectives provided by BOEM, other objectives were added by BOEM through time (e.g. SOAR projects, oil spill trajectory analysis). Additional objectives were provided by the whalers (e.g., winter overlap with pot fisheries, use of Camden Bay for feeding). We used findings from this study to test and refine hypotheses. We reported our results widely by providing weekly maps of tagged whales when they were on the air to our >250 member e-mailing list and we archive maps at our website: (http://www.adfg.alaska.gov/index.cfm?adfg=marinemammalprogram.bowhead). We shared data from this project for use in many other projects. We produced nine peer-reviewed publications as lead and co-authors using data from this project. We presented results as many abstracts, posters, and oral presentations at scientific conferences, the International Whaling Commission, and presentations at AEWC and Barrow Whaling Captain's meetings (See Appendices).

Task 4 – Integration of Findings with other Tasks.

We provided maps and data to BOEM and others for integration into other projects, one paper was published in 2015 using data from this project for SOAR (Phase I):

1) "Ecological characteristics of core-use areas used by Bering-Chukchi-Beaufort (BCB) bowhead whales, 2006–2012" (Citta et al. 2015).

Three papers were published in 2018 using data from this project for SOAR (Phase II):

1) "*Oceanographic characteristics associated with autumn movements of bowhead whales in the Chukchi Sea*" (Citta et al. 2018a).
2) "*Multi-species marine mammal use of the Bering, Chukchi, and Beaufort seas*" (Citta et al. 2018b).
3) *"Trends in sea ice cover within bowhead whale use areas in the Pacific Arctic*" (Druckenmiller et al. 2018).

We have accommodated many requests for our tagged bowhead movement data to augment other projects and efforts. As examples:

1) We contributed to the U.S. Coast Guard effort for planning shipping lanes in Bering Strait.
2) We provided reports to the International Whaling Commission on general movements and stock structure (Quakenbush et al. 2012; 2018, Appendix S).
3) We conducted specific analyses for the NSB/Shell and AEWC Camden Bay study to evaluate lingering (i.e., assumed feeding) behavior in the vicinity of the Beaufort Sea leases (Appendix T).
4) We made our maps and other products available through our website http://www.adfg.alaska.gov/index.cfm?adfg=marinemammalprogram.bowhead Many consulting companies, agencies, researchers, and other entities download and use these maps for their reports.
5) We contributed gray whale photos and genetics for identification to assist with stock identification.
6) We provided monthly maps (July–November) of tagged bowhead whale locations relative to Quintillion's fiber optic cable route to NMFS, Alaska Region for preparation of a biological opinion (Appendix O).
7) We provided information on tagged bowhead movements, behavior, and timing near the Liberty prospect for preparation of the biological opinion also at the request of NMFS, Alaska Region (Appendix U).
8) We participated in developing best practices guidelines for large cetacean tagging with an international group of cetacean researchers.
9) We provided locations of tagged bowheads in Canadian waters to Department of Fisheries and Oceans Canada for maps to be used in the creation of a Marine Protected Area Network in the Western Arctic.

Task 5 – Data Management and Archival. We archived data collected during all phases of this study. We worked with ATN and the Alaska Ocean Observing System to improve metadata requirements and online presentation of data to assist ATN in becoming what federal agencies and researchers need for a data archive. Our data archive and access policies are consistent with standards adopted by BOEM, the National Oceanographic Data Center, NOAA, and other federal agencies.

Task 6 – Local Coordination, Outreach and Permitting. We coordinated with the NSB when tagging near Utqiaġvik and with the local Whaling Captain's Associations for each community where tagging occurs. In Canada, we coordinated with the Department of Fisheries and Oceans and with the local Hunter's and Trapper's Associations. We also prepared posters and gave presentations at many AEWC meetings (Table 1, List of Publications and Products, Appendices).

Our primary method of outreach was our weekly maps with the most recent tagged whale locations and a description of any additional pertinent information. We often got responses and discussion among recipients in real time when maps were sent. The e-mail list included many subsistence hunters and whalers as well as agency personnel. The maps were then archived on our ADFG website
http://www.adfg.alaska.gov/index.cfm?adfg=marinemammalprogram.bowhead
where they are available along with other information about the bowhead tagging project.

We maintained a U.S. Federal Marine Mammal Research Permit from NMFS throughout the project. We also maintained annual Institutional Animal Care and Use Committee (IACUC) protocols from ADFG for our cetacean research in the U.S. For research conducted in Canadian waters we also obtained research and IACUC permits required by Canada.

Task 7 – Logistics/Safety Plan. 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. A safety boat accompanied each tagging boat. Radio communication was established among boats and with a contact on shore. In addition to marine VHF radios, radio beacons, satellite telephones were on board. In the Point Barrow area, a "float plan" was filed with the NSB Search and Rescue office prior to departure.

Discussion

Coordination

The collaboration among AEWC, NSB, Whaling Captain's associations, individual whalers, Canadian hunters, DFO, and BOEM proved to be an excellent framework for conducting bowhead whale tagging and for exchanging information during all phases of this study.

Our tagging Study Plan was designed, modified, approved, and conducted by the partners. Decisions about where and when to tag were made with AEWC and the local whaling captains associations prior to tagging operations. How tagging occurred relative to subsistence whaling was also left to the captains. One of our primary goals was that tagging would not interfere with subsistence whaling and to achieve that goal we proposed to avoid the whaling season and deploy tags at other times or places. The AEWC, the Barrow whaling captains, and the Gambell and Savoonga whaling captains, however, felt that there were ways that tagging could occur during whaling that would not interfere. For example, in spring near Utqiaġvik when the lead is narrow and the whalers are waiting for the lead to open wide enough so that a struck whale will not be lost under the ice, the whalers felt that whales that came up in the narrow leads could be tagged from the ice edge. In Gambell and Savoonga, crews dedicated to tagging where chosen and the tagging activities were coordinated by the captains and tags were deployed during whaling without conflict or complaint.

To keep AEWC informed of the study's progress and for them to relay questions and concerns we have made regular oral presentations at AEWC meetings and provided handouts for the commissioners (Appendices C, E, P, V, and W). To keep as many people informed as possible, we sent weekly maps of the locations and movements of tagged bowheads to partners and anyone that expressed an interest in receiving them. The e-mail list contained >250 addresses; many people also forwarded our maps to their own list of addresses. We also met with the tagging crews in Gambell and Savoonga to provide updates and equipment prior to each tagging season.

Often map recipients replied to the list with their thoughts, questions, or other information about current whale observations. This stimulated on-line discussions that provided valuable real time information on the movements of the tagged whales relative to the rest of the population. For example, once we sent out a map showing when the first tagged whales entered the Bering Sea, whalers on St. Lawrence Island then informed us they were already observing whales and were whaling. This type of information is extremely valuable in helping us interpret how representative the tagged whales are and serves as a reminder that the tagged whales do not represent all whales. This is an important point that the AEWC made at the origin of this study and why we added the traditional knowledge component to the early phases of this study (see Huntington et al. 2016, 2017).

After the maps were e-mailed, they were placed on the ADFG website
http://www.adfg.alaska.gov/index.cfm?adfg=marinemammalprogram.bowhead
for people without e-mail access. We know that the website was checked regularly because if we were late posting a map we received inquiries. We also posted publications, analyses, posters, and other products there as well. These products are used by many entities including for environmental assessments, biological opinions, incidental harassment applications and authorizations, in oil company reports, and in species and habitat maps.

Tagged Whales and Tag Performance

Satellite tags (including CTD tags). Tag performance was generally good. During the project period, the average longevity of SPLASH10 tags was 231 days (range = 0–716 days). The average longevity of CTD tags was 67 days (range = 4–203 days). CTD tags do not last as long as SPLASH10 tags nor are they as reliable, partly because the salinity sensors draw more power from batteries; the CTD tags were expected to last 3 to 4 months. We had to send SMRU CTD tags back to SMRU several times for battery issues that occurred before tags could be deployed.

Acoustic tag. The Acousonde 3S prototype has been configured to be module capable and an acoustic detector module specific to bowhead vocalizations and seismic pulses was developed and tested. Software has been developed and tested for compatibility with tag hardware, preliminary power requirements and battery consumption have been bench tested as has the communication link to the satellite. The satellite-linked acoustic recorder (Acousonde 3S) is ready for field testing.

Gray Whale Photo-identification. Movements of three gray whales tagged near Sakhalin Island, Russia in 2010 and 2011 raised questions regarding the discreteness of gray whale stocks. These whales, thought to be part of the small (~130) endangered Western Pacific population left the Sakhalin area and migrated across the Okhotsk Sea, the southern Bering Sea, and the Gulf of Alaska. One tag stopped transmitting in the Gulf of Alaska, another near the central Oregon coast, but the third whale was tracked to the breeding grounds of the Eastern Pacific population along the coast of Baja California arriving there in February 2012 (Mate et al. 2015). This whale was also tracked back to Sakhalin Island leaving Baja in mid-March and arriving at Sakhalin Island in mid-May. Photo-id catalogs of the two stocks were compared and matches were found for one of these whales indicating that it had been photographed within the ranges of both stocks. Until these recent events, gray whales summering in the Bering and Chukchi seas were thought to belong to the Eastern Pacific population but now it is possible there is more movement between the Eastern and Western Pacific groups than realized. To determine where gray whales summering in the Bering and Chukchi seas go in other seasons photographs are needed to compare with existing catalogs. Matches contribute greatly to understanding the movements of gray whales across the Pacific. Our intention was to conduct gray whale work near Gambell and Point Barrow in summer, however changes in movement patterns of bowheads increased our focus and funding on bowheads, which did not leave enough time or resources to also study gray whales.

Conclusions

During this study we collected and analyzed extensive data regarding bowhead whale movements throughout their range. We worked with Native subsistence whalers in the U.S. and Canada to explore study questions and deploy tags. We continued to work with tag manufacturers to improve tag data and longevity and we worked with Greeneridge Sciences, Scripps, and GINR to develop and test a satellite-linked acoustic tag. We shared our results with subsistence whalers and their communities, scientists, oil company personnel, agency personnel and other interested parties by sending out weekly maps and information updates. We maintained an active website that allowed for access to our data products and was used by many for diverse purposes including species and habitat maps, environmental assessments, biological opinions, incidental harassment applications and authorizations. We published nine papers in peer-reviewed journals: (1) *Potential for bowhead whale entanglement in cod and crab pot gear in the Bering Sea* (Citta et al. 2014), (2) *Presence and behavior of bowhead whales in the Alaskan Beaufort Sea in July 2011* (Christman et al. 2013), (3) *Ecological characteristics of core-use areas used by Bering-Chukchi-Beaufort (BCB) bowhead whales, 2006–2012* (Citta et al. 2015), (4) *Effects of changing sea ice on marine mammals and subsistence hunters in northern Alaska from traditional knowledge interviews* (Huntington et al. 2016), (5) *Evaluating the effects of climate change on indigenous marine mammal hunting in northern and western Alaska using traditional knowledge* (Huntington et al. 2017, (6) *Movements and inferred foraging by bowhead whales in the Canadian Beaufort Sea during August and September, 2006–2012* (Harwood et al. 2017), (7) *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. 2018b), (8) *Trends in sea-ice cover within bowhead whale habitats in the Pacific Arctic* (Druckenmiller et al. 2018), and (9) *Oceanographic characteristics associated with autumn movements of bowhead whales in the Chukchi Sea* (Citta et al. 2018a). In addition, we have three papers and a book chapter in press, in review, and in preparation: (1) *Use of the Alaskan Beaufort Sea by bowhead whales tagged with satellite transmitters* (Olnes et al. *In review*); (2) *Dive behavior of bowhead whales within the Cape Bathurst polynya in spring* (Citta et al. *In prep*.); (3) *Declining winter sea ice is associated with a northward shift of bowhead whale winter range* (Citta et al. *In prep*.); and (4) *Distribution and behavior of Bering-Beaufort-Chukchi bowhead whales as inferred by telemetry* (Citta et al. *In press*). We made numerous oral and poster presentations at conferences, symposia, and meetings (See Appendices).

Results from this study contributed greatly to knowledge regarding the distribution, movements, and biology of bowhead whales. These include, but are not limited to:

1. We further documented the extensive summer movements and timing of western Arctic bowhead whales. Some tagged bowhead whales use the entire Beaufort Sea in summer by "looping" between Amundsen Gulf and the Chukchi Sea in addition to the spring and fall migration trip (Fig. 14).

2. We quantified six areas where whales spend time (Fig. 3), and are likely feeding, two in Canada (Cape Bathurst and the Tuktoyaktuk Shelf); one in Alaska (Point Barrow); and three in Russia (Northern Chukotka with Bering Strait, Anadyr Strait, and the Gulf of Anadyr). We have analyzed the oceanographic factors that concentrate krill to better understand the conditions that drive bowhead movements (Citta et al. 2015).

3. We have analyzed the more variable fall migratory corridor in the Chukchi Sea between Point Barrow and Bering Strait (Fig. 16), which includes the time bowheads spend in the Chukchi Lease Sale 193 area in the fall. These movements also appear to be related to prey availability as determined by oceanographic factors that concentrate krill. Whales followed waters that originated in the Pacific Ocean and the Bering Sea as they crossed the Chukchi Sea. These waters of Pacific origin, Bering Sea/Anadyr Water (BSAW) and Pacific Winter Water (PWW), are known to contain high zooplankton density. Whales actively avoided Alaska Coastal Water (ACW) and Siberian Shelf Water (SSW); both of which are known to have relatively low densities of zooplankton. The western boundary of bowhead whales on the shelf is largely defined by the presence of SSW. This is fresh coastal water that pools on the shelf to the west of Wrangel Island (Citta et al. 2018a).

4. Bowheads tagged near St. Lawrence Island show similar movements as those tagged near Point Barrow and Tuktoyaktuk, although the sample size is small (n = 3).

5. We summarized the movements of bowhead whales, gray whales, beluga whales, ice seals, and walruses in the Bering, Chukchi, and Beaufort seas and then overlaid these data to identify multi-species core-use areas. The range of bowhead whales overlapped the most with the ranges of several beluga whale stocks. In summer, bowhead whales overlapped most with the Eastern Beaufort stock of belugas. In winter, bowhead whales

overlapped large amounts of the ranges of belugas from three stocks: Eastern Beaufort Sea, Eastern Chukchi Sea and Anadyr (Citta et al. 2018b).

6. In the winter of 2017/18, we documented a northward shift in bowhead winter range associated with a decline in sea ice in what was the primary wintering area in the Bering Sea. Tagged bowheads wintered in the Chukchi Sea in 2017/18 when ice was absent in their typical wintering area. During the winter of 2018/19, sea ice was present, and bowheads remained in the northern portion of the Bering Sea wintering area (Fig. 15).

7. Bowhead whales sometimes shift their distribution in the fall away from the coast of Chukotka, Russia, and towards the north-central Chukchi Sea (Fig. 16). Whales rarely lingered in the central Chukchi in 2006, 2007, 2008, or 2010; however, use of the north-central Chukchi was extensive in 2009, 2012, 2014, 2015, 2017, and 2018 (Citta et al. 2018a). Results were equivocal for 2011 and 2016; in those years too few whales were tagged to determine if the north-central Chukchi was used extensively. In most of the early years of the study (4 of 5 years prior to 2011) whales did not linger in the north-central Chukchi. In contrast, the north-central Chukchi received extensive use in almost all years after 2011 (5 of 6). Hence, it appears that use of the north-central Chukchi as a fall feeding area is increasing. Preliminary analyses indicate that this is related to the prevalent wind patterns in the region; when east winds are weaker, there is more foraging in the north-central Chukchi and when east winds are stronger there is less foraging in the north-central Chukchi. Because west winds are becoming more common, bowheads may be shifting their fall distribution away from the Russian coast and into the central Chukchi Sea. The shift towards more use of the north-central Chukchi Sea will have implications for any oil and gas development within the Chukchi Sea.

Recommendations

1. The Arctic and its oceans are warming, patterns of wind are shifting, sea ice thickness and extent are declining. As a result, we see that the distribution of bowhead whales is shifting. We have already seen the winter range of bowhead whales shift northwards and find that, in years with fewer or less sustained east winds, bowhead whales shift their fall distribution in the Chukchi Sea away from the Russian coast and towards the Alaskan coast. This will have implications for future oil and gas activities in the Chukchi Sea as whales will spend more time in Alaskan waters. We recommend that tagging studies be renewed to monitor changes in movements if the climate continues to warm.

2. Bowhead whales have already become more difficult to hunt, due to larger storms and less, more variable sea ice. We recommend that local knowledge be collected and compared with Traditional Ecological Knowledge to better understand changes in bowhead whale behavior if the climate continues to warm.

3. Offshore industrial activity within the bowhead range creates noise that may negatively affect bowhead whale behavior. We recommend field testing the Acousonde 3S acoustic tag and deploying it on bowhead whales in Alaskan waters.

4. Our sample was slightly biased towards immature male bowhead whales. We recommend that future tagging efforts tag more mature females including females with calves.

5. Distribution and stock origin for gray whales using the Bering, Chukchi, and Beaufort seas is little known and could be determined with a dedicated study using photographic identification and satellite telemetry. As sea ice declines more gray whales are likely to summer in the Bering, Chukchi, and Beaufort seas and are likely to stay longer. This will have implications for future oil and gas activities in the Chukchi and Beaufort seas.

6. There is some evidence that killer whales are becoming more common in the Chukchi and Beaufort seas in summer and as large whale predators may influence bowhead whale distribution, especially if sea ice is not available as escape habitat. Studies of bowhead, gray, and killer whales may be warranted.

Acknowledgments

This cooperative project involved contributions and hard work from many individuals, organizations, and agencies. We greatly appreciate assistance from the Alaska Eskimo Whaling Commission (the late Arnold Brower, Sr., Harry Brower, Jr., and Ray Koonook, George Noongwook, Merlin Koonooka), the North Slope Borough (John “Craig” George, Billy Adams, Robert Suydam, Bobby Sarren, Quayaan Leavitt, and Ambrose Leavitt), the Barrow and Kaktovik Whaling Captain’s Associations (Eugene Brower, Lloyd Hobson, Carl Nayakik, Jared Nayakik, Mike Donovan, Jordan Kippi, Justin Gatten, Fenton Rexford, Joe Kaleak, George Tagarook, and Eddie Arey), the Barrow Arctic Science Consortium (Lewis Brower), St. Lawrence Island crews (Thomas Akeya, Carl Pelowook, Clarence Irrigoo, Edgar Campbell), Aklavik and Tuktoyaktuk Hunters and Trappers Committees (Charles Pokiak, James Pokiak, Gary Raddi, Sr., Gary Raddi, Jr., Sammy Gruben, Joeseph Felix, Jr., Raymond Ettagiak, Dennis Arey, Larry Arey, Pat Kasook, Buddy Gruben, Douglas Panaktalok, Mikkel Panaktalok, and Max Kotokak, Sr., and the Department of Fisheries and Oceans Canada (DFO) (Lois Harwood, Kevin Bill, Tim Leblanc, Patrick Ryan, Terry Stein, Angus Alunik, Ellen Lea, Kate Snow, Deanna Leonard, Connie Blakeston), and Dr. Stephen Raverty of the BC Animal Health Center all assisted with field operations. Captain Michael Fleming and R/V Ukpik provided vessel support in Canada. We appreciate Robert Small’s lead of the early Canadian field efforts and his assistance in manuscript preparation. The Greenland Institute of Natural Resources (Mads Peter Heide-Jørgensen, Mikkel and Anders Villum Jensen) was critical for general tag development, deployment, in the early development of the acoustic tag prototype, and in manuscript review. Greeneridge Sciences, Inc., especially Bill Burgess was responsible for the development and programing of the Acousonde 3S and Susanna Blackwell contributed greatly by providing advice and acoustic data for testing. Aaron Thode was critical in the development of module software for summarizing bowhead and seismic acoustic data. Stephen Okkonen provided valuable oceanographic information, insight and interpretation. Funding for this research was provided by the Bureau of Ocean Energy Management with support and assistance from Charles Monnett, Jeffery Denton, Carol Fairfield and Heather Crowley. Much of the operations in Canada were funded by Fisheries and Oceans Canada, the Fisheries Joint Management Committee, Ecosystem Research Initiative (DFO), and Panel for Energy Research and Development with extensive support and coordination from Lois Harwood and Ellen Lea. Funding was also provided by the Office of Naval Research for the deployment of CTD tags with support Michael Weise (contract N00014-16-1-3019). Bowhead whale research has been conducted in the U.S. under Marine Mammal Protection Act permits issued to National Marine Fisheries Service (No. 782-1719) to the Alaska Department of Fish and Game (Nos. 14610 and 18890) and under the Alaska Department of Fish and Game's Animal Care and Use Committee (Protocol Nos. 06-16, 09-21, 2010-13R, 2012-20, 2013-20, 2014-03, 2015-25, 2016-23, 0027-2017-27, and 0027-2018-29). In Canada, research was conducted under Department of Fisheries and Oceans License to Fish for Scientific Purposes Nos. S-07/08-4007-IN, S-08/09-4000-IN, S-09/10-4005-IN-A1, S-14/15-1027-NU, S-16-17-3035-YK Lea, S-17-18-3034-YK-Lea, and Animal Care Protocols FWI-ACC-2007-2008-013, FWI-ACC-2008-031, FWI-ACC-2009-019, FWI-ACC-2014-048, AUP 2016-045, and AUP-2017-35.

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Appendix A.

Industrial activities and western Arctic bowhead whales: what we have learned from satellite telemetry

L.T. Quakenbush[1], L. Harwood[2], J.J. Citta[1], J.C. George[3], R. J. Small[4], M.P. Heide-Jørgensen[5], H. Brower[3], B. Adams[3], L. Brower[6], J. Pokiak[7], C. Pokiak[7], and G. Tagarook[8]

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Offshore industrial activity is increasing within the range of the western Arctic stock of bowhead whales (*Balaena mysticetus*); however, how often individual whales encounter activities, and whether multiple encounters occur, has not been known. A satellite tagging study, funded by MMS/BOEM, tracked bowhead whales (2006–2010) to determine movements and habitat use, and minimum annual encounter rates of individuals with industrial activities. Most tagged whales made a >6,000 km annual migration, from the Bering Sea (winter range) through the Chukchi and Beaufort seas to the Canadian Beaufort Sea (summer range), and back. Their migration takes them through active oil and gas lease areas in U.S., Canadian, and (possibly) Russian waters. In summer, most whales (36 of 37) spend up to 3 months feeding in the Canadian Beaufort Sea, where 2D and 3 D seismic surveys have been conducted since 2006. In fall, whales pass near or through active oil and gas exploration and development areas in the Alaskan Beaufort Sea. Each year, all tagged whales passed through at least one active industrial area and most (36 of 37) passed through two (one in the U.S. and one in Canada). One whale was documented within three seismic survey areas. The current level of activity has not prevented this population from growing; however, industrial activity is expected to increase, which will increase the frequency bowhead whales encounter industrial disturbances, which may have negative population-level consequences. Other potential effects are of concern to subsistence hunters, such as altered movement patterns. This study has demonstrated that individual bowhead whales currently encounter multiple industrial activities annually. Future studies will include the use of acoustic tags to determine individual bowhead call rates relative to ambient noise levels. Understanding bowhead call behavior will aid the interpretation of passive acoustic data currently collected near seismic and drilling sites.

Abstract and oral presentation at the U.S.-Canada Northern Oil and Gas Research Forum, 13–15 November, Anchorage, AK.

Appendix B.

Industrial activities and western Arctic bowhead whales: what we have learned from satellite telemetry

L.T. Quakenbush[1], L. Harwood[2], J.J. Citta[1], J.C. George[3], R. J. Small[4], M.P. Heide-Jørgensen[5], H. Brower[3], B. Adams[3], L. Brower[6], J. Pokiak[7], C. Pokiak[7], and G. Tagarook[8]

[1] *Alaska Department of Fish and Game, Fairbanks, USA*
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Alaska Marine Science Symposium, 21-25 January 2013, Anchorage, Alaska

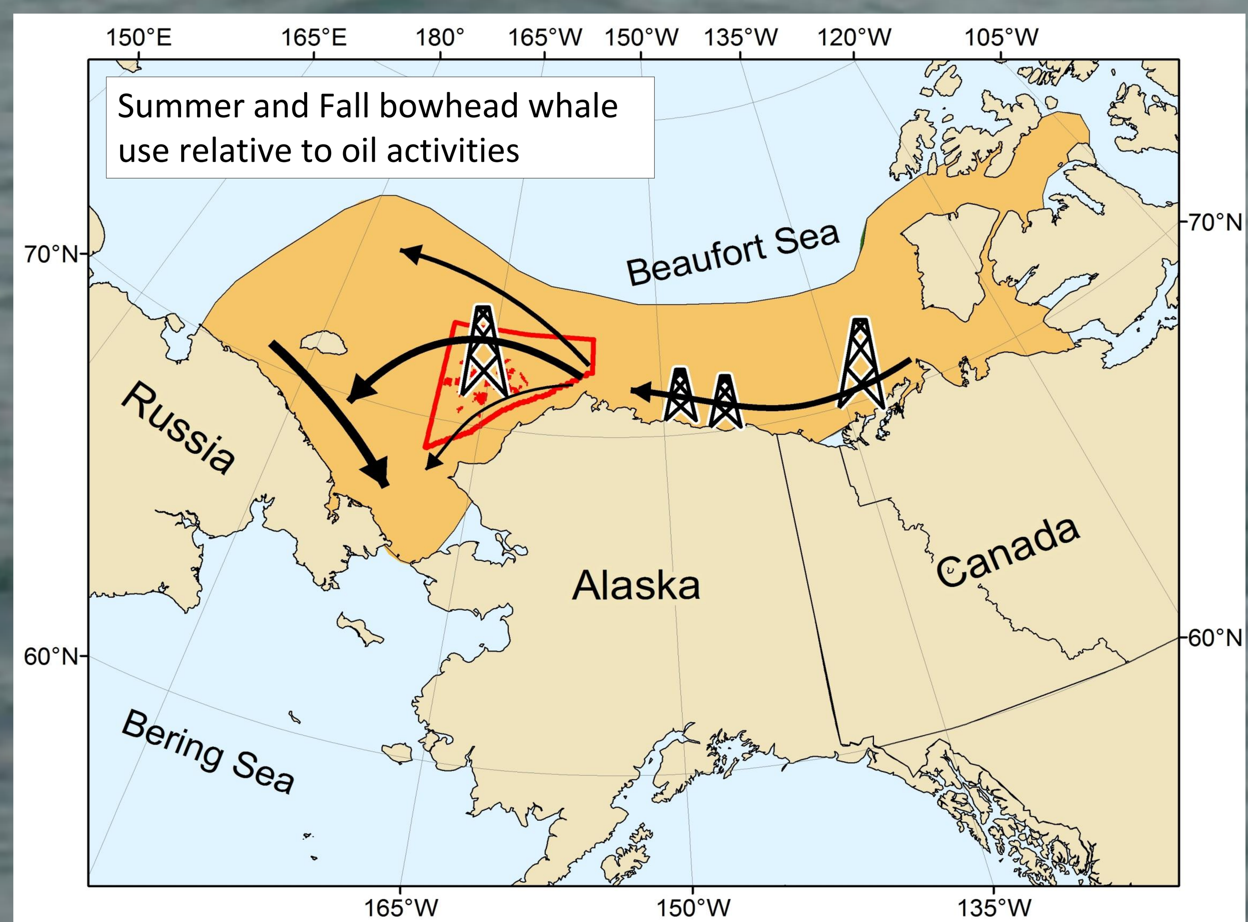
Appendix B.

Industrial Activities and Western Arctic Bowhead Whales: What We Have Learned From Satellite Telemetry

Lori Quakenbush[1], Lois Harwood[2], John Citta[1], John C. George[3], Robert Small[1], Mads Peter Heide-Jørgensen[4], Harry Brower[3], Billy Adams[3], Lewis Brower[5], James Pokiak[6], Charles Pokiak[6], and G. Tagarook[7].

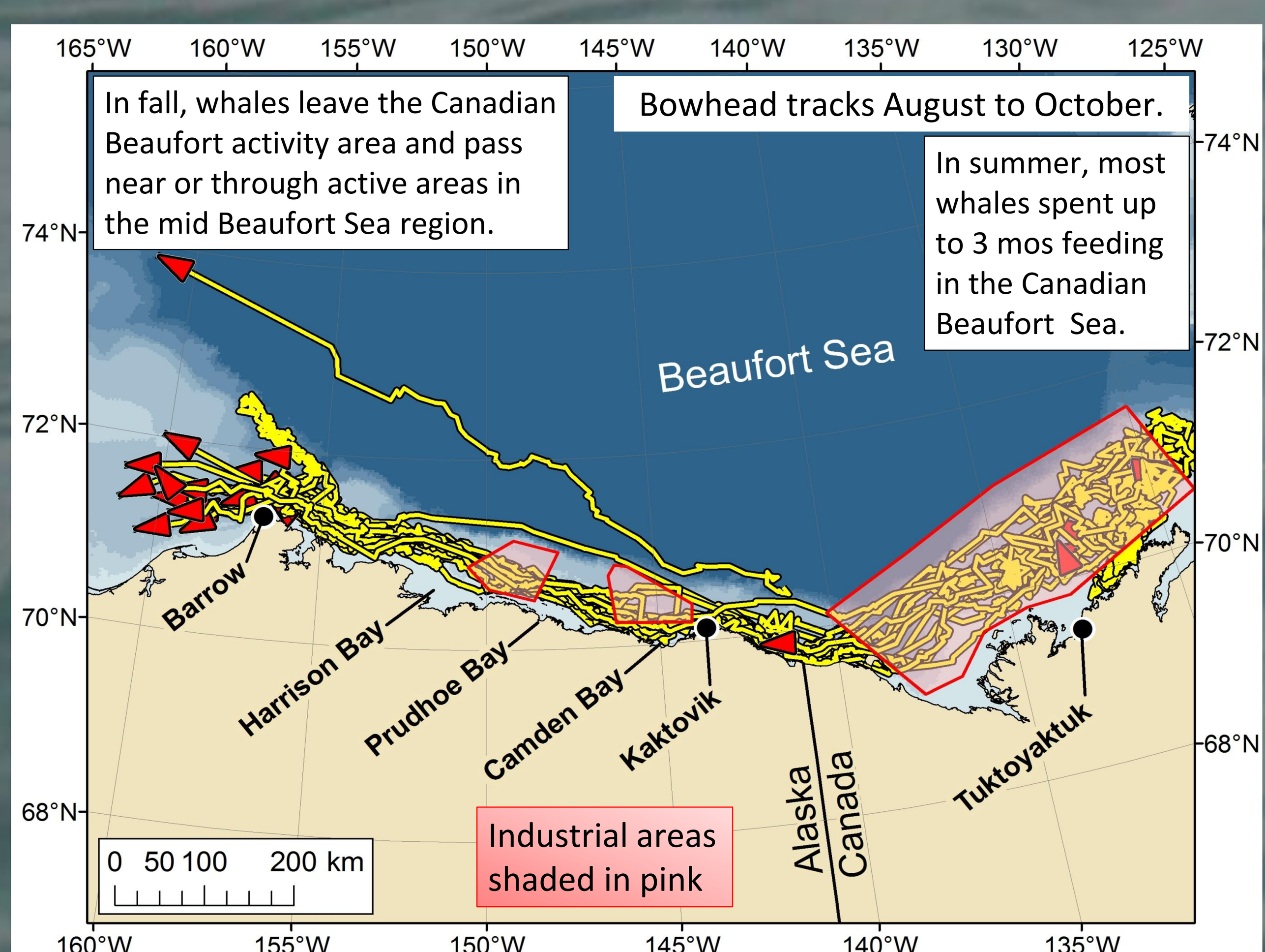
[1]Alaska Department of Fish and Game, Lori.Quakenbush@alaska.gov; [2]Department of Fisheries and Oceans, Yellowknife, NT, Canada; [3]North Slope Borough, Barrow AK; [4]Greenland Institute of Natural Resources, Copenhagen Denmark; [5]Barrow Arctic Science Consortium, Barrow AK; [6]Tuktoyaktuk Hunters and Trappers Committee, NT, Canada; Kaktovik Whaling Captains Association, Kaktovik AK

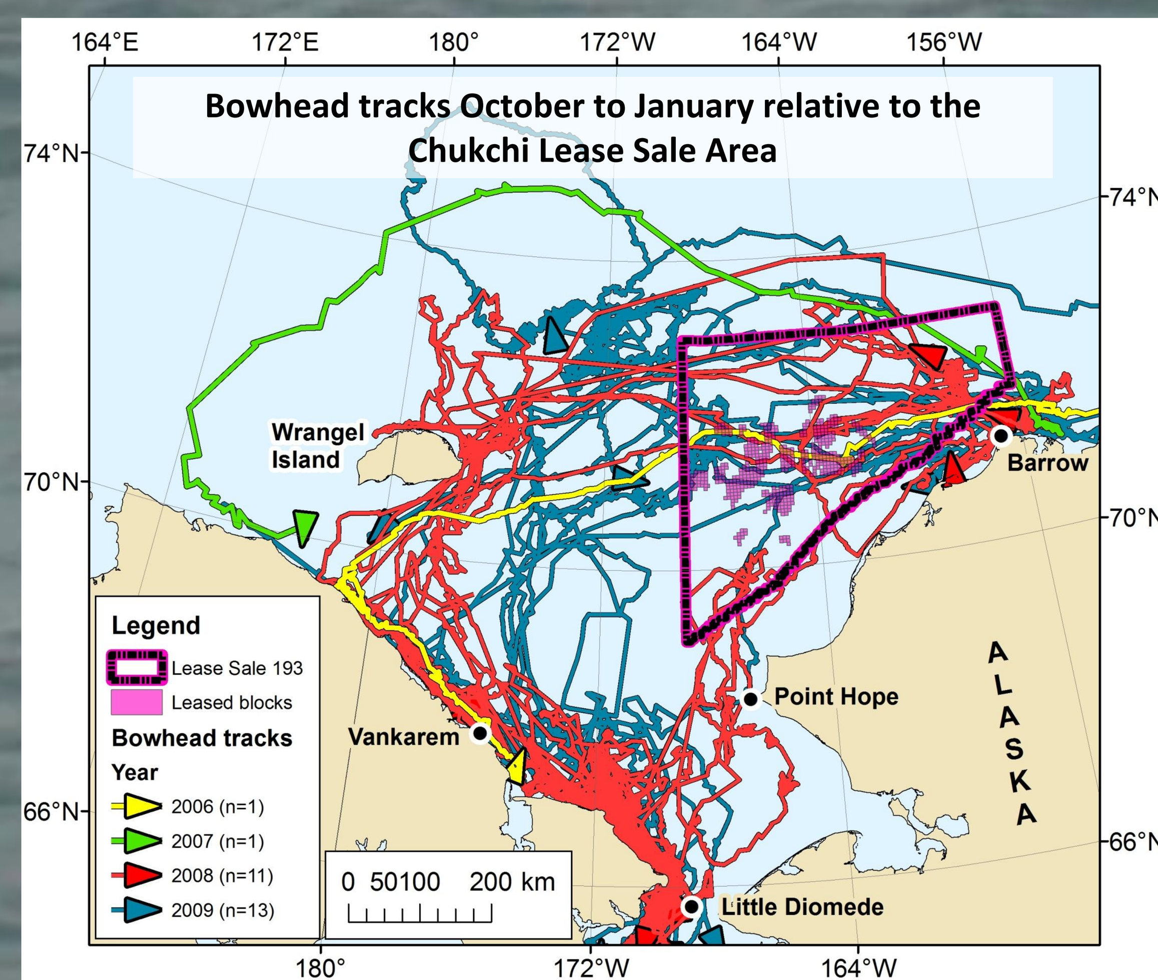
INTRODUCTION. In 2005, the Alaska Department of Fish and Game began a cooperative project with the Alaska Eskimo Whaling Commission and others, in part, to study movements of the western Arctic stock of bowhead whales (*Balaena mysticetus*) relative to oil and gas activities. Bowheads were known to occur near all areas of activity, but how often individual whales encountered activities annually was unknown.

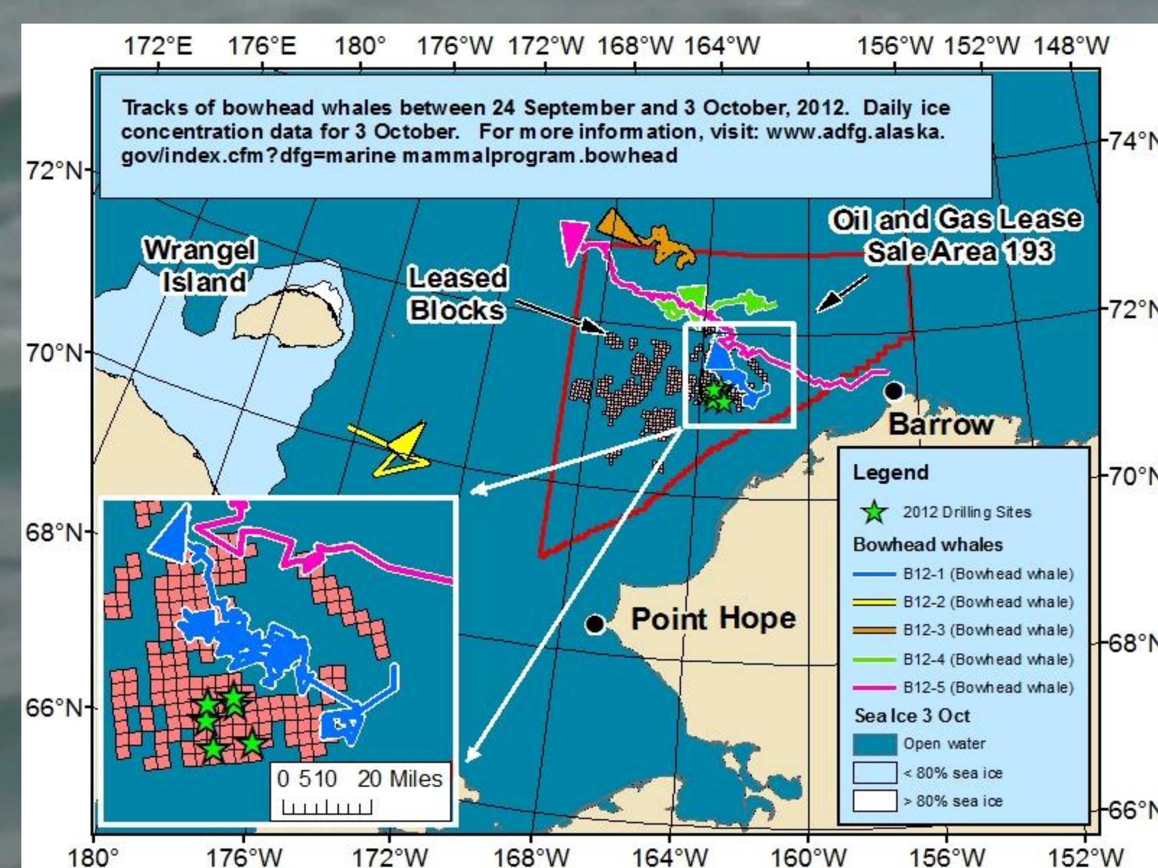


Area of tagged whale use and oil activities in the Canadian Beaufort Sea in summer and in the mid Beaufort and the Chukchi seas in fall.

METHODS. Between 2006 and 2010, 57 satellite transmitters were placed on bowhead whales in Alaska and Canada. The majority of the tags were deployed near Barrow and others were deployed near Tuktoyaktuk Canada and near the Alaska-Canada border by Native subsistence whalers and hunters from Alaska and Canada.





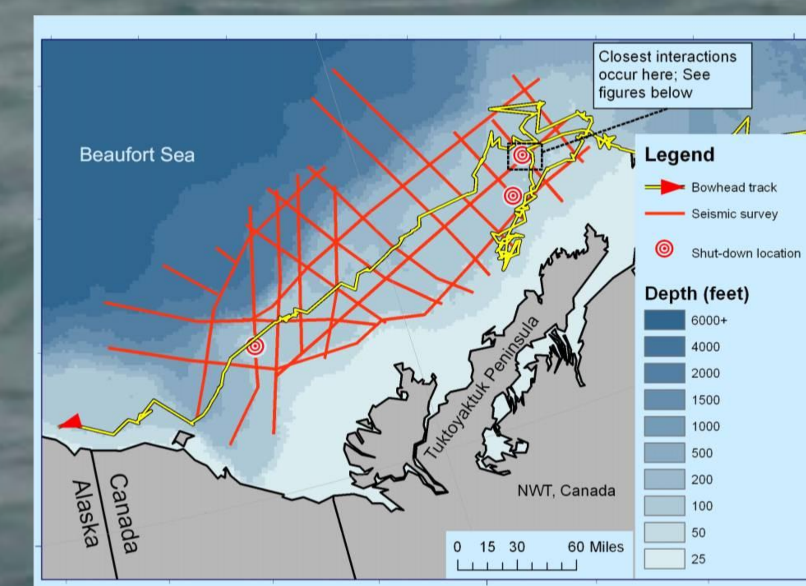


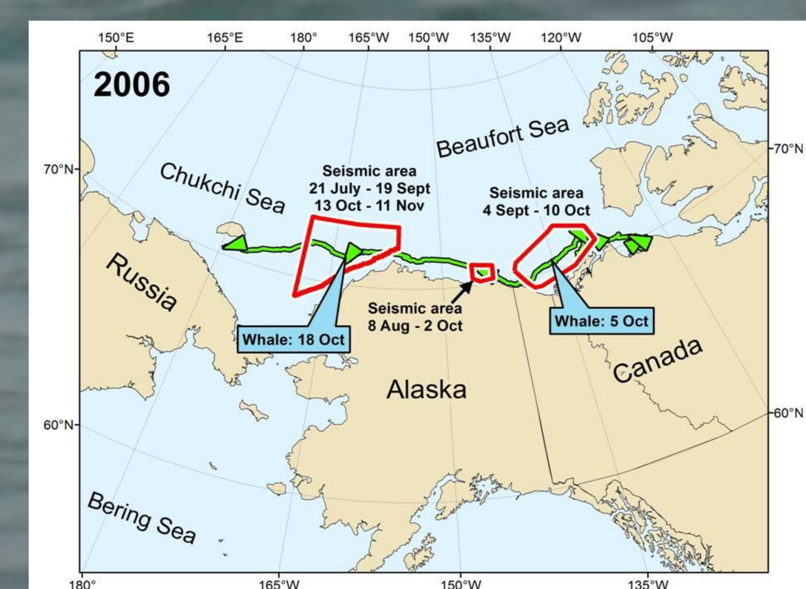
RESULTS. Tag duration has allowed us to track individual bowhead whales throughout their ~6,000 km annual migration (23 tags >3mos, 14 tags >6 mos, 9 tags >12 mos).

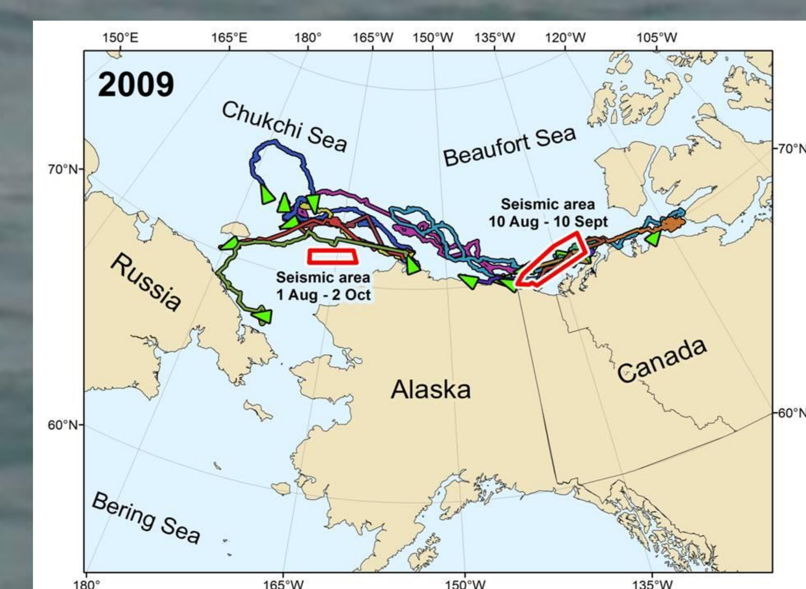
-The current level of industrial activity has not prevented the population from growing: however, oil and other activity (e.g., shipping) are expected to increase.

- Altered movement patterns caused by activity concern subsistence hunters because they could decrease hunting success and make hunting more dangerous.

Detail of whale and seismic ship tracks in the Canadian Beaufort industrial area in 2006.







Tagged whales passed through at least one active industry area and most (36 of 37) passed through two. In 2006, 2 of 3 areas were active when the whale went by.

CONCLUSIONS. Individual bowhead whales encounter multiple industrial activities annually at the current level of activity.

RECOMMENDATIONS. Activities conducted in the Chukchi Sea in July-August and in the Beaufort Sea in October would minimize bowhead encounters with oil and gas activities.

FUTURE. To study whale behavior during encounters by using acoustic tags to measure individual vocalization rates relative to ambient noise levels. Understanding call behavior will aid our interpretation of passive acoustic data collected near seismic and drill sites.

ACKNOWLEDGMENTS. Funded by the Bureau of Ocean Energy Management and conducted in collaboration with the Alaska Eskimo Whaling Commission, and the co-authors agencies. Special thanks to Mikkel and Anders Jensen for their expertise in tag deployment. This research was conducted under the following permits: NMFS 782-1719 and 14610, ADF&G ACUC 06-16, and in Canada AUP FWI-ACC-2007-2008-027. Background photo by: Chuck Gruben.

Appendix C. **Satellite Tracking of Bowhead Whales**

Project Update to AEWC – 16 July 2013

Study Plan. Our current study plan was approved by AEWC in July 2011. The priorities are 1) deploy specialized tags to learn about the environmental conditions (e.g., noise and ocean conditions) in areas where bowheads spend time, 2) tag bowheads near St. Lawrence Island, and 3) try to find and photograph previously tagged whales to determine what effects the tags have on the whales.

Acoustic tag. We are working with a contractor to develop a tag that records sound. It will record the sounds the bowhead makes and the noise level in the general area of the bowhead. The oil companies are using listening buoys to record the presence of bowhead whales and other marine mammals by the sounds they make. They have found that when seismic noises start the bowhead call rate goes down. With this type of tag we hope that we can determine whether bowheads move away from the loud noise or if they stop calling because it is too loud to hear each other. Two tags were tested in Greenland in April on eastern Arctic bowhead whales with promising results. Songs were recorded with little background noise.

Oceanographic tag. One oceanographic tag was deployed near Barrow in September 2012. As the whale swam through Barrow Canyon and back up on the shelf, the tag sampled the water and provided information about the water temperature and salinity by depth. It also recorded the diving pattern of the whale. From all of this information we can determine the water conditions at the depth the whale spent the most time and determine whether it is likely to be feeding there. See Figure 1 below.

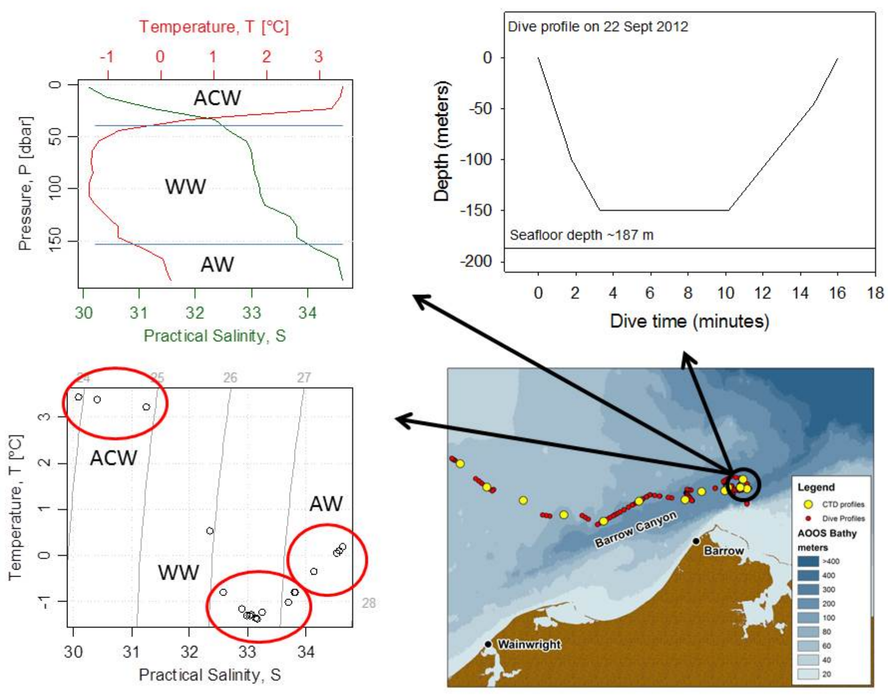


Figure 1. Example from an oceanographic tag within Barrow Canyon. The temperature and salinity plots show that the area within ~50 m of the surface is Alaska Coastal Water (ACW). Between 50 and 150 m is Winter Water (WW) from the Chukchi shelf. Around 150 m, the water is warmer, saltier Atlantic Water (AW). A dive profile (upper right chart) shows that during a dive that lasted 16 minutes, the whale spent 6 minutes at the depth of the lower boundary of WW and AW. Boundary areas between water masses can concentrate food like krill. This appears to be a feeding dive.

Differences in Fall Movements by Year. We have seen differences from year to year in how bowheads migrate across the Chukchi Sea. Last fall, 2012 was most similar to 2010.

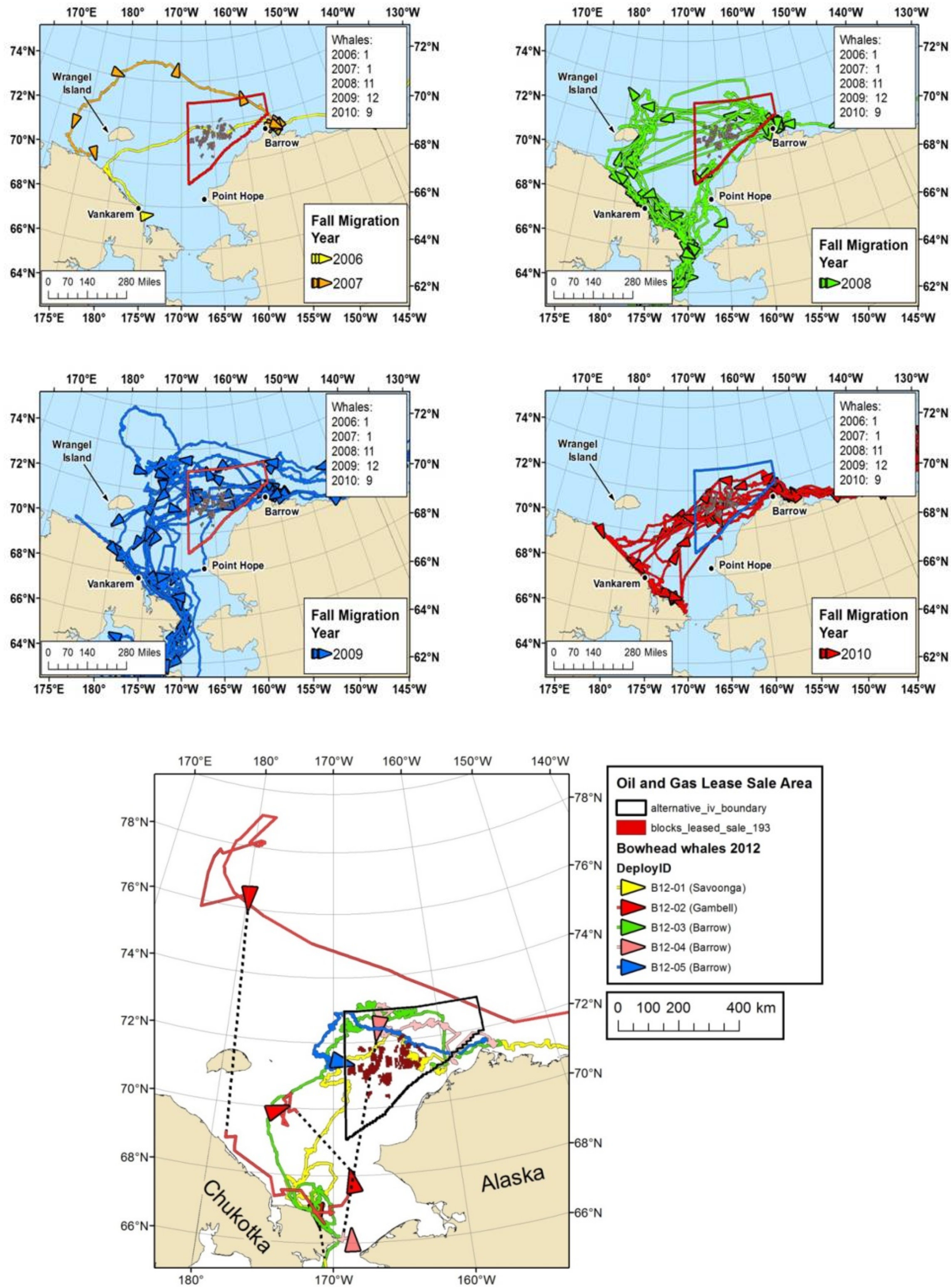


Figure 2. Tracks of bowhead whales across the Chukchi Sea in fall by year from 2006–2012. Dotted lines are straight lines drawn between signals received from the transmitter that are widely spaced in time.

Bowhead Whale Movements during Drilling. In fall 2012, the tagged bowheads spent more time in the central Chukchi Sea than in previous years. In previous years, tagged bowheads passed through the Lease Sale Area and spent time along the Russian coast. This was the first year during the tagging project that drilling occurred in the Chukchi Sea Lease Sale Area. In addition to the tagged whales, marine mammal observers and others saw many bowhead whales in the drilling area during drilling.

Although the whales stayed near the area of drilling activity, we do not think that they were attracted by it. It may be that the ocean conditions concentrated krill near the drilling operations and bowheads were feeding there.

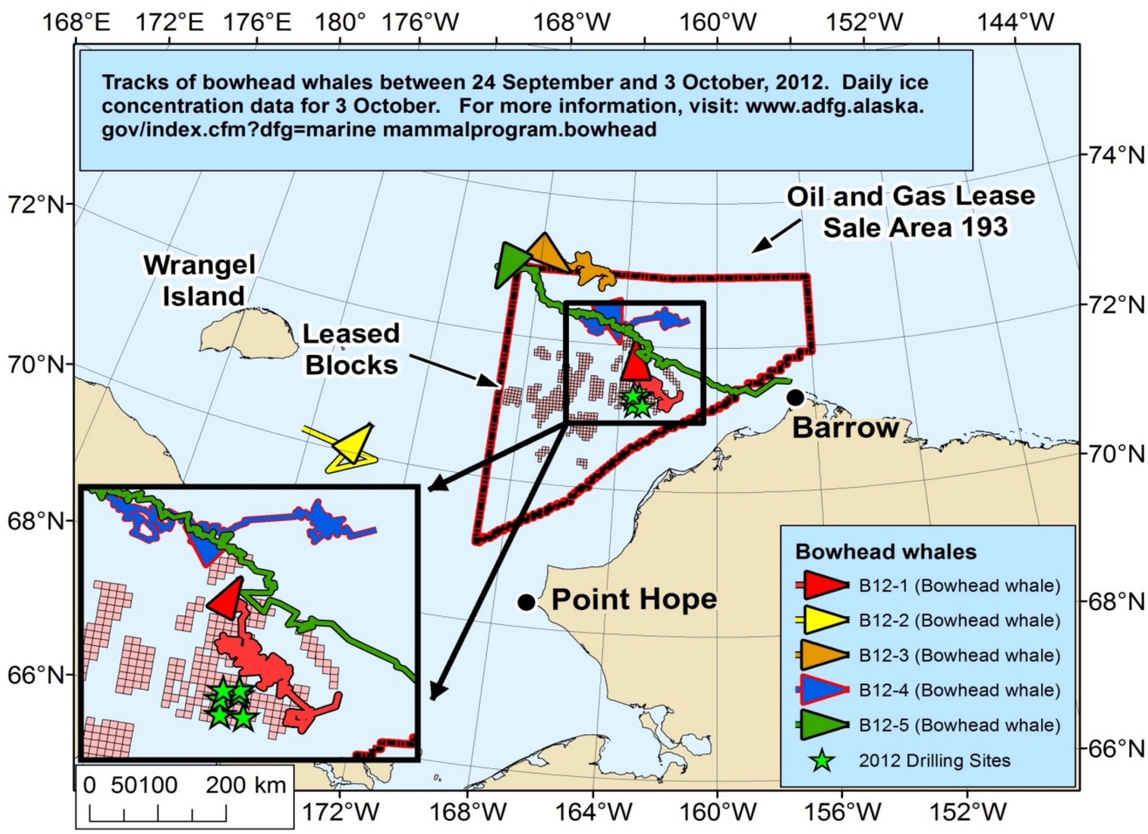


Figure 3. Tracks of tagged bowhead whales within Chukchi Sea Lease Sale Area during drilling in 2012. Green stars represent potential drilling sites, but only one of them was active in 2012.

Active Oil and Gas Areas and Bowhead Whale Movements. Using all of the locations from all of the whales tagged through the years we can put together a good picture of the timing of when whales move through the various active oil and gas areas and we can start to understand how multiple seismic operations per year may affect bowheads (See Figure 4 on next page). Because satellite tags transmit locations wherever bowheads go we can also see when bowheads are in Canadian and Russian waters. The Mackenzie-Tuktoyaktuk area in Canada has an active oil and gas area and is also an important summer feeding area for bowheads. The areas in Russian waters are proposed for oil and gas development, but they are not active now (See Figure 4 on next page).

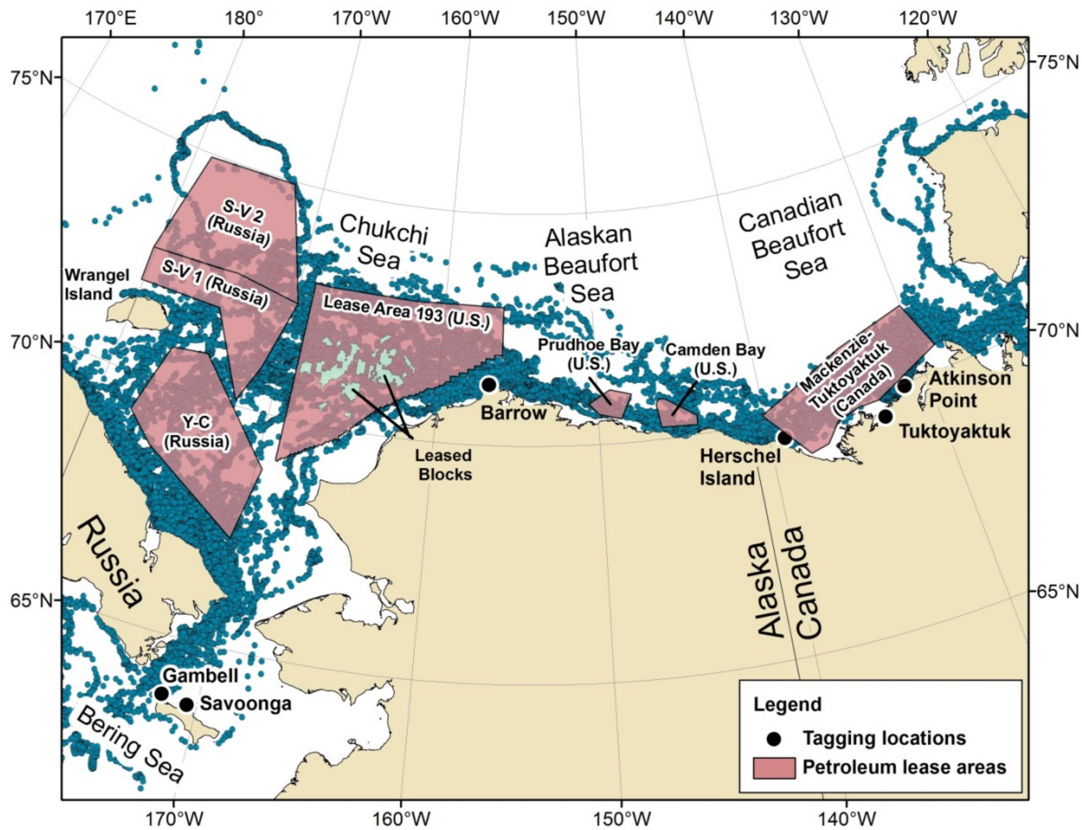


Figure 4. Locations for 63 bowhead whales with satellite transmitters (blue circles) between July and December, 2006–2012, relative to active (Alaska and Canada) and proposed (Russia) petroleum areas.

Recent Project Activities and Current Plan. Two whales were tagged near Pugughileq, St. Lawrence Island, in April by crews from Savoonga. One whale (B13-01) was a male and is still on the air. Another whale was tagged but then struck and lost by a whaling crew. Gambell also tried tagging this spring but their ice and weather did not cooperate. No tagging was attempted at Barrow this spring. Ice conditions near Barrow did not allow a whale to be harvested until late June.

We hope to put out three oceanographic tags from Barrow this summer or fall and some regular tags that are set up to last up to 2 years. Tagging from Gambell and Savoonga may also happen in the fall if both Whaling Captains Associations approve. We are planning to tag next August near Tuktoyaktuk and will be talking to Kaktovik whalers for their assistance. Tagging near Tuktoyaktuk next year will be important for getting tags out before the 2014 fall migration that will likely occur during drilling operations in the Chukchi Sea.

Prepared by Lori Quakenbush (907) 459-7214 or toll free 1-800-478-7346. E-mail: lori.quakenbush@alaska.gov. Visit the website for the latest bowhead maps: http://www.adfg.alaska.gov/index.cfm?adfg=marinemammalprogram.bowhead

Appendix D.

Special Technical Report

Kernel Densities of Locations from Satellite-Tracked Bowhead Whales, 2006–2012, for use in Determining Environmental Resource Areas for Oil Spill Response Analysis

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Prepared for:

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August 2013

Introduction

The Bureau of Ocean Energy Management (BOEM) is identifying Environmental Resource Areas by time and space for sensitive biological resources including bowhead whales. These Environmental Resource Areas will be used in their Oil Spill Response Analysis. BOEM has requested that we provide probability (kernel) densities of bowhead whales from locations collected using satellite telemetry from 2006 to 2012. Specifically, the request was for kernel densities at two-week intervals for all 12 months of the year. The objectives of this report are to provide: 1) a description of how the kernel densities were constructed; 2) maps of the kernel densities for each two-week period; 3) the files necessary to plot density contours (shape and layer files); 4) specific information about how to interpret the kernel densities to minimize potential misuse, and 5) an offer to assist with interpretation when needed.

Data sharing

Much of these data have not been published. It is our intention as described in our contract (BOEM No. M12PC00005) to publish these data; therefore, we are requesting that BOEM not disseminate what we have provided here to other researchers and only use the data internally.

Methods

Choice of kernel method

BOEM requested kernel densities be estimated from the bowhead whale location data from 2006–2012 at two-week intervals. The selection of a two week interval has implications for how densities are estimated. Because of the short time interval, there were not enough data to reliably estimate a separate density for each whale as required for advanced approaches to estimating density, such as those that account for sequential observations (*e.g.*, Brownian Bridges; Benhamou and Cornelis 2010). To allow us to use data from all whales, we calculated an average daily location for each whale and then pooled the data within each two-week interval.

Kernel density estimation is a non-parametric method for calculating the probability that an animal occurs at each point in space. When calculating a kernel density, we overlay each location with a 2-dimensional probability density function (PDF), known as a kernel function. For example, a “normal” kernel is based on a normal probability density function, in which the shape of the kernel is described by a mean and a variance. For each dimension, the mean of the kernel is equal to the point location in that dimension (*i.e.*, the latitude or longitude). However, because each kernel corresponds to a single location, the variance of the kernel, also known as the bandwidth, cannot be calculated using standard formulas for variance. Bandwidth is important because it determines the “smoothness” of the resulting density. We compared three different bandwidth estimators: 1) the reference bandwidth (Worton 1989), 2) least-squares cross-validation (LSCV, *e.g.*, Silverman 1986), and 3) smoothed cross-validation (SCV, Duong and Hazelton 2005; as used in Quakenbush *et al.* 2010 and Citta *et al.* 2012 for bowhead data). We found that the first estimator, the reference bandwidth, over-smoothed the data and yielded density in areas where we have never observed tagged whales (Fig. 1A). The second, LSCV, resulted in under-smoothing and density contours that were tightly clustered around point locations and yielded many areas where whales were known to exist yet had little density *(i.e.*, “holes” and “gaps” in the density surface; Fig. 1B). We chose to use the third estimator, SCV (Fig. 1C), as used in Quakenbush *et al.* (2010) and Citta *et al.* (2012) because it provided the best overall description of the pattern in whale locations. The SCV bandwidth was estimated using package *ks* (Duong 2007, updated in 2013) in R version 3.0.1.

Grid and projection

Due to the large area under consideration, we estimated density on a grid with 10 km spacing. Grids with finer spacing cause estimation issues within R and memory issues in ArcMap. To achieve 10 km spacing, we used an equidistant projection (Fig. 2) that was centered on Barrow (71.3 N, 156.7 W). The grid was large enough to contain the entire density surface for bowhead whales; the four grid corners were located at: 1) 177.54W, 51.40N; 2) 132.62W, 50.63N; 3) 87.81W, 73.8N; and 4) 138.0W, 75.7N.

Definition of period and day

BOEM requested bowhead densities at two week intervals throughout the year. We split each month into two periods; the first period lasted from the 1st to the 14th day of each month and the second went from the 15th to the end of each month. The study area extends from approximately 105° W to 170° E (*i.e.*, 85° range of longitude) where solar noon (the time at which the sun is highest in the sky) varies by approximately 5 hours. To develop a consistent definition of day we used the latitude and longitude for each location to covert Coordinated Universal Time (UTC) to local sun time. We disregarded the dateline in our calculations such that whales would not automatically change days if they crossed the dateline within a given solar day.

Projection information

The original grid used to estimate densities and the percent density contours (shapefiles) are in:

Sphere_Azimuthal_Equidistant
Projection: Azimuthal_Equidistant
False_Easting: -156.700000
False_Northing: 71.300000
Central_Meridian: -156.700000
Latitude_Of_Origin: 71.300000
Linear Unit: Meter
GCS_Sphere
Datum: D_Sphere

Results

Sample sizes by month are presented in Table 1. Figures 2–5 are provided so the user knows what the shapefile should look like when correctly projected. We included the point locations used to estimate the densities so the user can judge how well contours cover the range of observations.

Access to files and file names
Projected shapefiles (*.prj, *.sbn, *.shp, and *.shx) and layer files (*.lyr) are accessible for two weeks on the State of Alaska ftp server:
ftp://ftpr3.adfg.state.ak.us/JCitta/Kernel_density_contours/

File names begin with the starting date of the time period. For example, "Mar15contours.lyr" is the layer file for kernel density contours between 15 and 31 March. Layer files are color-coded as in Figures 2–5.

Interpretation
Kernel density methods are useful for identifying general patterns in whale distribution. The method is most useful for determining areas used by many tagged whales (*i.e.*, high density areas). However, the utility of kernel density estimation (and satellite tagging in general) is limited for accurately describing the boundaries of areas used by a few whales (*i.e.*, low density areas). The complete home-range of bowhead whales is likely underestimated by this method and the user should be very cautious when interpreting the boundaries of the 95% density. For example, low densities of bowhead whales may exist in the Chukchi Sea in July and August, even though there are large areas that fall outside of the 95% density contours (Fig. 4). While we might be confident that the main concentration of whales is within the Canadian Beaufort Sea during July and August (Fig. 4), we cannot reliably comment on the boundaries of bowhead whale distribution in the Chukchi Sea during these months. This is why kernel densities are limited in their ability to accurately identify the distribution of whales in low density areas.

If BOEM has questions regarding the interpretation of density data, we encourage them to contact us. We are providing this information as requested, but accept no responsibility for its misinterpretation without consultation.

Discussion

We have provided the information and data requested and have described the details of the method including its strengths and weaknesses. We have also included precautions and examples of potential misinterpretations. Applications and interpretations of these data, however, may arise that were unanticipated by us and may not be appropriate, therefore we encourage BOEM to contact us regarding the use and interpretations of these data so that misinterpretations do not occur. If we are not contacted we accept no responsibility for misuse or misinterpretations. We appreciate that BOEM will not disseminate what we have provided here to other researchers and only use the data internally so that we can continue to publish data from this project as required under our contract.

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Table 1. The number of tagged whales by two week period, and the average number of days per whale in each period for which tags transmitted.

Period	**Start day**	**End day**	***n* whales**	**Average days/whale**
1	1-Jan	14-Jan	24	11.0
2	15-Jan	31-Jan	25	11.9
3	1-Feb	14-Feb	21	10.8
4	15-Feb	28-Feb	22	10.2
5	1-Mar	14-Mar	20	10.1
6	15-Mar	31-Mar	17	12.9
7	1-Apr	14-Apr	18	10.6
8	15-Apr	30-Apr	20	11.4
9	1-May	14-May	19	9.8
10	15-May	31-May	22	13.2
11	1-Jun	14-Jun	22	12.3
12	15-Jun	30-Jun	22	13.3
13	1-Jul	14-Jul	21	11.6
14	15-Jul	31-Jul	17	15.2
15	1-Aug	14-Aug	15	11.5
16	15-Aug	31-Aug	33	9.1
17	1-Sep	14-Sep	36	10.3
18	15-Sep	30-Sep	40	11.5
19	1-Oct	14-Oct	38	11.1
20	15-Oct	31-Oct	36	14.4
21	1-Nov	14-Nov	34	11.5
22	15-Nov	30-Nov	32	12.3
23	1-Dec	14-Dec	27	11.1
24	15-Dec	31-Dec	25	12.4

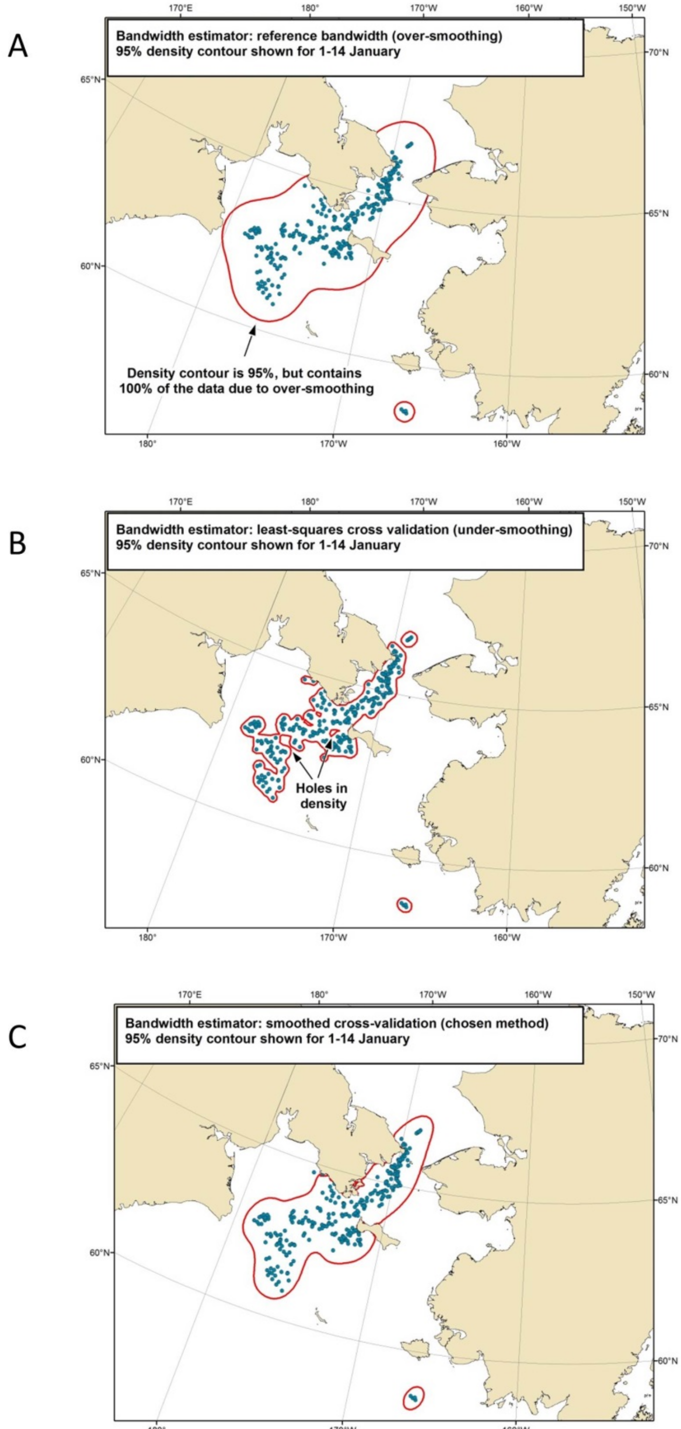


Figure 1. Comparison of three bandwidth estimators for bowhead location data. The reference bandwidth (A) over-smooths the data; the 95% contour contains 100% of the data and large areas with no data. The least-squares cross validation estimator (B) fits the data too closely (under-smoothing) and shows no density in areas that likely have whales. We chose to use (C) the smoothed cross-validation estimator of Duong and Hazelton (2005), as it provides a balance between over- and under-smoothing.

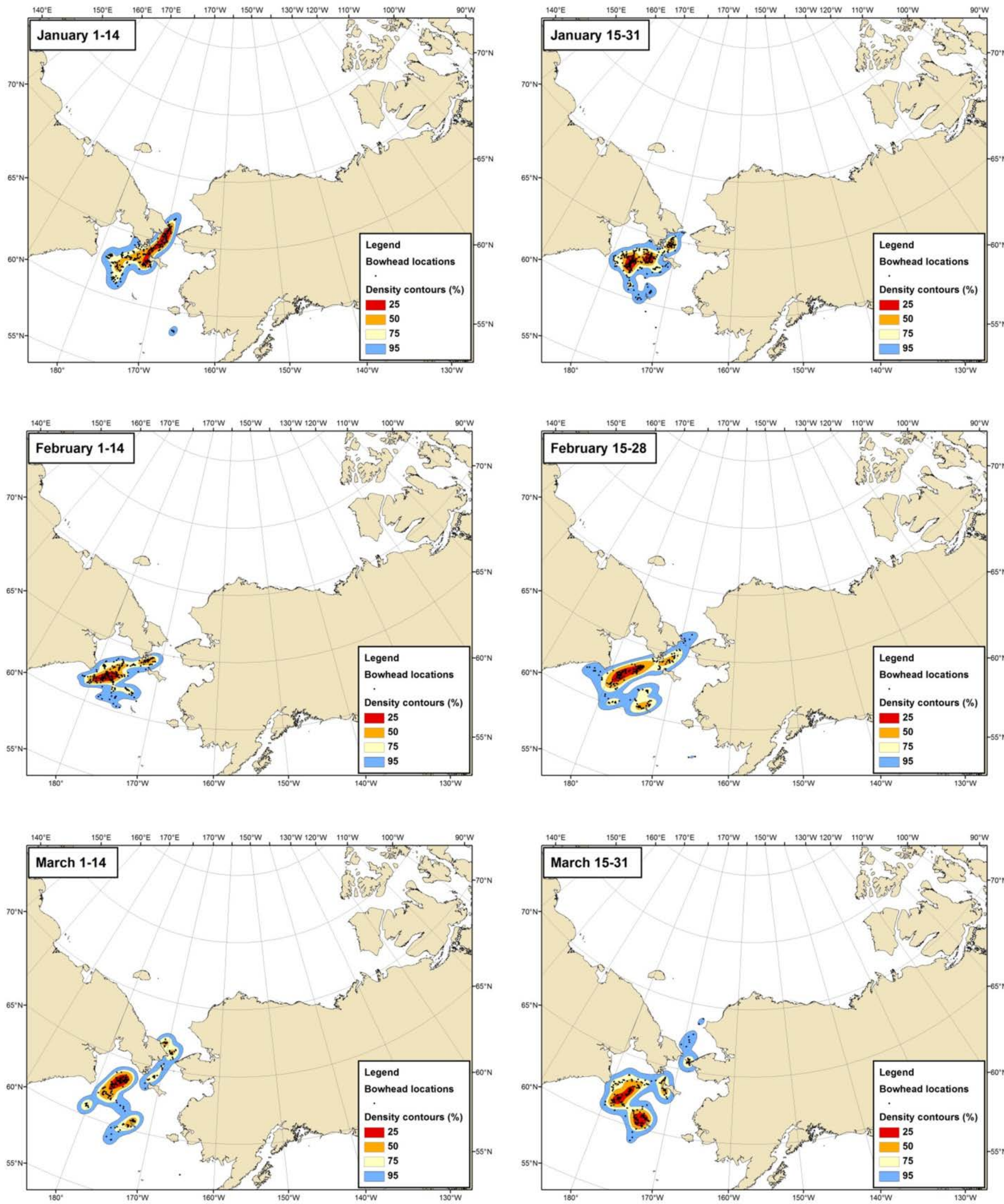


Figure 2. Kernel densities for two-week periods between 1 January and 31 March.

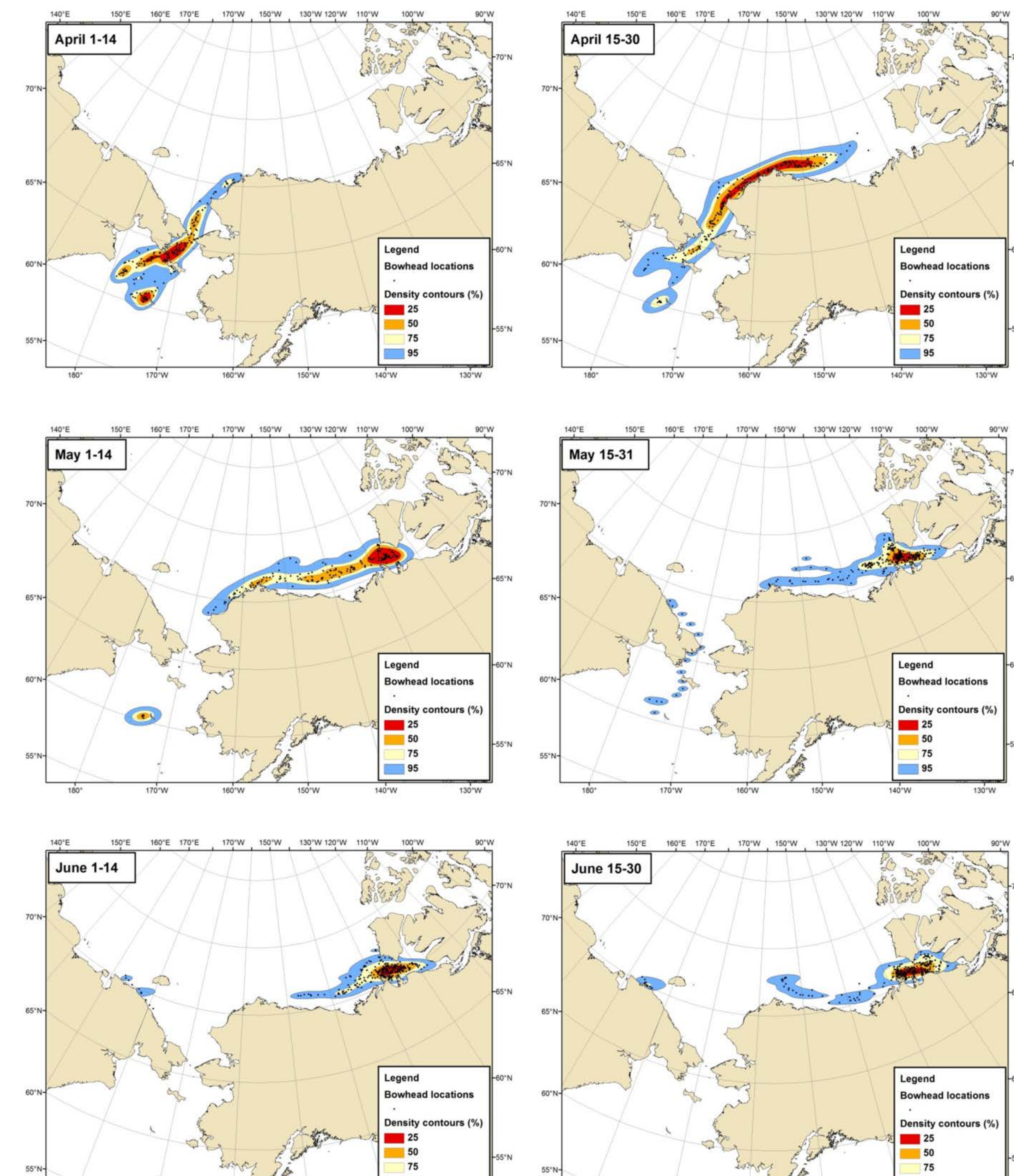


Figure 3. Kernel densities for two-week periods between 1 April and 30 June.

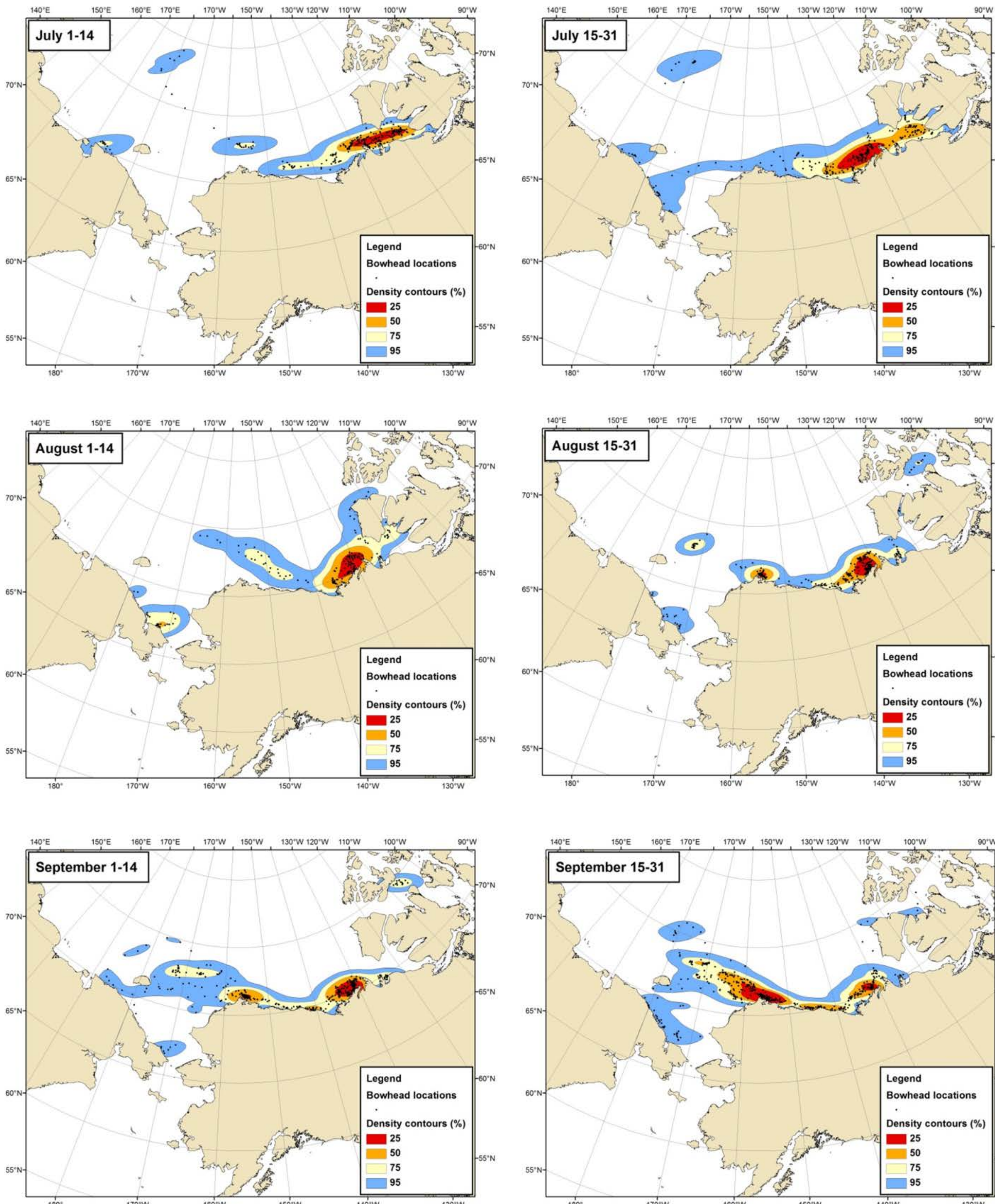


Figure 4. Kernel densities for two-week periods between 1 July and 31 September.

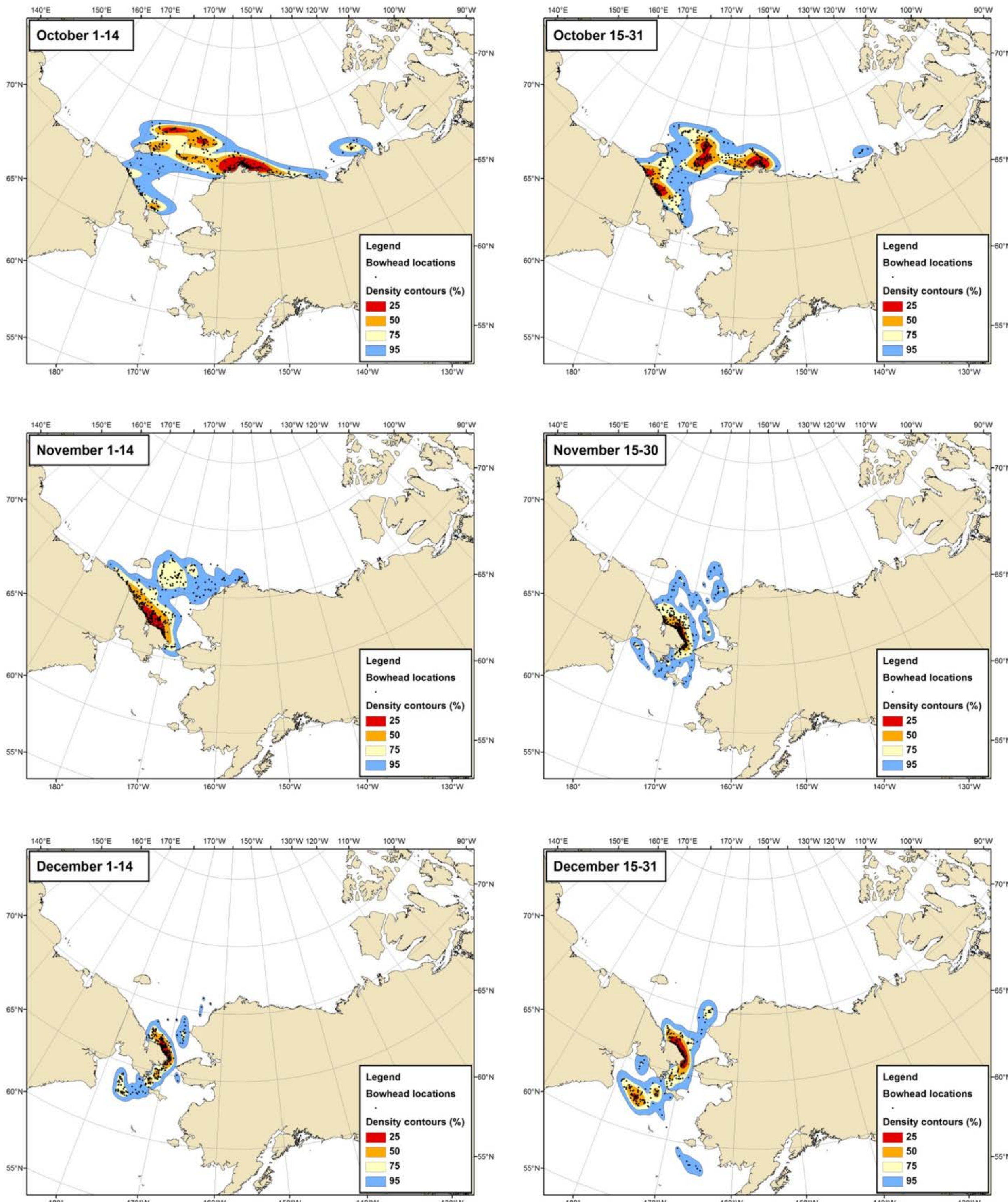


Figure 5. Kernel densities for two-week periods between 1 October and 31 December.

Appendix E.

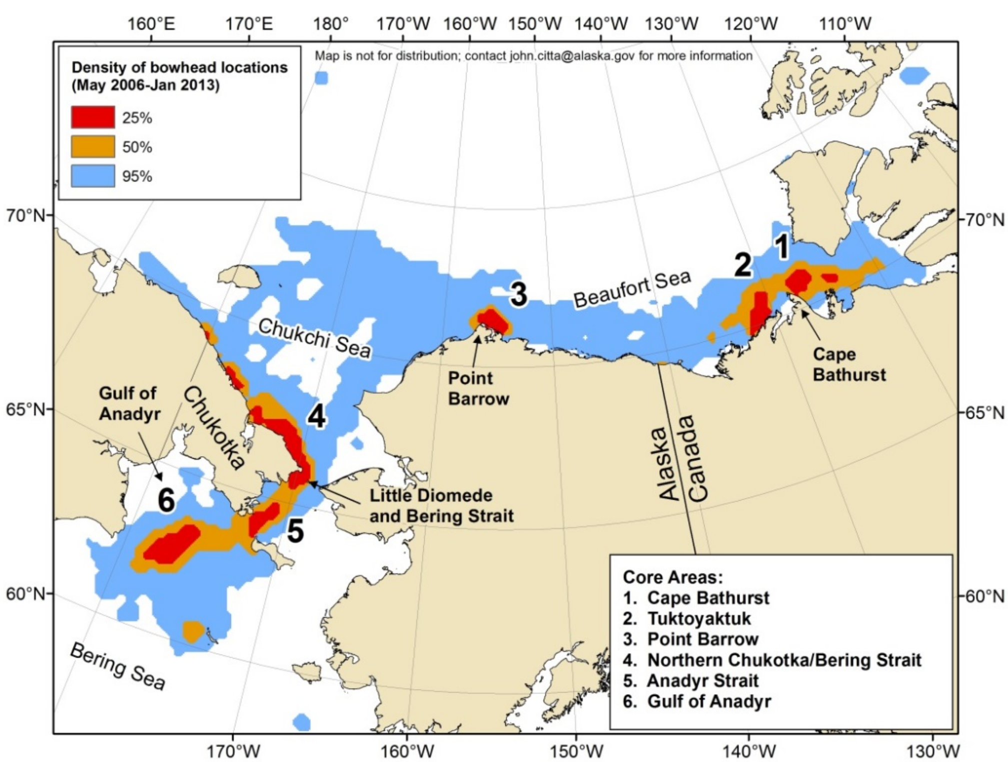
Satellite Tracking of Bowhead Whales

Project Update to AEWC – 18 Oct 2013

Study Plan. Our current study plan was approved by AEWC in July 2011. The priorities are 1) deploy specialized tags to learn about the environmental conditions (e.g., noise and ocean conditions) in areas where bowheads spend time, 2) tag bowheads near St. Lawrence Island, 3) tag small (~30 ft) and large (>40 ft) bowheads near Barrow and 4) try to find and photograph previously tagged whales to determine what effects the tags have on the whales.

Acoustic tag. We are working with a contractor to develop a tag that records sound. It will record the sounds the bowhead makes and the noise level in the general area of the bowhead. The oil companies are using listening buoys to record the presence of bowhead whales and other marine mammals by the sounds they make. They have found that when seismic noises start the bowhead call rate goes down. With this type of tag we hope that we can determine whether bowheads move away from the loud noise or if they stop calling because it is too loud to hear each other. Two tags were tested in Greenland in April on eastern Arctic bowhead whales with promising results. Songs were recorded with little background noise. I will play a sample of bowhead singing that the tag recorded at the meeting.

Hotspots, Oceanography, and Diving Depths.
Using all of the tag locations we can map bowhead "hotspots" or places that bowheads spend the most time. Those places are in red and orange on the map in Figure 1 below.



Now we are working with oceanographers to understand what happens in the water in these areas when bowheads are there. We are learning about how wind, currents, water temperature, and saltiness can create places that concentrate bowhead food. By matching up the depth of where food should be concentrated and the depth that whales are diving may help us understand why bowheads leave the

Appendix E.

Bering Sea in April to go to Canada and why they leave Canada in September to go to Barrow. We may also be able to tell whether bowheads are feeding in the Bering in winter and in Amundsen Gulf in early spring.

Tagging from St. Lawrence Island.
We hope to continue tagging from St. Lawrence Island in spring 2014. The bowhead tagged near Pugughileq in April is still on the air. It was a 30+ ft. male. Its full track is in Figure 2.

Tagging in Canada 2014.
We are planning a tagging effort in August-September 2014 near Tuktoyaktuk to test the acoustic tags. The acoustic tags do not transmit sound to satellites so we have to pick them up after they are released from the whale. Because bowheads spend several months in this area we have a good chance of getting the tags back.

Tagging near Tuktoyaktuk next year will be important for getting tags out before the 2014 fall migration that will likely occur during drilling operations in the Chukchi Sea. If there is no drilling it will also be important to collect movements without drilling to compare to. We will also try to resight and photograph as many tags as possible several weeks after tagging to learn about how tags affect the whale's skin and surrounding tissue.

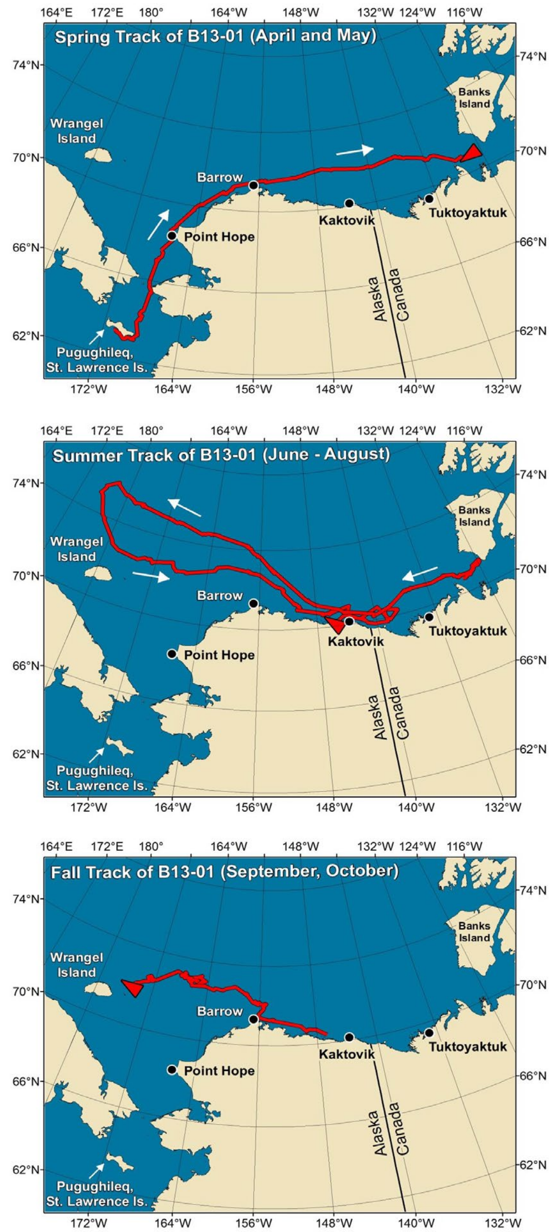


Figure 2. Seasonal track of a male bowhead whale (B13-01) tagged near Pugughileq, St. Lawrence Island on 21 April 2013.

Prepared by Lori Quakenbush (907) 459-7214 or toll free 1-800-478-7346.
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Visit our website for bowhead maps:
http://www.adfg.alaska.gov/index.cfm?adfg=marinemammalprogram.bowhead

Appendix F

Identifying hotspots for bowhead whales of the western Arctic stock

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The western Arctic stock of bowhead whales (*Balaena mysticetus*) ranges across the seasonally ice-covered waters of the Bering, Chukchi, and Beaufort seas. Declining sea ice has opened Arctic shipping lanes, facilitated oil and gas development, may expand commercial fisheries, and may affect the foraging ecology and conservation of this stock. We identified areas of concentrated use by bowhead whales, termed "hotspots," and describe the timing of use and associated physical characteristics (oceanography, sea ice, and winds). We used satellite locations from 55 bowhead whales, collected between 2006 and 2012, to map kernel densities across the stock's range and defined hotspots as occurring within the 25% density isopleth; six primary hotspots were identified. In spring, most whales migrate through heavy sea ice far offshore to the Cape Bathurst polynya, Canada (Area 1), an area known to have high zooplankton production. Whales were present in the polynya between 3 May and 9 July, and then most moved west to shallow waters offshore of the Tuktoyaktuk Peninsula, Canada (Area 2), until 16 October, where wind-driven upwelling promotes the production and concentration of zooplankton. Between 22 August and 5 November, whales congregate near Point Barrow, Alaska (Area 3), where zooplankton aggregate when east winds are followed by south or weak winds. East winds promote upwelling and move zooplankton onto the Beaufort shelf, while other winds promote the aggregation of zooplankton. Between 1 November and 15 January, whales congregate along the northern shore of Chukotka, Russia (Area 4), where zooplankton likely concentrate along a coastal front. The two remaining hotspots occur in the Bering Sea: Anadyr Strait (Area 5), used between 1 December and 26 April, and the Gulf of Anadyr (Area 6), used between 17 December and 15 April; both areas have highly fractured sea ice and are dominated by the Navarin Current.

Biennial Conference on the Biology of Marine Mammals, 9–13 December, Dunedin, New Zealand

Appendix F.

Ecological characteristics of core areas used by western Arctic bowhead whales, 2006–2012

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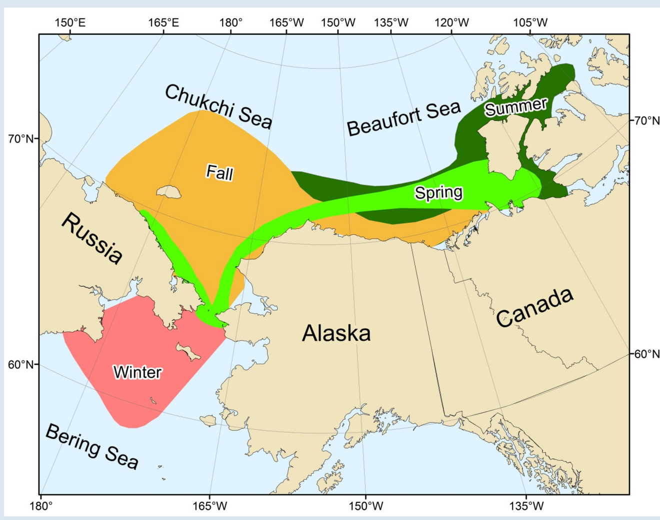
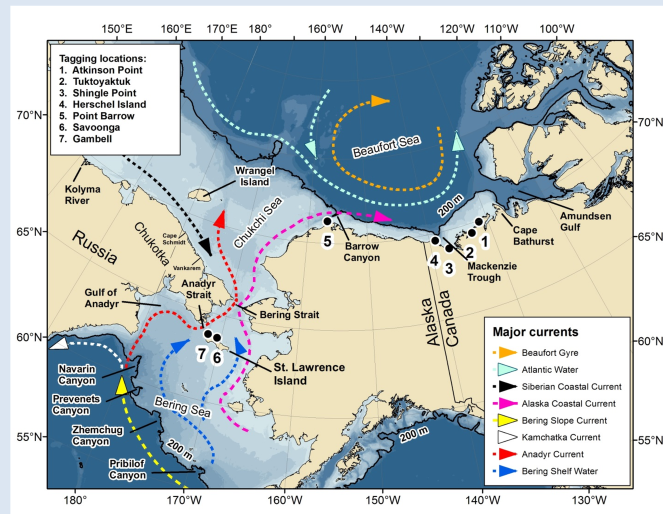
Introduction

The western Arctic stock of bowhead whales (*Balaena mysticetus*) ranges across the seasonally ice-covered waters of the Bering, Chukchi, and Beaufort seas. Declining sea ice has opened Arctic shipping lanes, facilitated oil and gas exploration, may expand commercial fisheries, and may affect the foraging ecology and conservation of this stock. We identified areas of concentrated use by bowhead whales, termed "core use areas," and describe the timing of use and physical characteristics (oceanography, sea ice, and winds) associated with these areas. We used satellite locations from 54 bowhead whales, collected between 2006 and 2012, to map kernel densities across the stock's range and defined core use areas as occurring within the 25% density isopleth; six primary core use areas were identified and these areas are discussed in turn.

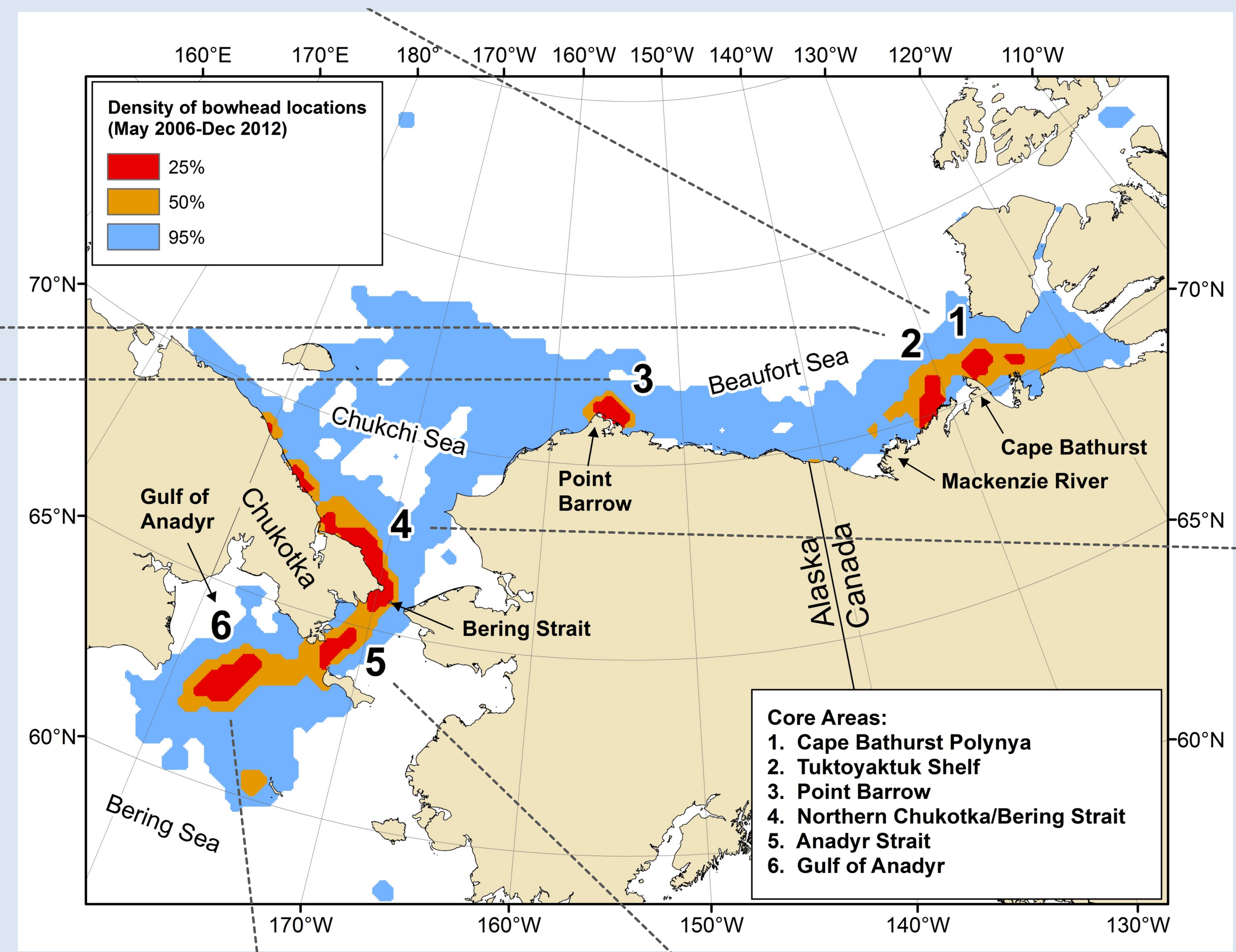
Annual range of the western Arctic stock



Tagging locations and currents



Six core use areas of western Arctic bowhead whales



Area 1: Cape Bathurst Polynya (7 May – 5 July)

- Most whales migrate to the polynya each spring (Fig. 1).
- There is weak or no upwelling within the polynya at this time (Figs. 2 and 3).
- Dive behavior (time-at-depth) indicates whales spend the most time within 75 m of the surface; this is within the euphotic zone where calanoid copepods are known to aggregate in spring.
- Movement away from Cape Bathurst corresponds with the initial descent of the large calanoid copepods in July.

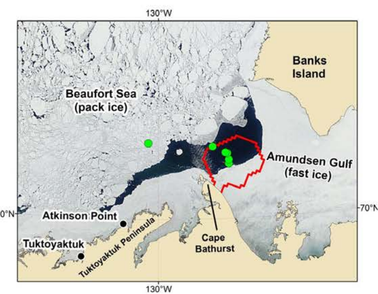


Figure 1. Whale locations in the polynya (30 May 2009))

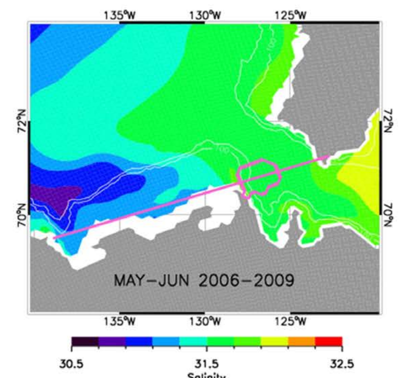


Figure 2. Salinity at 15-20 m (model data)

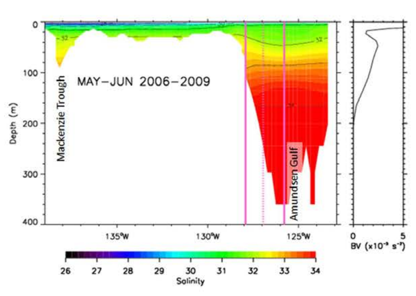


Figure 3. Salinity cross section (model data)

Area 2: Tuktoyaktuk Shelf (12 July – 25 Sept)

- Strong upwelling at Cape Bathurst begins (Figs. 4 and 5).
- This upwelling brings calanoid copepods onto the shelf (Walkusz et al. 2012).
- Mackenzie plume may provide a boundary to westward transport of zooplankton on the shelf.
- Whales spend more time at the seafloor than at other depths in 66% of 6-hr dive histograms (range 23-100% by whale).
- We suspect that whales leave when copepods descend too deep for upwelling to lift them onto the shelf (>100 m depth).

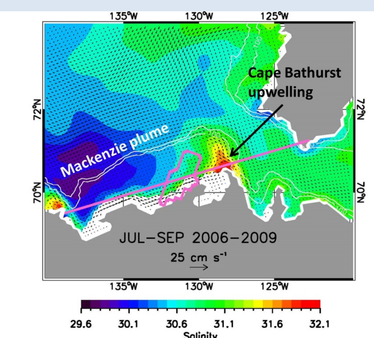


Figure 4. Salinity at 15-20 m (model data)

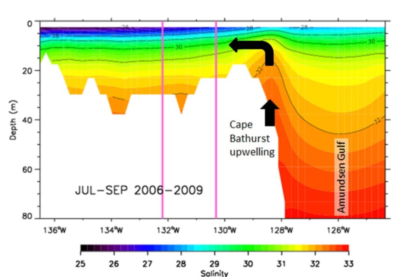


Figure 5. Salinity cross section (model data)

Area 3: Point Barrow (22 August – 2 November)

- East winds promote upwelling and advect zooplankton onto the shelf (Fig. 6).
- West or south winds prevent westward transport of zooplankton and trap them on the shelf (Fig. 7; Ashjian et al. 2010).
- Whales generally leave the area as sea ice forms (Fig. 8). Ice blocks winds and prevents upwelling at Barrow.

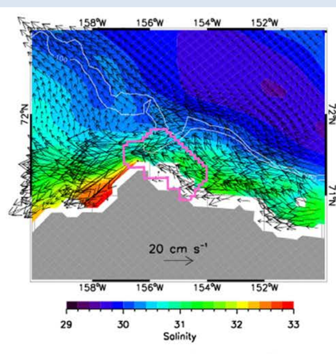


Figure 6. Velocity with east (upwelling) winds

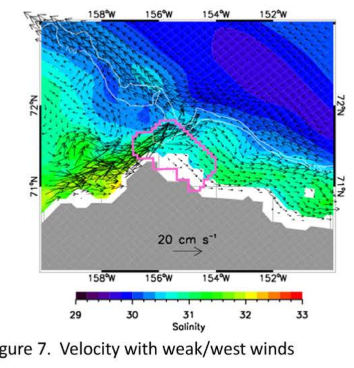


Figure 7. Velocity with weak/west winds

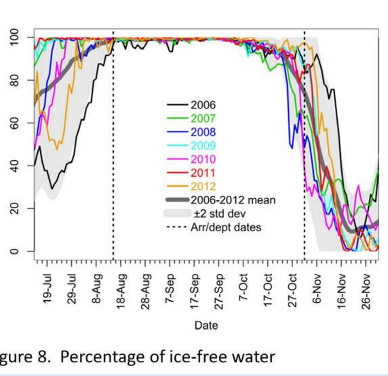


Figure 8. Percentage of ice-free water

Area 4: Northern Chukotka/Bering Strait (27 October – 8 January; some use year-round)

- Whales aggregate along a salinity front between the relatively fresh Siberian Coastal Current and salty water of Bering Sea origin (likely krill bearing; Moore et al. 1995) (Fig. 9).
- This front is strong in October but weakens as rivers freeze (Fig. 10).
- Movement of whales south, into the Bering Sea, largely corresponds with the weakening of this front, the weakening of currents through Bering Strait, and the formation of sea ice.

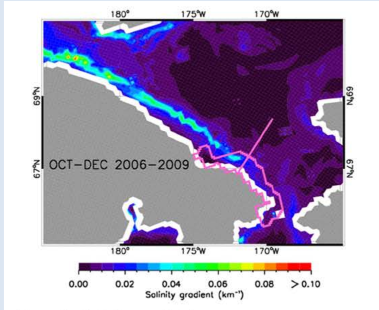


Figure 9. Salinity gradient

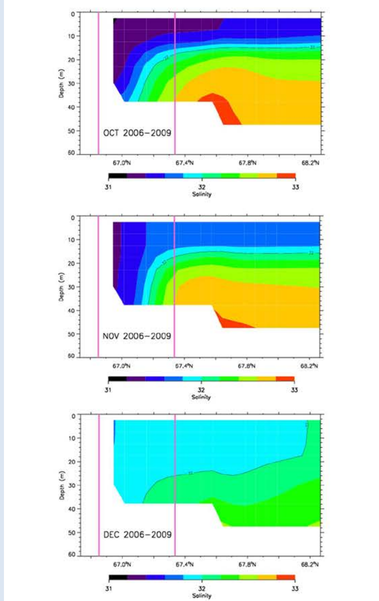


Figure 10. Cross-section of the Chukotka core use area between October and December (years averaged)

Area 5: Anadyr Strait (29 November – 20 April)

- Mostly ice-covered while whales are present.
- This area is co-located with an intrusion of relatively high (>32.5) salinity water originating in the Bering Slope region and the northern shore of the Gulf of Anadyr (Fig. 11).
- This salty water is mainly found at the seafloor (Fig. 12).
- Whales spent more time at the seafloor than at other depths in 36% of 6-hr histograms, but used the entire water column.
- Whales leave the area before waters are ice-free in spring.

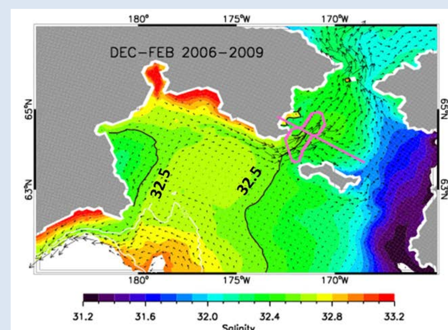


Figure 11. Bottom salinity (model data)

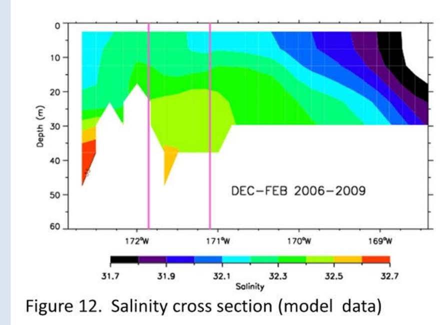


Figure 12. Salinity cross section (model data)

Area 6: Gulf of Anadyr (4 December – 1 April)

- Mostly ice-covered while whales are present (Fig. 13).
- The core use area lies in the middle of the region with salinities >32.5 (Fig. 14).
- Cross-sections of temperature show that the area is bounded on the north and west by cold Anadyr Water (Fig. 15 and 16).
- Dive behavior (time-at-depth) indicates whales spent 26-69% of each 6-hr histogram at 75-100 m. Whales spent more time at the bottom than at other depths in 82% of 6-hr histograms.
- Paired depth/temperature readings from a tag show a strong thermocline at 75-100 m, likely the boundary between cold Anadyr Water above and warm Bering Shelf/Slope water below (Fig. 17).
- Whales leave the area before waters are ice-free in spring; this corresponds to when zooplankton are expected to exit diapause and migrate to the surface.
- **This is the first evidence of winter feeding for this stock of bowhead whales.**

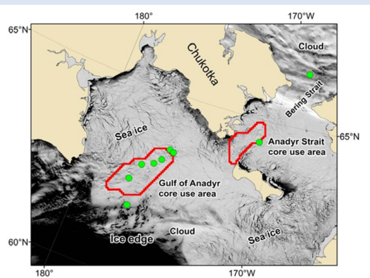


Figure 13. Sea ice and whale locations on 6 March 2009.

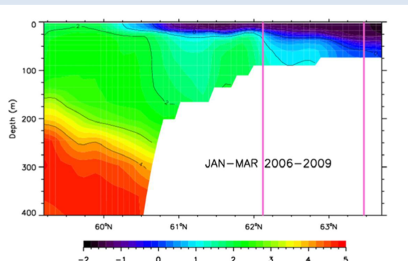


Figure 16. Temperature, section B (model projection)

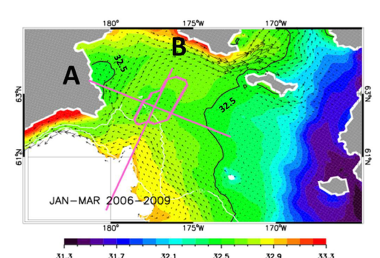


Figure 14. Bottom salinity (200 m limit; model projection)

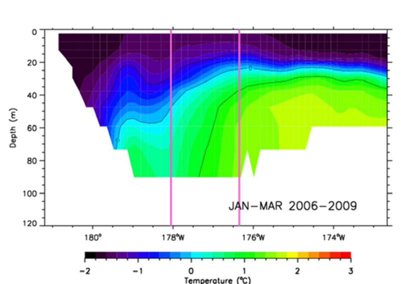


Figure 15. Temperature, section A (model projection)

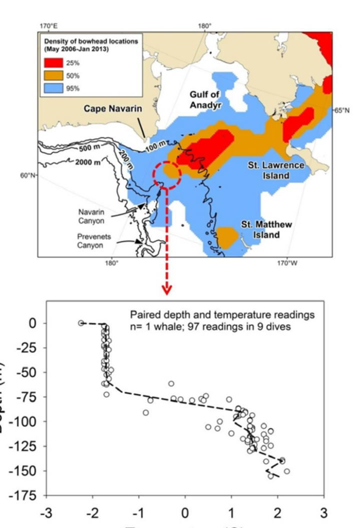


Figure 17. Paired depth and temperature data for a whale tagged in 2012. A strong thermocline is present between 75 and 100 m, the depth at which whales spend the most time.

Acknowledgements

This cooperative project involved contributions and hard work from many organizations, agencies, and individuals including the following: Alaska Eskimo Whaling Commission, North Slope Borough (Billy Adams, Robert Suydam, and Taqulik Hepa), Barrow and Kaktovik Whaling Captain's Associations (Eugene Brower, Fenton Rexford, Joe Kaleak, George Tagarook, and Eddie Arey), Barrow Arctic Science Consortium (Lewis Brower), Aklavik and Tuktoyaktuk Hunters and Trappers Committees (Dennis Arey, Larry Arey, Pat Kasook, Buddy Gruben, Douglas Panaktalok, Mikkel Panaktalok, Max Kotokak, Sr., Charles Pokiak, and James Pokiak), Department of Fisheries and Oceans Canada (DFO) (Kevin Bill, Tim Leblanc, Patrick Ryan, Terry Stein, Angus Alunik), Dr. Stephen Raverty of the British Columbia Animal Health Center, and the Greenland Institute of Natural Resources (Mikkel and Anders Villum Jensen). Gerald Darnis, Annette Wold, and Chris Stark provided helpful discussion regarding zooplankton. Funding for this research was provided by U.S. Minerals Management Service, now Bureau of Ocean Energy Management (BOEM), with support and assistance from Charles Monnett and Jeffery Denton. Much of the tagging operations in Canada were funded by the Fisheries Joint Management Committee, Ecosystem Research Initiative (DFO), and Panel for Energy Research and Development. Funding for Steve Okkonen and Matthew Druckenmiller was provided by the BOEM Environmental Studies Program through Interagency Agreement No. M11PG00034 with the U.S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA), Office of Oceanic and Atmospheric Research (OAR), Pacific Marine Environmental Laboratory (PMEL). Bowhead whale research has been conducted in the U.S. under a Marine Mammal Protection Act permit issued to National Marine Fisheries Service (No. 782-1719) and to the Alaska Department of Fish and Game (ADFG) (No. 14610) and under the ADFG Animal Care and Use Protocols (Nos. 06-16, 09-21, 10-13R, 12-020). In Canada, research was conducted under Department of Fisheries and Oceans Scientific License (No. S-07/08-4007-IN, S-08/09-4000-IN, S-09/10-4005-IN-A1) and Animal Care Protocols FWI-ACC-2007-2008-013, FWI-ACC-2008-031, and FWI-ACC-2009-019.

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Appendix G.

Inter-annual Variability in the Fall Movements of Bowhead Whales in the Chukchi Sea

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Each fall, the majority of bowhead whales (*Balaena mysticetus*) in the Bering-Chukchi-Beaufort (BCB) population migrate westward, from summering grounds in the Beaufort Sea, through the Chukchi Sea, to the Northern Coast of Chukotka, Russia. The Chukchi Sea is of major interest for oil and gas development and lease areas occur in both Alaskan and Russian waters. Most industrial activity occurs in summer and fall when sea ice is at its seasonal minimum and at a time coinciding with the westward migration of bowhead whales. As such, understanding the timing and direction of whale movements in the Chukchi Sea is important for managing disturbance and mitigating the effects of industrial activities. We used satellite-linked telemetry data from 35 bowhead whales collected between 2006 and 2012 to investigate inter-annual variability in where whales spend time within the Chukchi Sea. We limited our examination to data collected from September through December and used behavioral state-space models to classify whale locations as being associated with lingering, presumably feeding, behavior or directed travel. We then examined how locations associated with feeding behavior were distributed by year. We observed two main migration patterns. The first pattern, observed in 2006, 2008, and 2010, was characterized by a high density of feeding locations near Barrow, Alaska, and along the coast of Chukotka, Russia; whales generally did not linger in the central Chukchi in these years. The second pattern, observed in 2009 and 2012, was characterized by a high density of feeding locations in the central Chukchi. Of particular interest, in 2012 whales spent more time in the central Chukchi Sea, nearer to active oil and gas leases, than near Barrow or along the coast of Chukotka. The timing of movements past Barrow and into the Chukchi Sea is likely related to the presence and density of zooplankton near Barrow. Likewise, the presence of feeding locations in the central Chukchi is inferred to be related to the availability of zooplankton and variation in how oceanographic features, such as currents and fronts, may act to concentrate zooplankton. We are currently modeling the occurrence of feeding locations as a function of oceanographic variables.

Alaska Marine Science Symposium, 19–23 January, Anchorage, Alaska

Appendix G.

Inter-annual variability in the fall movements of bowhead whales in the Chukchi Sea

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Harry Brower, North Slope Borough Wildlife Department, Barrow, Alaska

Introduction

Each fall, the majority of whales in the Bering-Chukchi-Beaufort (BCB) population migrate westward, from summering grounds in the Beaufort Sea, through the Chukchi Sea, to the northern coast of Chukotka, Russia (Fig. 1). The Chukchi Sea is of major interest for oil and gas development and lease areas occur in both Alaskan and Russian waters. Most industrial activity occurs in summer and fall when sea ice is at its seasonal minimum and at a time coinciding with the westward migration of bowhead whales. As such, understanding the timing and direction of whale movements in the Chukchi Sea is important for managing disturbance and mitigating the effects of industrial activities. We used satellite-linked telemetry data from 35 bowhead whales collected between 2008 and 2012 to investigate inter-annual variability in where whales spend time within the Chukchi Sea.

Methods

We limited our examination to data collected from September through December and used behavioral state-space models (e.g., Jonsen et al. 2005 Ecology 86:2874-2880) to classify whale locations as being associated with lingering, presumably feeding, behavior or directed travel (Fig. 2). We then examined how locations associated with feeding behavior were distributed by year.

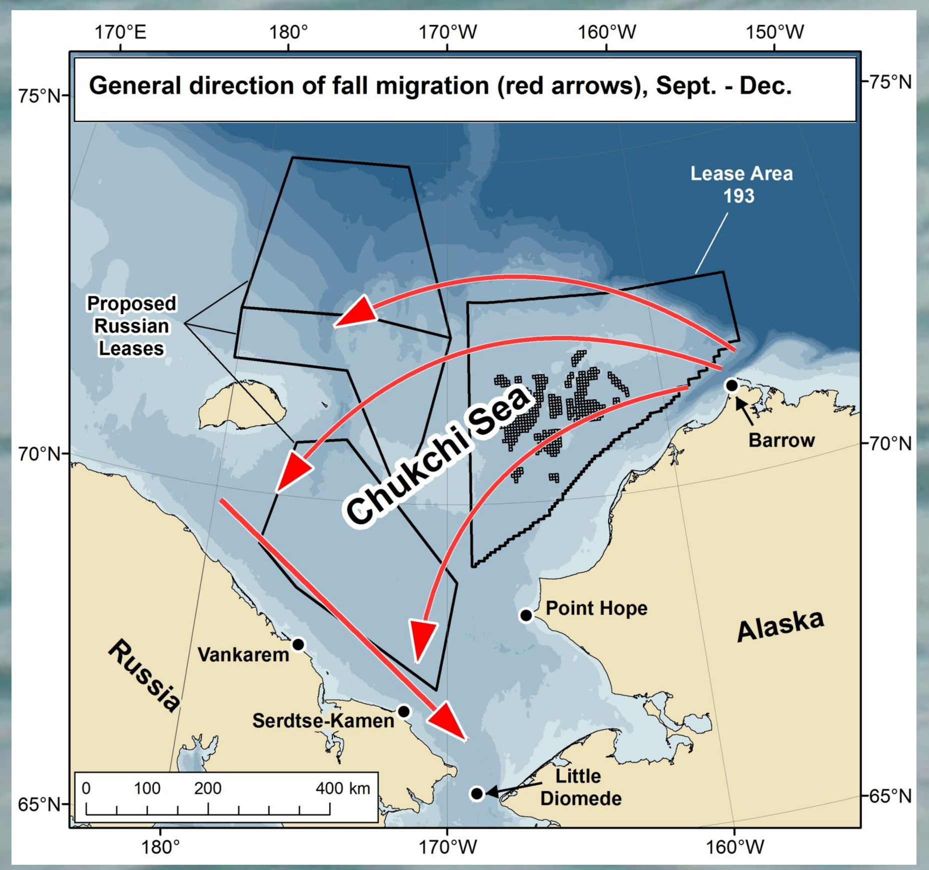

Figure 1. General migration routes in the Chukchi Sea.

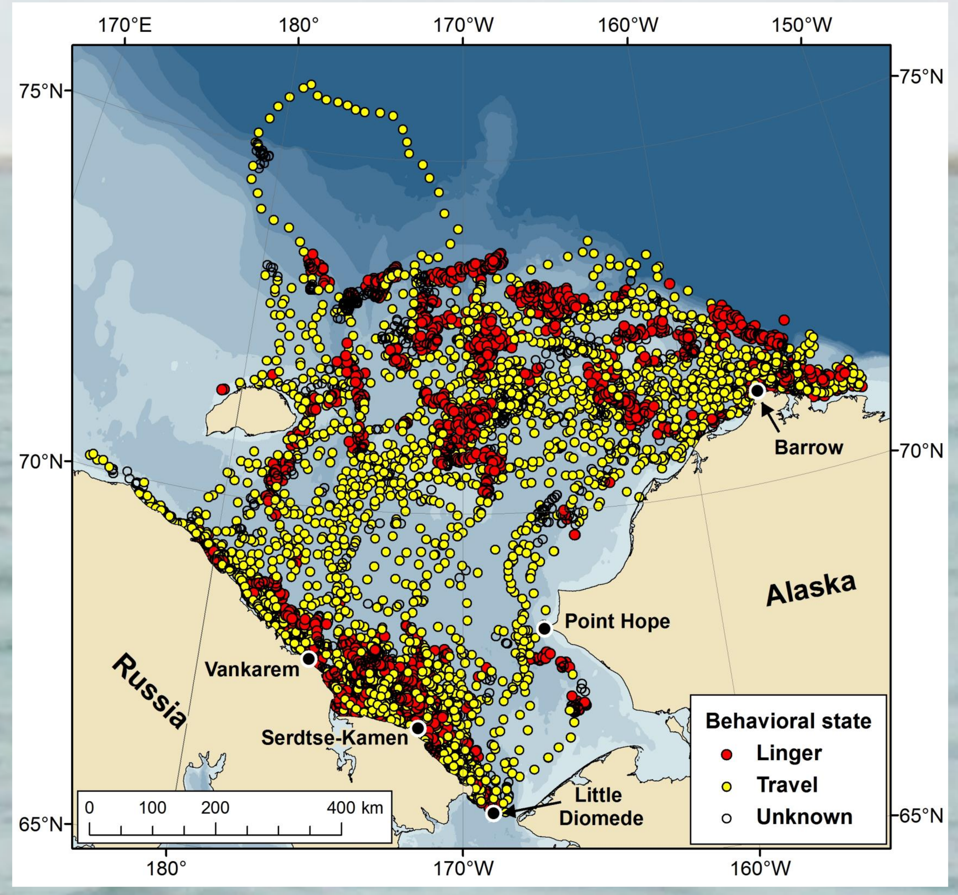

Figure 2. Estimated locations and behavioral states for 35 bowhead whales in the Chukchi sea, August and September (2008, 2009, 2010, and 2012).

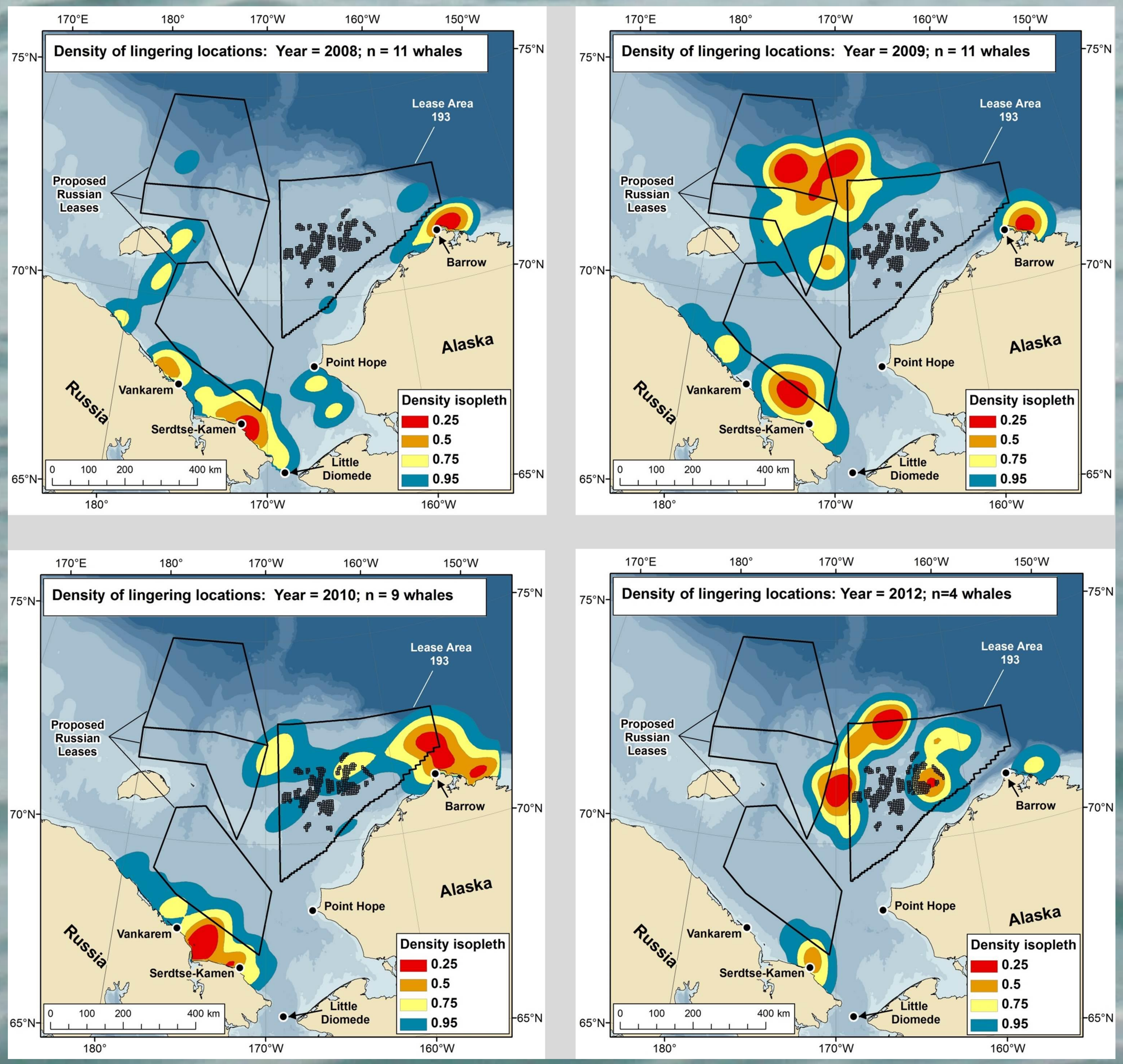

Figure 3. Density of lingering, presumably feeding, locations in the Chukchi Sea, for September – December, by year.

Results

1. We observed two main migration patterns. The first pattern, observed in 2008 and 2010, was characterized by a high density of feeding locations near Barrow, Alaska, and along the coast of Chukotka, Russia; whales generally did not linger in the central Chukchi in these years.
2. The second pattern, observed in 2009 and 2012, was characterized by a high density of feeding locations in the central Chukchi.
3. Of particular interest, in 2012 whales spent more time in the central Chukchi Sea, nearer to active oil and gas leases, than near Barrow or along the coast of Chukotka.

Current work

1. We are currently comparing locations classified as lingering with those classified as traveling or those of unknown behavioral state.
2. We will model the probability of lingering as a functions of oceanographic variables, including salinity, temperature, depth, and the local gradients of these variables.
3. We will do this separately for four oceanographic regions: a) Barrow, b) the Chukchi borderlands, c) the central Chukchi, and d) the Chukotka coast (Fig. 4).

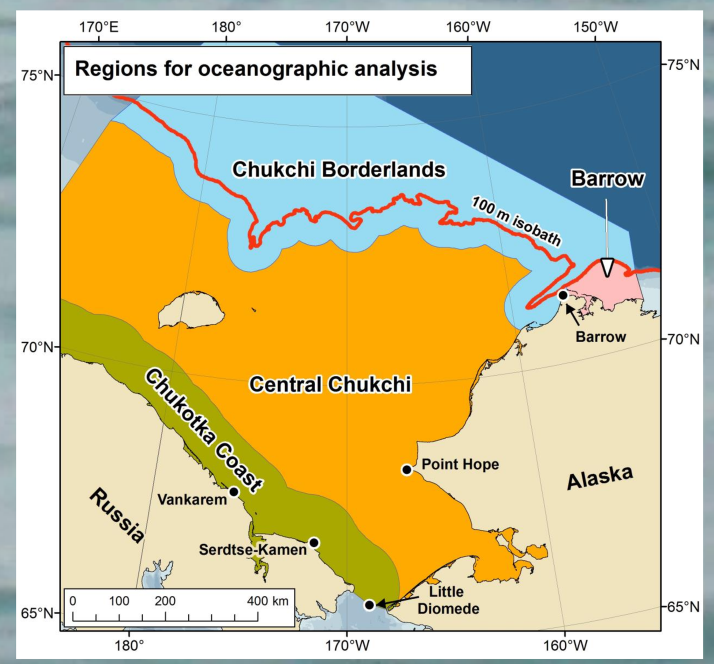

Figure 4. Oceanographic regions for modelling behavioral state in the Chukchi Sea.

Acknowledgements

This cooperative project involved contributions and hard work from many organizations, agencies, and individuals, including the following: Alaska Eskimo Whaling Commission, North Slope Borough (Billy Adams, Robert Suydam, and Taqulik Hepa), Barrow and Kaktovik Whaling Captain's Associations (Eugene Brower, Fenton Rexford, Joe Kaleak, George Tagarook, and Eddie Arey), Barrow Arctic Science Consortium (Lewis Brower), Aklavik and Tuktoyaktuk Hunters and Trappers Committees (Dennis Arey, Larry Arey, Pat Kasook, Buddy Gruben, Douglas Panaktalok, Mikkel Panaktalok, Max Kotokak, Sr., Charles Pokiak, and James Pokiak), Department of Fisheries and Oceans Canada (DFO) (Kevin Bill, Tim Leblanc, Patrick Ryan, Terry Stein, Angus Alunik), and the Greenland Institute of Natural Resources (Mikkel and Anders Jensen). Funding for this research was mainly provided by U.S. Minerals Management Service (now Bureau of Ocean Energy Management). This study is part of the Synthesis of Arctic Research (SOAR) and was funded in part by the U.S. Department of the Interior, Bureau of Ocean Energy Management, Environmental Studies Program through Interagency Agreement No. M11PG00034, with the U.S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA), Office of Oceanic and Atmospheric Research (OAR), Pacific Marine Environmental Laboratory (PMEL).

Bowhead whale research has been conducted in the U.S. under a Marine Mammal Protection Act permit issued to National Marine Fisheries Service (No. 782-1719) and to the Alaska Department of Fish and Game (No. 14610) and under Animal Care and Use permit Nos. 06-16, 09-21, 10-13R, 12-020. In Canada, research was conducted under Department of Fisheries and Oceans Scientific License No. S-07/08-4007-IN, S-08/09-4000-IN, S-09/10-4005-IN-A1 and Animal Care Protocols FWI-ACC-2007-2008-013 and FWI-ACC-2008-031, and FWI-ACC-2009-019.

Appendix H.

Environmental Influences on Bering-Chukchi-Beaufort Bowhead Whale Movements:
Do They Explain Why Bowheads Migrate?

Presented by Lori Quakenbush
at
Workshop: Baleen Whale Migration, Revisited
21st Biennial Conference on the Biology of Marine Mammals, 13 December 2015
San Francisco, CA

Much of the work presented is based on Citta et al. 2015. Ecological characteristics of core-use areas used by Bering-Chukchi-Beaufort (BCB) bowhead whales, 2006–2012. Progress in Oceanography 136:201–222. Co-authors are John J. Citta, Lori T. Quakenbush, Stephen R. Okkonen, Matthew L. Druckenmiller, Wieslaw Maslowski, Jaclyn Clement-Kinney, John C. George, Harry Brower, Robert J. Small, Carin J. Ashjian, Lois A. Harwood, and Mads Peter Heide-Jørgensen.

ABSTRACT: Baleen whales of the world are among the longest distance mammalian migrants but why they migrate has not been unequivocally determined. Bowhead whales (*Balaena mysticetus*) are restricted to arctic and subarctic waters and thus have shorter migrations. Most bowheads of the Bering-Chukchi-Beaufort population leave the Bering Sea in April just before it becomes the most productive ocean in the world. From wintering grounds in the Bering Sea, bowheads migrate >2,500 km to Amundsen Gulf, Canada, when sea ice is at its maximum extent and thickness in the Chukchi and Beaufort seas. Bowheads remain in Amundsen Gulf for ~2 months. During July–September, the distribution of bowheads shifts to the Tuktoyaktuk and Mackenzie shelf region in the southeastern Beaufort Sea. Bowheads begin their westward migration in September and October and they may or may not stop near Barrow before crossing the Chukchi Sea. Most spend considerable time (October–December) moving slowly southward along the Chukotka coast passing through Bering Strait to winter and breed in the Bering Sea. We used satellite telemetry data from 54 bowhead whales tracked between 2006 and 2012 to identify six primary core use areas and using environmental factors (oceanography, sea ice, and wind) explored the timing of use of these areas by bowhead whales. All six areas were found to be associated with physical mechanisms that concentrated zooplankton, although the mechanisms differed by area (e.g. wind-driven upwellings, haloclines, thermoclines, and a front between two opposing currents), supporting the hypothesis that bowhead whale migration is driven by resource tracking. Calf thermoregulation, the need for calm water, and avoidance of killer whale predation are not strongly supported reasons for bowhead migration. Although we know that whales migrating to Amundsen Gulf increase in body condition over the summer, thereby indicating that migration is beneficial, whales may also migrate due to behavioral traditions. Segments of the bowhead population that once summered in the Bering and Chukchi seas were extirpated by Yankee whaling. As such, the spring migration to Amundsen Gulf may be due to both resource tracking and tradition.

Appendix I.

Short-term effects of tagging on West Greenland bowhead whales (*Balaena mysticetus*)

L. Quakenbush, V. Delnavaz, M.P. Heide-Jørgensen, M. Kauffman, S.L. Rekdal, N.H. Nielsen, and S.B. Blackwell

Biennial Conference on the Biology of Marine Mammals, 13–18 December 2015, San Francisco, CA

To obtain meaningful results in behavioral research, researchers need to know when an animal is exhibiting natural and unperturbed behavior. Marine mammals are often studied with the use of archival tags that are attached to the animal. The attachment procedure often provokes an immediate reaction by the animal, and if the observer remains nearby to ensure retrieval of the tag, this may also affect the animal's behavior. We attached Acousonde tags to four whales in Disko Bay, West Greenland, and assessed disturbance by examining accelerometer and depth data collected by the tag. The Acousonde tags were attached using a small dart and remained on the whales for 8–25 hours. The duration in seconds (s) of individual strokes was measured throughout the records and expressed as a function of time since tagging. Stroke length was short following tagging, 3–5 s, and gradually increased to 8–12 s. Three of the four whales were pursued after tagging for ~16 minutes, to document the position and behavior of the tag on the animal. A piecewise regression on the stroke length data placed the breakpoint at about 1.8 hours, indicating it took nearly two hours for the stroke length to return to values that did not change significantly over the rest of the records. The whale that was not pursued slowed down its stroking rate much faster than the three whales that were pursued, suggesting that not pursuing the animal after tagging minimizes disturbance. Changes in the whales' behavior during surface intervals were also assessed and were of shorter duration, generally lasting 20–40 minutes. We conclude that the first two hours of data should be discarded, especially when animals are pursued post-tagging, because the data collected are not representative of normal bowhead whale behavior.

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Appendix I.

Short-Term Effects of Tagging on West Greenland Bowhead Whales (*Balaena mysticetus*)

L. Quakenbush[1], V. Delnavaz[2], M.P. Heide-Jørgensen[3], M. Kauffman[4], S.L. Rekdal[3], N.H. Nielsen[3], and S.B. Blackwell[5]

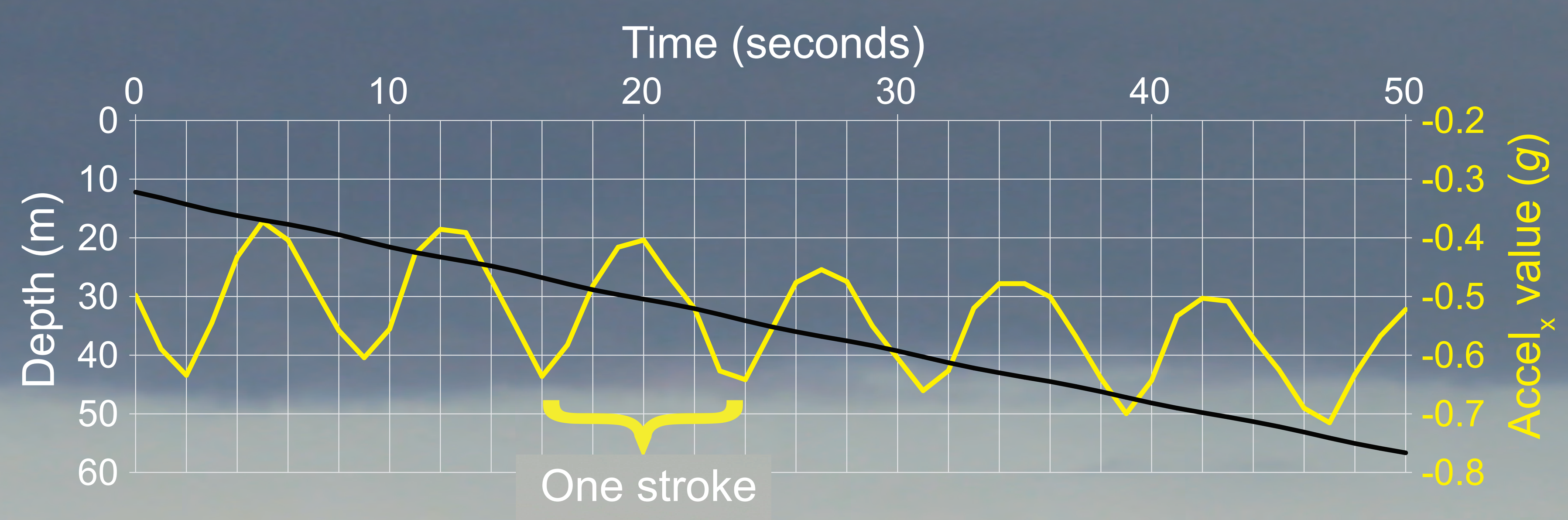
[1]ADF&G, Fairbanks, AK [2]Long Marine Lab, UCSC [3]GINR, Copenhagen, Denmark [4]WEST, Cheyenne, WY [5]Greeneridge Sciences, Goleta, CA

QUESTION: How long is bowhead behavior affected by pursuit and tagging?

We sought to answer this question by examining depth and accelerometer data collected with Acousonde™ tags deployed on bowhead whales in Disko Bay, West Greenland, in April 2013.

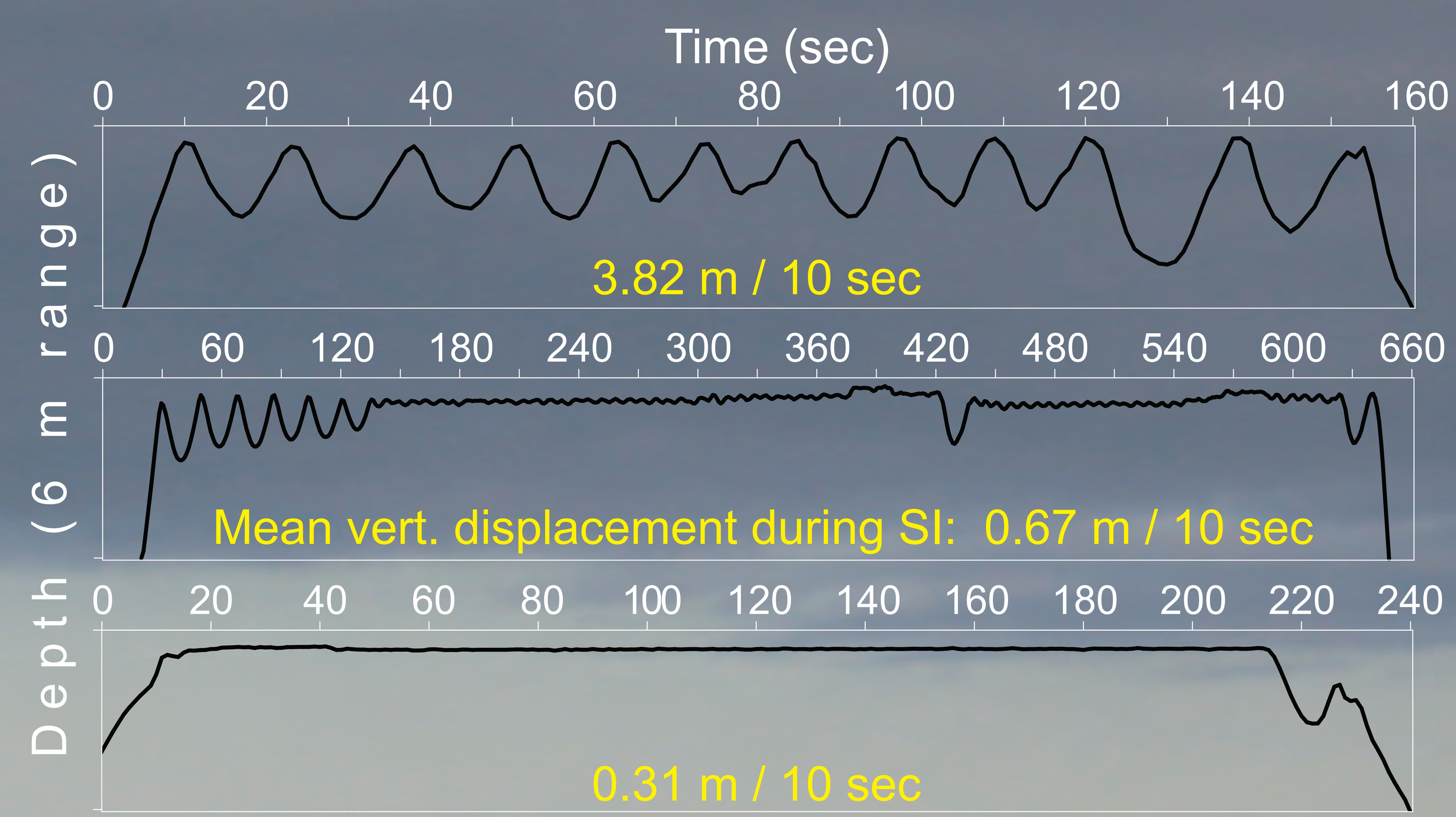
1. Four bowhead whales were tagged with multi-channel tags, attached with a small subdermal dart. The tags were trailing (0.5-1 m long tether). Record lengths were 8, 14, 20, and 25 h.

2. The lengths of the whales' swimming strokes were measured throughout each animal's record



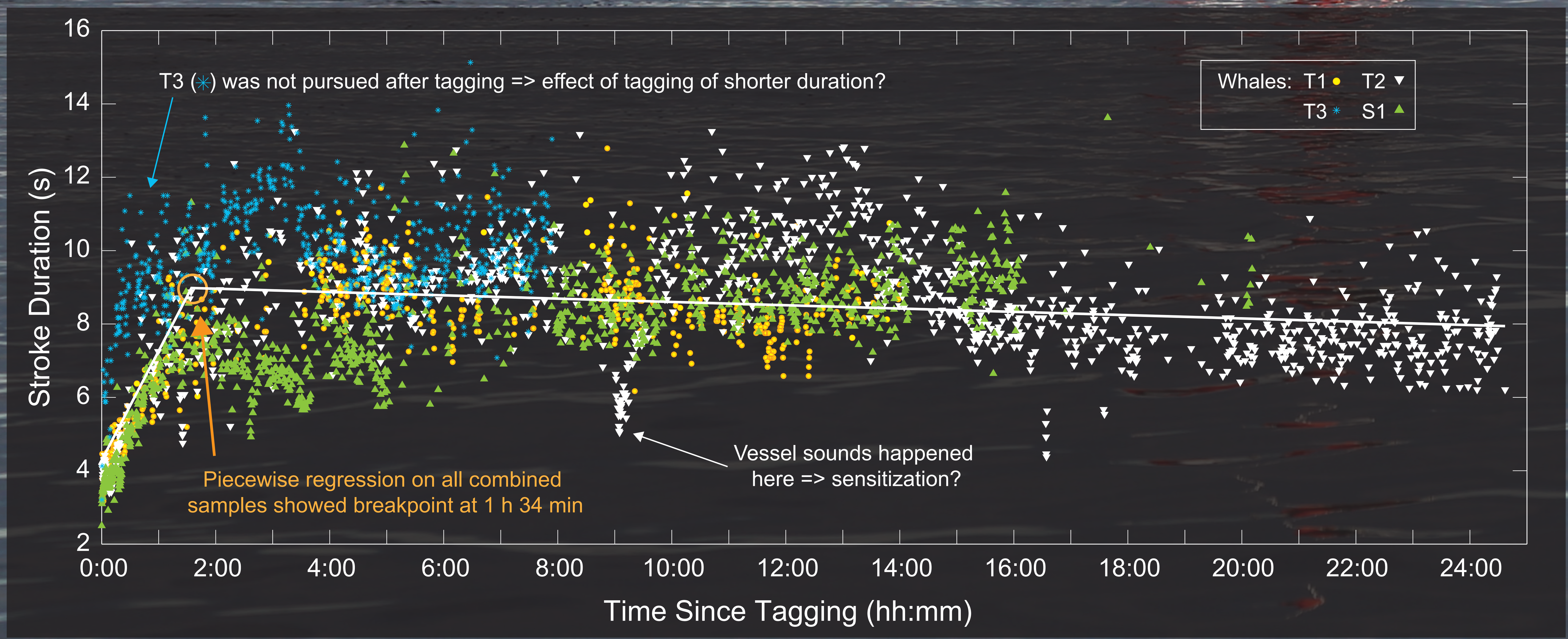
In this example, the whale is descending on a dive (——), and its swimming strokes can be deduced from the accelerometer's x-axis (——)

4. The whales' behavior during surface intervals (SIs), based on their depth record, was quantified:

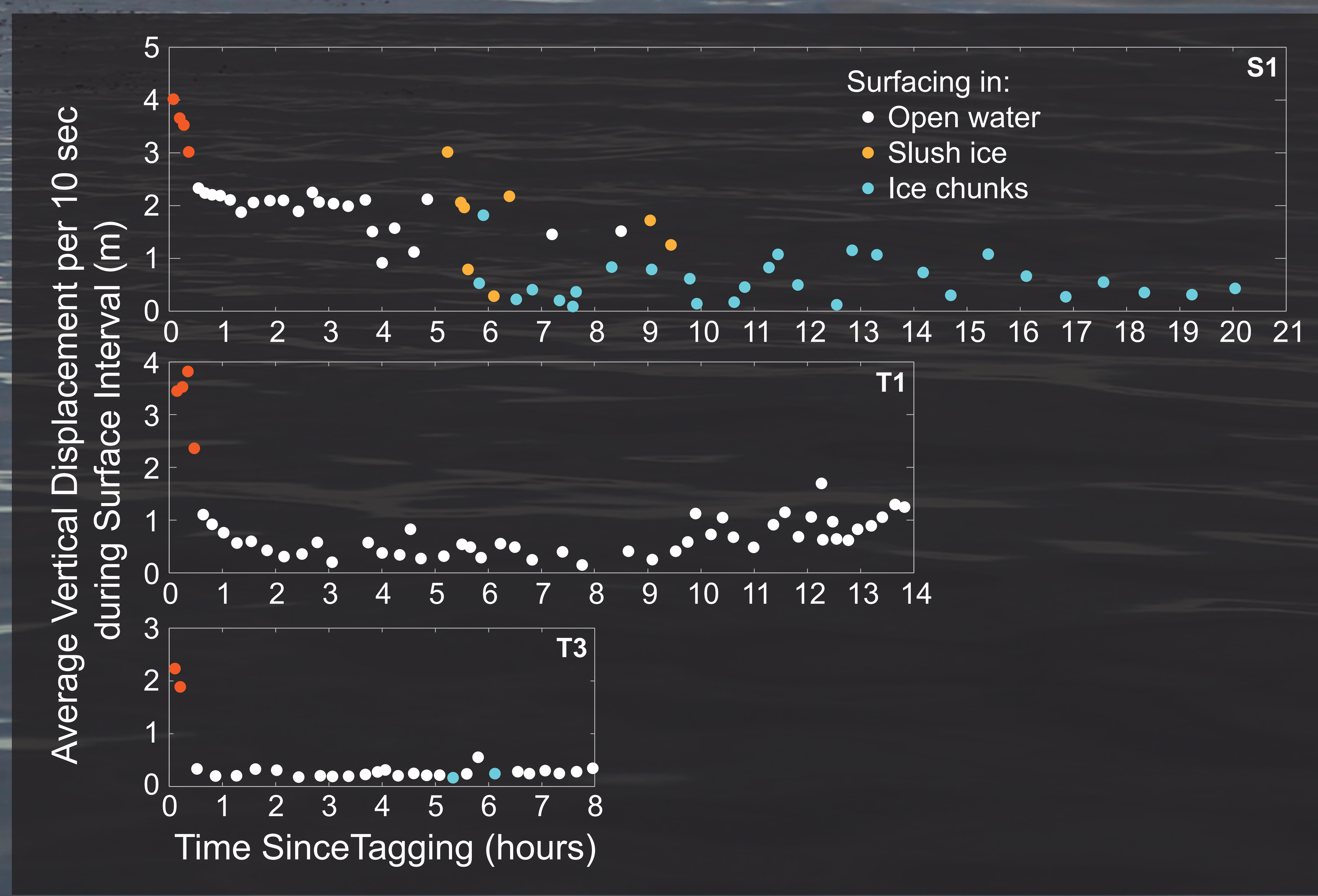


These three examples of surface intervals occurred soon after tagging (top), a few hours after tagging (middle), and many hours after tagging (bottom). We expressed this change by calculating the mean vertical displacement (in m) per 10 sec period.

3. The whales' stroke durations were plotted as a function of time since tagging:



5. The whales showed significantly (paired t-test) more movement during the first few surfacings (red dots):



CONCLUSIONS: • Whales are affected for ~0.5 h (behavior during SI) to ~1.5 h (stroking rates) after tagging. • Not pursuing the whale after tagging likely shortens the disturbance. • Whales may be sensitized to the experience (e.g., vessels) for some time after tagging. • It is important to exclude the initial data collection from analyses!

ACKNOWLEDGMENTS: Qeqertarsuaq hunters Abel Brandt, Ado Isaksen, Johannes Mølgård, and Tarfi Mølgård, Chris Nations (WEST, Inc.) for statistica advice. Study conducted under the general permission from the Greenland Government to GINR for tagging baleen whales. Acousonde funding: U.S. Department of the Interior, BOEM, contract M12PC00005.

Appendix J.

Late summer aggregations of bowhead whales in the Canadian Beaufort Sea region, 2006-2012

Harwood, L. A., Quakenbush L. T., Citta J. J., Small R. J., George J. C., Pokiak, J., Pokiak, C., Arey, D., Heide-Jørgensen M. P., Brower H.

Each spring, most bowhead whales of the Bering-Chukchi-Beaufort population migrate to summering habitats in the Canadian Beaufort Sea. Aerial surveys in the 1980s and 2000s showed that bowhead whales aggregate in shallow shelf waters in late summer (August–September). The distribution of bowhead whales during late summer overlaps with anthropogenic activity, including petroleum exploration. We fit behavioral state-space models to bowhead locations obtained by satellite telemetry during 2006–2012 from 16 bowhead whales, and classified locations as associated with lingering behavior (presumably feeding) or directed travel. While in the Canadian Beaufort Sea, on average the tagged whales spent 60% of their time lingering (range 20-100%). Using only locations associated with lingering behavior, we calculated kernel densities and defined areas within the 75% density contour as likely feeding aggregation areas. We identified five separate areas, of which three were located in shallow waters over the continental shelf. All tagged whales were observed to use one or more of these areas in a single season. The largest (10,877 km^2) of the three areas was located offshore of the Tuktoyaktuk Peninsula (5–52 m depth), and was used by all 16 whales. The other two shelf areas were located at the edge of the continental slope northwest of Cape Bathurst and offshore of the Mackenzie Delta. The remaining two areas, Viscount Melville Sound, located to the northeast in the Arctic Archipelago (416–503 m depth), and Darnley Bay, located within Amundsen Gulf (5–169 m depth), were used by the only two adults in our sample, both males. Together, the five areas comprised 25,341 km^2, only 14.1% of the total area used by the tagged bowhead whales in this study. As such, these relatively small areas appear particularly important to bowheads while on their summer range in Canadian waters.

Biennial Conference on the Biology of Marine Mammals, 13–18 December, San Francisco, CA

Appendix K.

Society for Marine Mammalogy Biennial Conference 2015

Abstract

Title: Inter-annual variability and oceanographic correlates of bowhead whale movements in the Chukchi Sea.

Authors: Citta, Okkonen, Quakenbush, George, Small, Harwood, Brower, Heide-Jørgensen

Each fall, bowhead whales in the Bering-Chukchi-Beaufort (BCB) population migrate westward from summering grounds in the Beaufort Sea through the Chukchi Sea to the northern coast of Chukotka, Russia. The Chukchi Sea is of major interest to the petroleum industry and industrial activity may coincide, both spatially and temporally, with the westward migration. The path of migration varies annually and whales often pause to feed. To investigate inter-annual variability in the fall migration, we fit behavioral state-space models to whale locations obtained during 2006–2012 from 35 bowhead whales and classified locations as associated with lingering behavior (presumably feeding) or directed travel. We examined how locations associated with lingering were distributed annually and determined the oceanographic features associated with the whales' path of travel and behavioral state in 2008 and 2009, two years for which we have oceanographic results from a pan-arctic coupled ice-ocean model. We observed two patterns in migration. The first pattern, observed in 2006, 2008, and 2010, was characterized by a high density of lingering locations near Barrow, Alaska, and along the coast of Chukotka, Russia. Whales generally did not linger in the central Chukchi in these years. The second pattern, observed in 2009 and 2012, was characterized by a high density of lingering locations in the north-central Chukchi. Using oceanographic results from 2008 and 2009, we found that whales generally followed water characterized by temperatures < 2 ºC and salinities > 31 psu, avoiding relatively warm, fresh Alaska Coastal Water. Along their paths, whales were more likely to linger in areas characterized by higher bottom salinity and lower current velocity. We found that bowhead whales followed oceanographic features and water masses known to have and aggregate zooplankton. Variation in the location of water masses largely explained differences in where whales crossed the Chukchi Sea.

Biennial Conference on the Biology of Marine Mammals, 13–18 December 2015, San Francisco, CA

Abstract

Ref No	c1bstx9ms8
Title	Oceanographic characteristics associated with bowhead behaviors in the Chukchi Sea.
Contact	John Citta john.citta@alaska.gov Alaska Department of Fish & Game 1300 College Road, , Fairbanks, Alaska, 99701, United States Phone: 907-459-7248 Fax:
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Abstract	Each fall, bowhead whales in the Bering-Chukchi-Beaufort (BCB) population migrate westward from summering grounds in the Beaufort Sea through the Chukchi Sea to the northern coast of Chukotka, Russia. The Chukchi Sea is of interest to the petroleum industry and industrial activity may coincide, both spatially and temporally, with the westward migration. The path of migration varies annually and whales often pause to feed. To investigate inter-annual variability in the fall migration, we fit behavioral state-space models to whale locations obtained during 2006-2012 from 35 bowhead whales and classified locations as associated with lingering behavior (presumably feeding) or directed travel. We examined how locations associated with lingering were distributed annually and determined the oceanographic features associated with the whales' path of travel and behavioral state in 2008 and 2009, two years for which we have oceanographic results from a pan-arctic coupled ice-ocean model. We observed two patterns in migration. The first pattern, observed in 2006, 2008, and 2010, was characterized by a high density of lingering locations near Barrow, Alaska, and along the coast of Chukotka, Russia. Whales generally did not linger in the central Chukchi in these years. The second pattern, observed in 2009 and 2012,

was characterized by a high density of lingering locations in the north-central Chukchi.Using oceanographic results from 2008 and 2009, we found that whales generally followed water characterized by temperatures < 0 ºC and salinities 31.5–34.5 psu. Bowhead whales avoided Alaska Coastal Water and Siberian Shelf Water (the latter of which defined the western limit of their range) likely due to lower intrinsic densities of zooplankton prey. Along their tracks, whales were more likely to linger in areas characterized by stronger gradients in bottom salinity. Variation in the location of water masses largely explained differences in where whales crossed the Chukchi Sea.

Funding Agency	Bureau of Ocean Energy Management
Presentation	Oral Presentation
Section	Arctic/Mammals

- Abstract represents a final report.
- Proposed presenter is required to present as a condition of attending.

Report on acoustic studies of bowhead whales in Disko Bay April - May 2016

Circulation: Internal, Lori Quakenbush ADFG.

Participants:

Mads Peter Heide-Jørgensen (MPHJ), *Greenland Institute of Natural Resources (GINR)*
Susanna Blackwell (SB), *Greeneridge Sciences Inc.*
Mads Fage Christoffersen (MFC)
Outi Tervo (reporting, OT), *Greenland Institute of Natural Resources (GINR)*

Local hunters:

Abel Brandt (AB)
Ado Isaksen (AI)
Johannes Mølgård (JM)
Tarfi Mølgård (TM)

Objectives:

The overall objective is to deploy Acousonde tag recorders on bowhead whales. Two types of deployments will be tested; suction cup or spear-mount attachments. The aims of the project are to 1) obtain flow noise measurements from an acoustic recorder attached to the whales, 2) obtain recordings of bowhead calls for identification of calls in future automatic filtering of recordings, and 3) identify the sex of the singing whales.

Background:

Two Acousonde recorders (orange) were provided by ADFG and the plan was to deploy the tags several times to collect recordings from bowhead whales. The Acousonde records the sound produced from the tagged bowhead whale as well as background and surrounding acoustics. It also provides data on depth, temperature, light and is equipped with orientation sensors (compass and accelerometer). The Acousonde will be deployed by a pole with a special grip that holds the instrument during tagging.

The Acousonde is set to sample the accelerometer channels at 400 Hz sample rate in order to record the vibrations of the body while the animal is vocalising.

The bowhead whale is one of the five species of baleen whales that are known to sing, in addition to the humpback whale (*Megaptera novaeangliae*), blue whale (*Balaenoptera musculus*), fin whale (*B. physalus*), and minke whale (*B. acutorostrata*). Singing in baleen whales is assumed to have significance in sexual behaviour, and in the species where sex of the singer has been studied, the singers are always males. The sex of the singer in bowhead whale is not yet known.

The project serves as a trial study for future protocols in making recordings of acoustics from whales. Biopsy samples were also taken, either by the pole (when deploying tags) or from a crossbow for genetic studies and for sex identification.

Funding

The Acousonde tags were provided by a study conducted for the Alaska Department of Fish and Game. Salary for OT was obtained by a post doc at the GINR.

Narrative:

Tuesday 12.04.2016
OT and MFC depart from Copenhagen and get as far as Aasiaat where the helicopter is cancelled due to bad weather further up the coast.

Wednesday 13.04.2016
Arrival in Qeqertarsuaq at 9 am. No ice on the helicopter route, good visibility and one bowhead whale close to Kronprinsens Ejland.

Meeting the local hunters at the Arctic Station and finding gear from the attic. OT tests the satellite transmitter and VHF transmitter on Piuminaq (the two Acousondes are Piuminaq and Arsarnerit, see Table 1) and prepares the tag for deployment. Hunters mount the deployment tower on Abel´s boat. Everything is ready for tomorrow.

Thursday 14.04.2016

After conferring with AB early in the morning, we decide to wait for calmer weather before sailing out. We will check the weather again at 1 pm.

Later, the weather calms down and we sail out at 13:40. TM is already outside Qaqqaliaq where there are bowhead whales. Piuminaq is deployed at 14:58 (Table 2) after a very short (< 5 min) approach phase. There is no reaction by the whale. A biopsy # 740 is collected by the dart on the pole. JM and AB are the taggers. The tag is placed on the right side of the whale (Figure 1). OT and AI sail together and keep at a distance from the tagging in order not to disturb the whale. TM is ready to shoot a biopsy with crossbow if necessary.
After tagging, engines are shut down but we stay in the area. AB can hear the VHF signal and after 15 minutes he is sure that the tag has fallen off since he can here the signal constantly. We find the tag floating east of us close by at 15:23 (Figure 2).

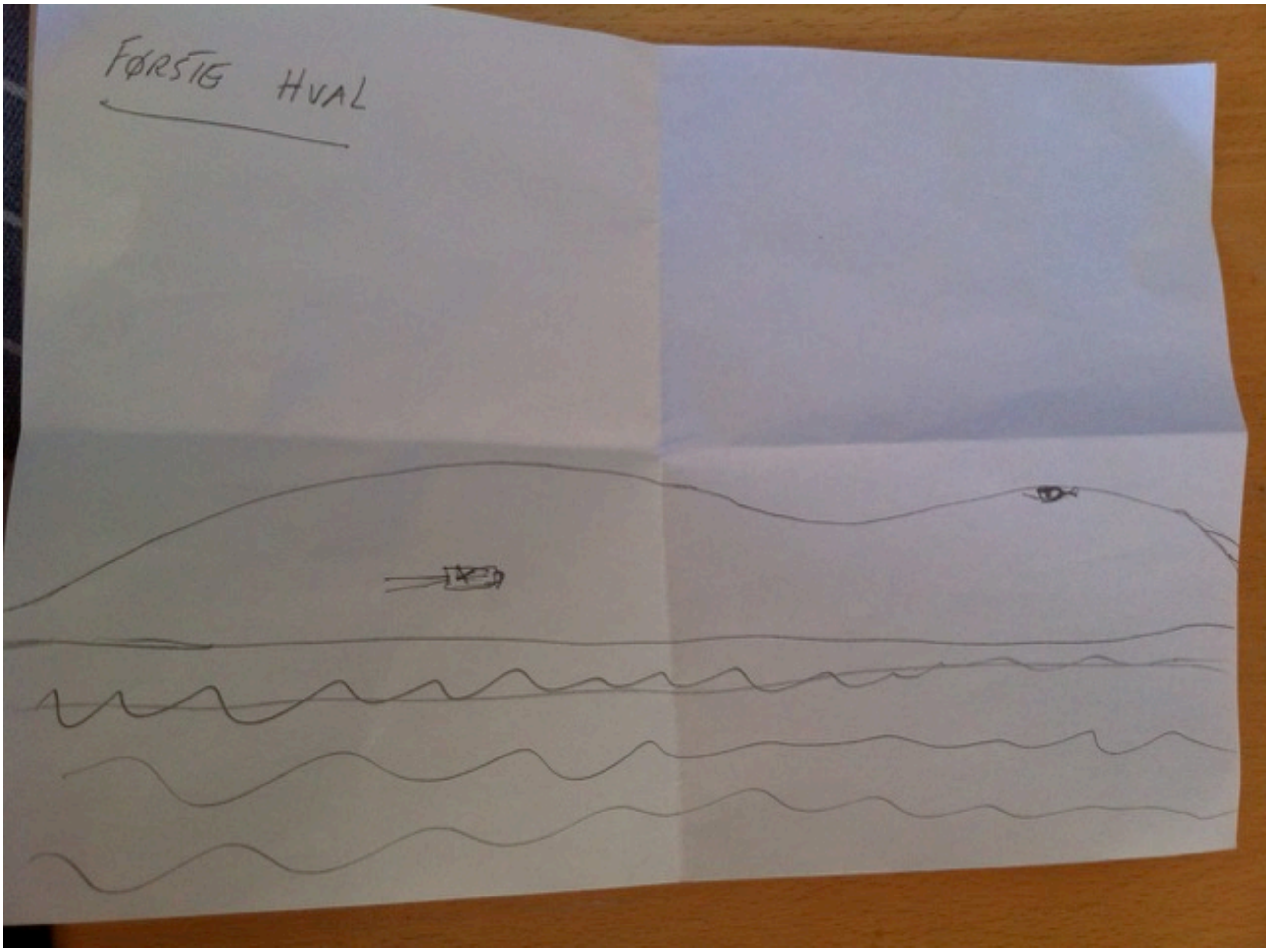


Figure 1. Abel's drawing showing how Piu1 (tag Piuminaq, first deployment) was placed on the whale.

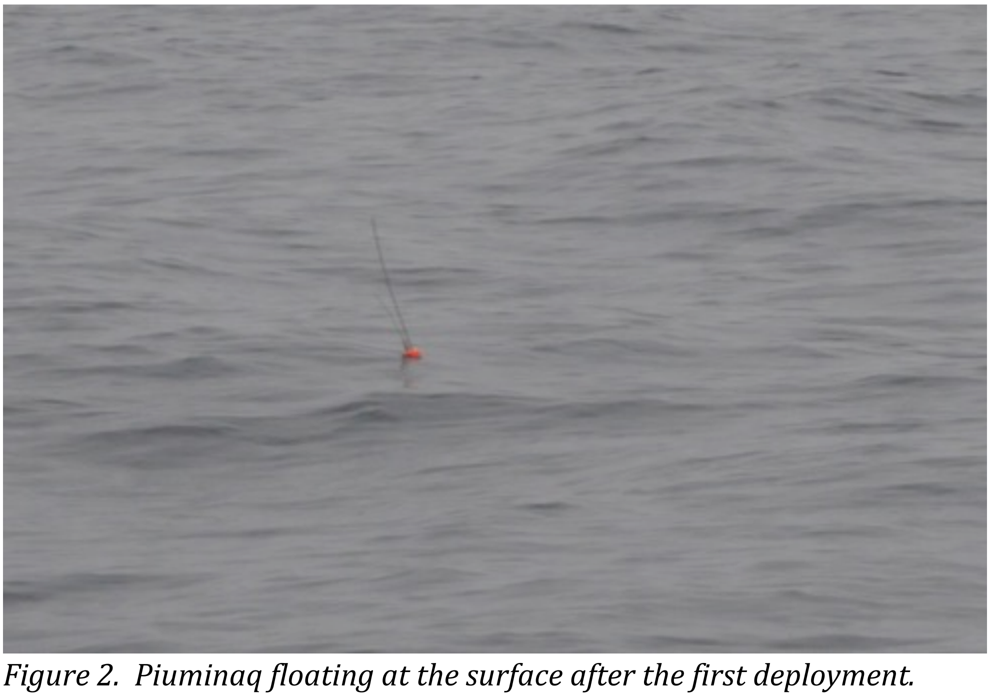


Figure 2. Piuminaq floating at the surface after the first deployment.

OT decides to return home to download the data and we sail out to sea again at 18:00. The visibility is lower due to snowfall but we do manage to spot some whales. We follow two individuals and attempt to tag them without success. The last whale we try to tag is slapping continuously its tail (every 10 – 15 seconds for 3 - 4 minutes) (Figure 3). On the way home we stop outside Qaqqaliaq and make sound recordings for 25 minutes from 21:45 to 22:10. The system used is as follows: HTI-94-SSQ hydrophone (−170 dB re: 1 V/_Pa; High Tech, Inc., Gulfport, MS) at ca. 10 m depth, Etec preamplifier at 30 dB and Olympus LS-11 digital recorder set at 16 bits and sampling at 44 kHz. Lots of bowhead whale singing! We sail slowly in darkness and are in the harbour at 22:30.

Friday 15.04.2016

Conferring with AB at 8:00. Too much wind and poor visibility, so we decide to call again at 13:00. OT and MFC are preparing the other tag, Arsarnerit, for deployment. A new VHF tag is mounted (used 5 days) (Table 1).

Checking the data from Piu1, collected yesterday. It turns out that the deployment lasted only 9 minutes (Table 2),

Figure 3. The tail slapping bowhead whale.

There is an impact of some sort 7 minutes into the deployment and 2 minutes after that the tag is detached (Figure 4).

At 16:00 we cancel the day due to increasing wind and snow.

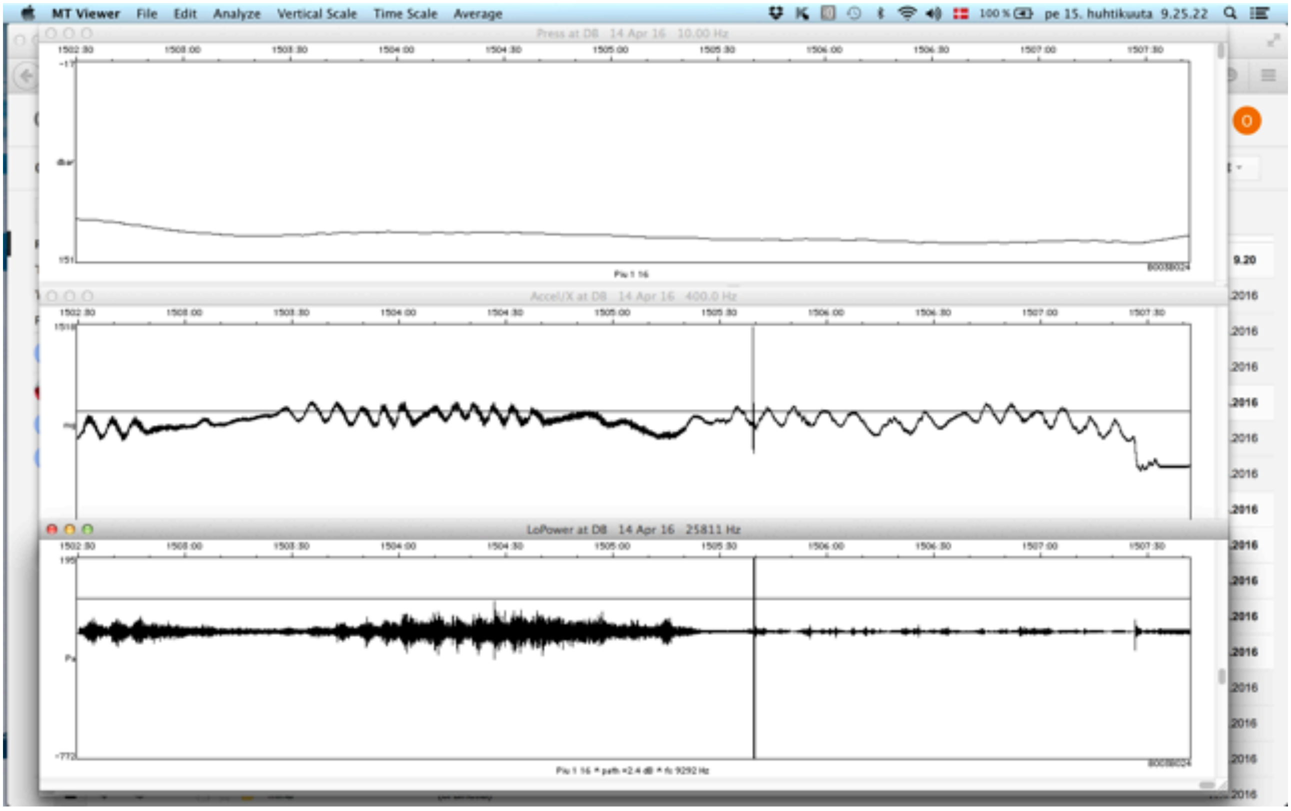


Figure 4. Pressure channel (top), x-accelorometer (middle) and sound (bottom) from deployment Piu 1.

Saturday 16.04.2016

The westerly wind from yesterday has packed the harbour with ice. The boats are stuck.

OT and Finn Steffens walk up to the first ridge behind Rød elv. The wind has brought a lot of ice close to the town. There are strips of open water as well and the floe size is luckily small.

At 18:00 AB calls to say that the boats are free and now located in the Oqqussaq harbour. The weather (visibility) is still not good so we decide to wait until tomorrow.

OT is analysing data. MFC working on the Qaqqaliaq listening station setup.

Sunday 17.04.2016

We wake up to bright sunshine and a strong easterly wind. The *Pajuuttat* freigt ship is breaking ice in the harbour, hopefully making it easier to get in and out of the harbour.

We confer with AB at 8:00. The boats are still on the other side in Oqqussaq harbour but the wind is too strong and the ice is moving swiftly. At 10:00 we are still waiting for the wind to die down. There is no ice east of us and we hope to sail later today. Doing tests with Piuminaq.

AB and OT drive with snowmobiles up on the foot of Lyngsmarksfjeld to see the ice situation. The ice is packed around Qeqertarsuaq but the rest of the bay is almost totally free of ice.

Figure 5. View from Lyngmarksfjeld showing concentration of ice outside Qeqertarsuaq.

Heading out to sea at 14:00. It takes us 1,5 hours to get through the ice outside Oqqussaq harbour. We sail west and later east and see some whales but make no deployments. It is a cold day out on the sea. We return to the main harbour at 20:00.

Figure 6. Negotiating ice on our way out off Oqqussaq harbour.

Monday 18.04.2016

Cloudy day with slight wind but good enough weather to sail out. We leave the harbour at 10:00 am and head west towards Fortunabay. Already before Fortunabay we spot the first whale and OT makes Piuminaq ready for deployment when suddenly the battery of the tag dies. We switch to using Arsarnerit instead. We get close 2 times but not close enough for deployment. The whale dives in cycles of 30 minutes and after 4 surfacings we loose the whale.

Sailing closer to Fortunabay. The wind has now calmed down. There are pieces of ice floating around but nothing that will prevent tagging. We spot two whales and approach one of them. It surfaces once and on the second surfacing after a slow and quiet pursuit (close to idling and for < 3 minutes) JM deploys Arsarnerit 1 at 12:11[1]. The tag is placed on the left side rear end (after the midline of the whale). The tagging occurs under the water so we get no proper pictures of the positioning of the tag (Fig 6). Biopsy is taken with the long dart on the pole.

Figure 6. Deployment of Arsarnerit 1. It stayed on for 21 minutes.

We stop the engines and Abel starts to listen for the VHF tag in case Arsarnerit has fallen off. OT makes acoustic recordings for 25 minutes from 12:30 to 12:55. There is fine bowhead whale singing. After ca. 25 minutes Abel picks up the VHF signal. We find the tag close by floating between small pieces of ice.

We are home at 15:30.

Tuesday 19.04.2016

We decide to remove the biopsy dart from the pole and instead use a crossbow to collect a biopsy. We depart at 11:00 and head east. We see one whale offshore of Kuannit but cannot get close to it. Tarfi is further east, scouting, and reports a calm and curious whale surfacing close to him over and over again. We sail to him and quickly find the whale. It is a smaller individual and swims just under the surface so that the tail prints are easy to see. It zigzags under the surface swimming parallel to the boat, we can see its eye through the water and it

[1] JM later tells that he used more force for this deployment then for the previous.

surfaces on its side showing its fin. In the end we get close enough to tag and JM places the tag on the left side of the whale, quite high on the back. The whale reacts to the tag by suddenly lifting its fluke under the boat and we hit it. We see the whale surfacing a few times further away and get a picture of the tag (Fig. 7). AB starts to listen to the VHF and can immediately hear that the tag has already fallen off.

Figure 7. Arsarnerit 2 on the whale. It stayed on only for 2 minutes.

The wind picks up and we start to sail towards home. We are at Oqqussaq at 17:30.

Wednesday 20.04.2016

We sail out at 9:00 from Oqqussaq harbour. We decide to use crossbows for collecting the biopsies instead of the long dart on the pole due to the fear that the long dart might be effecting the deployment of the Acousonde.

We head west towards Fortunabay but there is a southerly wind, which is getting stronger. Snow in the air is making visibility poor. Tarfi sees two whales but they disappear from us before we can get close. Also the dense drifting pack-ice is now moving towards Qeqertarsuaq and we are aware of the danger of getting blocked out. By 11:30 we have almost given up and are sailing home but decide to try to the southeast. Suddenly the wind dies down and we have absolutely flat water between strips of drift ice. We spot three whales but none of them can be approached. They surface for only one or two blows.

We are home at 16:30.

Thursday 21.04.2016

Storm with easterly wind. No sailing today.

Friday 22.04.2016

Too strong southerly wind. No sailing today.

Saturday 23.04.2016

Heavy snowfall. No sailing today.

Sunday 24.04.2016

Departure at 8:00. There is a light southerly wind so we sail east. The first whale is spotted outside Kuannit. We stay with it but never get close enough for tagging and finally we loose it. The second whale is seen further east but it is swimming away and disappears from us. Outside Siniffik we make acoustic recordings for 30 minutes and hear bowhead whale singing in the distance.

JM spots a pair of whales further offshore (about 7 nm from land). While approaching them AB and JM see a whale breaching 3 times in the distance. In addition, one whale is tail-slapping. The pair of whales is swimming fast and changing directions while at the surface – we can´t get close enough. The third whale accompanying the pair swims like "Tarfi´s whale" from the other day – moving fast just under the surface, we follow the fluke prints and get close a few times but never close enough.

We head home at 16:30 and sail home in rain.

Monday 25.04.2016

Three boats are out. Tarfi scouting into Laksebugten for approximately 1,5 hours, but sees no whales.
South of Fortuna bay a whale is seen close by and the animal is behaving calmly. The tag boat idles and drifts toward the whale and the suction cup tag Arsarnerit 3 is mounted on the left side of the animal 25-50 cm from the dorsal line and a little more than half way down the length of the whale. A biopsy is taken with a cross bow a few seconds later before the whale has reacted to the tag. Then the whale arches its back and dives. Reaction to deployment and biopsy is moderate to low. Biopsy is recovered at once. The tag is found on the surface after 20 min. See Figure 8.

Some more whales are spotted in the distance towards Kronprinsen but all of them are too far. After an hour of moving slowly around in the same area we register at least 3 whales within a radius of 3 nm and we start to follow one at low pace. The animal in focus keeps on evading us, doing shallow dives making flukeprints on the surface that enable us to keep track of it. We keep following but not intercepting the whale, traveling on parallel courses a little behind the animal. After almost one hour we manage to get the tag (Piuminaq2) and a biopsy at the same moment, but the whale is still evasive and the biopsy and tagging take place while the animal is moving quite a lot. As a consequence, the tag detaches immediately. Biopsy is recovered at once. After total of 5-6 hours we return to Qeqertarsuaq due to increasing wind.

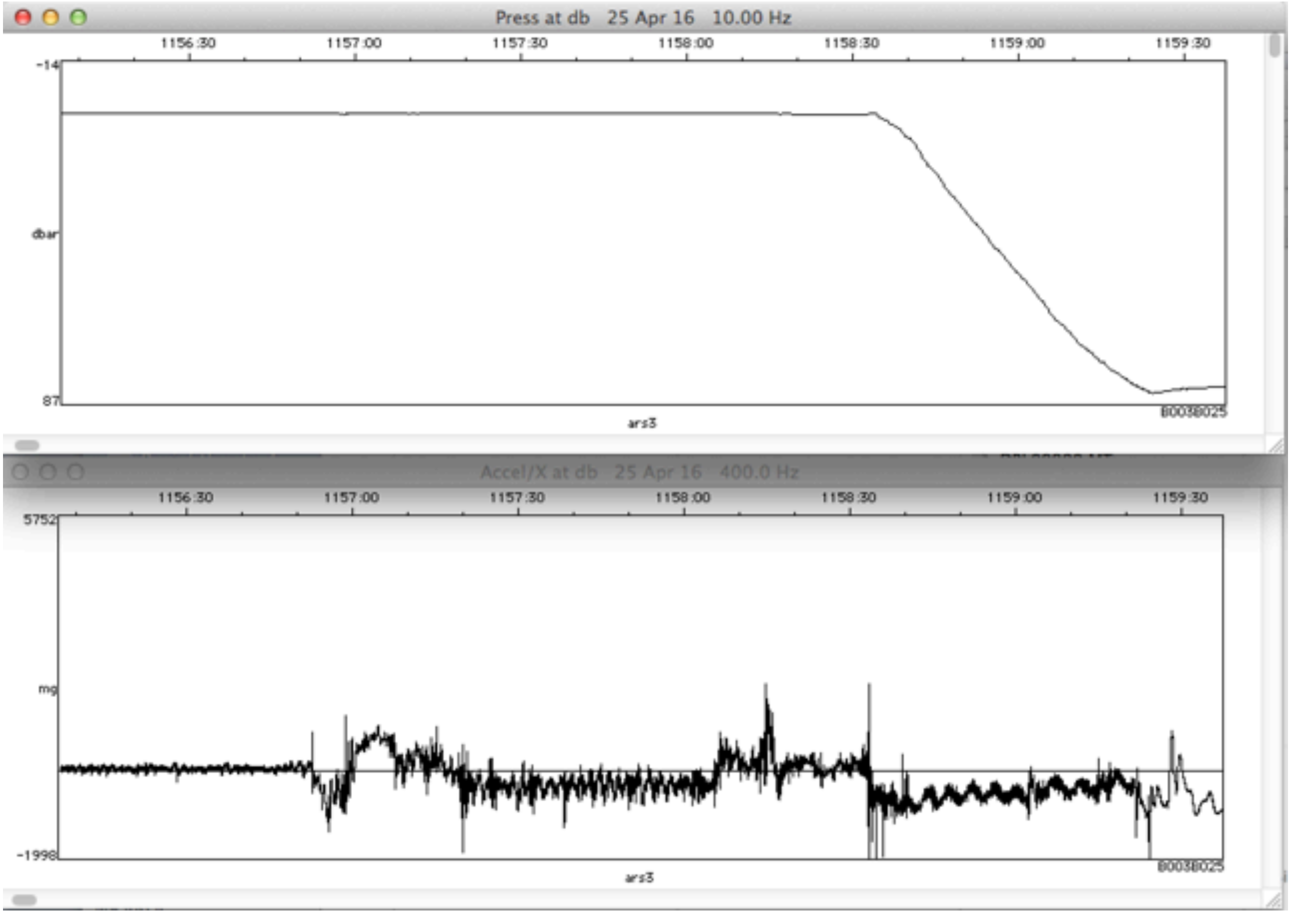


Figure 8. Record of Ars3. The tag dislodged at 84 m depth 1 minute after attachment.

Tuesday 26.04.2016

Departure at 10:00. We sail west towards Fortunabay. There are two whales in the area but they are reacting to us by surfacing only shortly and swimming away. We make acoustic recordings but hear no whale song at all.

We decide to sail east in order to see if we can find some calmer whales. Making new recordings offshore Skarvefjeld and record again bowhead whale singing. We spot no whales.

Back at the harbour at 18:00.

Wednesday 27.04.2016

Windy day but the weather forecast is promising calm weather for the evening. We depart at 18:00 and sail towards the east because the hunters have heard about bowhead whales outside Mudderbugten. After Skarvefjelden the sea is completely flat. The first whale is spotted between Brededalen and Siniffik. It is a large individual, calm and curious and approaches us. We had talked about loosening the grip of the blue “hand” that holds the Acousonde in order not to pull the tag off the whale after deployment. It turned out that the hand was slightly too loose and the tag falls off the pole before JM manages to attach it to the whale. We see the whale once more in the distance but then it disappears and we never get a second chance.

We sail further east and stop outside Tuappat to make recordings without seeing any whales – there is whale song. Using an iceberg as a shield at Skansen (length 120 m, height 20-30 m, grounded) and making recordings west of it, we conclude that there are singing whales west of Skansen.

We are at the harbour at 00:30.

Thursday 28.4.2016

Thick fog with almost no visibility so no sailing.

Friday 29.4.2016

Foggy morning, no wind – we depart at 11:00. There is a northerly wind west of Disko so we sail east. First whale offshore between Skarvfjeld and Siniffik. It is calm and approaches us, JM puts the tag on but it falls off immediately. The blue hand on the pole had twisted and the suction cups never made contact with the whale. We try again but the whale is aware of us now and we don't get a second chance.

We spot 4 whales further east but they spend only little time at the surface and we cannot get close enough in order to tag (we are still using the calm approach method).

MPHJ and SB arrive at the Arctic Station. They had seen 4 whales from the helicopter between Ilulissat and Qeqertarsuaq.

We are back at the harbour at 20:30.

Saturday 30.4.2016

Meeting with the hunters. Decision made about using the spear attachment from now on.

Sunday 1.5.2016

Dept. 12:00. Several whales (some breeching at a distance) about 30 min. from harbour – at least 5 seen. Chasing two but we gave up due to swell from the north. Moved east and found another whale in calmer water. Chased it 4-5 times. We gave up on the slow approach method and decided to go for the cowboy-method; i.e., sailing fast towards the whale and tiring them. First approach on this whale gave a left side touch but the biopsy tip and its holder were too long and caused the Acousonde to get bent to the side (Figs. 9 and 10). Fortunately the Acousonde is secured with yarn (Fig. 11) that prevents it from slipping off the blue grip before it is deployed and thereby falling in the water where it will go to the bottom because of the heavy spear attachment device.

The biopsy tip got a skin sample of the whale; we decide to remove the biopsy tip for the 2nd approach, which was successful. The tag was placed on the left side below the water line and behind the middle of the whale (Fig. 12). The Acousonde is pointing forward and a 3rd approach gave a series of photos that document the deployment. The blue grip got bent and it got a small cut in the blue material, nothing serious but we decided to remove the biopsy tip holder as well to avoid conflict with the Acousonde grip.

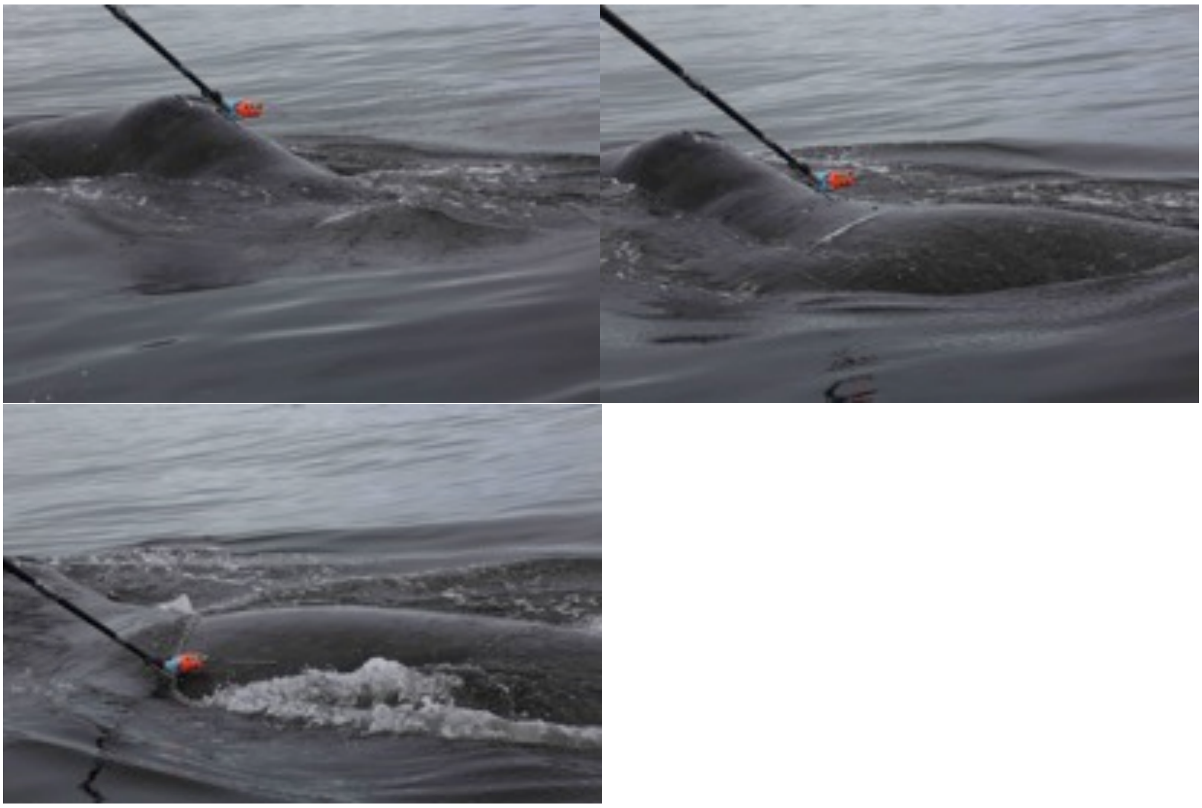


Figure 9. Low-quality picture series of the deployment on Arsarnerit 4 with the biopsy tip and holder in conflict with Acousonde.

Figure 10. Low-quality enlargement of the photo of the deployment where the biopsy tip pushes off the Acousonde on Arsarnerit 4.

Figure 11. Low-quality picture of the Acousonde secured with yarn around the blue grip.

It is likely that the failed deployments with the suction cups are at least in part due to the conflict with the biopsy tip/holder.

MP recommendation: Either don't use the biopsy tip with the Acousonde or make sure that it is in line with or below the main body of the Acousonde. The flip side is that you then may need to chase the whale one more time to get the biopsy with a crossbow.

Figure 12. Low-quality picture of the 1st spear-mounted deployment of Arsarnerit 4 on 1 May 2016.

After this first deployment with the spear-mounted Acousonde we decided – after inspection of the photos – to try another deployment with the other Acousonde.

We chased two whales and got a chance on the second one; we made a left deployment low and in behind the mid line. In order to get a biopsy of the whale we had to make post-deployment approach and use the crossbow (Fig. 13).

Figure 13. Acousonde on Piuminaq 3 on 1 May 2016. Note the biopsy dart in front of the tag.

Return to town at 20:00 after 8 hrs at sea.

Monday 2.5.2016

Sporadic non-positioning signals received from both tags during the night.
The mallards arrived today and they walk around on the ice on the lake in front of the station.
Arsarnerit 4 came off this morning and was picked up in the afternoon. It looked unharmed aside from very minor scratches.

Tuesday 3.5.2016

No news from Piuminaq 3, which is presumably/hopefully still on the whale.

The data from Arsarnerit 4 revealed a deployment of 18 hrs (Table 2). The whale performed shallow dives down to appr. 30 m. There is bowhead whale singing in the background but so far no vocalising by the tagged individual.

Other guests at the Arctic Station saw 8 whales from the helicopter including a juvenile.

Bowhead whale is spotted outside Arctic Station at 13:30.

Wednesday 4.5.2016

We decide not to make any further deployments until Piuminaq has appeared again – this despite good weather conditions and frequent sightings of bowhead whales.

Thursday 6.5.2016

Waiting for Argos signals from Piuminaq. OT and MFC work on the Qaqqaliaq listening station.

Friday 7.5.2016

Waiting for Argos signals from Piuminaq. OT and MFC make recordings off Qaqqaliaq.

Saturday 7.5.2016

Organisation of biopsy samples. Party for Suulut who has a 50-yr anniversary in government service.
Waiting for Argos signals from Piuminaq.

Sunday 8.5.2016

Outi leaves for Denmark. Rain and snow all day. Waiting for Argos signals from Piuminaq.

Monday 9.5.2016

Meeting with the hunters and packing of equipment.

Calm weather all day.

At 20:00 we got positions from Piuminaq in the area where the whale was tagged. At 21:00 three boats went out to pick it up. They heard the signals from the VHF transmitter from about 6 nmi and they had an easy time locating it. The tag still had the attachment hook from the Mg-bolt and it had a couple of amphipods or similar small bottom crustaceans attached to it, but there was otherwise nothing unusual about the tag.

There was plenty of bowhead whales in the area with the tag.

Tuesday 10.5.2016

Twelve hours of downloading of data from Piuminaq 3; the tag was still collecting acoustic data (25 kHz sampling rate) after nine days, but only 3 days of auxiliary data were obtained due to the high sampling rate of the accelerometer (see Table 1). Apparently the tag came off while the whale was at the surface, 15 hours after tagging, and went straight to the bottom (~450 m) where it stayed until it appeared on the surface on May 9.
The 15 hrs of data collection provide useful acoustic and accelerometer data from the whale, that are yet to be analysed.

Wednesday 11.5.2016

Packing and copying of data. Sunny, bright and calm day with 10 bowheads visible from the station.

Thursday 12.5.2016
SB and MP were supposed to return to Copenhagen today but the helicopter was cancelled due to fog.

Friday 13.5.2016

Helicopter cancelled again today. Fog and low ceiling. Next chance for departure is Sunday by ferry.

Saturday 14.5.2016

About 6-7 bowheads right outside the station.

Sunday 15.5.2016

Sunny calm day with 7+ bowheads outside the station. Ferry dept. at 15.15 and 20-30 bowheads observed <3 nmi from Disko Island. Arrival at Ilulissat 23.15.

Monday 16.5.2016

SB and MPHJ return to Cph.

CONCLUSION

The two long and some short deployments provided high quality data for estimating the flow noise. The obtained recordings are of both adequate quality and duration for the software development for the SLAR.

Examination of the recordings will reveal if any calls were recorded. Distant singing was heard on the Arsarnerit 4 recording.

Very much new information on tagging methods was gained during this field effort.

- Suction cup deployments are apparently not a very reliable way of tagging bowhead whales.
- Great care should be taken when mounting the biopsy tip on the pole as it may be in the way of the tag and could have caused some failed deployments.
- The spear mount technique performed as expected and provided deployments on the whales of good length and quality.
- When tagging in deep water (>50 m), we recommend adding extra floatation to make sure the tag has sufficient buoyancy to return to the surface if it drops to the bottom with the spear mount.
- A white staining of the antenna on the VHF transmitter may improve the chances for retrieving the tag.
- If the high-speed accelerometer setting is used there is no point in doing deployments that last for more than 3 days.
- When on a whale, the Mg links seem to always corrode faster than their rating predicts, thus a 2-day bolt may only be good for 1 day etc.

Table 1. Tag settings. Satellite tag is set to send 1) 200 transmission per day, 2) all hours and 3) all days in April and May.

Instrument		**Sampling rate**				**Deployment method**	
Acousonde ID/name	**Satellite tag/VHF**	**Acoustics (Hz)**	**Aux**	**Gain (db)**	**File size (Mb)**	**First**	**Second**
024/ Piuminaq	# 7929/ 155.125	25811 (fc 9292)	20/ 400	0	100	Thin kevlar (red) with type 8 knots, suction cup	Double spear mount
025/ Arsarnerit	# 7928 /154.337 /155.355[1)]	25811 (fc 9292)	20/ 400	0	100	Thick kevlar (purple stripy) with metal talorites, suction cup	Double spear mount

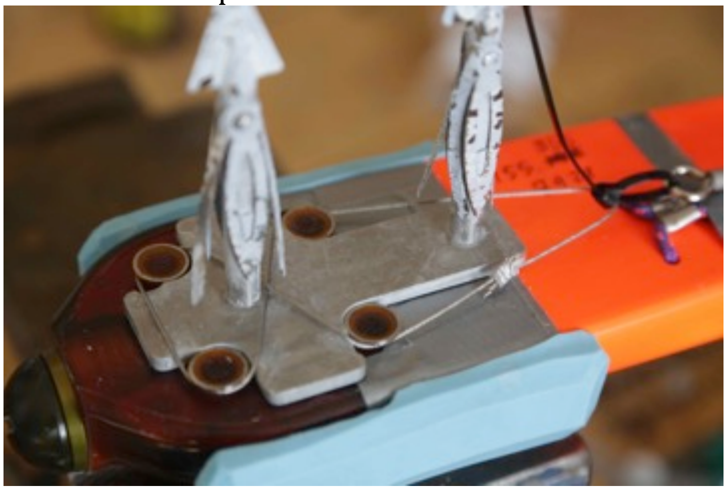
1) Ten days usage.

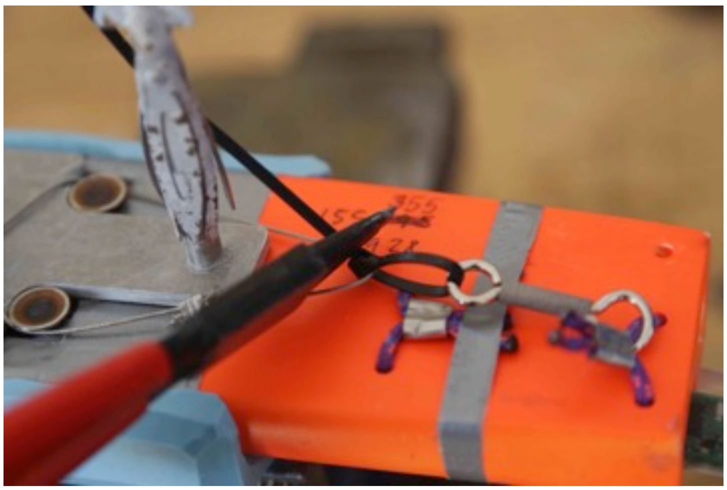
Table 2. Deployment data. SC = suction cup, SM = spear mounted

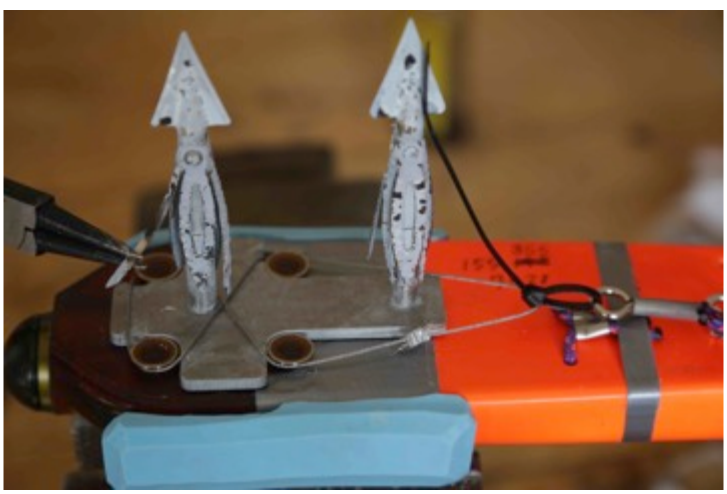
Deploy-ment #	**Acousonde ID/name**	**Satellite tag/VHF**	**Date**	**Start of deploy-ment**	**Mg bolt**	**Biop-sy #**	**GPS pos**	**End of deploy-ment**	**GPS pos**	**Duration of deploy-ment**
Piu1 SC	024/ Piuminaq	# 7929/ 155.125	160414	14:58	-	740	69 13 069 53 32 865	15:07		00:09 min
Ars1 SC	025/ Arsarnerit	# 7928 /154.337	160418	12:11	-	741	69 14 129 53 50 720	12:32		00:21 min
Ars2 SC	025/ Arsarnerit	# 7928 /154.337	160419	15.58	-	742		16:00		00:02 min
Ars3 SC	025/ Arsarnerit	# 7928 /154.337	160425	11:58	-	743	69 14 345 53 46 769	11:59		00:01 min
Piu2 SC	024/ Piuminaq	# 7929/ 155.125	160425	?	-	744	69 13 22 53 42 600	?		
Ars4 SM	025/ Arsarnerit	# 7928 /154.355[1)]	010516	15:23	2 ds	745	69 14 411 53 07 967	020516	69 16 817 52 40 817	18:30 hrs
Piu3 SM	024/ Piuminaq	# 7929/ 155.125	010516	18:55	2 ds	746	69 14 714 53 00 450	090516	69 17 500 52 41 950	15 hrs

[1)] Ten days usage

Attachment of spear mount on the Acousonde:







Storage at Arktisk Station

3 functioning poles
7 deployment cups for SWING SPLASH
3 deployment cups for Mk10
2 deployment cups for mini SWING SPLASH
2 deployment cups for SPOT5
8-10 biopsi tips
2 tubes for poles (gråt lille rør)
15 darts
8 crossbows plus extra bow wire
3 dl DMSO and salt

MP's Baffin Boots
Susanna's Baffin Boots
Mikkel's Baffin Boots
MP's Mustang Suit
Misc. boots

Appendix N.

Dive behavior of bowhead whales within the Cape Bathurst polynya.

Citta, John J., Lori T. Quakenbush, Steven R. Okkonen, Matthew L. Druckenmiller, Lois A. Harwood, John "Craig" George, and Mads Peter Heide-Jørgensen

Each spring, the majority of bowhead whales (*Balaena mysticetus*) of the Bering-Chukchi-Beaufort (BCB) stock leave their wintering grounds in the Bering Sea and migrate northeast towards the Canadian Arctic. Satellite tagging studies indicate that most of these whales migrate to the Cape Bathurst polynya within the entrance of Amundsen Gulf, Canada. These whales leave the Bering Sea prior to the spring ice retreat in April and May, shortly before the Bering Sea becomes one of the most productive seas in the world, and it is unknown if foraging conditions in May and June are better for whales at their destination within the Cape Bathurst polynya than if they had remained within the Bering Sea. Although we know that satellite tagged whales migrate to the Cape Bathurst polynya, the diving behavior of whales within the polynya has yet to be formally examined. Here we examine the diving behavior of 17 bowhead whales tagged with satellite-linked transmitters between 2008 and 2015. To allow us to comment on the likelihood that whales are feeding within the polynya each spring, we characterize the dive behavior of these whales, summarizing dive depths, the time whales spend at depth, and the frequency of diving, both within the polynya and under adjacent sea ice. We also use paired measurements of depth and temperature for two tags (1 in 2014 and 1 in 2016) to describe the water masses whales frequent.

Alaska Marine Science Symposium, 25–29 January, Anchorage, Alaska (Abstract)

Appendix N.

Dive behavior of bowhead whales in the Cape Bathurst Polynya in spring

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Stephen R. Okkonen, University of Alaska, Fairbanks, Alaska
Matthew Druckenmiller, National Snow and Ice Data Center, Boulder, Colorado
John C. George, North Slope Borough Wildlife Department, Barrow, Alaska
Robert J. Small, Alaska Dept. of Fish and Game, Juneau, Alaska
Ellen Lea, Department of Fisheries and Oceans, Inuvik, NWT, Canada
Mads Peter Heide-Jorgensen, Greenland Institute of Natural Resources, Copenhagen, Denmark
Harry Brower, North Slope Borough Wildlife Department, Barrow, Alaska

Background

Each spring, the majority of bowhead whales (*Balaena mysticetus*) of the Bering-Chukchi-Beaufort (BCB) stock leave their wintering grounds in the Bering Sea and migrate northeast towards the Cape Bathurst Polynya in the eastern Beaufort Sea (Fig. 1). These whales leave the Bering Sea prior to the spring ice retreat in April and May[1], shortly before the Bering Sea becomes one of the most productive seas in the world.[2] The polynya is maintained by winds and the wind-driven upwelling of warm water.[3,4] Within the polynya, the spring bloom begins in May[4] when copepods are expected to exit diapause and rise to the surface to feed on phytoplankton, potentially providing bowhead whales with foraging opportunities. Here, we present a preliminary examination of the dive behavior of 16 whales within the polynya during May and June, 2008-2016 (Figs. 3 and 4).

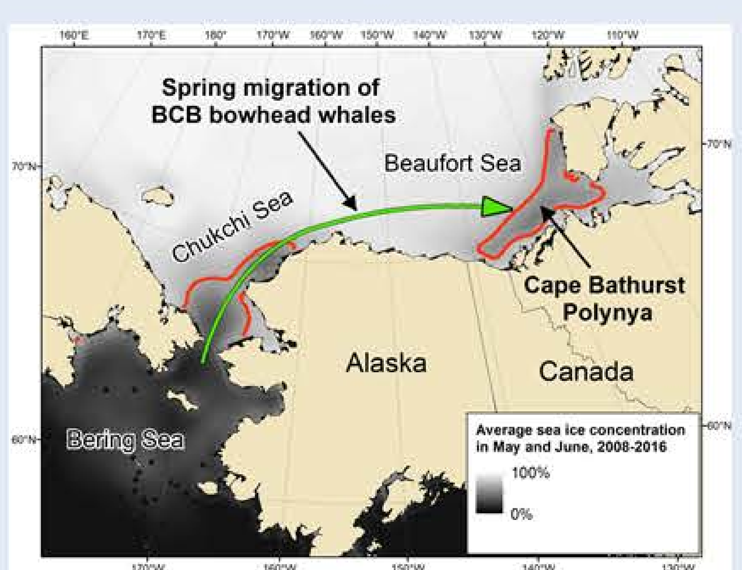

Figure 1. Location of the Cape Bathurst Polynya.

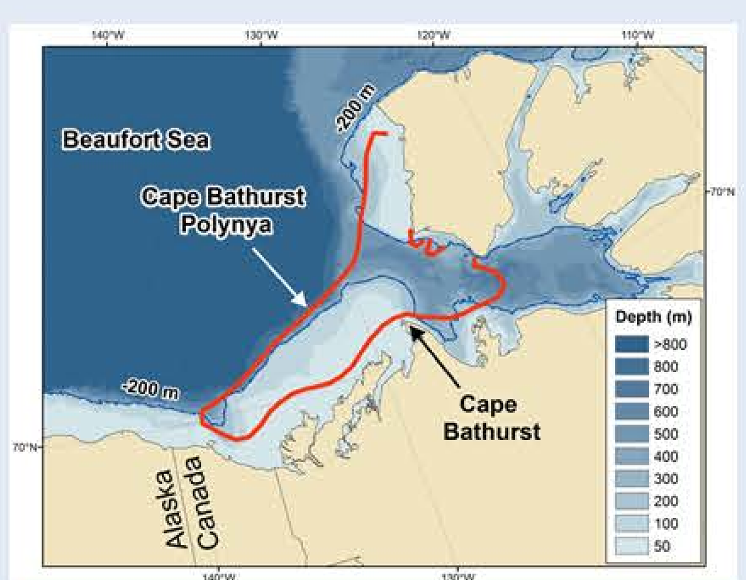

Figure 2. Depth within the Cape Bathurst Polynya. Approximately 63% of the polynya is composed of shelf habitat < 200 m depth.

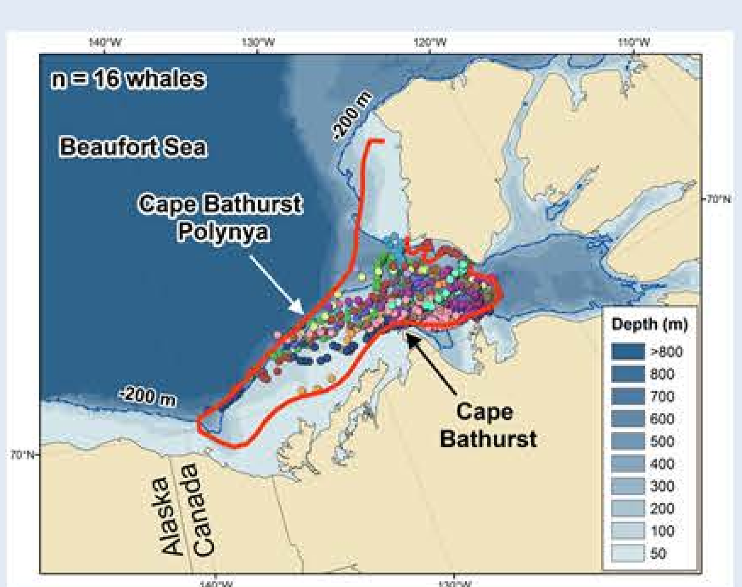

Figure 3. Locations (n=1,062) where dive data were collected from bowhead whales (n=16) within the Cape Bathurst Polynya, May and June, 2008-2016.

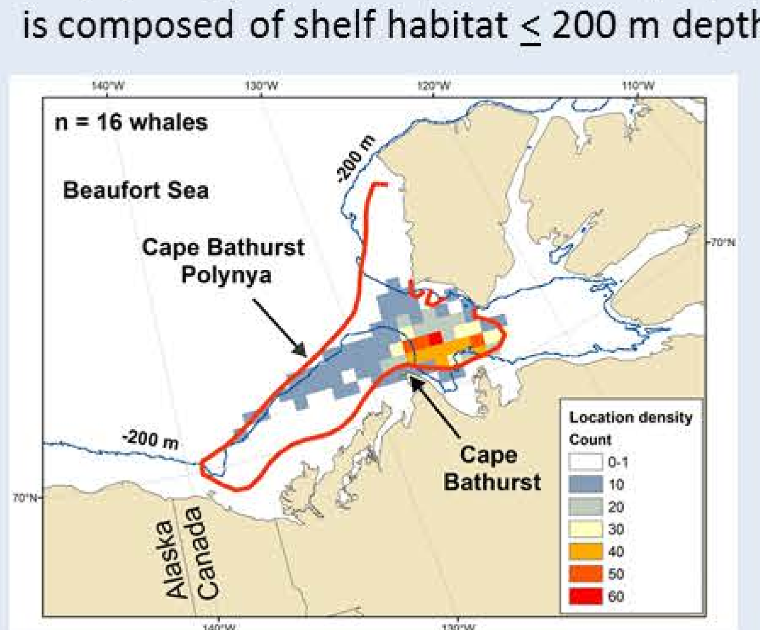

Figure 4. Density of dive locations within the Cape Bathurst Polynya.

Results

1. All 16 tags recorded the percentage of time spent within depth categories. Whales typically spent the most time within 100 m of the surface (Fig. 5, left). However, whales sometimes spent large amounts of time at many depths. For example, B10-14, an immature male, spent 80% of a 6-hr interval (4.8 hours) at 300 m (Fig. 5, right).

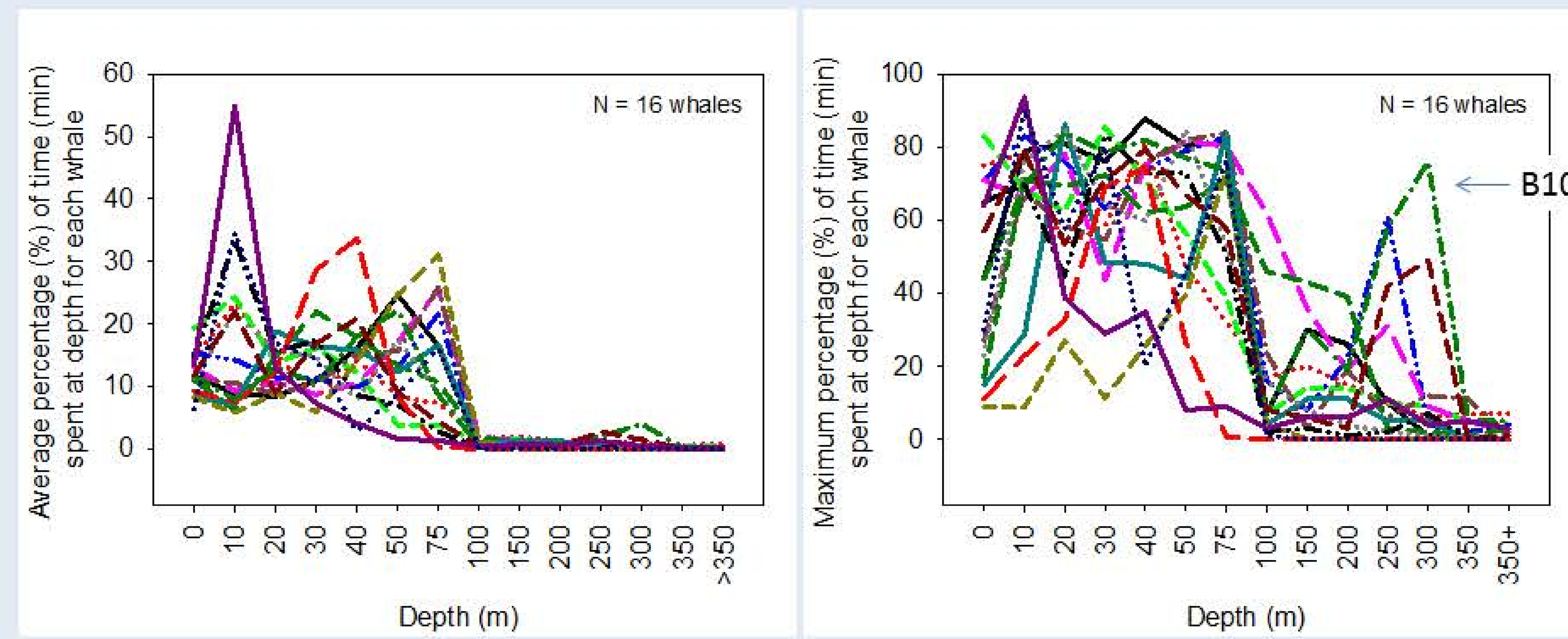

Figure 5. Average amount of time (left) and maximum about of time (right) spent in depth categories during 6-hr periods. Each line represents one whale.

2. Two tags were capable of recording detailed data on the duration and shape of dives, along with paired readings of depth and temperature. Within the polynya, most dives are square-shaped. Dives are classified as square-shaped when a whale remains near the bottom of a dive for >50% of the dive's duration, as opposed to 20-50% in U-shaped dives, and < 20% in V-shaped dives. (Table 1).

Table 1. Percentage of dives in each shape category.

Depth	Square-shaped	U-shaped	V-shaped	Total # dives
oceanic (>200 m)	56%	19%	14%	518
shelf (<200m)	5%	4%	2%	65
Total # dives	359	131	93	583

3. Bowhead whales rarely (~5%) dove to the seafloor. The large majority of dives to the seafloor were over the shelf, and very rarely at oceanic depths.(Table 2).

Table 2. Percentage of dives reaching the seafloor.

Depth	Square-shaped	U-shaped	V-shaped	Total
oceanic (>200 m)	1%	2%	1%	1%
shelf (<200m)	19%	48%	36%	32%
Total # dives	10	13	5	28

4. Representative depth-temperature profiles from 2013 and 2016 (Fig. 6) indicate that whales spend the most time in cold water of Pacific origin (i.e., Pacific Water; PW) and in the thermocline/halocline overlying warm (>~0 C) Atlantic Water (AW).

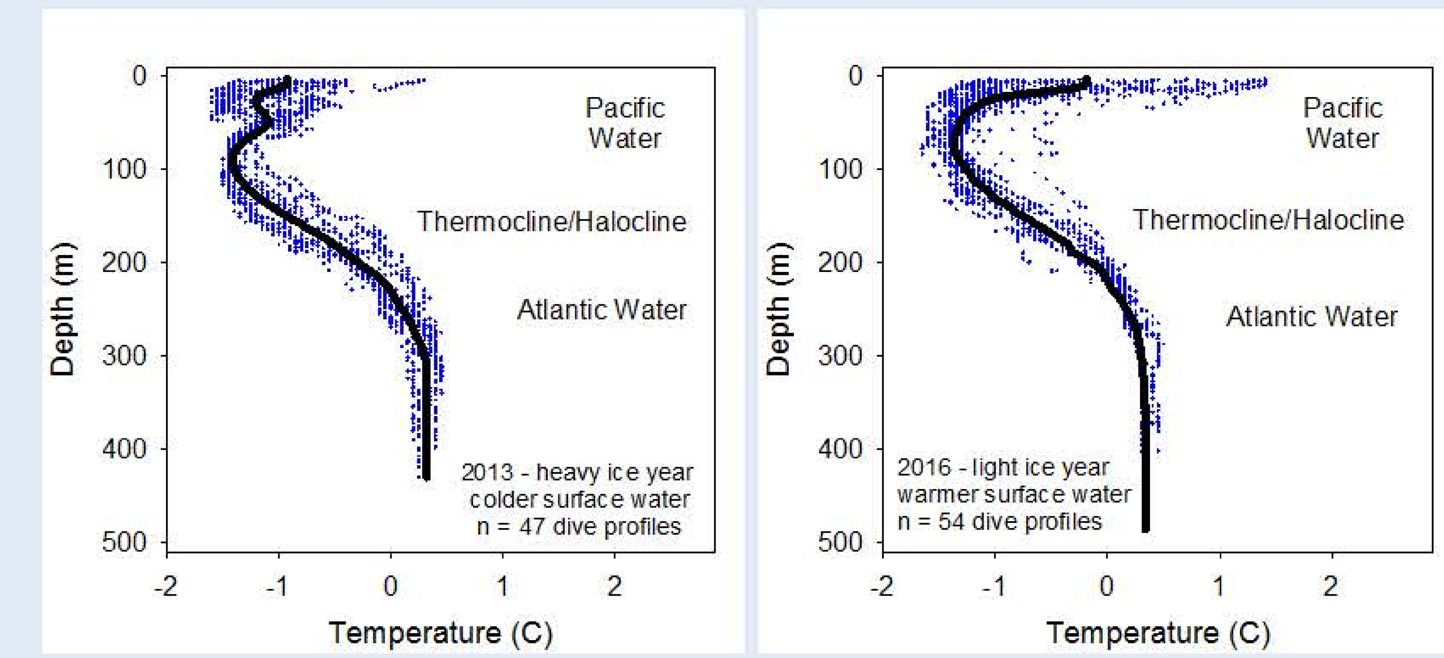

Figure 6. Depth (m) and temperature (C) profiles sampled by one whale in 2013 (left) and one whale in 2016 (right). Dots are depth and temperature values and the solid lines are smoothed fits to the pooled data.

Conclusions

1. Most dives are square-shaped and are likely indicative of feeding. Also, if a whale is spending 50-80% of its time at a particular depth, it is probably feeding there.
2. Most use of the polynya is within the deeper oceanic habitats (89%) and not shallow shelf waters (11%). Whales rarely dive to the seafloor within the polynya, and such dives are predominately over the shelf.
3. Whales are predominantly spending time in cold water of Pacific origin, but sometimes spend significant amounts of time within the thermocline/halocline above warmer Atlantic water.

Acknowledgements

This cooperative project involved contributions and hard work from many organizations, agencies, and individuals, including the following: Alaska Eskimo Whaling Commission, North Slope Borough (Billy Adams, Robert Suydam, and Taqulik Hepa), Barrow and Kaktovik Whaling Captain's Associations (Eugene Brower, Fenton Rexford, Joe Kaleak, George Tagarook, and Eddie Arey), Barrow Arctic Science Consortium (Lewis Brower), Aklavik and Tuktoyaktuk Hunters and Trappers Committees (Dennis Arey, Larry Arey, Pat Kasook, Buddy Gruben, Douglas Panaktalok, Mikkel Panaktalok, Max Kotokak, Sr., Charles Pokiak, and James Pokiak), Department of Fisheries and Oceans Canada (DFO) (Kevin Bill, Tim Leblanc, Patrick Ryan, Terry Stein, Angus Alunik), and the Greenland Institute of Natural Resources (Mikkel and Anders Jensen). Funding for this research was mainly provided by U.S. Minerals Management Service (now Bureau of Ocean Energy Management). Additional funds were provided by the Division of Fisheries and Oceans, Canada.

Bowhead whale research has been conducted in the U.S. under a Marine Mammal Protection Act permit issued to National Marine Fisheries Service (No. 782-1719) and to the Alaska Department of Fish and Game (No. 14610) and under Animal Care and Use permit Nos. 06-16, 09-21, 10-13R, 12-020. In Canada, research was conducted under Department of Fisheries and Oceans Scientific License No. S-07/08-4007-IN, S-08/09-4000-IN, S-09/10-4005-IN-A1 and Animal Care Protocols FWI-ACC-2007-2008-013 and FWI-ACC-2008-031, and FWI-ACC-2009-019.

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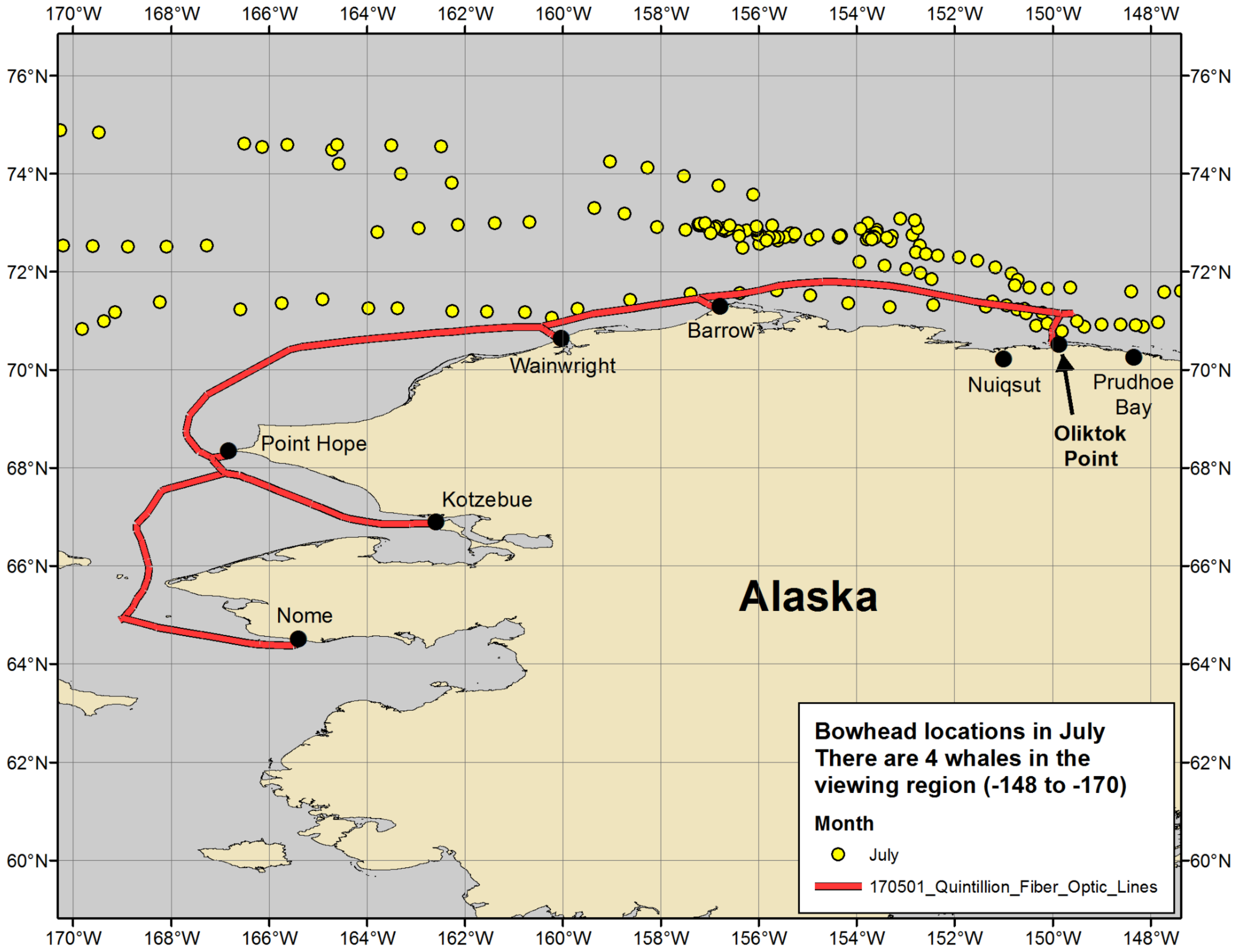
4. Arrigo and van Dijken. 2004. Geophysical Research Letters 31, L08304.

Appendix O.



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Nome
Alaska
Bowhead locations in July
There are 4 whales in the viewing region (-148 to -170)
Month
July
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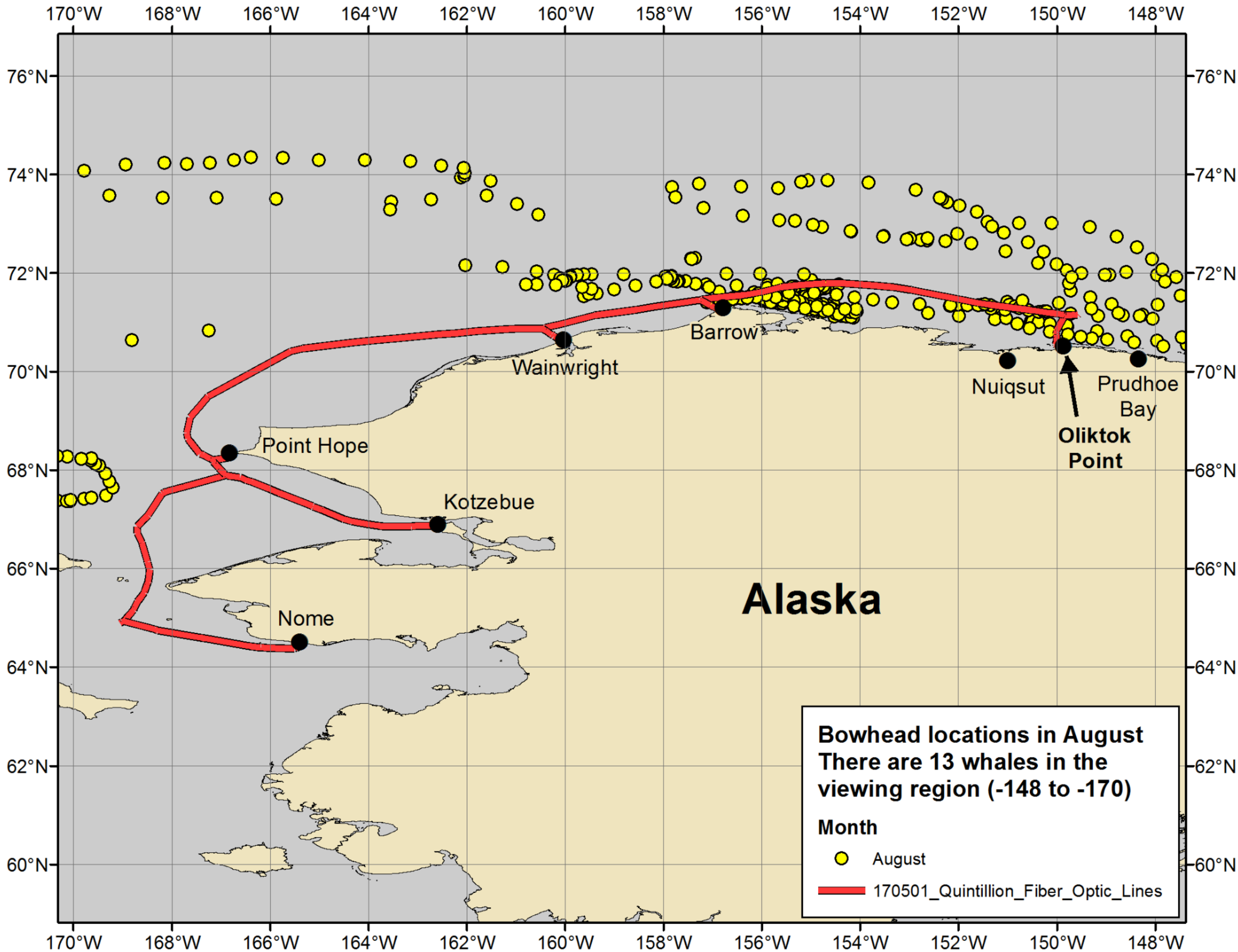

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Bowhead locations in August
There are 13 whales in the viewing region (-148 to -170)
Month
August
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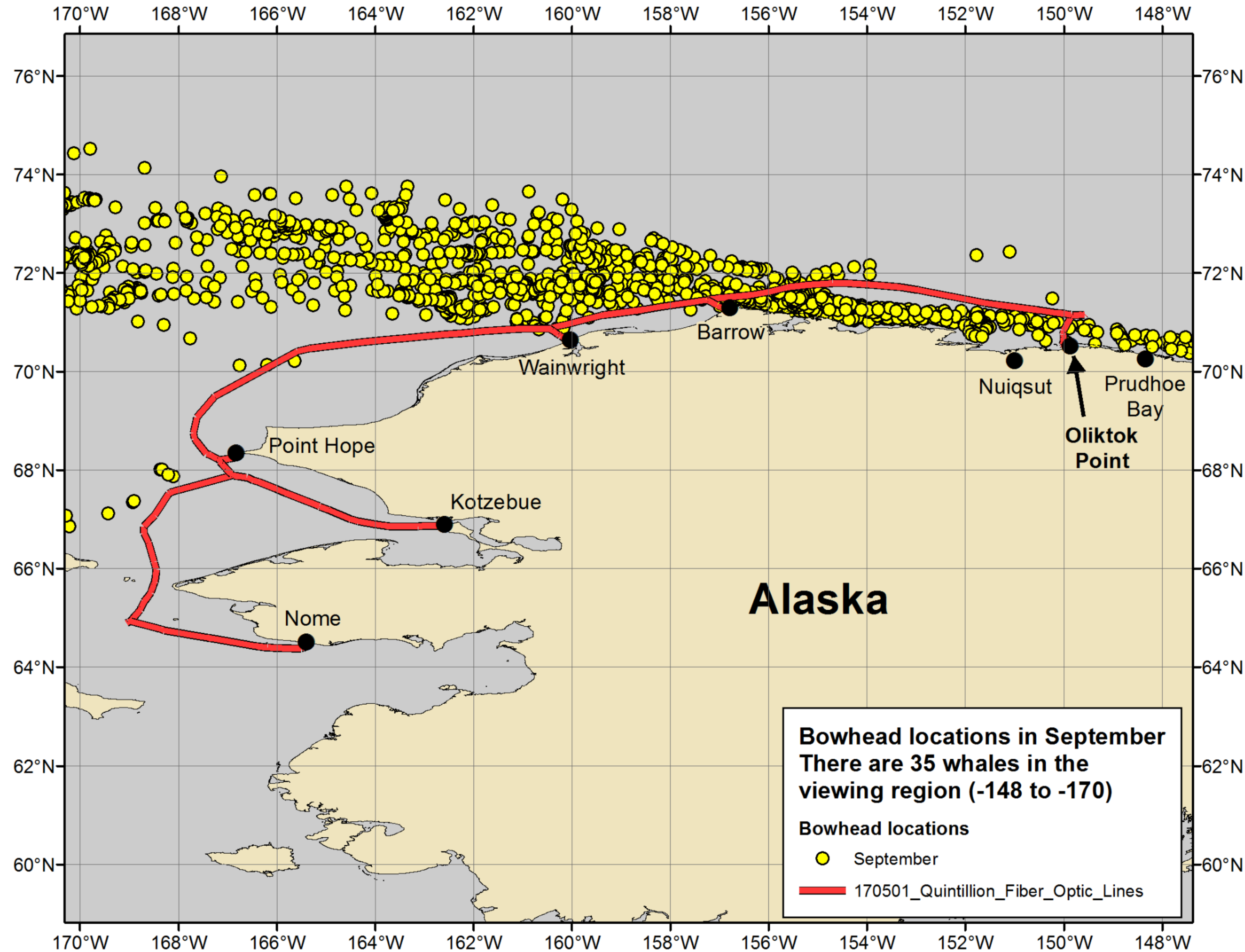

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Point Hope
Kotzebue
Nome
Alaska
Bowhead locations in September
There are 35 whales in the viewing region (-148 to -170)
Bowhead locations
September
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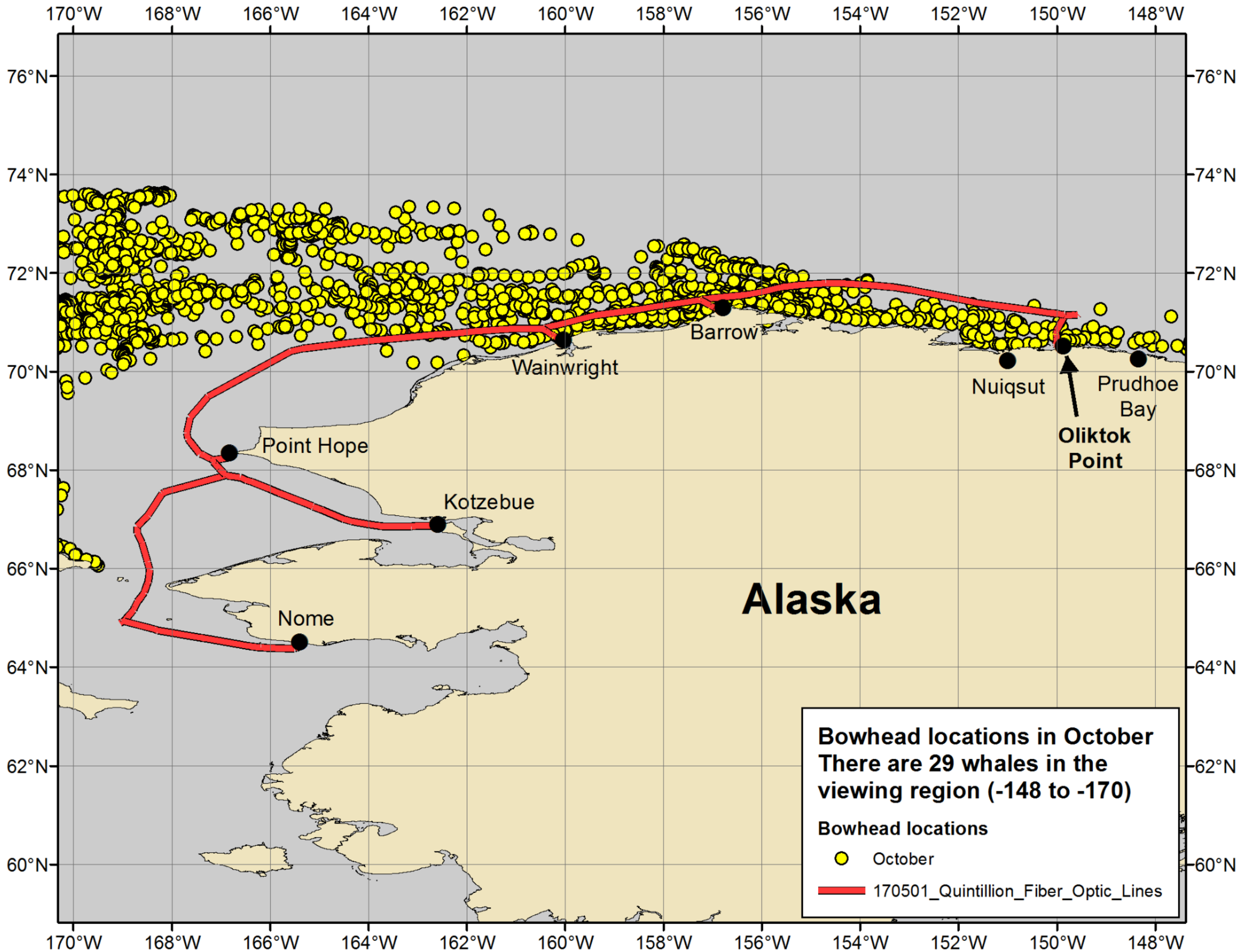

Bowhead locations in October
There are 29 whales in the viewing region (-148 to -170)
Bowhead locations
October
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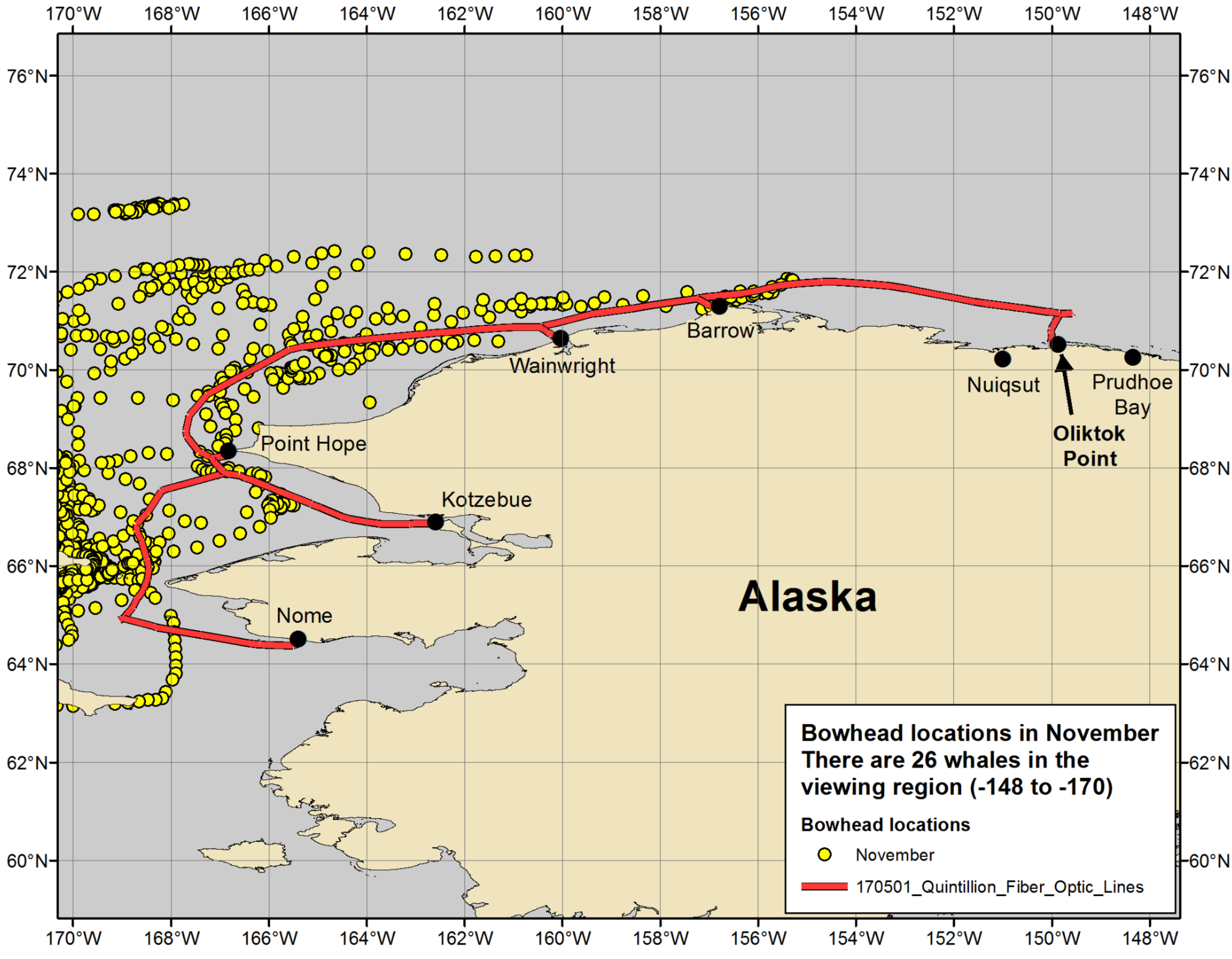

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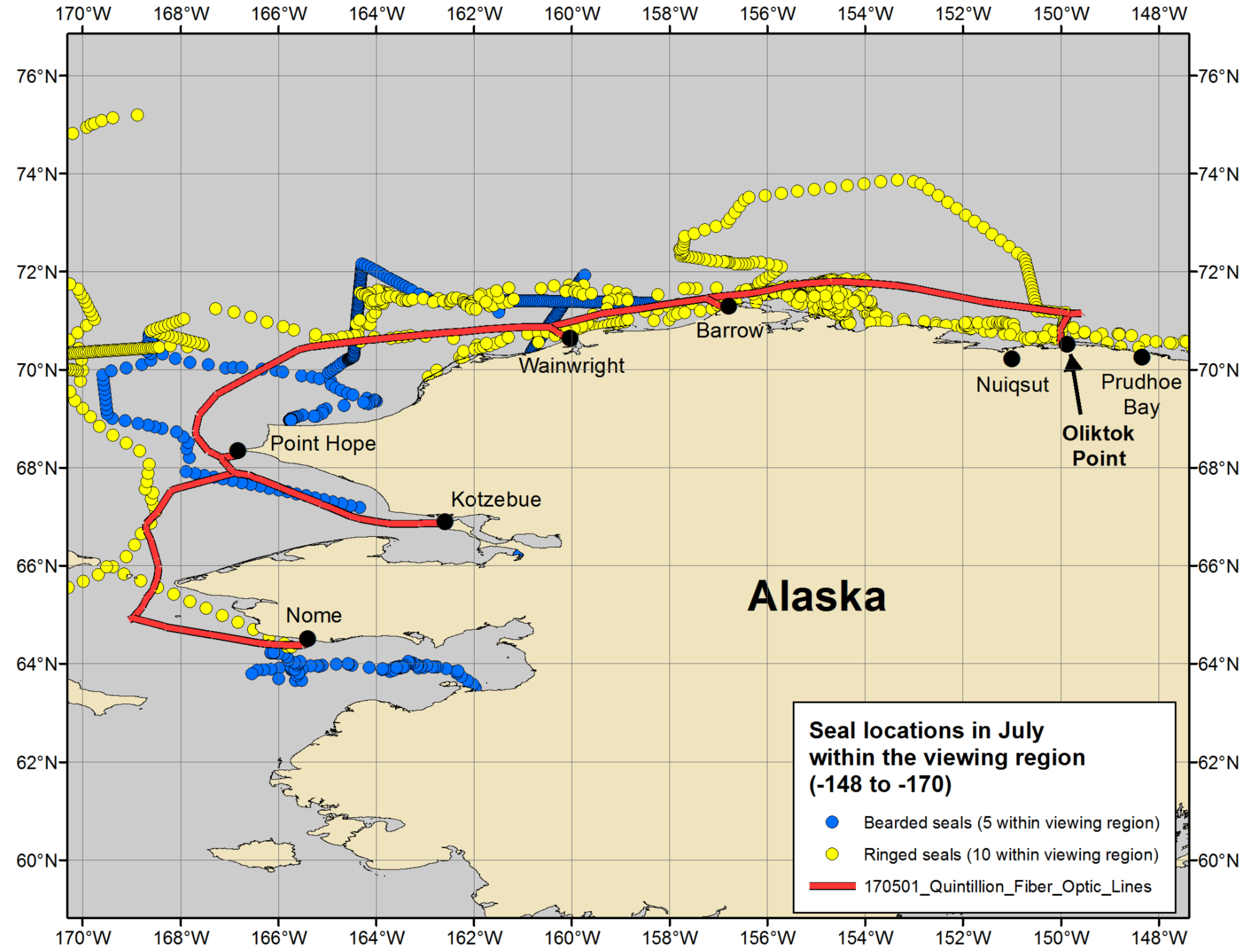
Prudhoe Bay
Oliktok Point
Point Hope
Kotzebue
Nome
Alaska
Bowhead locations in November
There are 26 whales in the viewing region (-148 to -170)
Bowhead locations
November
170501_Quintillion_Fiber_Optic_Lines



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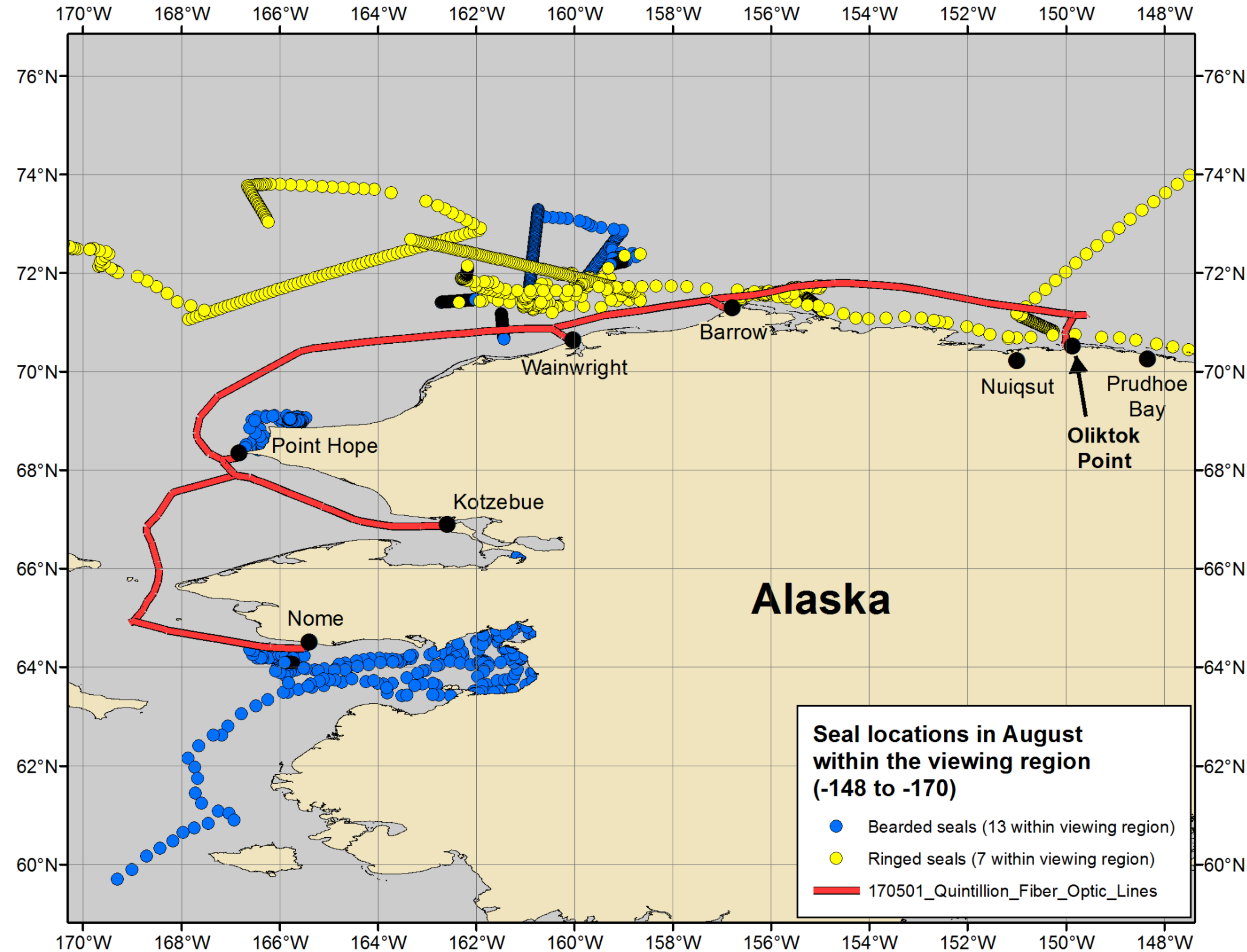
Prudhoe Bay
Oliktok Point
Point Hope
Kotzebue
Nome
Alaska
Seal locations in July within the viewing region (-148 to -170)
Bearded seals (5 within viewing region)
Ringed seals (10 within viewing region)
170501_Quintillion_Fiber_Optic_Lines



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Prudhoe Bay
Oliktok Point
Point Hope
Kotzebue
Nome
Alaska
Seal locations in August within the viewing region (-148 to -170)
Bearded seals (13 within viewing region)
Ringed seals (7 within viewing region)
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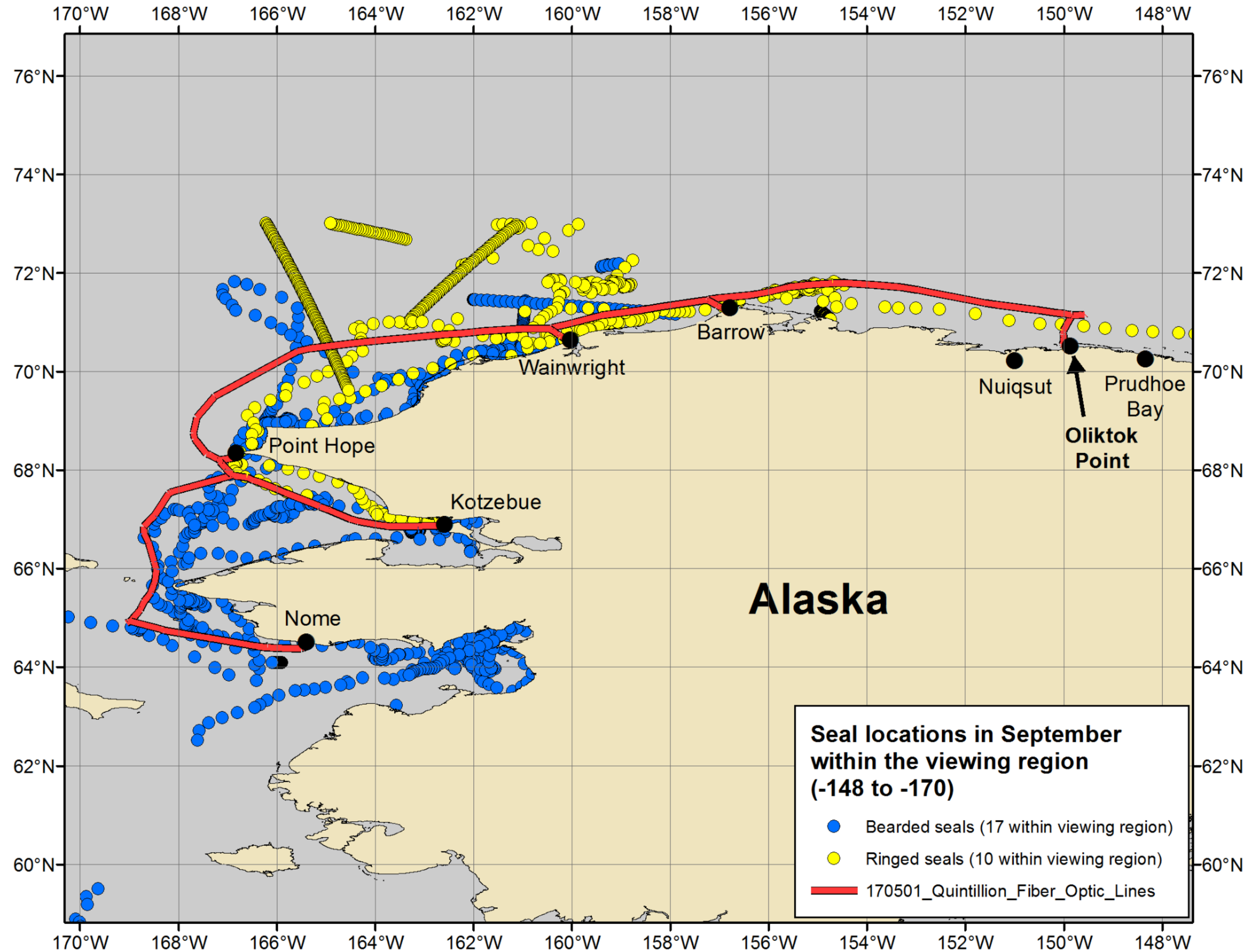
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Prudhoe Bay
Oliktok Point
Point Hope
Kotzebue
Nome
Alaska
Seal locations in September within the viewing region (-148 to -170)
Bearded seals (17 within viewing region)
Ringed seals (10 within viewing region)
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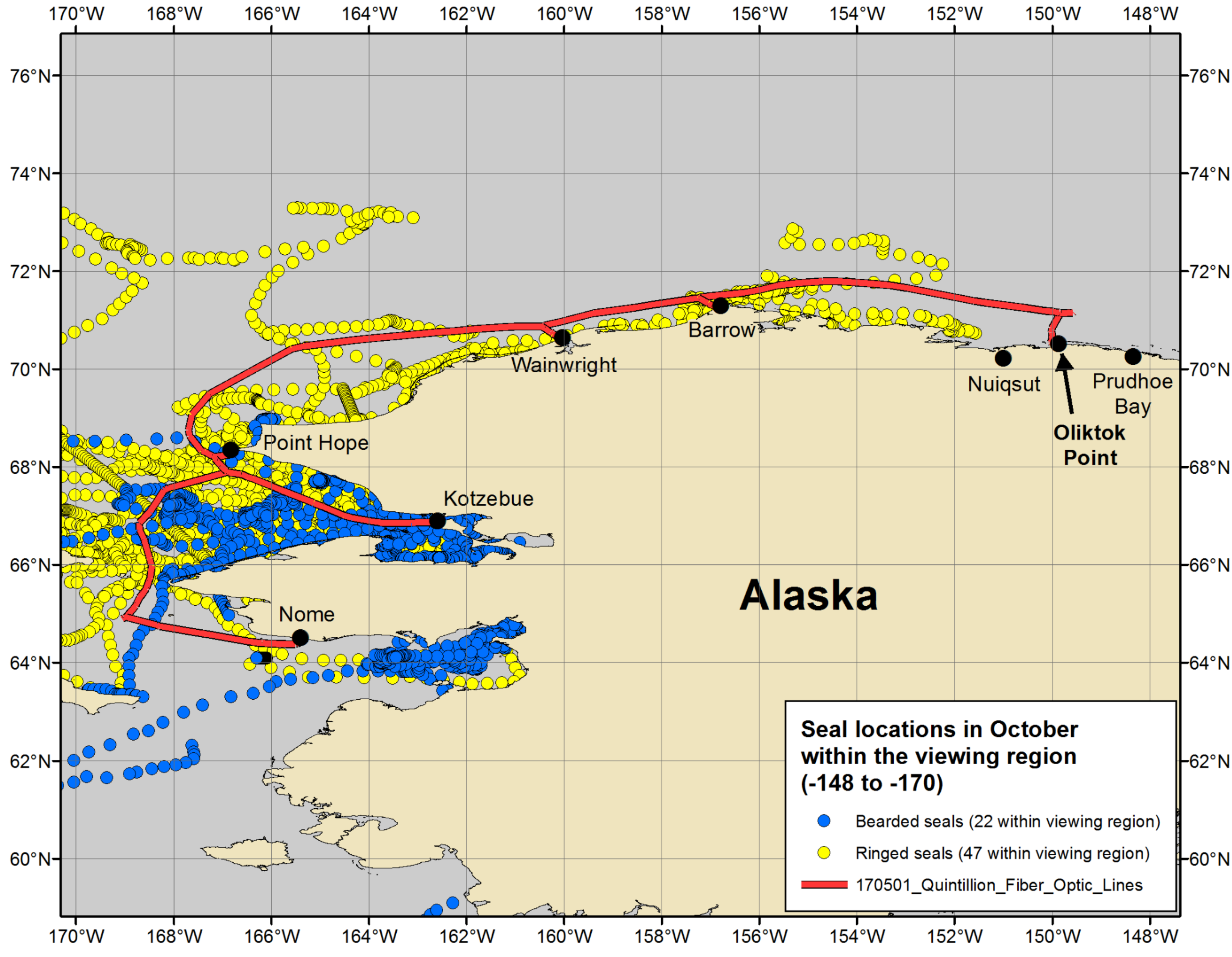

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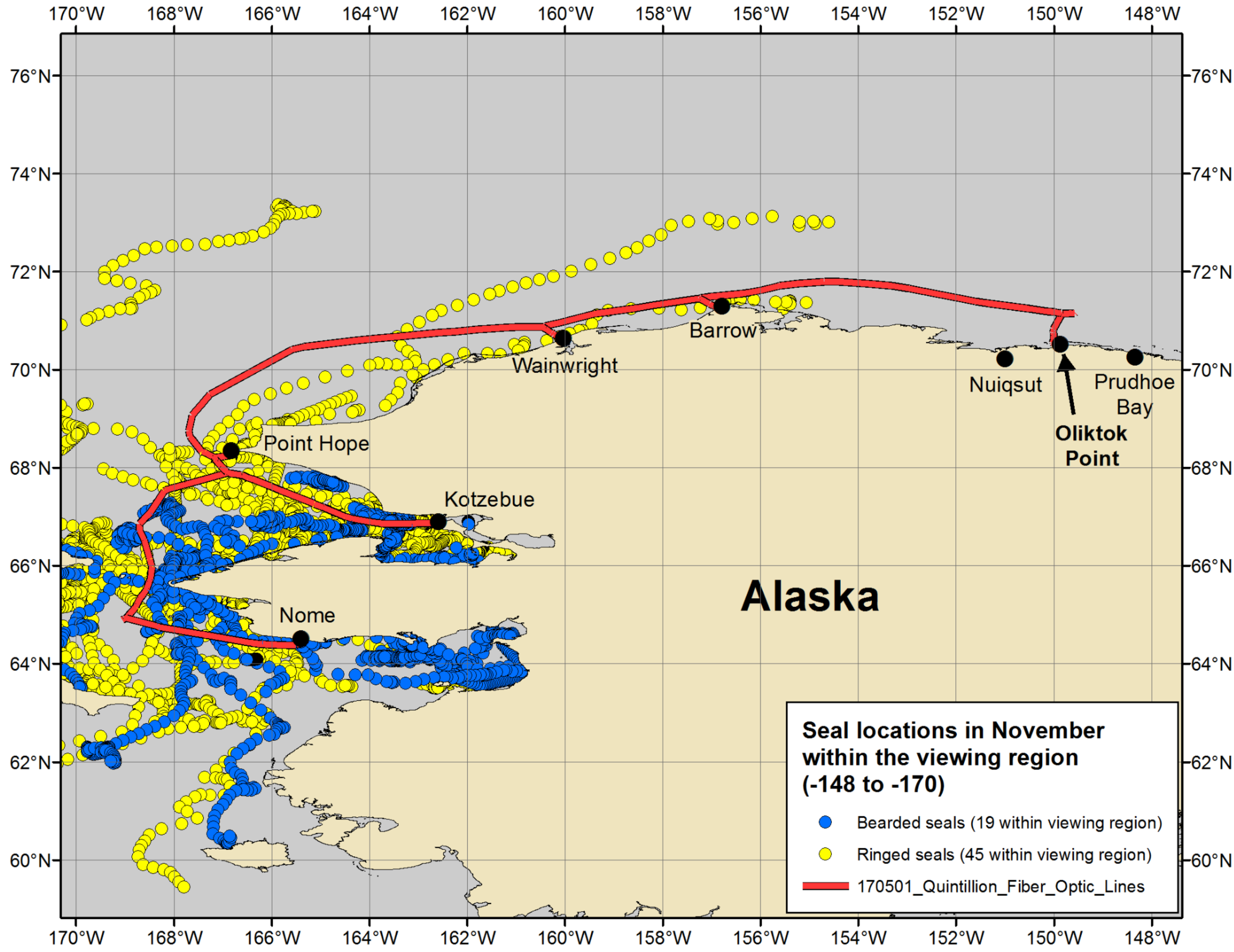
Prudhoe Bay
Oliktok Point
Point Hope
Kotzebue
Alaska
Nome
Seal locations in October within the viewing region (-148 to -170)
Bearded seals (22 within viewing region)
Ringed seals (47 within viewing region)
170501_Quintillion_Fiber_Optic_Lines



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Point Hope
Kotzebue
Nome
Wainwright
Barrow
Nuiqsut
Prudhoe Bay
Oliktok Point
Alaska
Seal locations in November within the viewing region (-148 to -170)
Bearded seals (19 within viewing region)
Ringed seals (45 within viewing region)
170501_Quintillion_Fiber_Optic_Lines

Appendix P. Barrow Whaling Captains Meeting
11 September 2017

Issue: Bowhead whales entangled in lines from crab fisheries.

Question 1: Are winter conditions changing so that bowheads are overlapping more with crab gear?

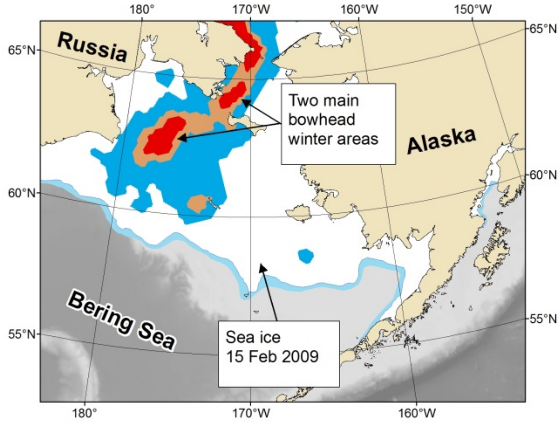


Fig. 1. Using locations from tagged whales, two main bowhead winter areas have occurred north of the ice edge in the Bering Sea. The red areas are where most tagged whales spent the winters during 2008-2010.

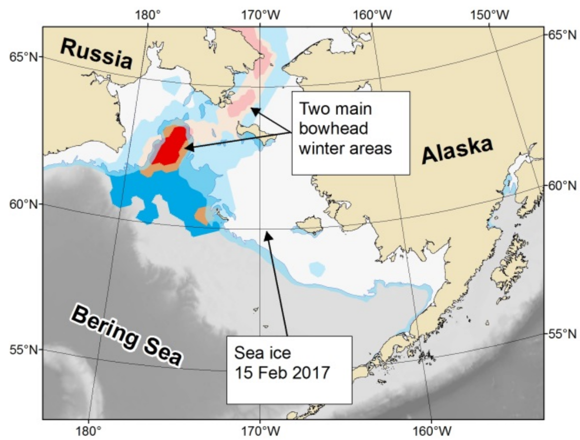


Fig. 2. In the winter of 2016-2017 one of the main winter areas was ice-free. We did not have any tags out in 2016 so we don't know how bowheads responded to this change in their winter habitat. We think they probably stayed with the ice and wintered north, west, and east of the main area.

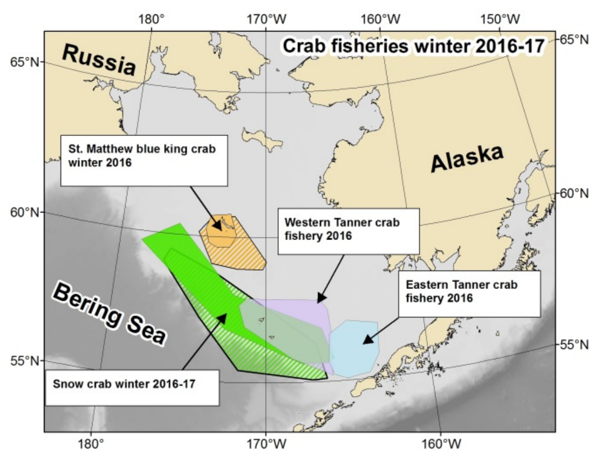


Fig. 3. Locations of the crab fisheries in 2008-2010 (orange stripes and green stripes) relative to fisheries in 2016/2017 (solid areas).

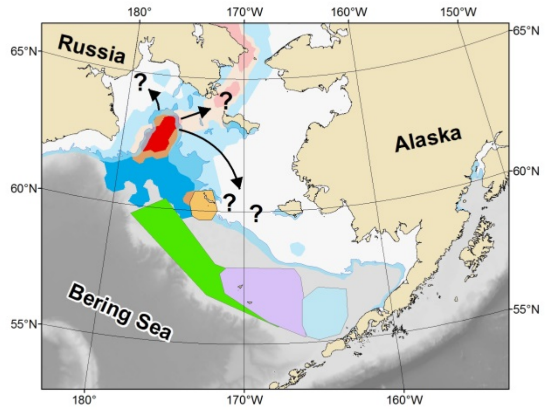


Fig. 4. Past bowhead wintering areas, ice edge in winter 2016/2017, and crab fishery boundaries in 2016/2017.

In August 2017, we worked with the Tuktoyaktuk Hunters and Trappers Committee and the Canadian government near Tuktoyaktuk to tag 7 bowheads. Three of the tags provide location and general dive information (called SPLASH tags) and four provide location, more specific dive information, water temperature, and salinity (called CTD tags).

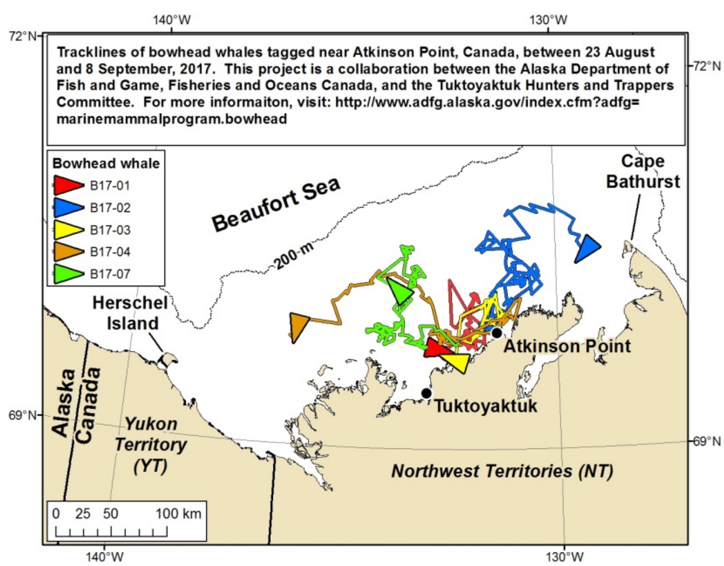


Fig. 5. Bowhead whale locations for tags deployed in August 2017 near Tuktoyaktuk, Canada.

We do not have any more SPLASH tags but we have 4 CTD tags available for bowheads that would last up to 6 months. If the Barrow tagging crew put the 4 CTD tags out this fall there would be 11 tags out could track bowheads this winter.

In addition, there is also an interest by the IWC and others in what stock the gray whales that summer in the Chukchi Sea belong to. We have 8 older tags (location only SPOT tags) that could be put on gray whales.

Lori Quakenbush
907-459-7214; lori.quakenbush@alaska.gov

Appendix Q.

Dive behavior of bowhead whales within the Cape Bathurst polynya.

Citta, John J., Lori T. Quakenbush, Stephen R. Okkonen, Matthew L. Druckenmiller, John "Craig" George, Mads Peter Heide-Jørgensen, Ellen V. Lea, and Harry Brower.

Each spring, the majority of bowhead whales (*Balaena mysticetus*) of the Bering-Chukchi-Beaufort (BCB) stock leave their wintering grounds in the Bering Sea and migrate to the Canadian Arctic. Most whales leave the Bering Sea prior to the spring ice retreat in April and May, shortly before the Bering Sea becomes one of the most productive seas in the world, to migrate to the Cape Bathurst polynya within the entrance of Amundsen Gulf, Canada. However, it is unknown if whales are feeding there in May and June and if foraging conditions are better within the polynya than where they came from in the Bering Sea. Here we provide an examination of the diving behavior within the polynya during May and June, using 16 bowhead whales tagged with satellite-linked transmitters between 2008 and 2015. Two tags, one in 2014 and one in 2016, were also capable of collecting paired depth and temperature readings to describe water masses. Approximately 63% of the polynya is comprised of shelf habitat (<200 m); however, bowhead whales preferentially used deeper (>200 m) oceanic habitats (89% of whale locations). Within oceanic habitats, most use was within 100 m of the surface, in water of Pacific origin. Whales sometimes spent large amounts of time (25% to 80% of a 6-hr interval) between 100 and 300 m, within the thermocline between Pacific Water and Atlantic Water. There were virtually no dives below 300 m in the polynya, indicating that whales were not using deeper Atlantic Water. Most dives were square-shaped and are likely indicative of feeding. Other studies suggest that there are high densities of large zooplankton within 100 m of the surface in May and June. As such, whale use of the polynya in May and June appears corresponds to both the timing and location of copepod prey.

Oral presentation at the Biennial Conference on the Biology of Marine Mammals, 23–27 October, Halifax, Novia Scotia, Canada

Appendix R.

Summer movements of western Arctic bowhead whales outside of the Canadian Beaufort Sea

AUTHORS: Lori Quakenbush *[1], John Citta[1], John C. George[2], Lois Harwood[3], Ellen Lea[3], Mads Peter Heide-Jørgensen[4]
[1] Alaska Department of Fish and Game, 1300 College Road, Fairbanks, Alaska 99701, USA
[2]North Slope Borough, P.O. Box 69, Barrow, Alaska 99723, USA
[3]Department of Fisheries and Oceans Canada, Yellownife, NT, Canada
[4]Greenland Institute of Natural Resources, Copenhagen, Denmark

**Presenter: lori.quakenbush@alaska.gov*
Alaska Marine Science Symposium, 22–26 January 2018

A primary summering area for the western Arctic stock of bowhead whales is the Tuktoyaktuk Shelf region in the Canadian Beaufort Sea. Other summer areas used by one or more tagged whales documented by satellite telemetry include east of Tuktoyaktuk in Darnley Bay and Viscount Melville Sound, and west in the Alaskan Beaufort Sea (between Harrison Bay and Point Barrow), the northern Chukchi Sea, and the northern coast of Chukotka. Bowheads are known to travel long distances to areas with concentrated prey that provide good feeding opportunities. These feeding areas require specific physical oceanographic features (e.g., upwelling and fronts) that concentrate krill or copepods to form high quality feeding events. This combination of factors suggests that the locations, if not the timing, of these feeding areas are likely "known" (i.e., used before by some whales) and some of the locations are far apart. Using a state space model to separate traveling from lingering (likely feeding) shows a pattern of directed travel that ends in lingering (for days to weeks) followed by directed travel. Distances between lingering areas in summer can be long (e.g., >900 km), and trips may be repeated within the same summer season. For example, two bowheads in 2009 left the Canadian Beaufort Sea and traveled to an area north of Point Barrow where they stayed for several days before returning to the Canadian Beaufort prior to their fall migration. It appears that bowheads will travel long distances to investigate potential feeding areas and return or move on if nothing is there. Traveling behavior appears to be relatively direct and it does not appear that bowheads are searching for feeding opportunities as they travel. This behavior also suggests that traveling long distances to potential feeding events may not be as energetically costly as expected or, although somewhat risky, the feeding opportunities they seek are high quality and contain large amounts of concentrated food making the excursion worthwhile — or both.

Appendix R.

Summer movements of western Arctic bowhead whales outside of the Canadian Beaufort Sea

Lori T. Quakenbush, Alaska Department of Fish and Game, Fairbanks, AK, USA
John J. Citta, Alaska Department of Fish and Game, Fairbanks, AK, USA
John C. George, North Slope Borough, Utqiaġvik (Barrow), AK, USA
Lois Harwood, Department of Fisheries and Oceans Canada, Yellowknife, NT, Canada
Ellen Lea, Department of Fisheries and Oceans Canada, Yellowknife, NT, Canada
Mads Peter Heide-Jørgensen, Greenland Institute of Natural Resources, Copenhagen, Denmark

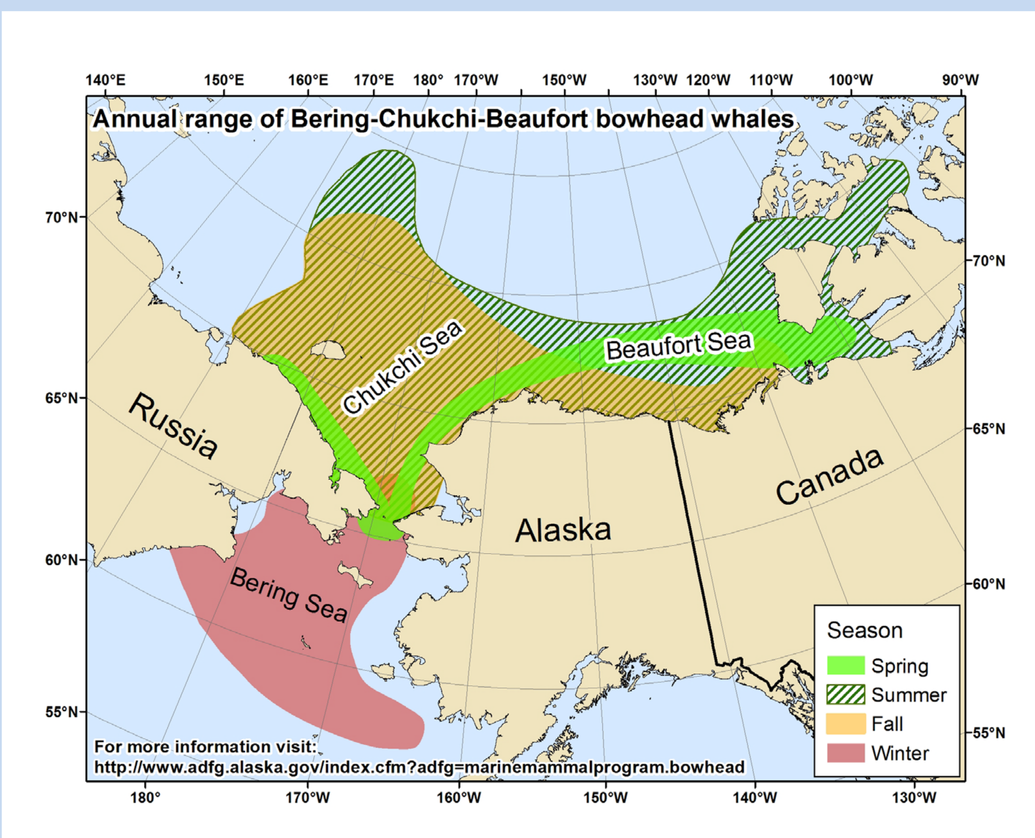
BOEM Bureau of Ocean Energy Management

Alaska Department of Fish and Game

Fisheries and Oceans Canada

Background

Each spring, most bowhead whales (*Balaena mysticetus*) of the Bering-Chukchi-Beaufort (BCB) stock leave their wintering grounds in the Bering Sea and migrate to summer ranges in the eastern Beaufort Sea (see map below). We worked with subsistence hunters and whalers to attach satellite tags to bowhead whales in order to study their summer movements and the factors that determine those movements. Here, we present data from 45 bowhead whales tagged between 2006 and 2016.

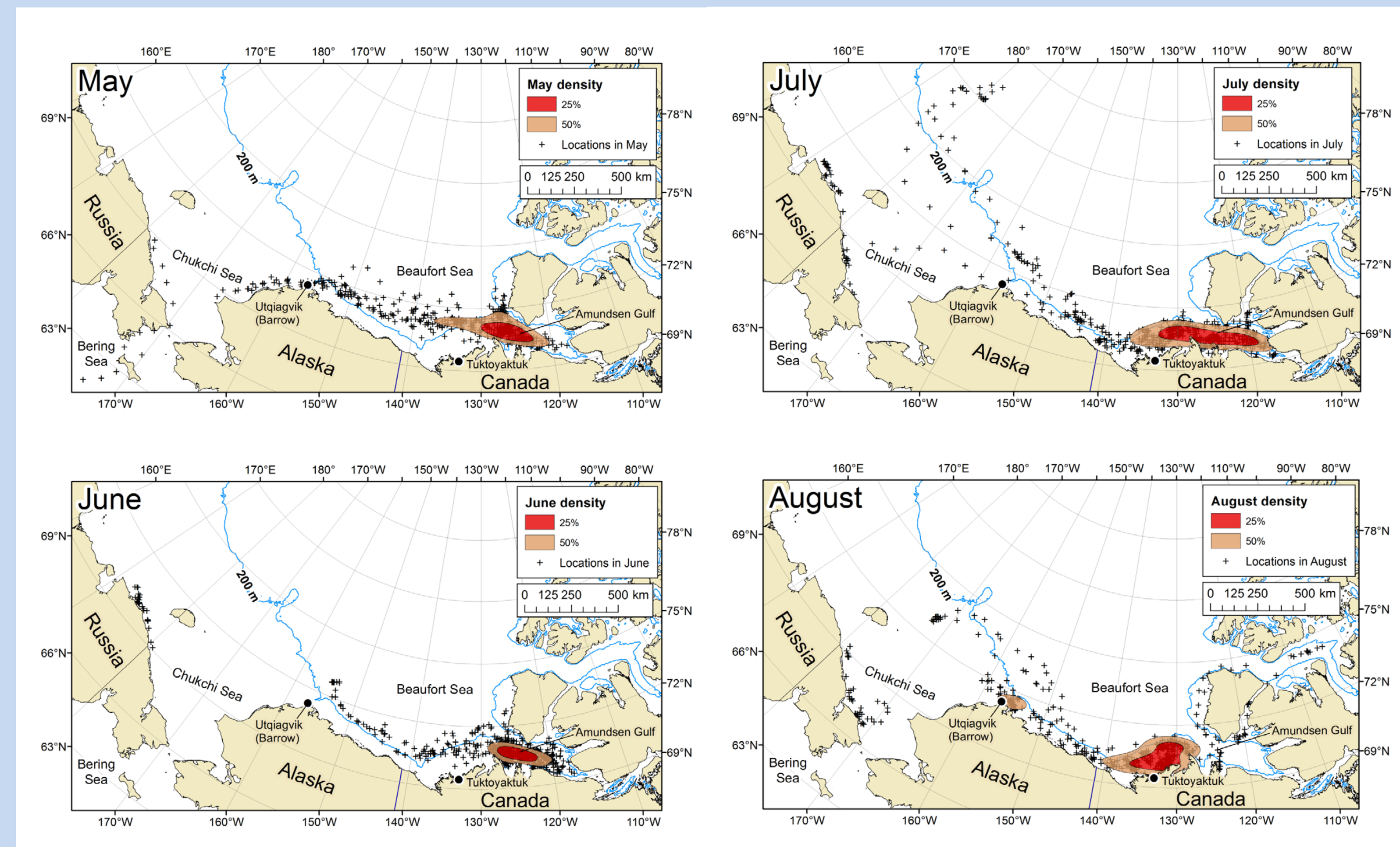


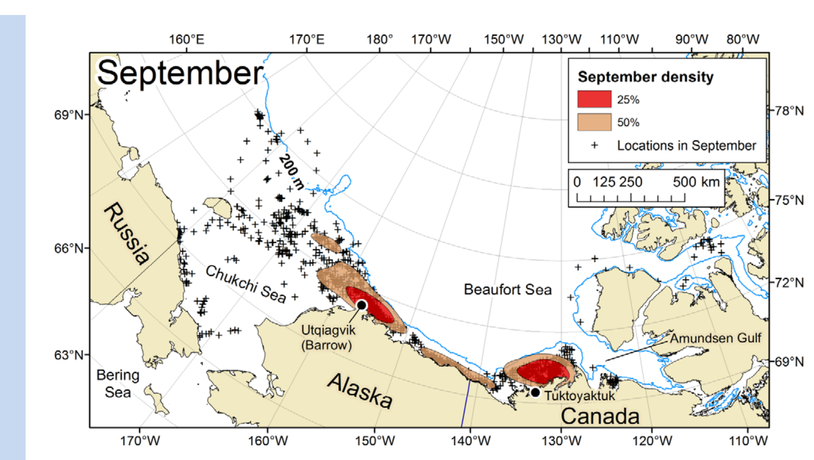
Acknowledgements

This cooperative project involved contributions and hard work from many organizations, agencies, and individuals, including the following: Alaska Eskimo Whaling Commission, North Slope Borough (Harry Brower, Jr., Billy Adams, Robert Suydam, and Taqulik Hepa), Barrow and Kaktovik Whaling Captain's Associations (Eugene Brower, George Tagarook, and Eddie Arey), Barrow Arctic Science Consortium (Lewis Brower), Aklavik and Tuktoyaktuk Hunters and Trappers Committees (Dennis Arey, Larry Arey, Pat Kasook, Buddy Gruben, Douglas Panaktalok, Mikkel Panaktalok, Max Kotokak, Sr., Charles Pokiak, and James Pokiak), Department of Fisheries and Oceans Canada (DFO) (Kevin Bill, Tim Leblanc, Patrick Ryan, Terry Stein, Angus Alunik, Kate Snow), and the Greenland Institute of Natural Resources (Mikkel and Anders Jensen). Funding for this research was mainly provided by U.S. Minerals Management Service (now Bureau of Ocean Energy Management). Additional project funding and support was provided by the Department of Fisheries and Oceans Canada and the Fisheries Joint Management Committee.

Bowhead whale research has been conducted in the U.S. under a Marine Mammal Protection Act permit issued to National Marine Fisheries Service (No. 782-1719) and to the Alaska Department of Fish and Game (No. 14610) and under Animal Care and Use permit Nos. 06-16, 09-21, 2010-13R, 2012-020, 2013-20, 2014-03, 2015-25, and 2016-23. In Canada, research was conducted under Department of Fisheries and Oceans Scientific License No. S-07/08-4007-IN, S-08/09-4000-IN, S-09/10-4005-IN-A1, S-10/11-318-YK and Animal Care Protocols FWI-ACC-2007-2008-013, FWI-ACC-2008-031, FWI-ACC-2009-019, and FWI-ACC-2010-034.

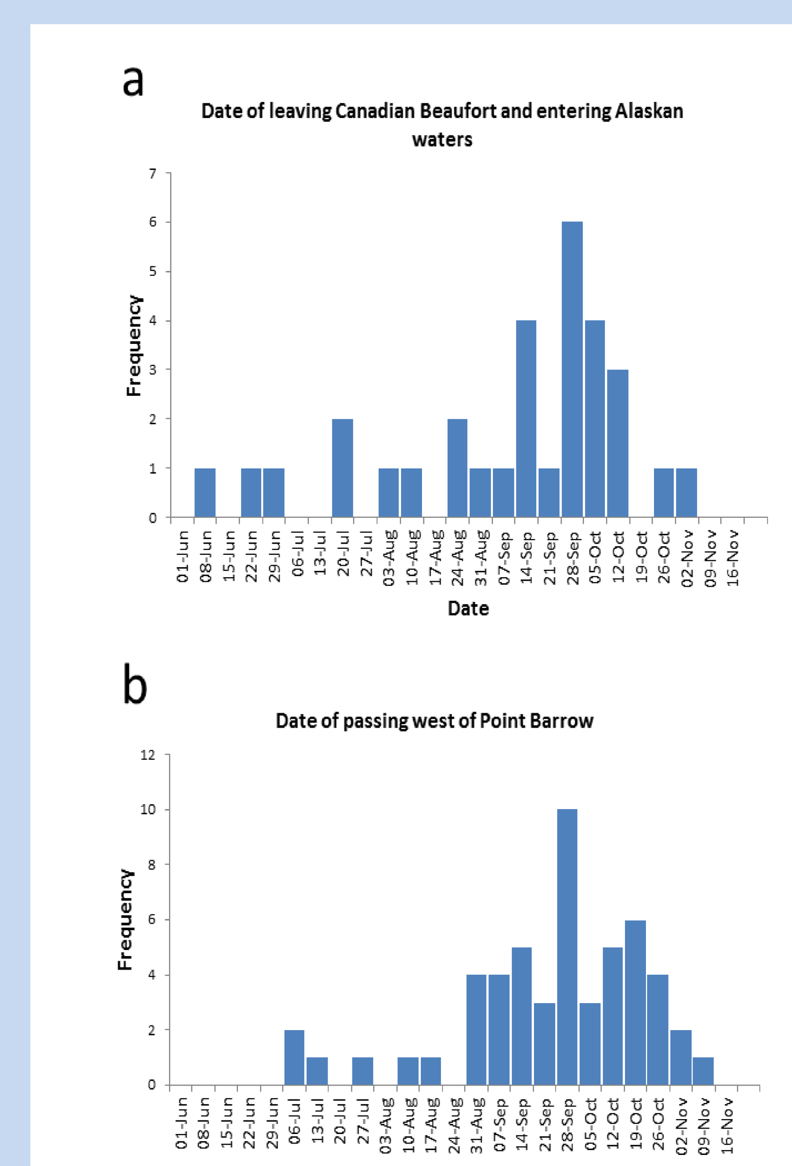
Results

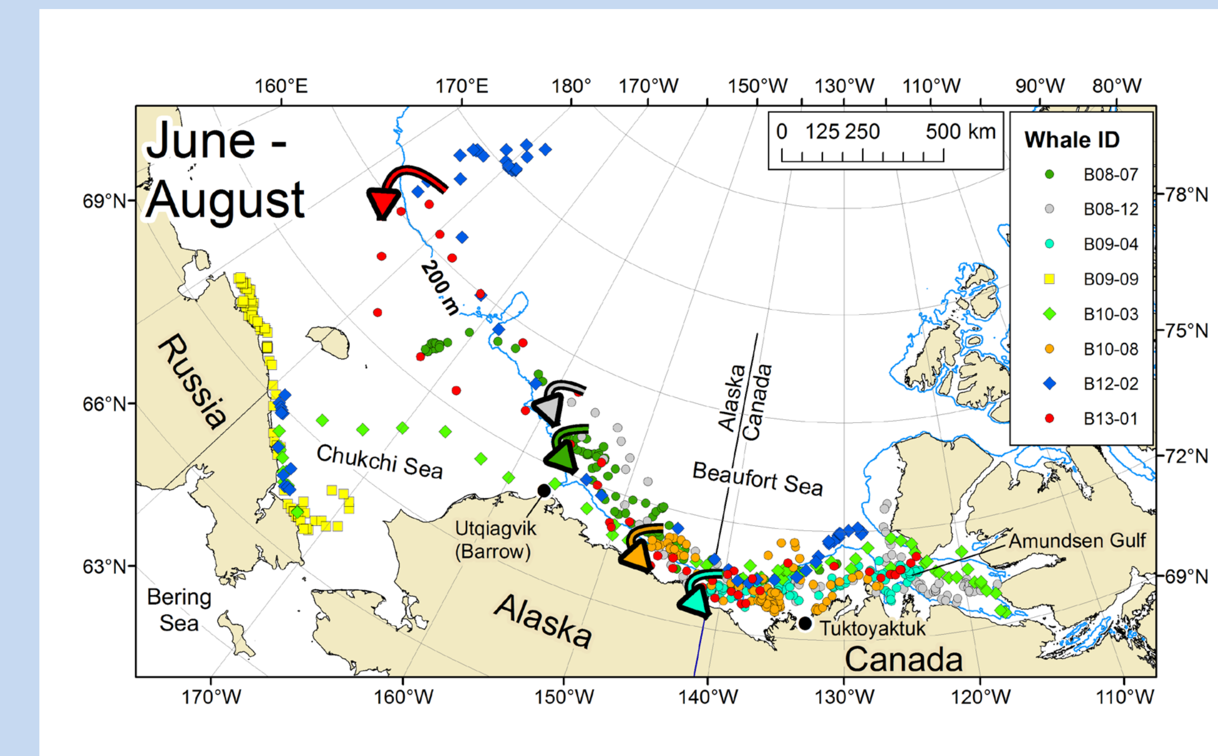




1. **The summer core use areas (shown in red and orange) are all located in the Canadian Beaufort Sea.** Core use areas are located near Amundsen Gulf during May-July, shift towards Tuktoyaktuk in August, and towards Utqiagvik in the Fall (i.e., September).

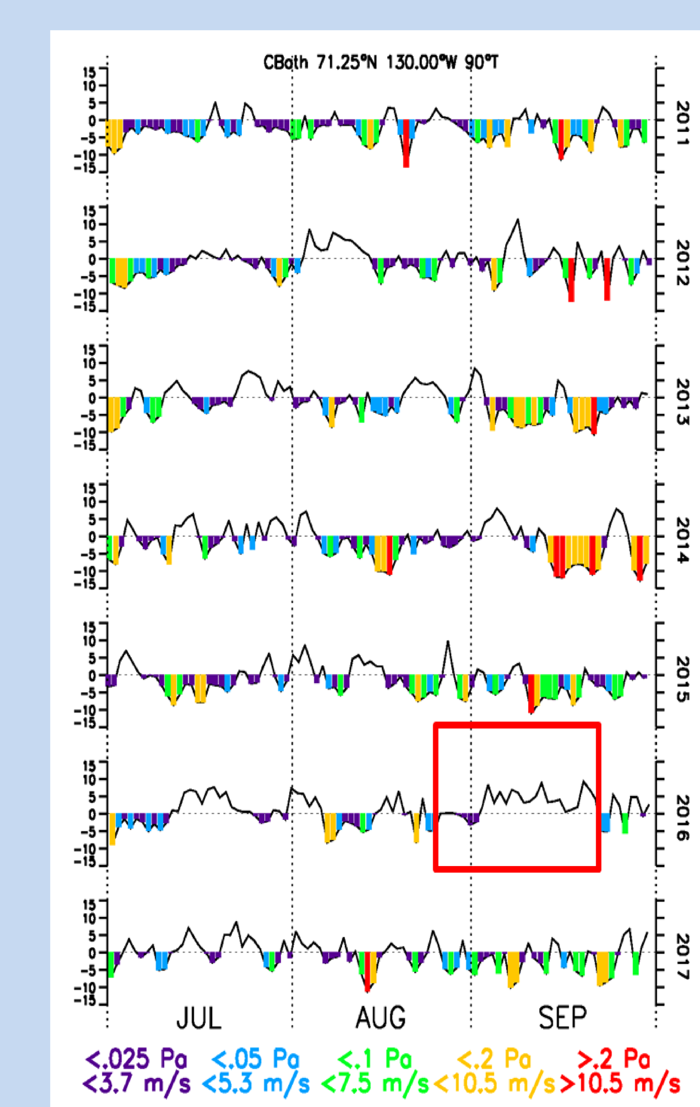
2. Although peak migration from the Canadian Beaufort occurs in September, tagged whales returned to Alaskan waters as early as 8 June and pass west of Barrow as early as 1 July. To date, all tagged whales observed in summer or autumn near Utqiaġvik (Barrow) were returning from Canada. **Hence, whales spotted off the Alaskan coast in summer are not late migrants from the Bering Sea, but are returning from the Canadian Beaufort prior to the peak migration in September.**





3. **Tagged whales that returned to Alaskan waters in summer either "looped" back into Canadian waters (n=5) or continued on into Russian waters (n=2).** In the plot above, circles are whales that left Canadian waters and then returned (arrows indicate where whales turned-around and returned to Canadian waters), diamonds are whales that migrated to Russia mid-summer, and squares indicate a whale that summered in Russian waters. Looping whales may pass west of Point Barrow twice, once in mid-summer and once during the fall migration. **Such behavior is not uncommon, of the 45 tagged whales used here, seven (20%) left the Canadian Beaufort Sea prior to the autumn migration in September.**

4. **We suspect that whales are more likely to leave the Canadian Beaufort in summer when feeding opportunities are poor.** Tagging crews found few bowheads in the Canadian Beaufort Sea in August and September 2016 when an unusually large number of bowheads were spotted in the Alaskan Beaufort Sea by aerial survey crews (ASAMM survey; Janet Clarke, pers. comm.). Upwelling favorable winds are from the east and lift zooplankton from deeper off shelf water advecting them onto the shelf where they become concentrated in the shallow water where whales can efficiently feed on them. Virtually no upwelling winds occurred on the late summer feeding grounds in 2016 (see red box in figure).



East winds are represented by negative values. Upwelling-favorable winds are strong east winds colored green, yellow, and red.

Bering-Chukchi-Beaufort Stock of Bowhead Whales: 2006–2017 Satellite Telemetry Results with Some Observations on Stock Sub-Structure

Lori Quakenbush[1], John Citta[1], John C. George[2], Mads Peter Heide-Jørgensen[3], Harry Brower[4], Lois Harwood[5], Billy Adams[2], Charles Pokiak[6], and James Pokiak[6], Ellen Lea[5]

[1]Alaska Department of Fish and Game, Fairbanks AK, USA, Lori.Quakenbush@alaska.gov
[2]North Slope Borough, Barrow AK, USA; [3]Greenland Institute of Natural Resources, Copenhagen Denmark; [4]Alaska Eskimo Whaling Commission, Barrow AK, USA; [5]Department of Fisheries and Oceans, Canada; [6]Tuktoyaktuk Hunters and Trappers Association, Tuktoyaktuk, Canada.

ABSTRACT

Sixty-four satellite transmitters provided data on bowhead whales from the Bering-Chukchi-Beaufort (BCB) stock between 2006 and 2017 to study their movements and behavior. Sixty-one of which were tagged in the Beaufort Sea and three were tagged in the Bering Sea. In winter, bowhead whales used the western Bering Sea in areas of heavy ice with little use of open water areas. All but one tagged whale migrated past Point Barrow in spring and went to Amundsen Gulf. That whale migrated up the Chukotka coast and summered in the Chukchi Sea. While most whales summered within the Canadian Beaufort Sea, extensive summer movements included travel far to the north and northeast to overlap with bowhead whales from the Baffin Bay-Davis Strait stock. Other summer movements included trips between the Canadian Beaufort and Barrow and back again. One whale, tagged near Point Barrow, traveled to the northern coast of Chukotka, Russia, in the following summer, and did not return to Canada that summer. Fall movements coincided in space and time with oil and gas activities and potentially with shipping activities. Core-use areas that are likely important feeding areas included Amundsen Gulf in spring and summer; Tuktoyaktuk Shelf in summer; Point Barrow in summer and fall; the northern Chukotka coast in fall; and the western Bering Sea in winter. Recent changes in late summer movements (i.e., greater use of mid and western Beaufort Sea) and less use of previous core-use areas in the Bering Sea in winter that were largely ice-free in winter 2016/17 and 2017/18 have occurred and may become more common. None of the movements from tagged whales suggest a multi-stock condition exists within the BCB bowhead whale population.

INTRODUCTION

The Bering-Chukchi-Beaufort (BCB) stock, also known as the Western Arctic stock, is one of five recognized stocks of bowhead whales that occupy Arctic waters (Moore and Reeves 1993). The BCB stock is hunted by indigenous people of Alaska and Russia and is highly valued for food, materials, and cultural significance. Harvest is regulated by a strike quota determined by the International Whaling Commission and locally managed by the Alaska Eskimo Whaling Commission (AEWC). Although the BCB population numbers approximately 17,000 individuals (Givens et al. 2015), the reduction of summer sea ice and other factors associated with climate change (e.g., increased oil and gas activity, shipping, and fishing) require that we know more about BCB movements, important habitats, and behavior in order to best plan shipping lanes and develop effective mitigation measures for industrial activities. A better understanding of movements related to possible stock structure was also an initial objective for tagging bowheads.

In 2005, the Alaska Department of Fish and Game (ADF&G) began a cooperative project (with AEWC, the North Slope Borough, and the Greenland Institute of Natural Resources; funded by Minerals Management Service, now Bureau of Ocean Energy Management) to study the BCB stock of bowhead whales, including their movements and behavior using satellite telemetry. The project expanded to north western Canada in 2007 and the Department of Fisheries and Oceans and Tuktoyaktuk Hunters and Trappers became cooperators. The specific objectives of the project were to work with native subsistence hunters to deploy satellite tags, use satellite telemetry to identify important habitats, and to document the timing and location of movements and behavior relative to industrial activities and physical conditions (e.g., ice, bathymetry, and distance from shore). Before we began this study, general seasonal movements and their timing were best known near the coast and during the whaling seasons. However, little was known about offshore and winter movements (Fig. 1).

Tracking many individual bowhead whales over long distances and time periods (sometimes more than a year) has greatly expanded our knowledge of bowhead range; variability in movements (Citta et al. 2018; Quakenbush and Citta 2018; Quakenbush et al. 2010), summer and fall use areas (Quakenbush and Citta 2018; Harwood et al. 2017; Citta et al. 2015), winter use areas (Citta et al. 2012; Citta et al. 2015); influence of sea ice and physical oceanographic parameters on movements (Citta et al. 2015, Druckenmiller et al. 2017); interaction with disturbances (Quakenbush et al. 2010b) and fisheries (Citta et al. 2014); and evidence of sub-structure in the BCB stock (this paper).

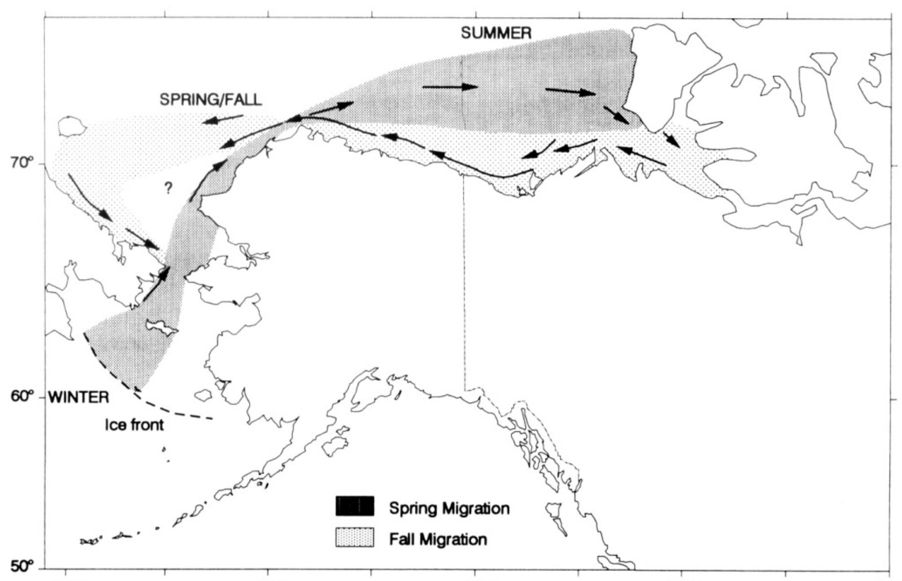


Figure 1. Generalized seasonal occurrence and migration corridor for the BCB bowhead stock prior to 1990, depicting spring and fall pathways (Fig. 9.7, pg 337 from Moore and Reeves (1993)).

METHODS

We used satellite transmitters manufactured by Wildlife Computers (Redmond, Washington, USA) and by the Sea Mammal Research Unit (University of St. Andrews, Scotland) and the attachment and deployment system was developed by the Greenland Institute of Natural Resources (Heide-Jørgensen et al. 2001, 2003; Quakenbush et al. 2010a). Transmitters were placed on bowhead whales in Alaska and Canada in 2006–2017. Most of the tags were deployed by Alaskan and Canadian Native subsistence hunters and boat drivers. Three types of tags were deployed; one that transmitted location only and one that transmitted location and diving information (Quakenbush et al. 2010a), and one that transmitted location, diving, and oceanographic (conductivity and temperature at depth) information. Skin biopsies were collected either by crossbow or by a biopsy rod on the tagging pole. DNA in the skin was used to determine sex of tagged whales (Citta et al. 2012). Transmitter locations acquired from the Argos satellite system were processed using a filter developed by Freitas et al. (2008). Bowhead whale locations that resulted in swim velocities of over 1.94 m/s were removed unless they were within 5 km of the previous location. The threshold velocity of 1.94 m/s is the maximum observed migration speed of bowheads not fleeing vessels or assisted by currents (e.g., Zeh et al., 1993). The filter also has an angular component to account for locations with a high degree of location error that often fall far from the line of travel, forming acute angles between adjacent locations. We used default settings to define the angular components of the filter; within 2.5 km of the track line, locations resulting in angles less than 15˚ were removed and locations between 2.5 and 5 km of the track line were removed if they resulted in angles under 25˚. We then removed locations that fell on land to establish the final set of locations used in our analyses. In order to show areas of concentrated use we used kernel density estimation (Worton 1989, Wand and Jones 1995). Following Quakenbush et al. (2010a), we selected a bandwidth matrix for each whale using Smoothed Cross-Validation (SCV; Duong and Hazelton 2005, Duong 2007).

RESULTS AND DISCUSSION

Sixty-four tags transmitted location and/or dive data between 2006 and 2017. Sixty-one tags were deployed in the Beaufort Sea: 40 tags near Point Barrow, Alaska (6 in the spring, 34 in the fall), and 21 near the Mackenzie River Delta, Canada in the fall. Three tags were deployed from St. Lawrence Island in the spring. Fifteen of the tags transmitted location only and 49 also transmitted dive information. Sex was determined for 41 whales; 14 were females and 27 were males.

Overall Range. This study has extended the boundaries of what was recognized as the range of bowhead whales in every season (compare Figs. 1 and 2). Whales tagged recently are still contributing to the extension of range boundaries indicating that the current boundaries (Fig. 2) will likely be further extended as more whales are tagged. It is unknown whether this range extension is because tagging to date has been insufficient to document the overall range, the increase in population size (Givens et al. 2015) is contributing to an expanded distribution, or if the range is changing as sea ice deceases, or if it is some combination of these. We began to see changes in what we thought was established behavior in the summer of 2016 (e.g., reduced use of the Tuktoyaktuk Shelf summer feeding area and increased use in mid and western Beaufort Sea) and the lack of ice in the primary Bering Sea winter area in the winter of 2016 and 2017 may have altered the wintering area; both may be related to climate change (Quakenbush and Citta 2018) or population increase.

We documented summer (August and September) movements north of Banks Island, Canada, in 2006, and through Prince of Wales Strait into Viscount Melville Sound, Canada, in 2010, a main route of the Northwest Passage. In 2010, a BCB whale left Viscount Melville Sound a few days before a Baffin Bay-Davis Strait stock whale tagged in West Greenland arrived and spent time there in September. Although both whales returned to their respective ranges and did not overlap in time their movements do indicate the two stocks can now intermingle in summer with less ice in the Canadian Arctic archipelago (Heide-Jørgensen et al. 2011; Quakenbush et al. 2012).

Tagged whales moved north of 75 degrees latitude in 2009, 2010, 2012, 2013, 2015, and 2017. These movements occurred north of Banks Island in 2010, north of Wrangel Island in 2009, 2012, 2013, 2015, and 2017, and in the central Beaufort Sea in 2017. Whether bowhead whales have used these offshore areas in summer in the past or if this is recent behavior related to the decrease in sea ice is unknown. The summer and fall range boundary was also extended to the west beyond Wrangel Island in the western Chukchi Sea (Quakenbush et al. 2010; Citta et al. 2018; Quakenbush et al. 2016).

The winter range in the Bering Sea was extended to the east with the movements of a whale tagged in 2012. This whale was included in the analysis to identify primary core-use areas (Citta et al. 2015), but not in the winter movements analysed in Citta et al. (2012 and 2014).

The analysis for spring includes 23 tagged whales that transmitted during the spring migration, and all but one passed Point Barrow and migrated through the Beaufort Sea to Amundsen Gulf, Canada (Quakenbush et al. 2012; Quakenbush and Citta 2018). That one whale (B09-09) migrated a month later than other tagged whales, passing Cape Pe'ek, Russian Federation, on 26 May (Fig. 3) and stayed in the western Chukchi Sea for the summer. This whale was tagged near Point Barrow the previous summer on 29 August 2009, but did not return to Point Barrow the following year, at least through 21 August 2010 when the tag stopped transmitting. We do not know where B09-09 summered prior to being tagged near Point Barrow in 2009. In 2010, we think it unlikely that this whale returned to Point Barrow prior to the fall migration after the tag stopped transmitting. We have some evidence from locating tagged bowheads from the air that they are accompanied by other bowheads (Christman et al. 2013). Thus, we suggest that there may be interannual variation in movements; that is, some whales may not follow the same migration routes each spring or return to the same areas each year and not all bowheads summer in the Beaufort Sea every year as suggested by observations made along the Chukotka coast in summer (Melnikov and Zeh 2007).

That bowheads occur in the western Chukchi in spring is not new. In 2001, Melnikov and Zeh (2007) counted 470 (95% CL 332 to 665) bowhead whales passing Cape Pe'ek, near Uelen, Russia (Fig. 3), between 23 May and 14 June. The spring migration past Point Barrow was believed to be over by 7 June 2001 (George et al., 2004). Based upon travel velocities observed by Melnikov and Zeh (2007), few of the whales observed at Pe'ek in June could have migrated past Point Barrow before 7 June. As such, Melnikov and Zeh (2007) suspected that the whales they observed were remaining in the Chukchi Sea for the summer. Based upon the movements of B09-09, it is clear that some whales do not migrate past Point Barrow every year in spring and that spring migration counts near Barrow (e.g., Zeh et al. 1993, George et al. 2004) do not count the entire BCB stock.

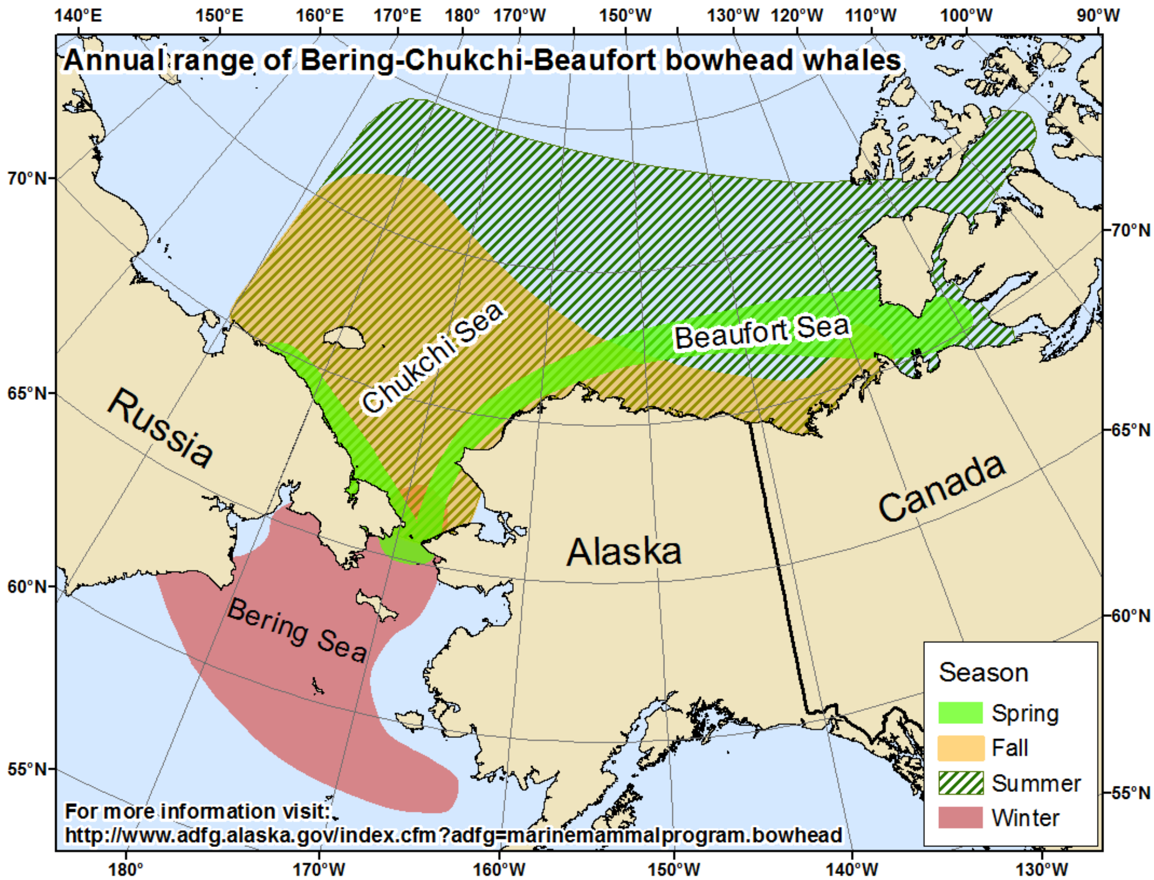


Figure 2. Generalized annual range of the Bering-Chukchi-Beaufort stock of bowhead whales by season from satellite tracking data collected 2006–2017.

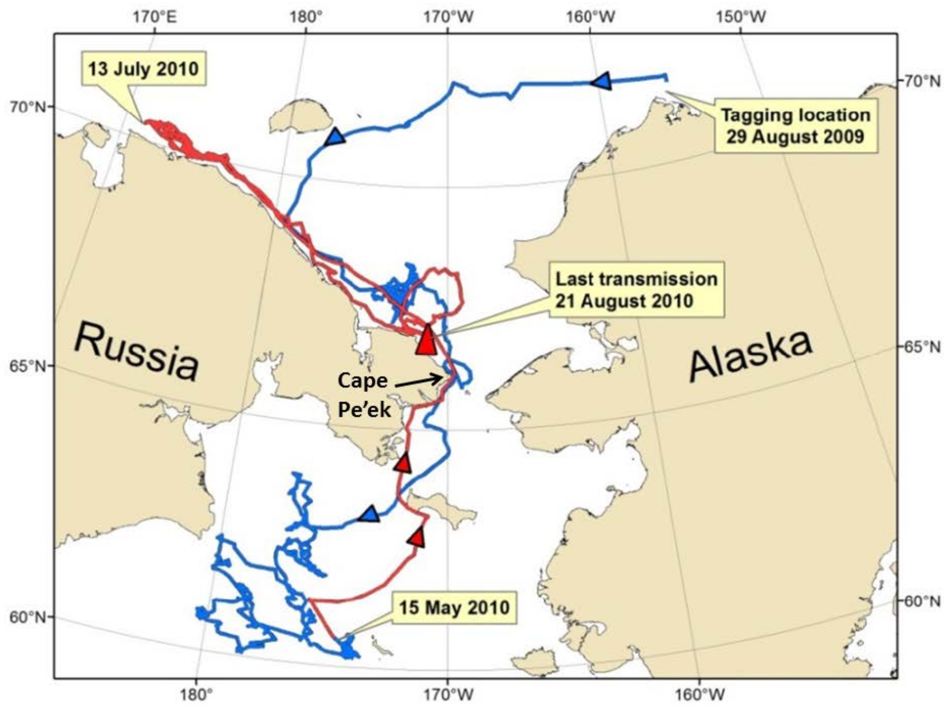


Figure 3. Complete track of B09-09 the only tagged whale of 23 that did not pass Point Barrow in the spring for the Canadian Beaufort Sea but spent spring and summer in the Chukchi Sea. Blue track is 29 August 2009–15 May 2010. Red track is 16 May–29 August 2010.

Feeding Areas. The six primary core-use areas identified in Citta et al. (2015) are believed to be feeding areas that develop seasonally when physical characteristics (oceanography, sea ice, and winds) concentrate zooplankton in areas accessible to bowheads.

In spring, most bowheads leave the wintering area in the Bering Sea and migrate to the Cape Bathurst polynya, Canada (Area 1 in Citta et al. 2015; Fig. 4 below). Here bowheads spent the most time at depths of <75 m within a halocline in the euphotic zone where calanoid copepods are expected to ascend from depths after the winter diapause. Use of the polynya included early May–early July. Whales generally left this area in July when copepods are expected to descend to deeper depths.

During summer and fall (mid-July–late September), most whales moved to the shallow Tuktoyaktuk shelf (Area 2) where favorable (east) winds promote upwelling of copepods onto the shelf where they are concentrated in the shallow water. Whales also concentrated near Point Barrow (Area 3) between late August and early November where east winds also promote upwelling of zooplankton onto the Beaufort Shelf (Fig. 4).

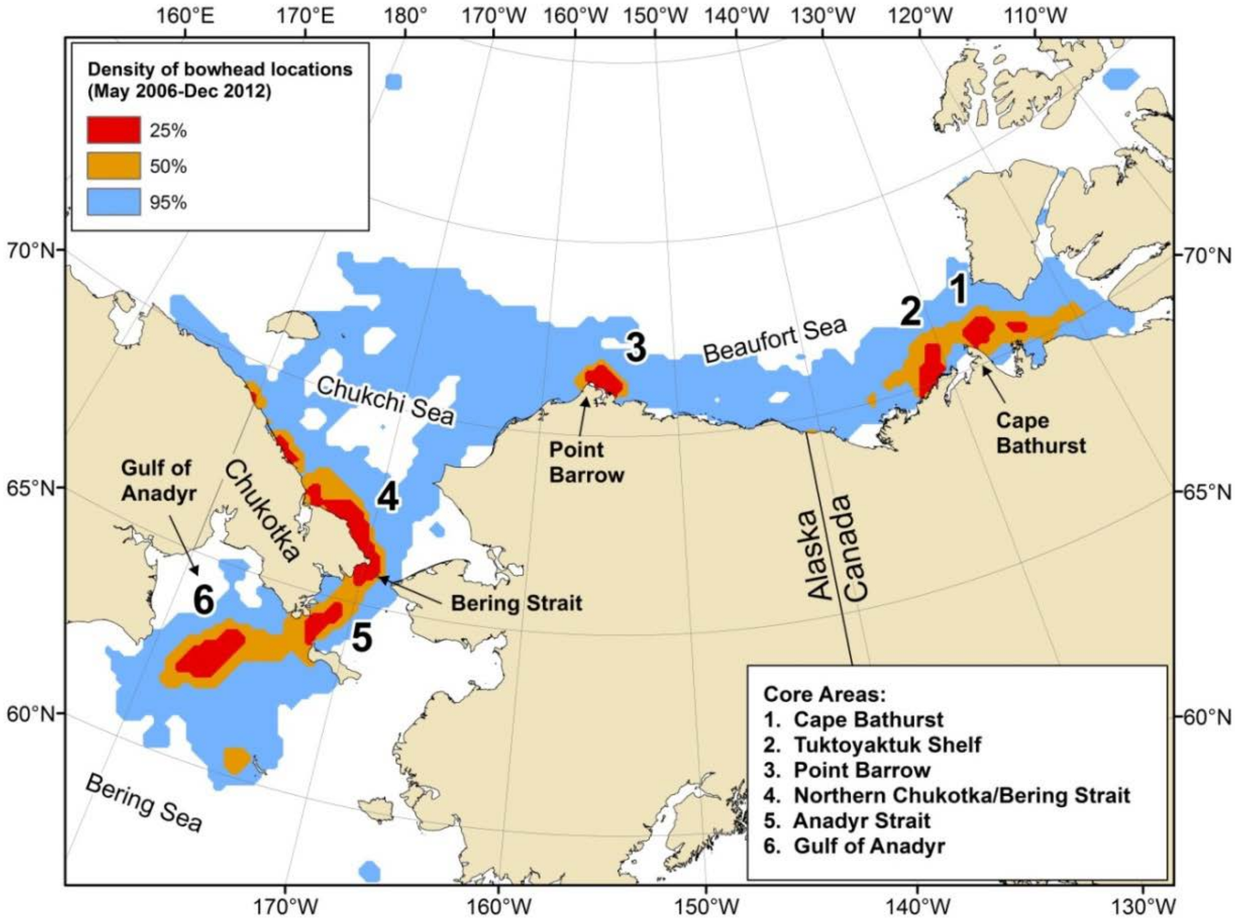


Figure 4. Utilization distribution for western Arctic bowhead whales with satellite tags, 2006-2011. Core areas, areas of high bowhead concentration, were defined as lying within the 25% density contours. Six primary core areas are identified. Figure from Citta et al. (2015).

During winter (late October–early January) whales congregated and moved slowly southward along the Chukotka coast, Russia (Area 4; Fig. 4), where zooplankton were likely concentrated along a coastal front between the Siberian coastal current flowing south-eastward and the Bering Sea waters flowing northward. Between late November and mid-April, bowheads were in the Bering Sea in Anadyr Strait (Area 5) and the Gulf of Anadyr (Area 6). Both areas were characterized by heavy but highly fractured sea ice. Whales in these areas spent much of the time near the bottom where overwintering copepods and euphausiids are expected to aggregate (Citta et al. 2012). We analysed 889 dive intervals (6-hr) and in all but five intervals (99.4%) tagged whales dove to the bottom at least once (Fig. 5). Water depths in the area ranged from 25 to 300 m (Quakenbush et al. 2010b; 2012). Such frequent use of the bottom supports feeding on an overwintering layer of copepods or euphausiids in winter. Bowhead use of these wintering areas ends in April with the timing of zooplankton ascent, well before the sea ice has withdrawn (Citta et al. 2015).

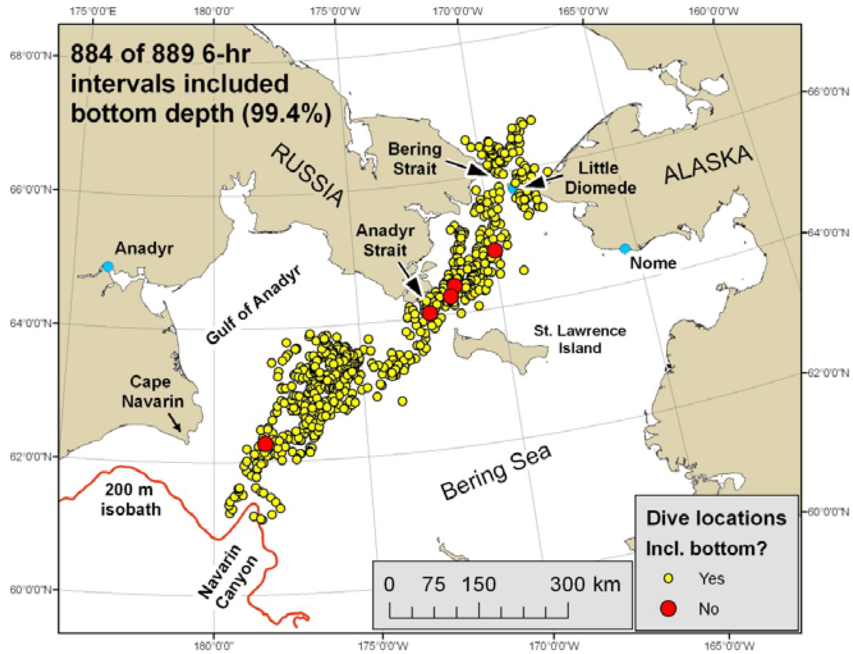


Figure 5. Tagged bowhead whale locations in the Bering Sea between January and April 2009 for which there are dive data. Red circles represent the only locations where a bowhead whale did not dive to the bottom during a 6-hr period. Nearly all dive intervals (99.4%) included the bottom. Figure from Quakenbush et al. (2012).

Also in winter, tagged whales used offshore areas of heavier, yet fractured, ice despite the availability of areas with open water near shore. Within a random sample of bowhead locations, only 1 of 102 locations (i.e., ~1%) fell within an open water area (polynya) during the winter of 2009/08 (Citta et al. 2012). Only 3 of 53 locations (~6%) fell within polynyas during the winter of 2009/10. Figure 6 shows the locations of seven tagged bowhead whales relative to ice and open water areas on 6 March 2009.

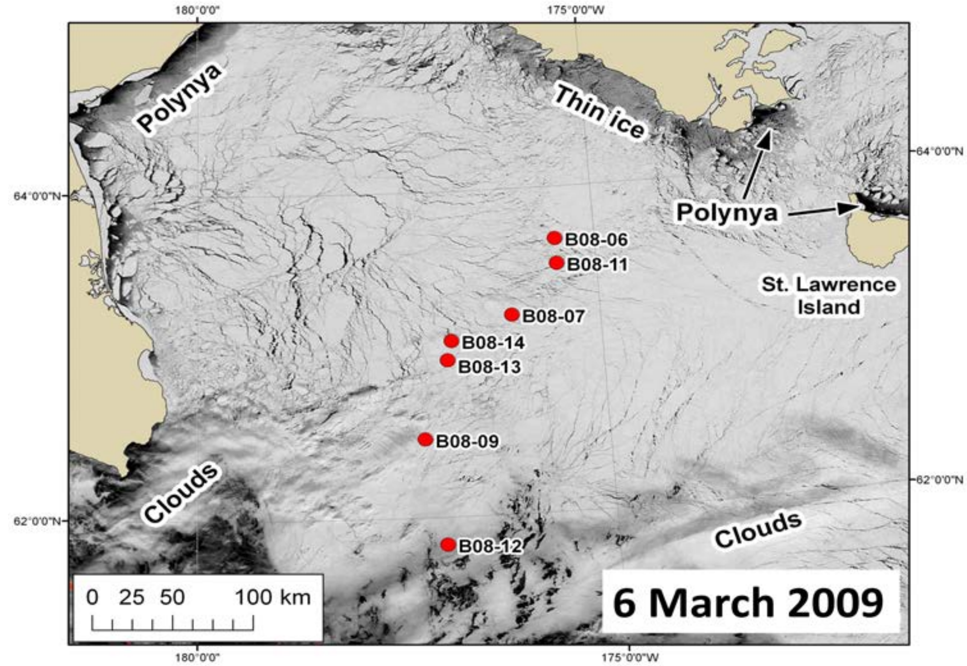


Figure 6. Locations of satellite-tagged bowhead whales (red circles) in March 2009 relative to open water areas (polynyas). Figure from Quakenbush et al. (2012).

The amount of sea ice present in this area in the winter of 2016/17 was remarkably low and there was no sea ice cover over much of the Gulf of Anadyr (Area 6). There were no tagged whales in winter 2016/17 to see how they responded to open water over much of their wintering area. If bowhead behavior was similar to that of the winters of 2008/09 and 2009/10, however, we would expect them to avoid the open water and move north or east or west rather than winter in open water (Fig. 7).

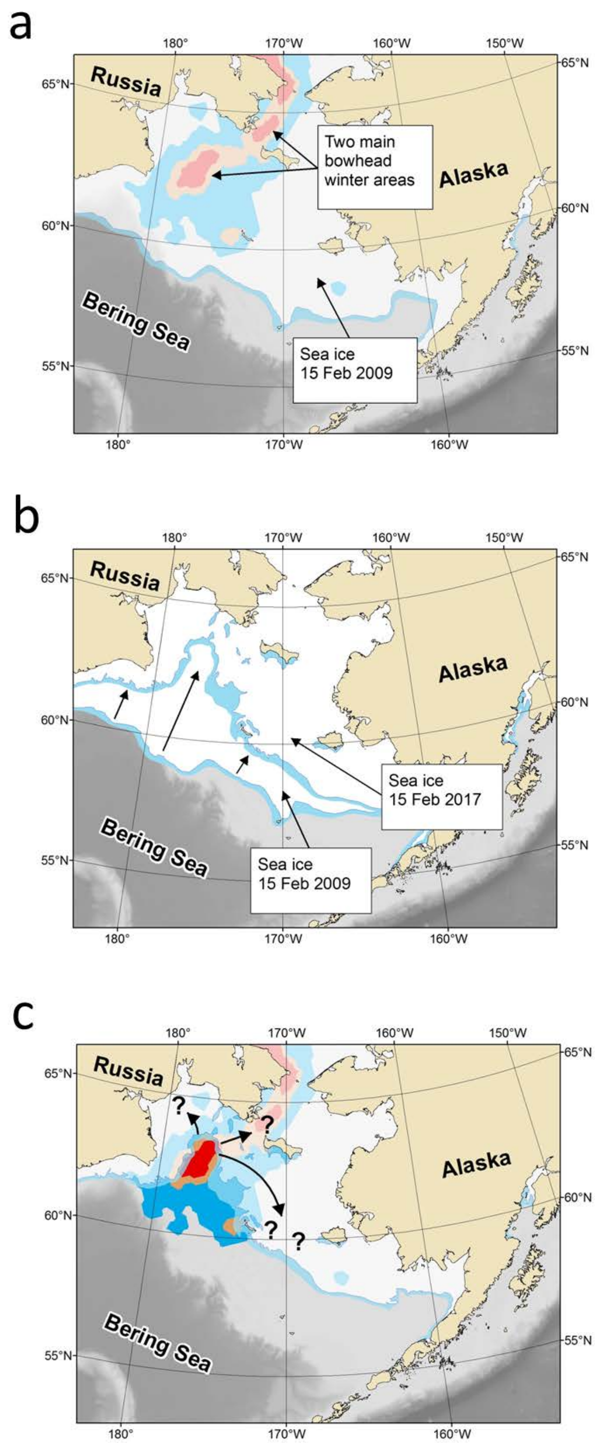


Figure 7. Sea ice extent in February 2009 (a) relative to two main bowhead whale winter areas. Change in ice extent between February 2009 and February 2017 (b) and sea ice extent in February 2017 relative to the two main bowhead whale winter areas. Question marks indicate that it is unknown where bowheads wintered because tagged bowheads have not wintered south of the ice edge or in open water during this study.

Movements and Variability of Movements. Movements among the core-use areas defined by Citta et al. (2015) appear to be timed with physical oceanographic conditions and the life history events of zooplankton (e.g., descent, ascent, and diapause) that affect the quality of an area for feeding rather than with ice retreat or formation. For example, the timing of when bowheads begin spring migration from the Bering Sea to Amundsen Gulf in the Canadian Beaufort Sea occurs before ice retreat such that bowheads are crossing the Beaufort Sea in May when the sea ice is at its heaviest of the year.

Although core-use areas are defined by repeated bowhead use, the timing and duration of use is variable. There are likely multiple ways that a core-use area may cease to be a quality feeding area. For example, zooplankton may not be present to up well even if winds are favorable, east winds may not be strong enough or last long enough, and alternatively they may last too long.

We have documented bowheads traveling to locations where they linger (assumed feeding) (Citta et al. 2015, Harwood et al. 2017) and to locations where they loop back to where they came from (Quakenbush et al. 2010, Quakenbush and Citta 2018). This return trip behavior may indicate low quality feeding at the time of the visit and a relatively low energetic cost of traveling to another location. Waiting for a location to develop into a good feeding area may include the chance that it will not develop, which may outweigh the energetic cost of traveling back to the previous feeding area or to a new potential feeding area.

The spring migration route appears to be fairly stable with bowheads leaving the Bering Sea and traveling along the Alaska coast past Point Barrow before turning east and crossing the Beaufort Sea (Fig. 11 in Quakenbush et al. 2012). Although there is often an east-west lead parallel to the coast, bowheads migrate north of it through heavy ice. The ice, however, is broken by the clockwise movement of the Beaufort Gyre (Fig. 8). This may be because the Amundsen Gulf feeding area is the only quality feeding area at that time of year and the quality may be highest early in the spring. As soon as the zooplankton concentration decreases in the Bering Sea there appears to be little incentive to stay and migration to Cape Bathurst begins.

The fall migration route is fairly stable westward in the Beaufort Sea but becomes more variable in the Chukchi Sea. Until 2017, bowheads traveling west generally stayed on or near the Beaufort shelf. One whale tagged in 2017 near Tuktoyaktuk, Canada, however traveled far offshore before heading west where it migrated over deep basin water (Quakenbush and Citta 2018).

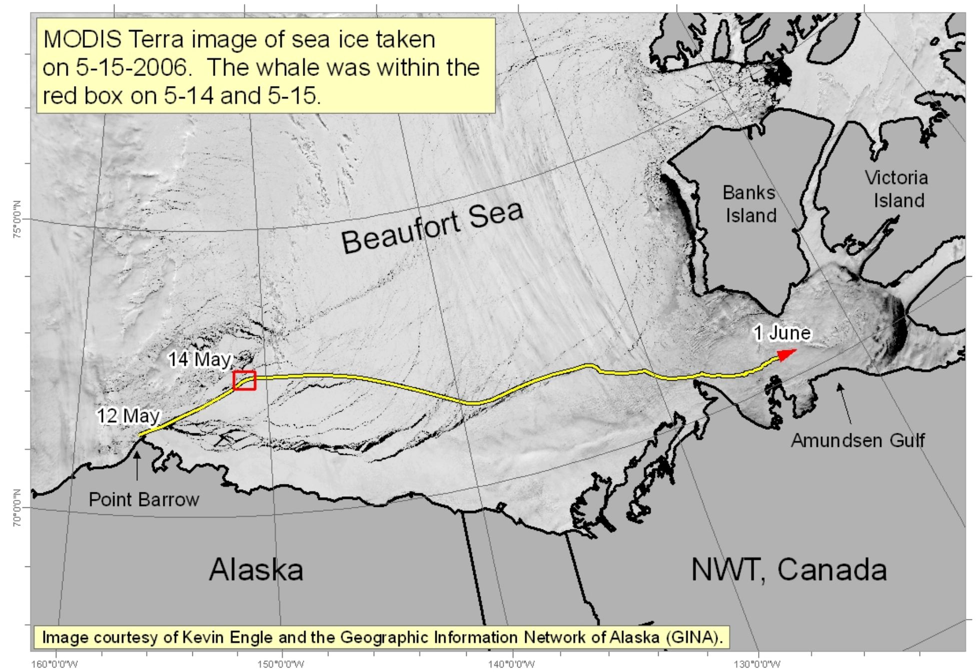


Figure 8. Spring migration route of B06-01showing the pattern of fracture of the sea ice caused by the Beaufort gyre, the east-west lead not used by bowheads, and the heavy ice in the Beaufort Sea during spring migration.

Once past Point Barrow, however, there is more variation in the route across the Chukchi Sea to the northern coast of Chukotka, Russia. Routes whales use when crossing the Chukchi Sea vary by year; in some years, whales migrate directly to the northern coast of Chukotka while in other years, whales may pause migration and linger, presumably to feed, in the central Chukchi Sea. To investigate how whale movements may be related to oceanographic variables we examined bowhead whale habitat selection within the Chukchi Sea in autumn (September–November) at two spatial scales (Citta et al. 2018). First, at the landscape scale (i.e. the Chukchi Sea), we compared oceanographic variables (e.g., temperature, salinity, and current velocity) at locations within used and randomly available tracks (i.e., paths of travel) to determine how oceanographic features are associated with where whales cross the Chukchi Sea in autumn. Second, at a local scale, we examine how directed travel or lingering within a whale's track is associated with oceanographic variables (e.g., temperature, salinity, and current velocity). Whale location data for 24 bowhead whales were paired with oceanographic data from a pan-arctic coupled ice-ocean model, the Regional Arctic System Model (RASM; Maslowski et al., 2012), for 2006–2009 and 2012. From 2006 to 2010 and in 2012, satellite tags provided enough location data to estimate locations and behaviors for 39 whales: 1 in 2006, 1 in 2007, 11 in 2008, 11 in 2009, 11 in 2010, and 4 in 2012.

We found two main movement patterns; bowhead whales spent relatively little time lingering within the central Chukchi Sea in 2008 and 2010 compared to 2009 and 2012 (Fig. 9). Neither the whale tagged in 2006 nor the one tagged in 2007 lingered in the central Chukchi, before reaching the Russian coast. These patterns could largely be explained by differences in how water masses were distributed.

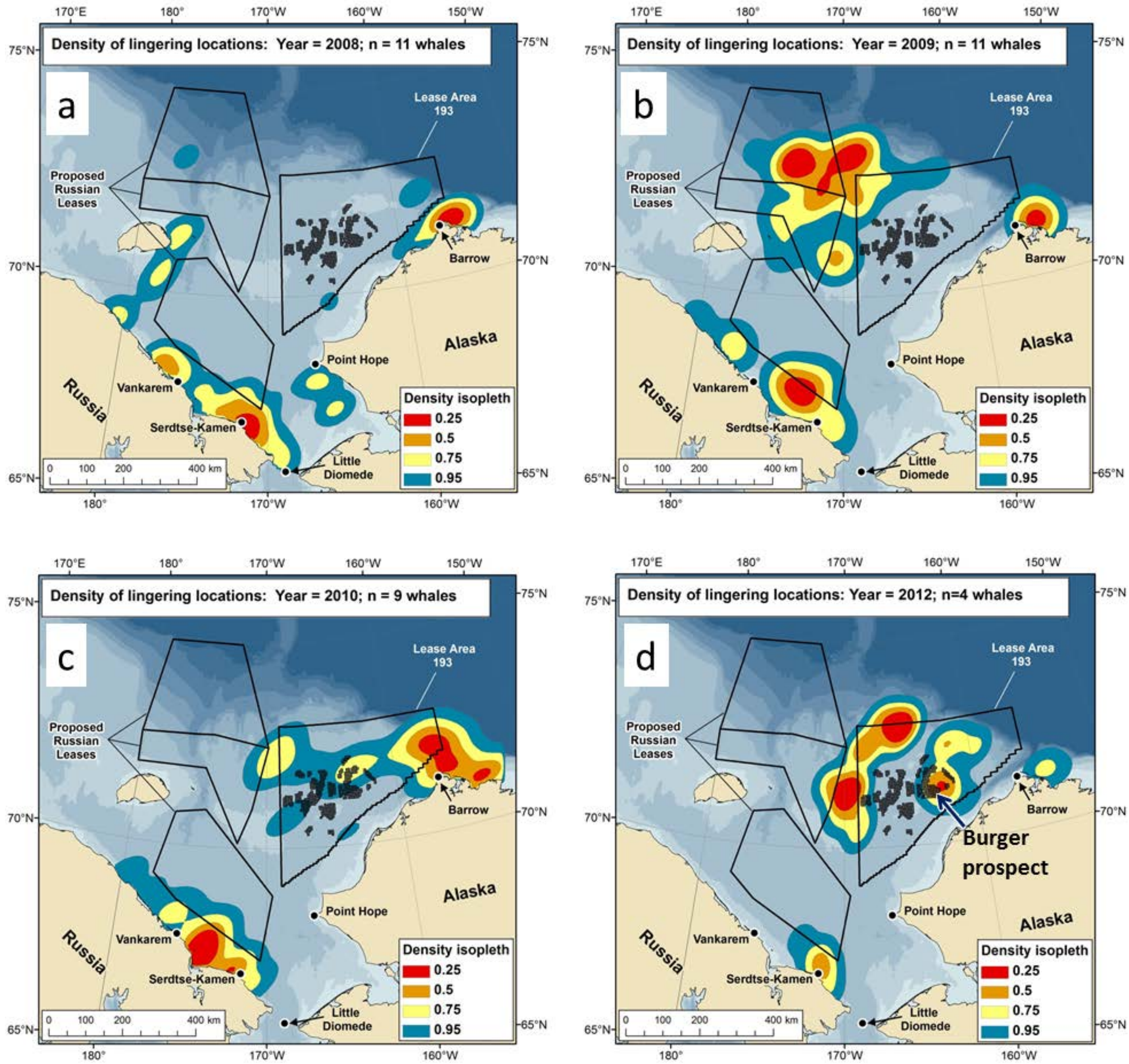


Figure 9. Kernel densities of bowhead whale locations classified as associated with lingering (presumed feeding) locations in the Chukchi Sea September–November in 2008, 2009, 2010, and 2012. Figure from Citta et al. (2018).

At the landscape scale, we found that whales generally followed water of Pacific origin characterized by temperatures < 0 ºC and salinities between 31.5–34.25 (Figs. 10 and 11). This water originates on the Bering Sea shelf and in the Gulf of Anadyr, and is known to have high densities of zooplankton (Eisner et al., 2013). In effect, bowhead whales are following the water masses that are more likely to have food. Bowhead whales avoided Alaskan Coastal Water and Siberian Shelf Water, the latter of which defines the western limit of their range. Both of these water masses are relatively fresh and they are both known to have lower densities of zooplankton (e.g., Eisner et al., 2013; Ershova et al., 2015). At the local scale, within whale tracks, whales were more likely to interrupt directed movements and linger in areas characterized by stronger gradients in bottom salinity (Fig. 12). This is likely because such gradients help aggregate zooplankton prey.

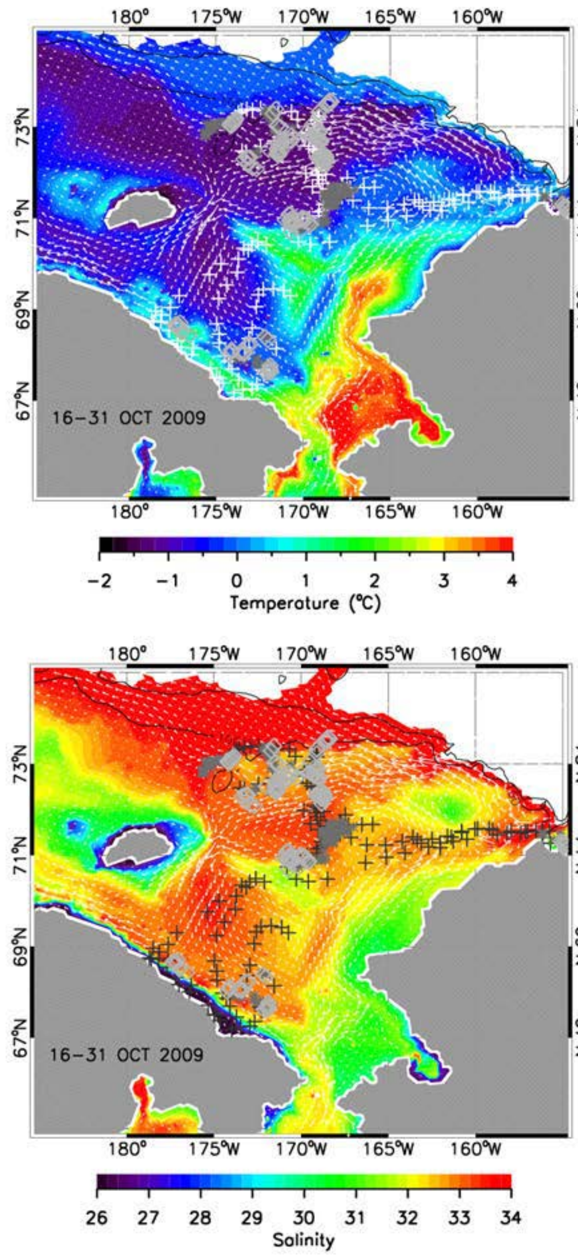


Figure 10. Example plot of temperature and salinity, averaged 16–31 October 2009. White arrows denote current vectors. Estimated bowhead whale locations and their behavior classifications overlie temperature and salinity layers. Crosses denote locations classified as "traveling", light gray open diamonds are classified as "lingering", and dark gray "x" denotes locations of unknown behavioral state. Figure from Citta et al. (2018).

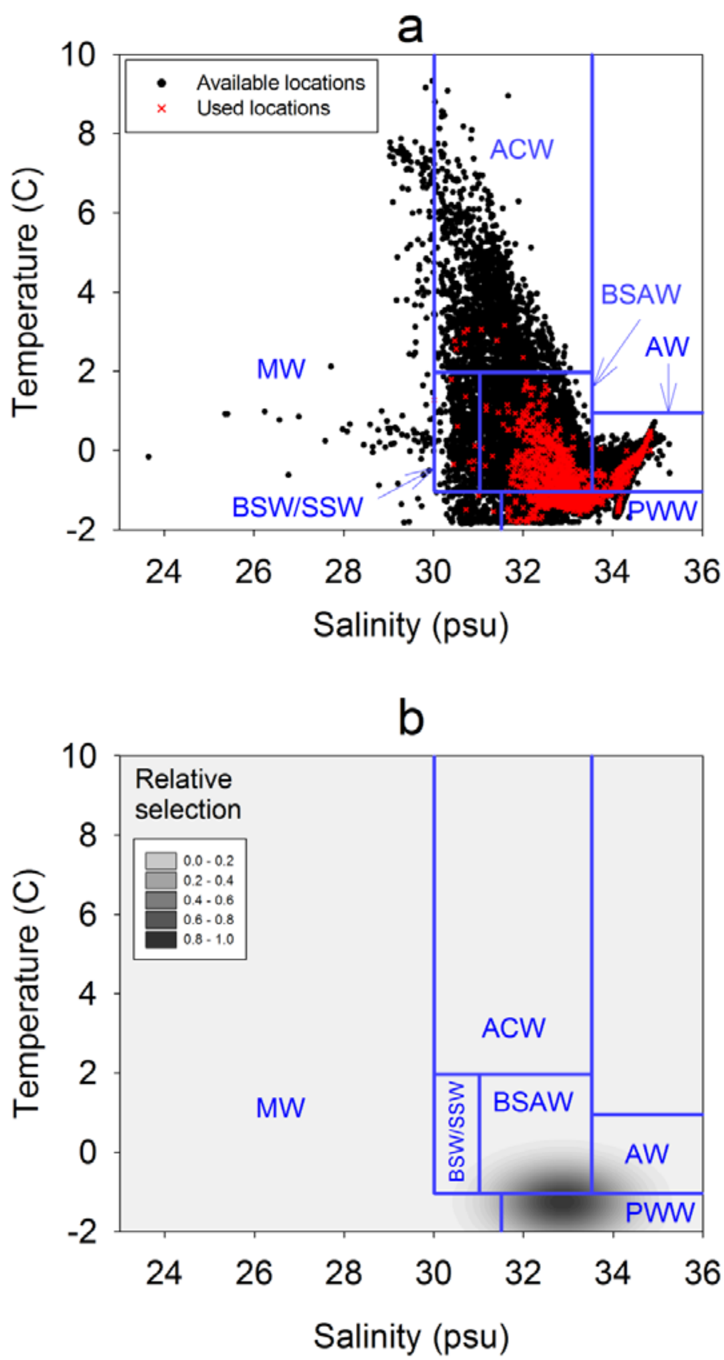


Figure 11. The distribution of all bowhead whale locations in temperature-salinity space (a) and the fit models of bowhead whale habitat selection based upon temperature and salinity (b). Tagged whales were most likely to occur in water -1.2 C and 32.75 psu; selection for other temperatures and salinities are scaled relative to this maximum. Blue boxes denote the approximate temperature-salinity signatures of different water masses, including melt water (MW), Alaskan Coastal Water (ACW), Bering Summer Water (BSW), Siberian Shelf Water (SSW), Bering Shelf/Anadyr Water (BSAW), Atlantic Water (AW), and Pacific Winter Water (PWW). Water mass boundaries are taken from Esiner et al. (2013), Gong et al. (2015), and Itoh et al. (2015). Figure from Citta et al. (2018).

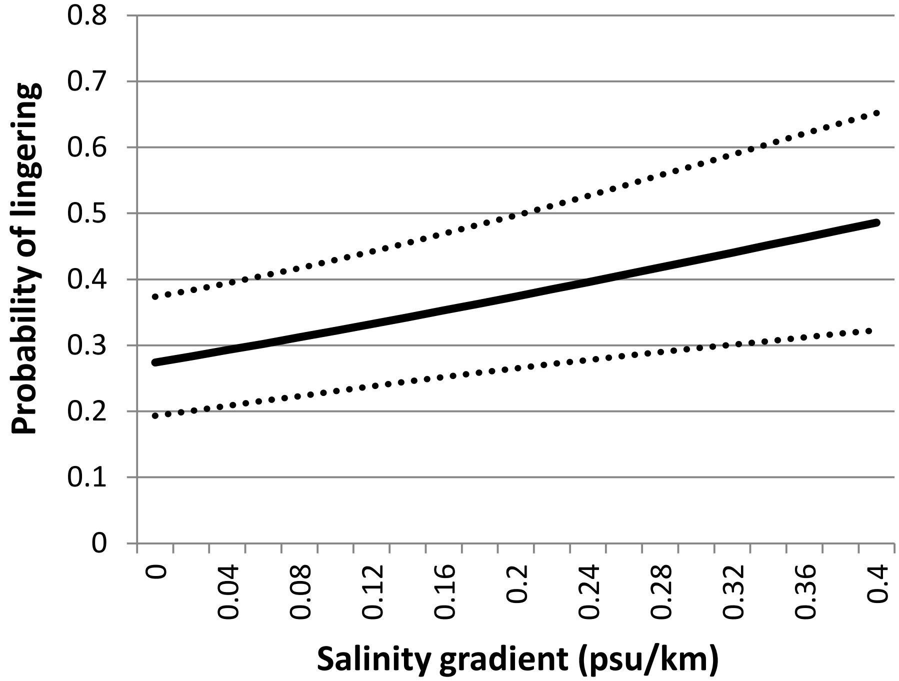


Figure 12. The probability of lingering (i.e., feeding) as a function of the maximum salinity gradient within 20 km. Dotted lines are 95% confidence limits. Figure from Citta et al. (2018).

Hence, we were able to largely explain the variation in how bowhead whales migrated across the Chukchi Sea, why bowheads do not typically migrate west of Wrangel Island (i.e., this is where relatively fresh Siberian Shelf Water occurs, which has a low density of zooplankton prey), and factors that help explain where whales pause to linger, such as salinity gradients that help aggregate prey. These relationships can be used to help predict how bowhead movements may shift as patterns in warming, winds, and/or currents change.

Prior to 2012, whales typically crossed the Chukchi Sea quickly and then traveled slowly southward along the Chukotka coast, eventually into the Bering Sea. In contrast to this, most whales in 2012 lingered within the Chukchi Sea Oil and Gas Lease Sale Area (Fig. 9d), co-occurring with drilling operations by Shell at the Burger Prospect. Whales remained in the central Chukchi Sea until sea ice formed along the northwestern coast of Chukotka. Whales then traveled to the coast of Chukotka near Bering Strait and entered the Bering Sea in early December. In 2009, whales also lingered in the north central Chukchi (Fig. 9b). During fall of 2017, one tagged whale (B17-02) entered the Chukchi Sea on 6 October from the north (through the Arctic Basin) and did not cross the Chukchi Sea shelf at all, but traveled to and along the Chukotka coast between Cape Schmidt and Vankarem from 20 October until 15 December when it left shore and by mid-January had joined the other whales tagged in 2017 lingering in the central Chukchi Sea between Vankarem, Russia, and Point Hope, Alaska. These other whales did not of migrate to the Russian coast but remained in the central Chukchi Sea until the end of January 2018 when they passed through Bering Strait into the Bering Sea.

Although we have demonstrated that bowheads prefer colder, saltier water masses (Fig. 11a and 11b) that are more likely to contain concentrations of zooplankton (Citta et al. 2018), why those water masses occasionally provide feeding opportunities in the Central Chukchi Sea is not known, but may be related to when northeast winds disrupt the Alaska Coastal current. Zooplankton are known to be advected onto the shelf near Point Barrow during east winds and get trapped when east winds slacken (i.e., “the krill trap”; Ashjian et al. 2010; Okkonen et al. 2011). However, when east winds persist, the “trap” may not develop and zooplankton may be advected west and available to bowheads in the north central Chukchi (Citta et al. 2018).

We have explored the physical oceanographic characteristics of core-use areas and found remarkable associations with conditions that concentrate weak swimming prey and the presence of bowhead whales (Citta et al. 2015, Citta et al. 2018). Alternatively, we have found that when those conditions break down, bowhead whales leave for another core-use area, and occasionally they loop back.

We have also explored the relationship of bowhead whales and sea ice. Ice cover has decreased more in the core-use areas, as defined by Citta et al. (2015), in the northern extent of bowhead range than in core-use areas in the southern extent. The number of open water days within the core-use areas near Point Barrow and along the northern Chukotka Coast during peak use has increased by 13 and 10 days/decade, respectively. The most dramatic reductions in sea-ice cover have taken place in the Alaskan Beaufort Sea where the number of open water days on the shelf and slope has increased by 20 and 25 days/decade, respectively (Druckenmiller et al. 2017). Using aerial survey data, we found that in the fall bowheads migrate closer to shore when there is less sea ice and farther from shore when there is more sea ice. We speculate that this might be because there are increased feeding opportunities closer to shore as a result of greater upwelling along the shelf break when the ice cover is farther from shore. Furthermore, the aerial survey data also revealed that high use areas within the Alaskan Beaufort Sea have shifted westward, toward Point Barrow, during fall in the period 1997–2014 compared to 1982–1996. As sea ice declines, we expect that northern core-use areas will be available to bowheads for longer periods, resulting in bowheads lingering in regions farther north through late fall, prior to entering the Bering Sea (see Discussion in Drukenmiller et al. 2017). The movement of bowhead whales away from the northern coast of Chukotka into the Bering Sea is correlated with ice formation and the breakdown of the strong coastal salinity front (Citta et al. 2015). Freeze-up restricts the input of fresh water entering the Siberian Coastal Current, weakening this front (see Fig. 8 in Citta et al., 2015) and possibly reducing the density of zooplankton. We would expect that a later freeze-up (as shown in Fig. 12) would lead to whales feeding along the northern Chukotka Coast for a longer period in fall. Salinity fronts created by Alaska Coastal water (Citta et al. 2018) may create similar feeding situations when Alaska Coastal Water plumes into the central Chukchi. We anticipate that bowheads will spend increasingly more time within summer and fall feeding areas, delaying their migration to the Bering Sea. Reduced ice coverage and thickness in the southern Chukchi Sea may make wintering there more common in the future. Indeed, the whales we tagged in 2017 delayed their entry into the Bering Sea until mid- to late-January 2018 and then returned north, well into the Chukchi Sea, in mid-February, when previous winter core-use areas that were ice-covered became ice free, possibly due to strong south winds.

Potential Disturbance. Commercial activities such as oil and gas exploration and development, fishing, and shipping have the potential to disrupt or displace bowhead movements, migrations, and feeding.

Oil and Gas: The areas of interest for oil and gas activities coincide in time and space with the major bowhead summer feeding area near the Tuktoyaktuk Peninsula in Canada (Fig. 13) and along the fall migration corridor in the Alaskan Beaufort Sea and in the Chukchi Sea (U.S. and Russia). For example, one tagged whale went through four active industrial areas in 2006, seismic operations were occurring in two of the areas when the whale passed (Fig. 14). If multiple seismic operations are planned in summer and fall within BCB bowhead range, timing should be coordinated to minimize interactions in time and space by multiple oil companies in multiple countries.

The one detailed occurrence of a tagged whale and a seismic operation suggested that when bowheads are feeding, the activities of a seismic operation may not totally displace whales from that feeding location. The closest distance of this whale to the ship conducting a 2-D seismic survey from 31 August to 4 October was 9.2 km. This whale remained in the active seismic area for 17 days. The whale left the area on 3 October to begin the westward migration, one day before the seismic operation was completed. This whale did not migrate early and such behavior suggests that feeding in this core-use area (Area 2 in Citta et al. 2015) is important and that feeding whales may be more tolerant of anthropogenic activities than migrating ones. This apparent tolerance of seismic activity also suggests that "ramping up" a seismic array so that the noise level increases slowly as airguns are turned on incrementally instead of all at once so that animals can leave the area before the noise reaches the maximum may not be effective for bowhead whales.

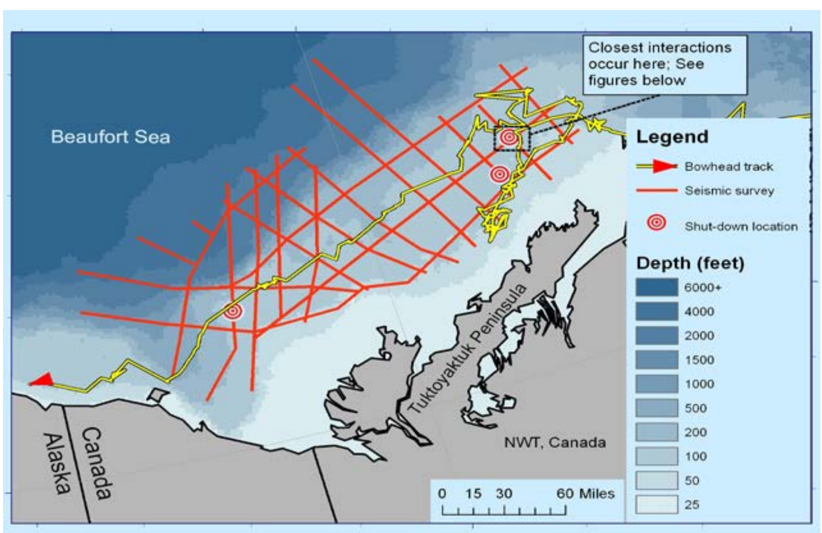


Figure 13. Tracks of a tagged bowhead whale (yellow line) within a marine seismic operation in the Canadian Beaufort Sea in 2006. The seismic operation occurred from 31 August to 4 October and the tagged whale remained in the seismic area from 16 September until 3 October when it began the westward migration. Note however the seismic area was identified as a core-use area (Area 2) by Citta et al. (2015) and likely important for feeding.

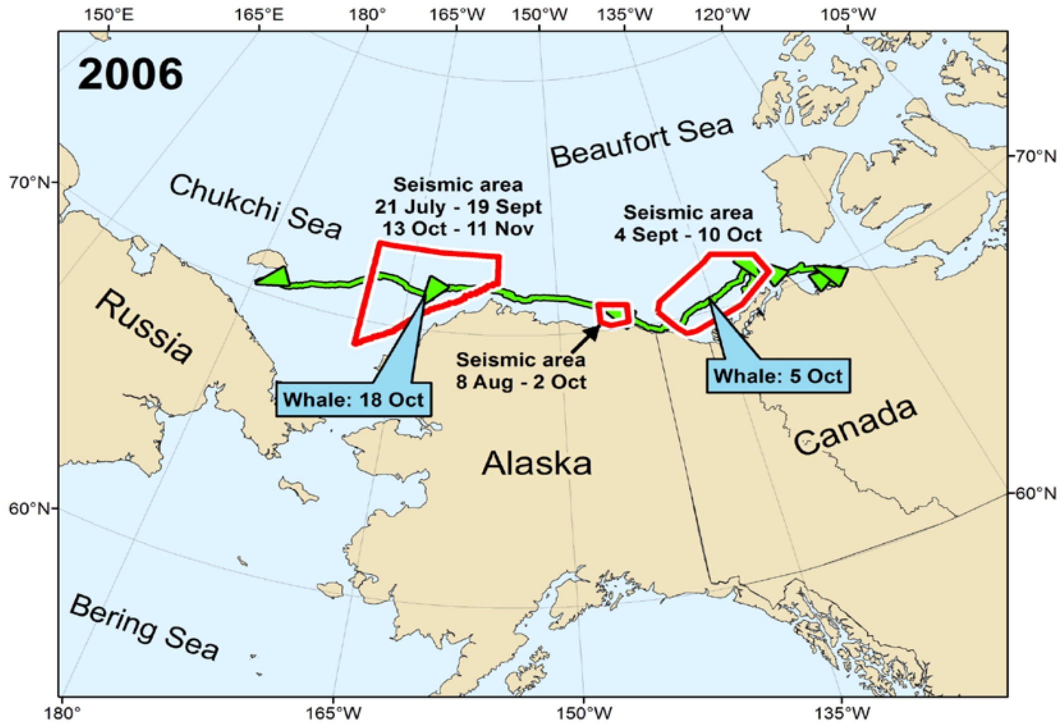


Figure 14. Track of a tagged bowhead whale and active industrial areas in 2006.

Commercial Fishing: Entanglement in fishing gear is a threat to bowhead whales. Harvested bowheads have a high incidence of scaring from lines thought to be mostly from pot gear used for cod and crab fishing in the Bering Sea (George et al. 2017). Bowhead whaling captains and the AEWC were concerned about the number of bowheads with scars from having been entangled and the number of whales towing gear. They requested an analysis of the overlap of tagged bowheads and the winter crab fisheries to better understand the spatial and temporal overlap and potential risk from entanglement. We analysed winter data from 21 tagged whales for the winters of 2008/09 and 2009/10 and found that in U.S. waters bowheads remained in areas with >90% ice cover, which is too heavy for crab boats to work in (Citta et al. 2014). Although pots are not dropped close to the ice edge, the ice can move quickly and overrun the active fishing gear, resulting in lost gear, which is the most likely cause of entanglement. During spring whaling near Utqiaġvik, Alaska, in 2017 two harvested bowheads were towing pot fishing gear (J.C. George, pers. comm.). Because there was so little ice in the Bering Sea in the winter of 2016/17 (Fig. 7) the whalers were concerned that bowheads were somehow becoming more vulnerable to entanglement in pot fishery gear. Another analysis showed that the pot fisheries in the U.S. had not moved north, however there were no tagged whales to provide information about bowhead distribution and use of the Bering Sea in that year. There are known to be Russian pot fisheries in the western Bering Sea as well, but no information could be found about the location and timing of their activities.

Commercial Shipping: Commercial shipping and ship-based tourism in the Arctic has increased as sea ice has decreased. Both shipping routes, the Northern Sea Route along the northern Russian coast, and the Northwest Passage through the Canadian Archipelago, go through Bering Strait. The entire population of BCB bowhead whales (>17,000 individuals) passes through Bering Strait each spring and fall between wintering and summering areas. As such, Bering Strait is an area of concern for interactions with ship traffic (Reeves et al. 2012). Ships traveling on the west side of the Diomedes and along the Chukotka coast between October and December could encounter a high proportion of the population (Figs. 15 and 16). Ship strikes in the Atlantic are the greatest source of mortality for right whales (*Eubalaena glacialis;* Moore et al. 2004). It is thought that bowhead whales may be as vulnerable to ship strikes as Atlantic right whales, due to their slow swimming speed and feeding behavior (Reeves et al. 2012); however, bowheads are known to be more sensitive and more difficult to approach during migration than when feeding(Richardson 1999).

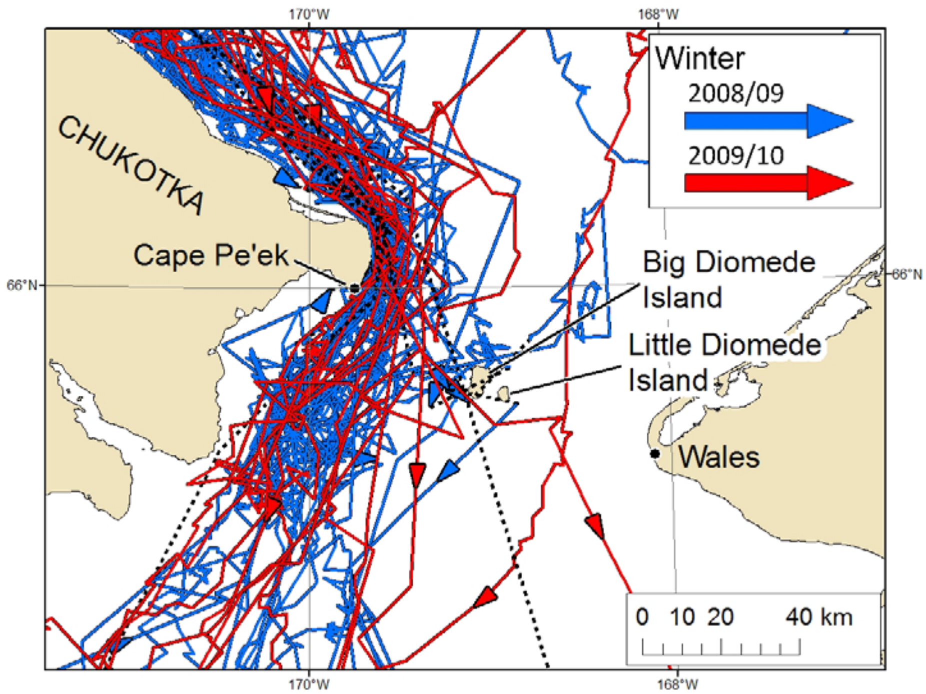


Figure 15. Tracks of tagged bowhead whales moving south through Bering Strait into the Bering Sea during the winters of 2008/09 (n=11) and 2009/10 (n=10). Dotted lines indicate connected locations that crossed landforms. Figure from Citta et al. (2012).

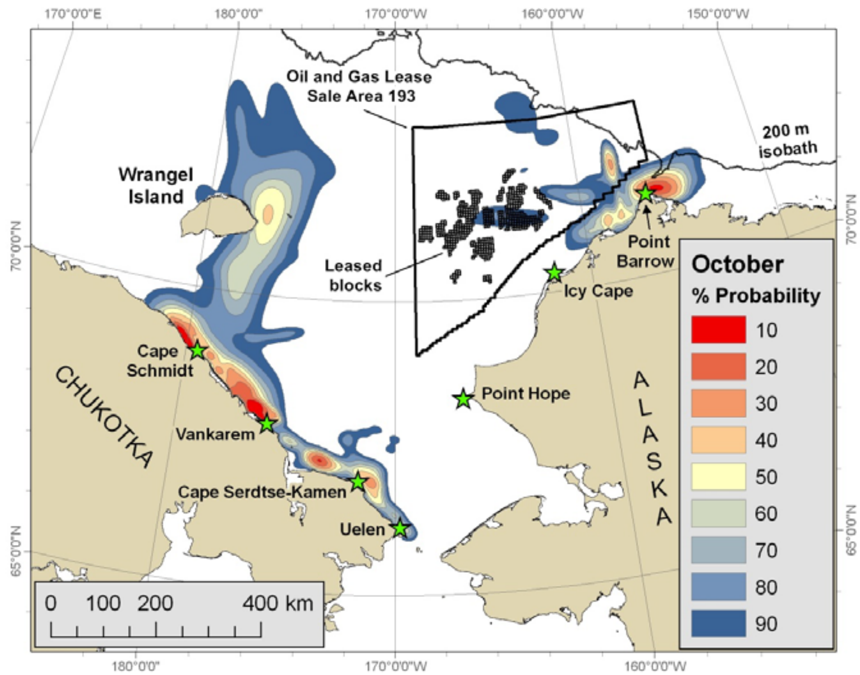


Figure 16. Kernel density contours showing the probability of use (%) by bowhead whales in October, 2006–2008. This is Figure 5 in Quakenbush et al. 2010a.

Evidence of Population Sub-structure. Satellite tagging studies are not ideal for studying stock structure if the location or movement behavior of separate stocks is unknown. For example, if two stocks existed and we tagged whales from one location, frequented by one stock, we may erroneously conclude that only one stock exists. With that said, satellite telemetry could identify separate stocks if individuals from each stock are tagged and then used winter, summer, or foraging areas unique to each stock. To-date, we have found no evidence from movements that sub-stock structure exists within the BCB stock. Whales tagged from St. Lawrence Island, Utqiaġvik, and a number of sites near the Mackenzie River Delta in Canada show similar movements.

Melnikov and Zeh (2007) documented whales migrating past Cape Pe'ek, on the Russian side of Bering Strait. Based upon swim speeds and the late date of observations, it was unlikely that these whales were migrating past Point Barrow—if they did it would have been mid-to-late June. As such, whales that summer along the Russian coast in the Chukchi Sea are the most likely candidate for a separate stock within the BCB population. However, movement data do not support the idea that there might be spatially distinct populations in summer. To-date, every tagged whale but one has migrated to the Canadian Beaufort in spring. The only whale that did not migrate to the Canadian Beaufort was B09-09, which was tagged near Point Barrow in the fall of 2009. The following year, this whale summered along the Russian coast of the Chukchi Sea (see Citta et al. 2012). We think it unlikely that this whale returned to Point Barrow that fall.

It is unlikely that whales summering in the Chukchi Sea are spatially separated from whales that summer in the Canadian Beaufort. The whale that summered in the Chukchi (B09-09) was tagged near Point Barrow and was likely migrating from the Canadian Beaufort (although this is unknown). Furthermore, we have observed that many other tagged whales leave the Canadian Beaufort Sea in mid-summer and migrate to this same area along the Russian coast in the Chukchi Sea. Such movements from the Canadian Beaufort to the Russian coast occurred in the summer of 2010 and 2012.

In addition, we found no evidence of spatial segregation on the wintering grounds (also the breeding season) in the Bering Sea. Although two main wintering areas have been identified (Area 5 and Area 6; Fig. 4; Citta et al. 2015), most whales use both areas in the same winter. Of the 28 whales that used Area 5 (Anadyr Strait), 19 (70%) also used Area 6 (Gulf of Anadyr). Furthermore, Areas 5 and 6 are not truly distinct because the entire corridor from Bering Strait, through Anadyr Strait, to the shelf break received high use and is within the 50% core use area. A difference in use between the two areas is more likely determined by sea ice extent. Bowhead whales do not typically migrate south of the sea ice boundary and the southernmost parts of their range are often ice-free.

Hence, the movement data collected to-date have not identified separate feeding or wintering areas that might be indicative of separate stocks.

Summary. In general, movements of tagged bowhead whales described here are consistent with published literature regarding migratory behavior (Braham et al. 1979, Moore et al. 1995, Mate et al. 2000, Moore and Reeves, 1993). However, our study provided new information including:

1) specific wintering areas, affinity for sea ice, and diving to the bottom in the Bering Sea;
2) a whale that did not pass Barrow on the spring migration, summered in the Chukchi Sea, and would not have been counted during spring ice-based surveys;
3) extensive summer movements include travel far to the north and northeast overlapping with bowheads from the Baffin Bay-Davis Strait stock, summer travel between Canada and Barrow, and between Canada and the Chukchi Sea, in addition to the spring and fall migrations;
4) fall movements coincided in space and time with industrial activities (i.e., oil and gas, potentially shipping);
5) six core-use areas were identified as probable feeding areas; these areas include: Amundsen Gulf, Tuktoyaktuk Shelf, Point Barrow, Chukotka coast, and two areas in the Bering Sea;
6) annual variability in migration routes and timing especially across the Chukchi Sea; and
7) recent changes in summer movements (i.e., greater use of mid and western Beaufort Sea) and speculated less use of previous core-use areas in the Bering Sea in winter that were largely ice-free in winter 2016/17 and 2017/18.

This telemetry study was not designed to address stock sub-structure, and more widely distributed tagging locations would be better for such an analysis. Nevertheless, none of the movements from tagged whales suggest a multi-stock condition exists within BCB bowhead whales. The one whale that did not pass Point Barrow in the spring and instead summered in the Chukchi Sea was tagged near Point Barrow in August the previous year. This behavior suggests that individuals may change their summer areas from year to year, possibly due to their reproductive condition. For the two BCB whales that traveled into the range of the Baffin Bay-

Davis Strait stock, both did so during the non-breeding season and both returned to their respective stock's range in fall prior to the normal fall migration.

ACKNOWLEDGMENTS
This project would not be possible without the hard work and intense interest of many people including the following cooperators: the North Slope Borough, the Alaska Eskimo Whaling Commission, the Barrow and Kaktovik Whaling Captains' Associations, Aklavik and Tuktoyaktuk Hunters and Trappers Committees, the Department of Fisheries and Oceans Canada, and the Greenland Institute of Natural Resources. Taggers included Harry Brower, Jr., Lewis Brower, Billy Adams, George Tagarook, James Pokiak, Charles Pokiak, and Gary Raddi, Jr. Robert Small assisted with tagging and logistics in Canada. Mikkel and Anders Villum Jensen built the tagging equipment and assisted with tagging. Stephen Okkonen provided valuable oceanographic information, insight and interpretation. GX Technology provided seismic data for 2006. Funding was provided by the U.S. Minerals Management Service (now the Bureau of Ocean Energy Management) with assistance from Charles Monnett, Jeffery Denton, and Carol Fairfield. Additional funding for tagging in Canada was provided by the Fisheries Joint Management Committee, Ecosystem Research Initiative and the Panel for Energy Research and Development. Research was conducted under the following permits in the U.S.: NMFS 782-1719 and 14610, 18890; ADF&G IACUC 06-16, 09-21, 2010-13R, 2012-20, 2013-20, 2014-03, 2015-25, and 2016-23.; and in Canada In Canada, research was conducted under Department of Fisheries and Oceans Scientific License Nos. S-07/08-4007-IN, S-08/09-4000-IN, S-09/10-4005-IN-A1, S-14/15-1027-NU, S-16-17-3035-YK Lea, and Animal Care Protocols FWI-ACC-2007-2008-013 and FWI-ACC-2008-031, FWI-ACC-2009-019, FWI-ACC-2014-048, AUP 2016-045.

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Appendix T.

Satellite Tracking of Bowhead Whales Relative to Camden Bay

Prepared for the Camden Bay Collaborative Study

Prepared by Lori Quakenbush and John Citta
Alaska Department of Fish and Game

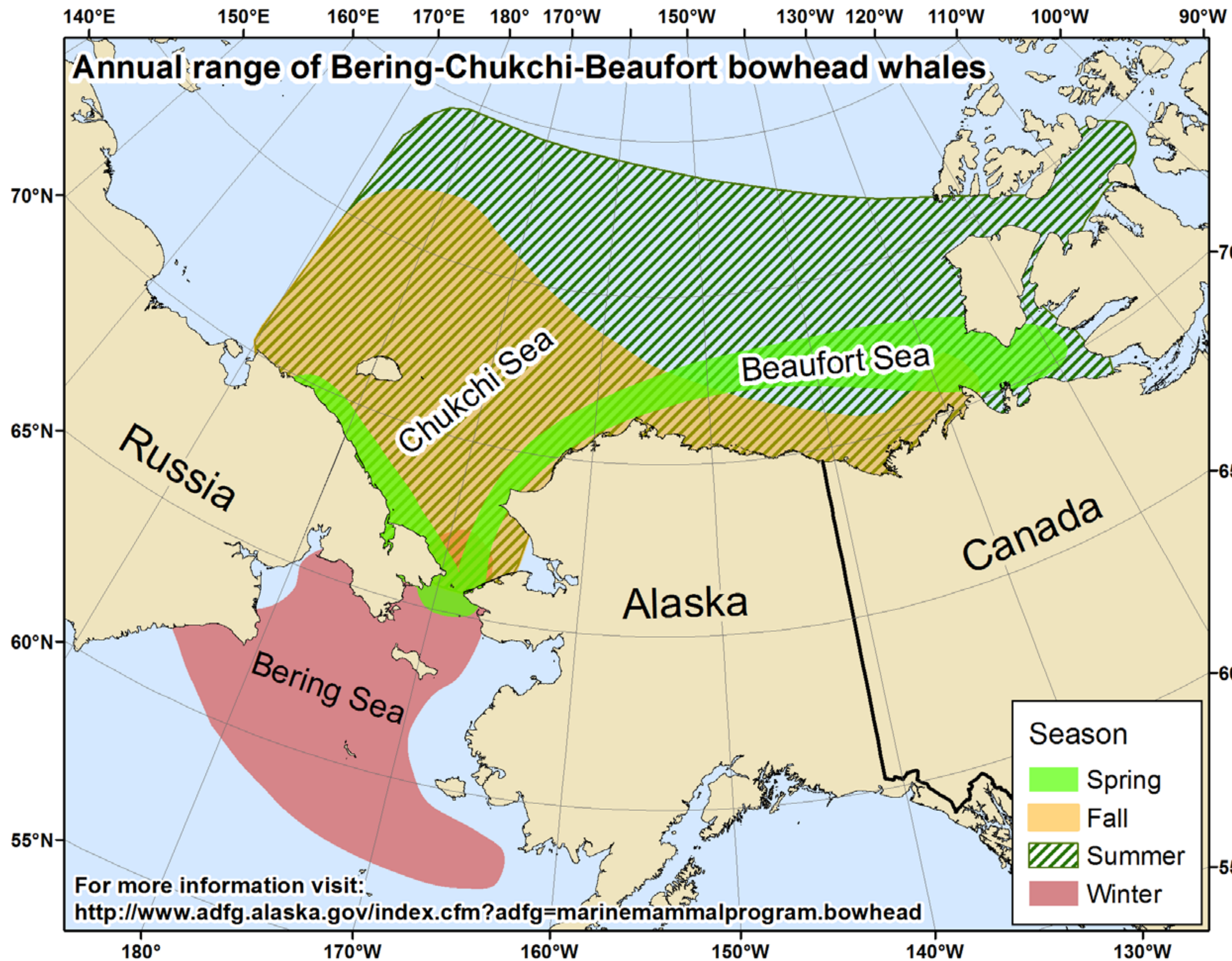
Project Partners include AEWC, NSB, DFO Canada, and Native Whalers as taggers, boat drivers and study consultants.

Project has been funded by MMS/BOEM since 2005 and by ONR since 2016

Data

Between 2006 and 2017, working with subsistence whalers in Kaktovik, Barrow, Savoonga, Gambell, in Alaska, and hunters in Tuktoyaktuk, Aklavik, and Inuvik, in Canada, to deploy satellite transmitters on bowhead whales.

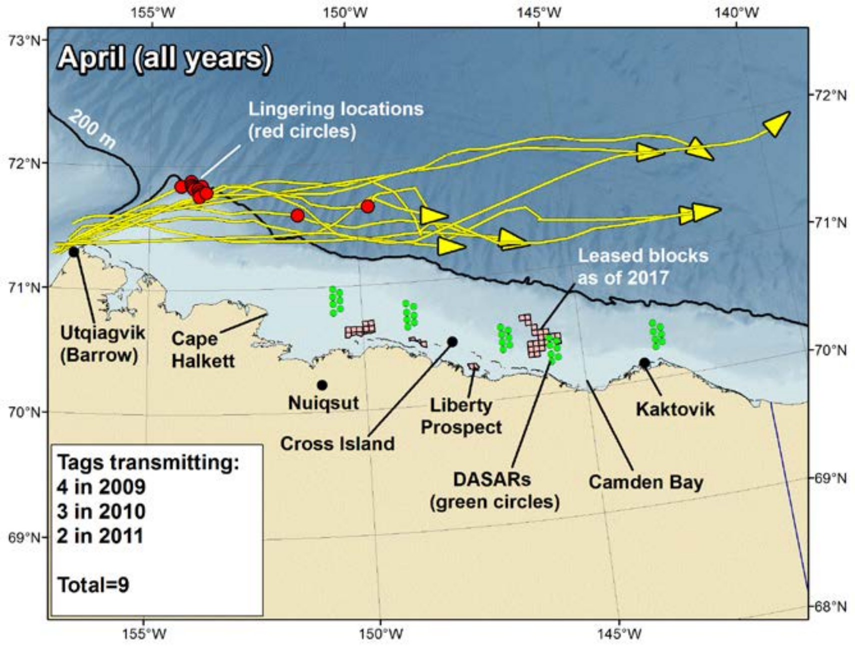
A total of 41 whales have enough data to map their movements through time in the Alaskan Beaufort Sea.

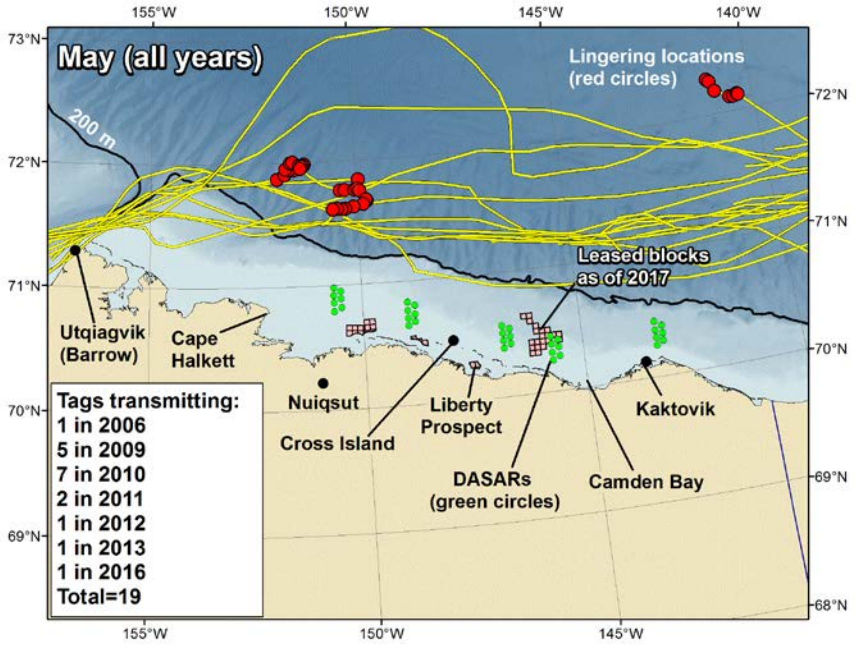


Annual range of Bering-Chukchi-Beaufort bowhead whales
140°E
150°E
160°E
170°E
180°
170°W
150°W
130°W
120°W
110°W
100°W
90°W
70°N
65°N
60°N
55°N
70°N
65°N
60°N
55°N
Chukchi Sea
Beaufort Sea
Russia
Canada
Alaska
Bering Sea
Season
Spring
Fall
Summer
Winter
For more information visit:
http://www.adfg.alaska.gov/index.cfm?adfg=marinemammalprogram.bowhead
180°
170°W
160°W
150°W
140°W
130°W

Results

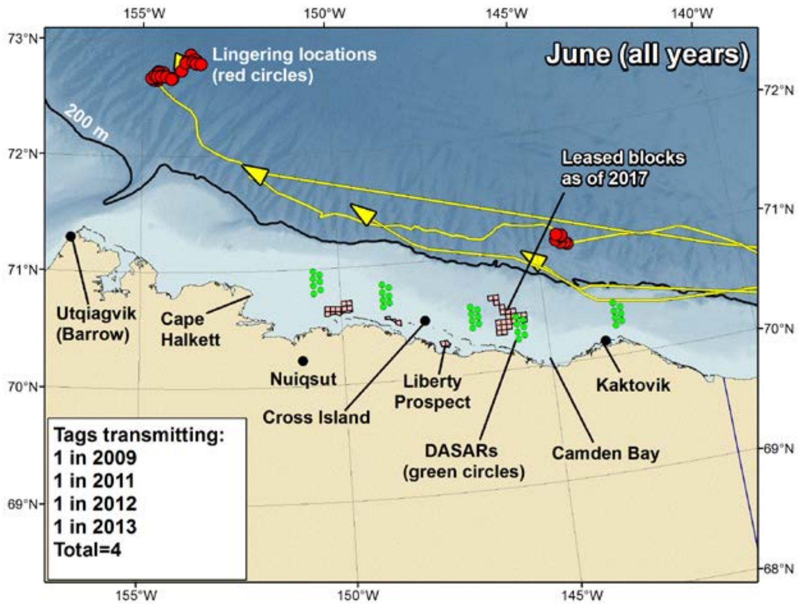
1. We observed few movements consistent with feeding during the spring migration (April-May)

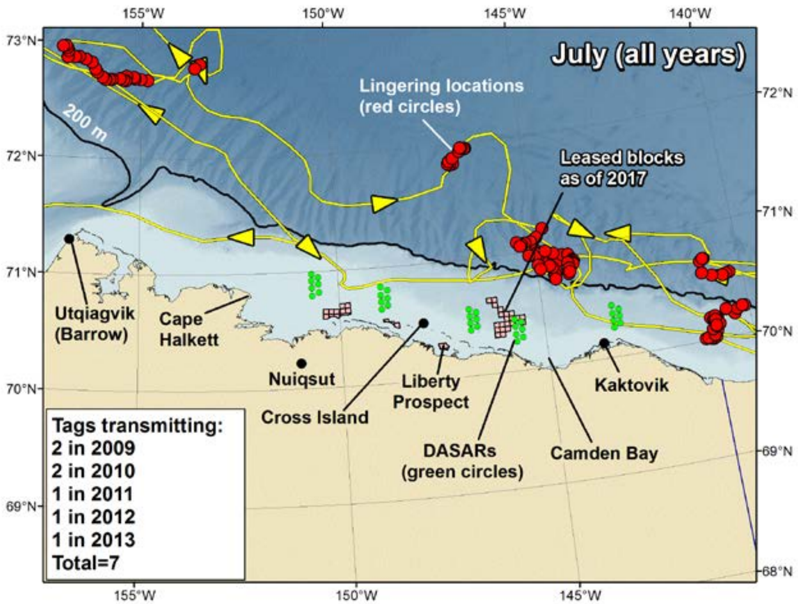


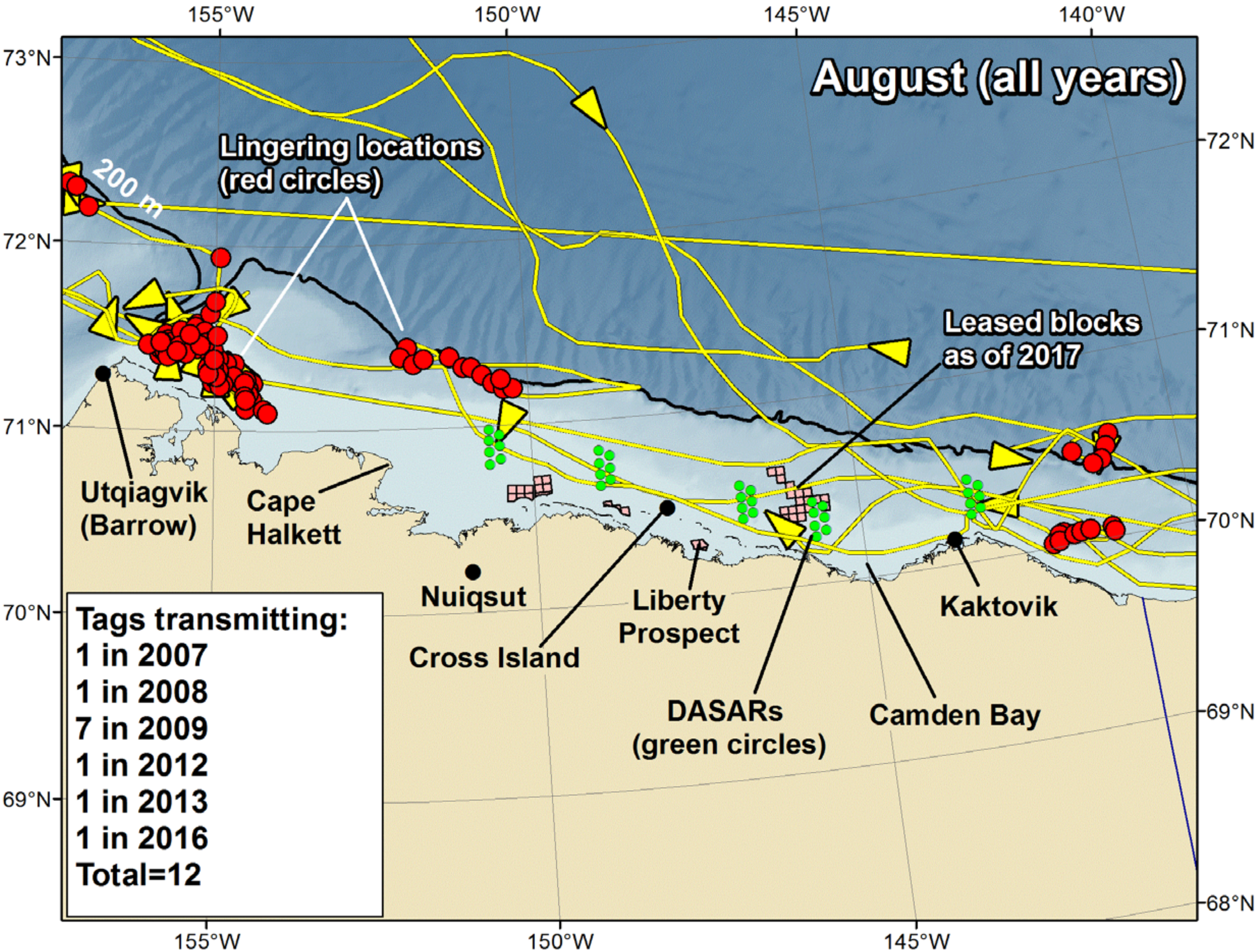


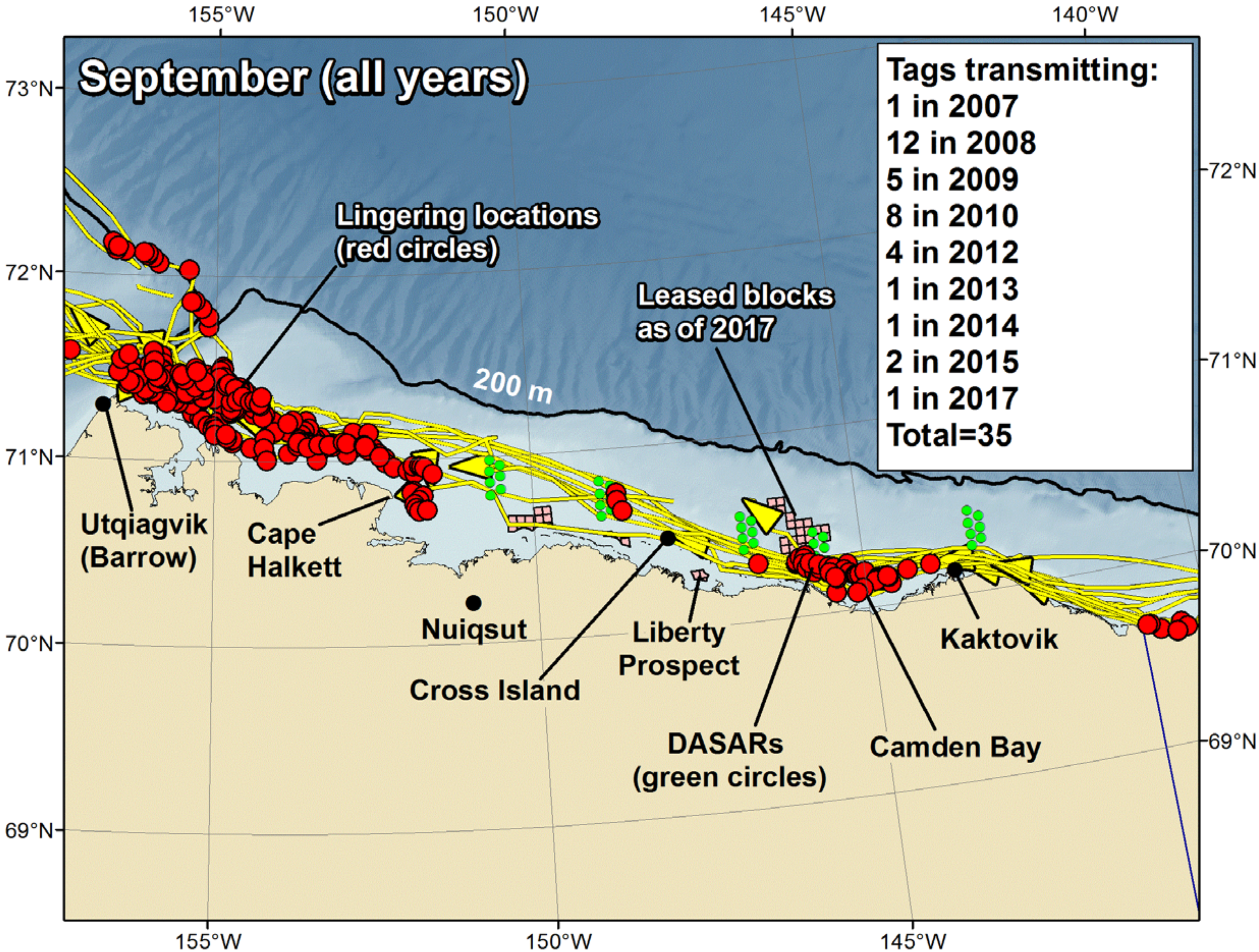
Results

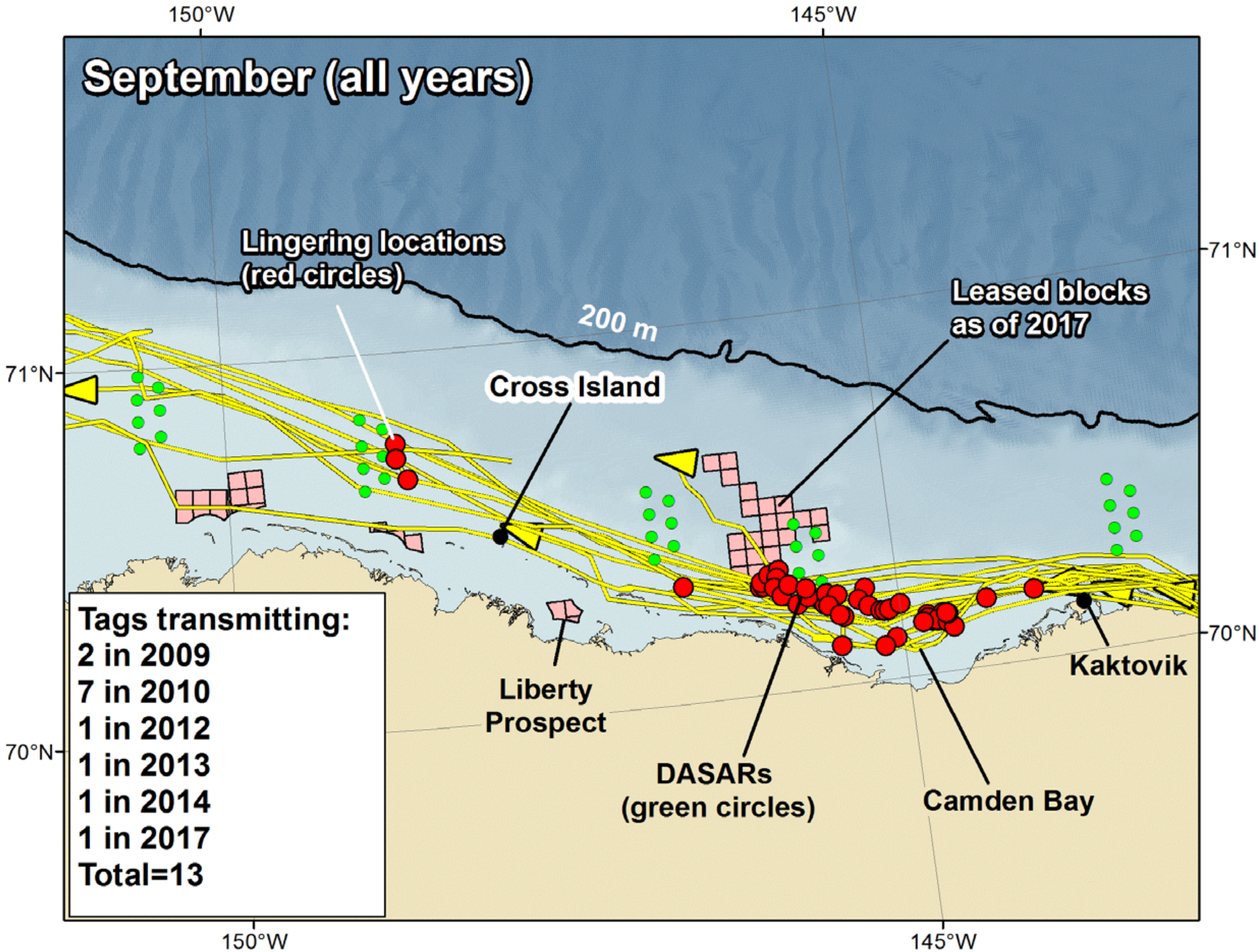
2. Some whales are in the Alaskan Beaufort between the spring and fall migrations. These migrated to the Canadian Beaufort before returning to Alaskan waters. Much of this movement is off-shore.

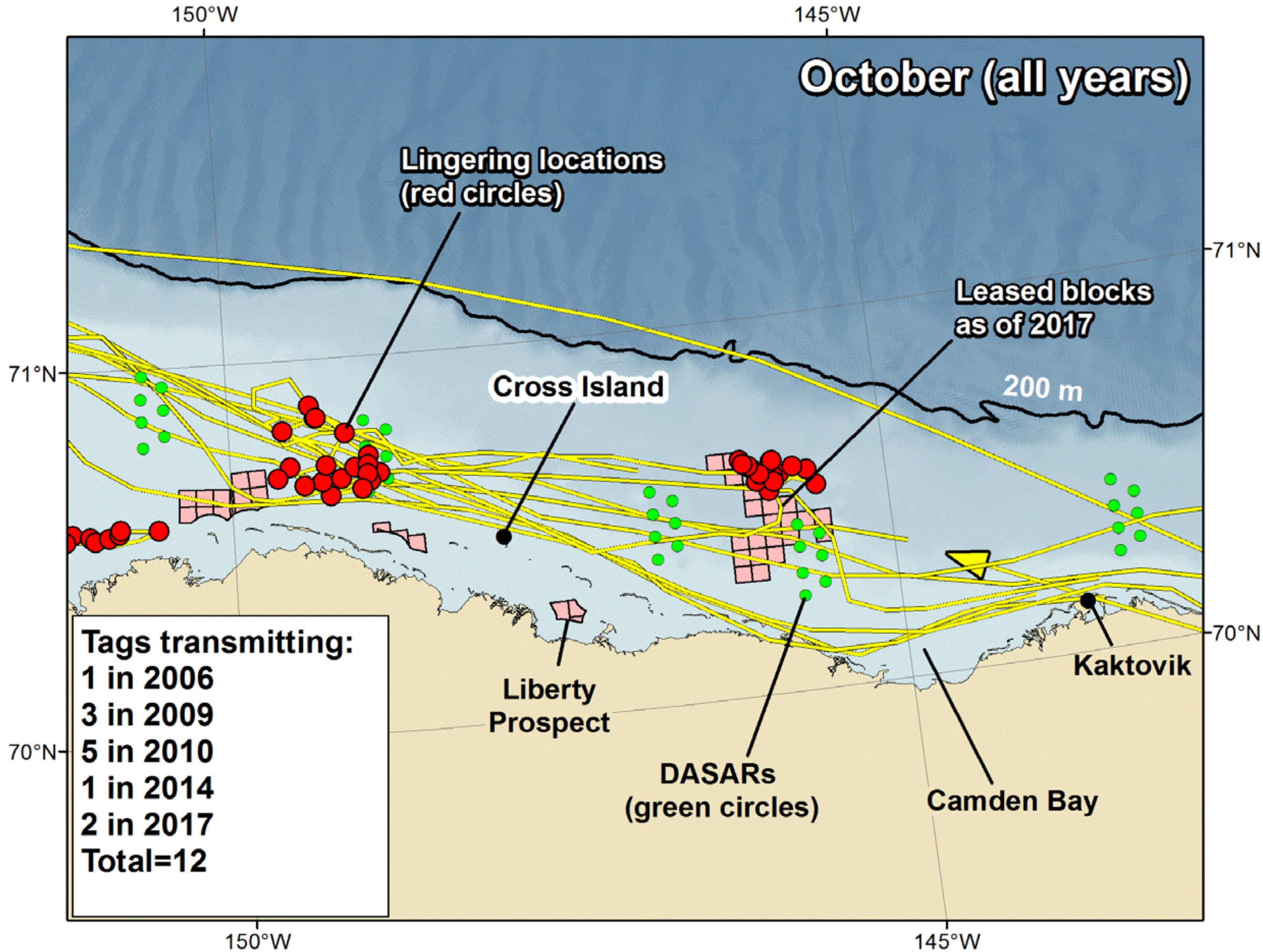





August (all years)
Lingering locations (red circles)
200 m
Leased blocks as of 2017
Utqiagvik (Barrow)
Cape Halkett
Nuiqsut
Cross Island
Liberty Prospect
DASARs (green circles)
Camden Bay
Kaktovik
Tags transmitting:
1 in 2007
1 in 2008
7 in 2009
1 in 2012
1 in 2013
1 in 2016
Total=12
155°W
150°W
145°W
140°W
73°N
72°N
71°N
70°N
69°N
68°N

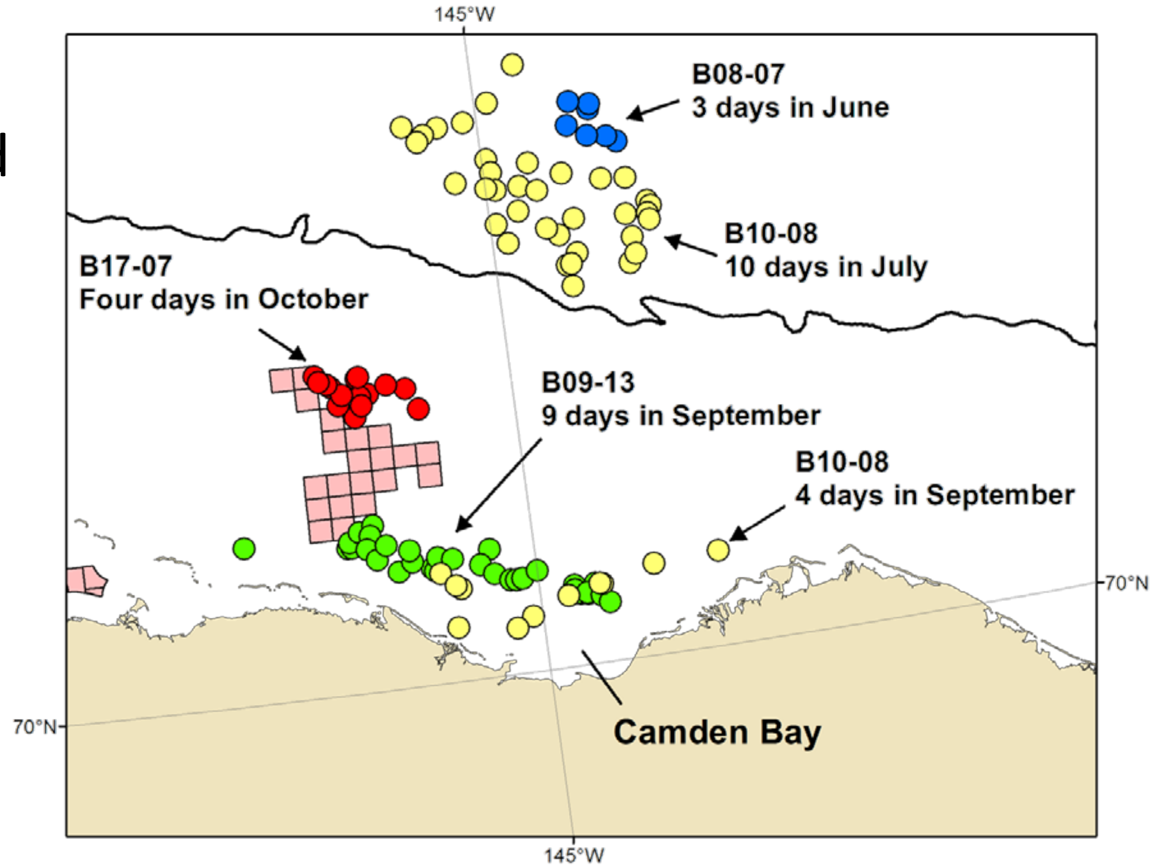

September (all years)
Tags transmitting:
1 in 2007
12 in 2008
5 in 2009
8 in 2010
4 in 2012
1 in 2013
1 in 2014
2 in 2015
1 in 2017
Total=35
Lingering locations
(red circles)
Leased blocks
as of 2017
200 m
Utqiagvik
(Barrow)
Cape
Halkett
Nuiqsut
Cross Island
Liberty
Prospect
DASARs
(green circles)
Camden Bay
Kaktovik
155°W
150°W
145°W
140°W
73°N
72°N
71°N
70°N
69°N


150°W
145°W
September (all years)
Lingering locations
(red circles)
200 m
Leased blocks
as of 2017
71°N
Cross Island
70°N
Liberty
Prospect
DASARs
(green circles)
Camden Bay
Kaktovik
Tags transmitting:
2 in 2009
7 in 2010
1 in 2012
1 in 2013
1 in 2014
1 in 2017
Total=13


150°W
145°W
October (all years)
Lingering locations
(red circles)
71°N
Leased blocks
as of 2017
71°N
Cross Island
200 m
70°N
Kaktovik
Tags transmitting:
1 in 2006
3 in 2009
5 in 2010
1 in 2014
2 in 2017
Total=12
Liberty
Prospect
70°N
DASARs
(green circles)
Camden Bay
150°W
145°W

Results

4. Bowhead whales sometimes feed near Camden Bay. Two whales lingered in Camden Bay (B09-13 and B10-08). One whale (B17-07) lingered in the leased blocks) northwest of Camden Bay. Two whales (B08-07 and B10-08) lingered north of the shelf break, north of Camden Bay.



Caveats

The state-space model underestimates behavior consistent with feeding. Short pauses in migration will not be detected.

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
P.O. Box 21668
Juneau, Alaska 99802-1668

March 5, 2018

Sam Cotten, Commissioner
Alaska Department of Fish & Game
P.O. Box 115526
Juneau, AK 99811-5526

Dear Commissioner Cotten:

Pursuant to the National Marine Fisheries Service's (NMFS) Revised Interagency Cooperative Policy Regarding the Role of State Agencies in Endangered Species Act Activities, 81 FR 8663 (February 22, 2016), NMFS submits this letter to inform you that Bureau of Ocean Energy Management (BOEM) has determined that the Liberty Development and Production Project is like to adversely affect the bowhead whale (*Balaena mysticetus*), Arctic ringed seal (*Phoca hispida hispida*), and Beringia Distinct Population Segment (DPS) bearded seal (*Erignathus barbatus*) and is not likely to adversely affect the blue whale (Balaenoptera musculus), fin whale (Balanoptera physalus), western North Pacific DPS Humpback whale (Megaptera novaeangliae), Mexico DPS Humpback whale, North Pacific right whale (Eubalaena japonica), sperm whale (Physeter microcephalus), or western DPS Steller sea lion (Eumetopias jabtus). Hilcorp Alaska LLC proposes to construct and operate an artificial gravel island, a subsea pipeline, and onshore support facilities to recover petroleum reserves in the Beaufort Sea. The biological assessment provided by BOEM is available upon request.

Consistent with the 2016 policy, please provide any relevant information, including any results of studies that relate to the effects of the action and cumulative effects on the bowhead whale, Arctic ringed seal, and the Beringia DPS bearded seal to assist with our formal consultation for this action under section 7 of the Endangered Species Act. We also solicit any information the State of Alaska may possess that would assist with our preparation of a biological opinion on this action. Please provide any response to Bonnie Easley-Appleyard at bonnie.easley-appleyard@noaa.gov within 30 days if possible. Thank you for your help.

Sincerely,

FOR James W. Balsiger, Ph.D.
Administrator, Alaska Region

Notes for the Liberty Prospect review:

Methods

1. Satellite telemetry locations have location error associated with them. Individual locations typically have hundreds of meters of error, but sometimes have multiple kilometers of error. Because of this, the data must be filtered or modeled to determine the true position of animals.

2. We fit a two-state switching correlated random walk (CRW) model, as described in Jonsen et al. (Ecology, 2006, 75:1046-1057) to bowhead whale location data.

3. Although the CRW model is complex, the results are relatively easy to understand. We used the model to statistically estimate whale locations at 6-h intervals based on locations obtained irregularly via the Argos satellite network. Unprocessed locations typically have an error ranging from a few hundred meters to many kilometers. The CRW model allows us to statistically estimate the location of a whale, providing a better estimate of the whale's true location, and will also classify each location as being associated with directed movement or lingering behaviors. Embedded within the model are two sets of movement parameters, one associated with directed movements and one associated with lingering behavior, and a parameter that allows us to classify the behavior associated with each estimated location. In practice, the model works well with track data for bowhead whales because they generally exhibit two distinct modes of travel, one in which whales move in a relatively direct fashion to a specific area and another in which they 'zig-zag' (i.e., linger) for multiple days or even months. Researchers typically assume that the lingering 'zig-zag' behaviors are associated with feeding. This seems reasonable for bowhead whales.

4. The CRW model will predict the true location of an animal in intervals for which there are no satellite location data. Although these predictions are usually reasonable if the gap in data collection is not too long, we only used estimated locations and their behavioral state from intervals in which satellite data were collected. If no data were collected within a 6-h interval, the estimated location and behavioral state were not used for analysis.

5. Prior to fitting CRW models, we filtered the location data to remove outliers that were not possible. Although the CRW model can deal with large outliers, we were interested in speeding up the optimization routine and guarding against the possibility that an extreme outlier be treated as being accurate. We did this by applying a velocity filter in R (Freitas et al. 2008, Marine Mammal Science 24:315-325). Bowhead whale locations that resulted in swim velocities of over 2 m/s were removed unless they were within 5 km

of the previous location. The filter also has an angular component to account for locations with a high degree of location error that often fall far from the line of travel, forming acute angles between adjacent locations. We used default settings to define the angular components of the Freitas et al. (2008) filter; within 2.5 km of the track line, locations resulting in angles less than 15˚ were removed and locations between 2.5 and 5 km of the track line were removed if they resulted in angles under 25˚. We then removed locations that fell on land to establish the final set of locations used in our CRW analyses.

Results

1. Bowhead whales are generally present in the Beaufort Sea between April and October. In April and May, whales are migrating east past the Liberty Prospect en route to Amundsen Gulf and the Cape Bathurst Polynya. At this time, whales are typically north of the shelf break, which is approximately 70 km north of the Liberty Prospect. There is very little feeding behavior at this time.

2. We see some tagged whales return to the Alaskan Beaufort Sea in June and July, prior to the main migration in September and October. Many (but not all) of these movements also occur north of the shelf break. There is limited feeding behavior at this time.

3. Tagged whales first began making inshore movements in August. A whale passed within 16 km of the Liberty Pospect in August of 2016.

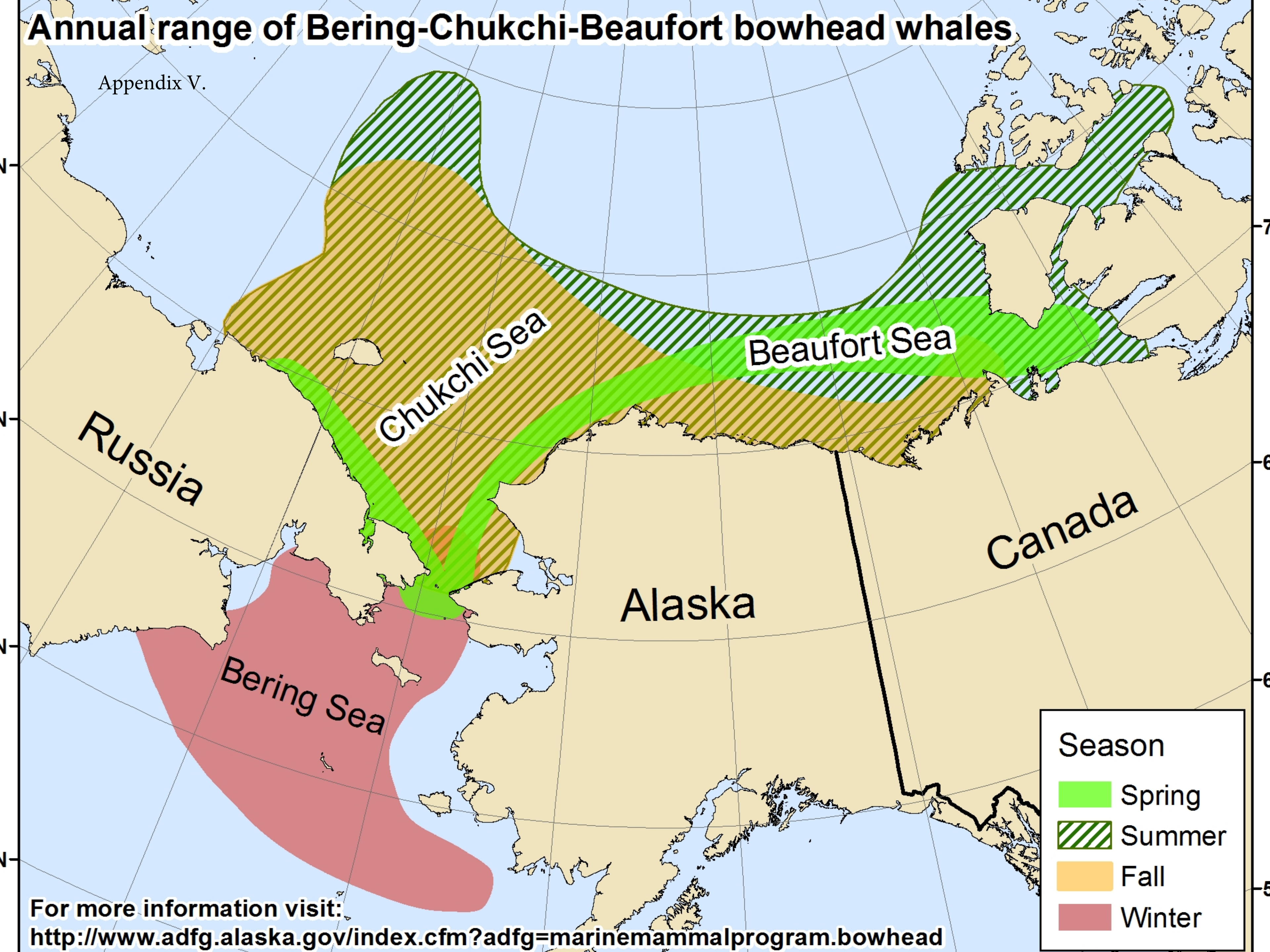
4. There is much movement of bowhead whales outside of the barrier islands in September and October. Although whales may migrate inshore of the barrier islands, the large majority of movement appears to be outside the barrier islands. The main migratory corridor for tagged whales began at the barrier islands, approximately 7 km north of Liberty Prospect, and extended approximately 40 km north of the barrier islands.

5. We did not identify feeding locations (lingering locations) closer than 30 km of the Liberty Prospect. One whale paused its migration in September of 2010 for a single 6-hr interval, approximately 30 km east-northeast of the Liberty Prospect. This does not mean that whales may not sometimes feed closer to the Liberty Prospect. However, the main feeding area in the Alaskan Beaufort Sea is west of Cape Halkett. Tag data also show limited feeding behavior in Camden Bay, where one whale lingered for four days and another lingered for nine days in 2010.

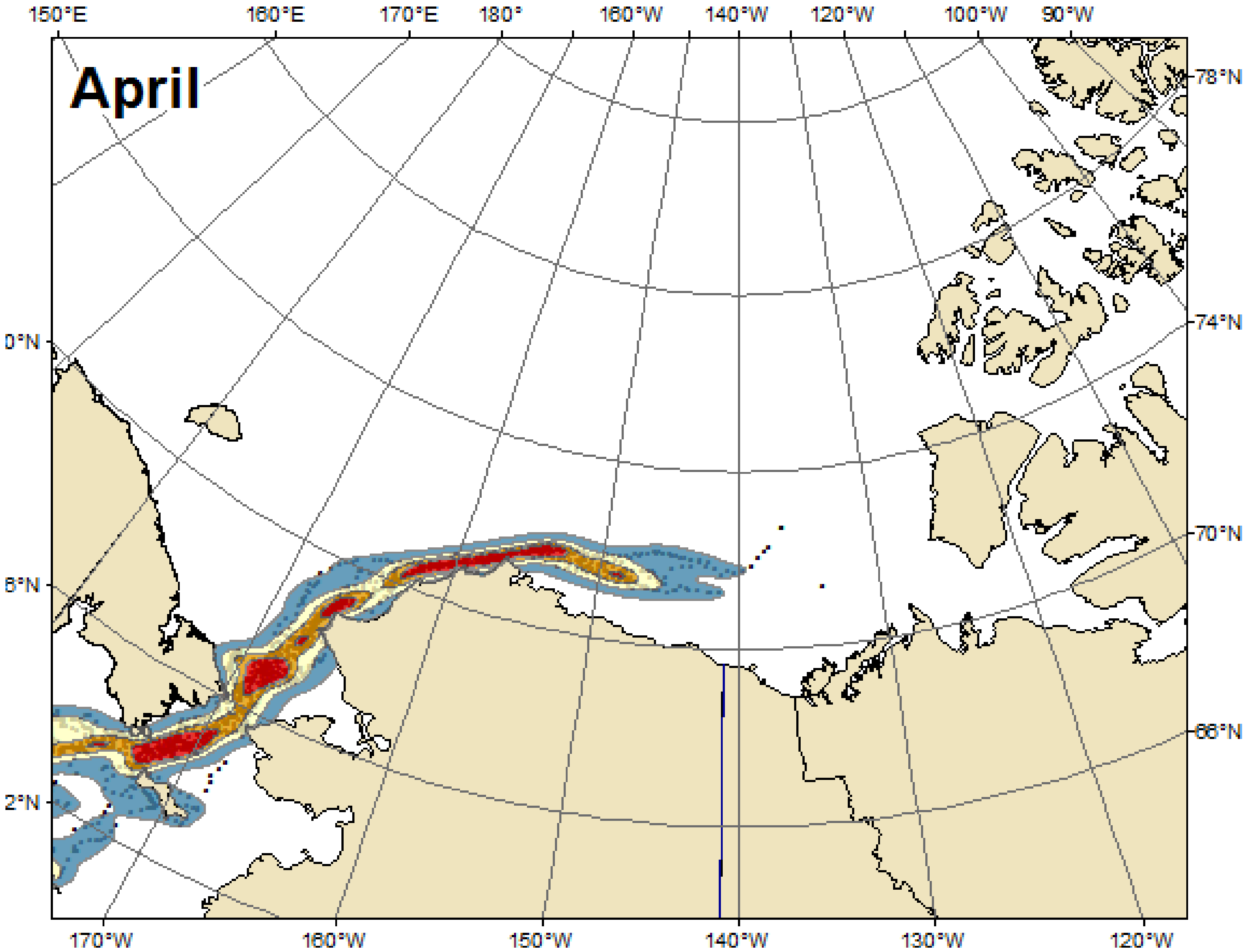
6. There were no locations of tagged bowhead whales east of Cape Halkett later than October.

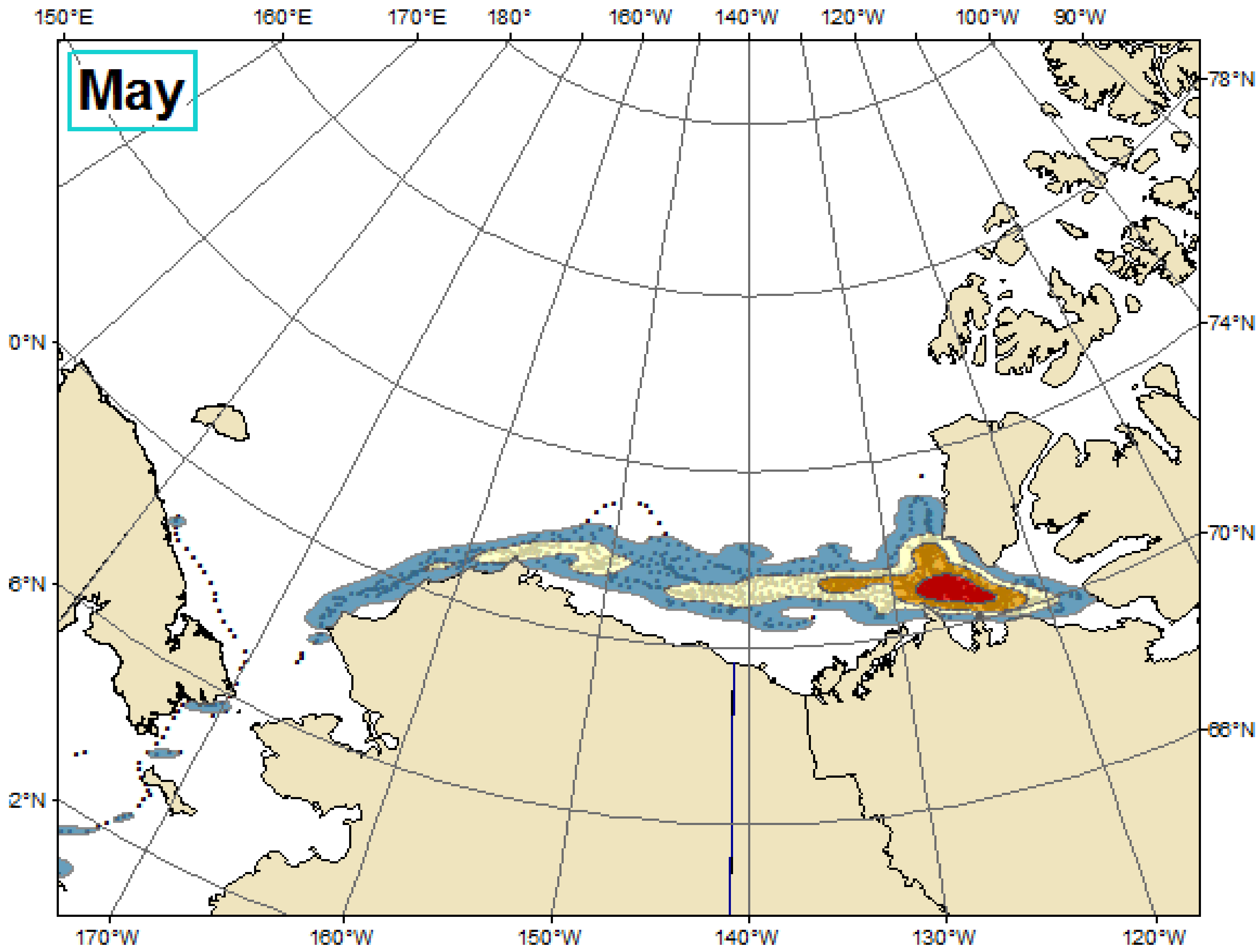
Although movements of tagged animals do not likely represent movements of the entire population they do indicate that bowhead whales are in the Liberty area in summer and fall.

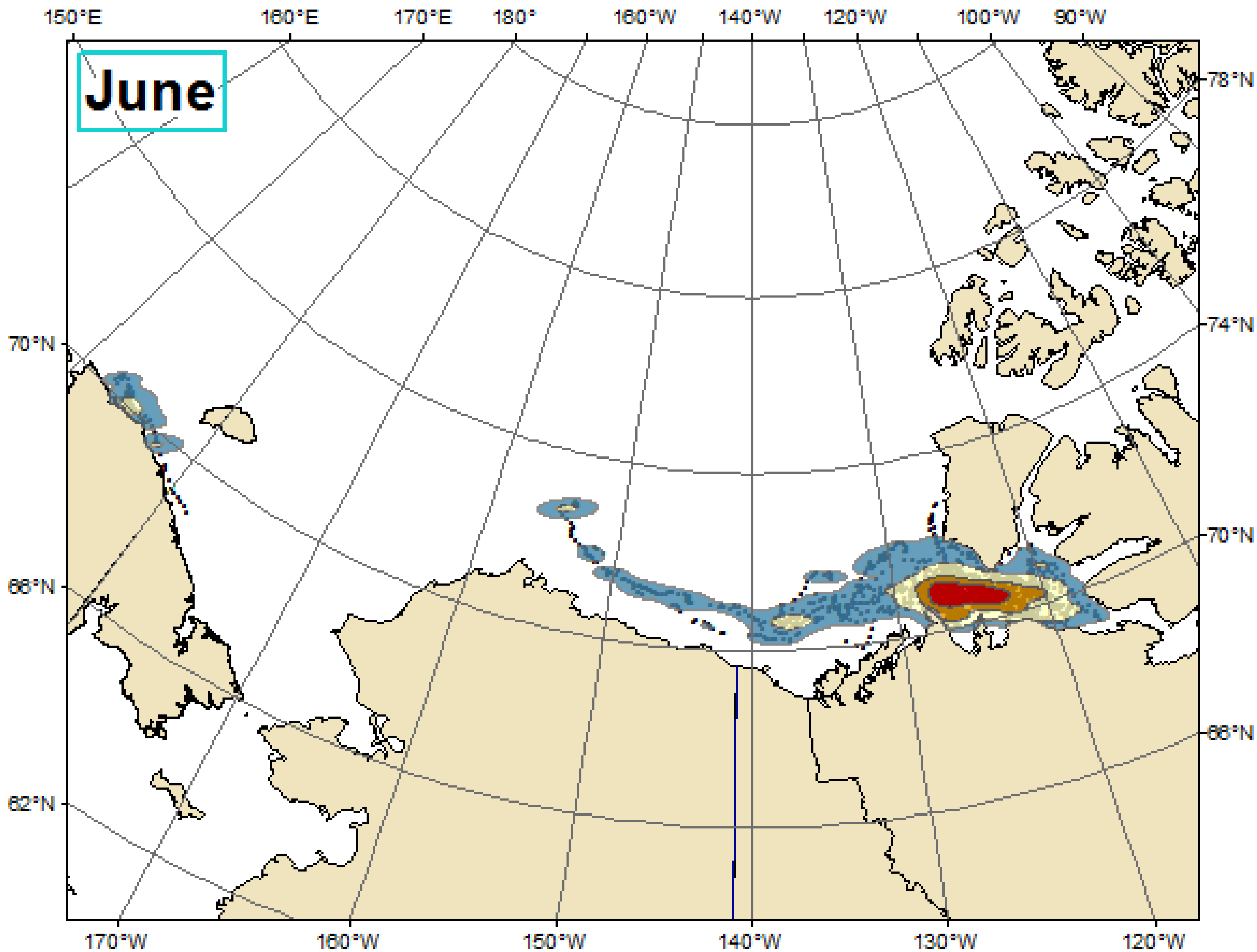
Submitted by Lori Quakenbush, Alaska Department of Fish and Game; lori.quakenbush@alaska.gov



Annual range of Bering-Chukchi-Beaufort bowhead whales
Appendix V.
Chukchi Sea
Beaufort Sea
Russia
Canada
Alaska
Bering Sea
Season
Spring
Summer
Fall
Winter
For more information visit:
http://www.adfg.alaska.gov/index.cfm?adfg=marinemammalprogram.bowhead


April
150°E
160°E
170°E
180°
160°W
140°W
120°W
100°W
90°W
78°N
74°N
70°N
66°N
0°N
6°N
2°N
170°W
160°W
150°W
140°W
130°W
120°W


May
150°E
160°E
170°E
180°
160°W
140°W
120°W
100°W
90°W
78°N
74°N
70°N
66°N
0°N
6°N
2°N
170°W
160°W
150°W
140°W
130°W
120°W


June
150°E
160°E
170°E
180°
160°W
140°W
120°W
100°W
90°W
78°N
74°N
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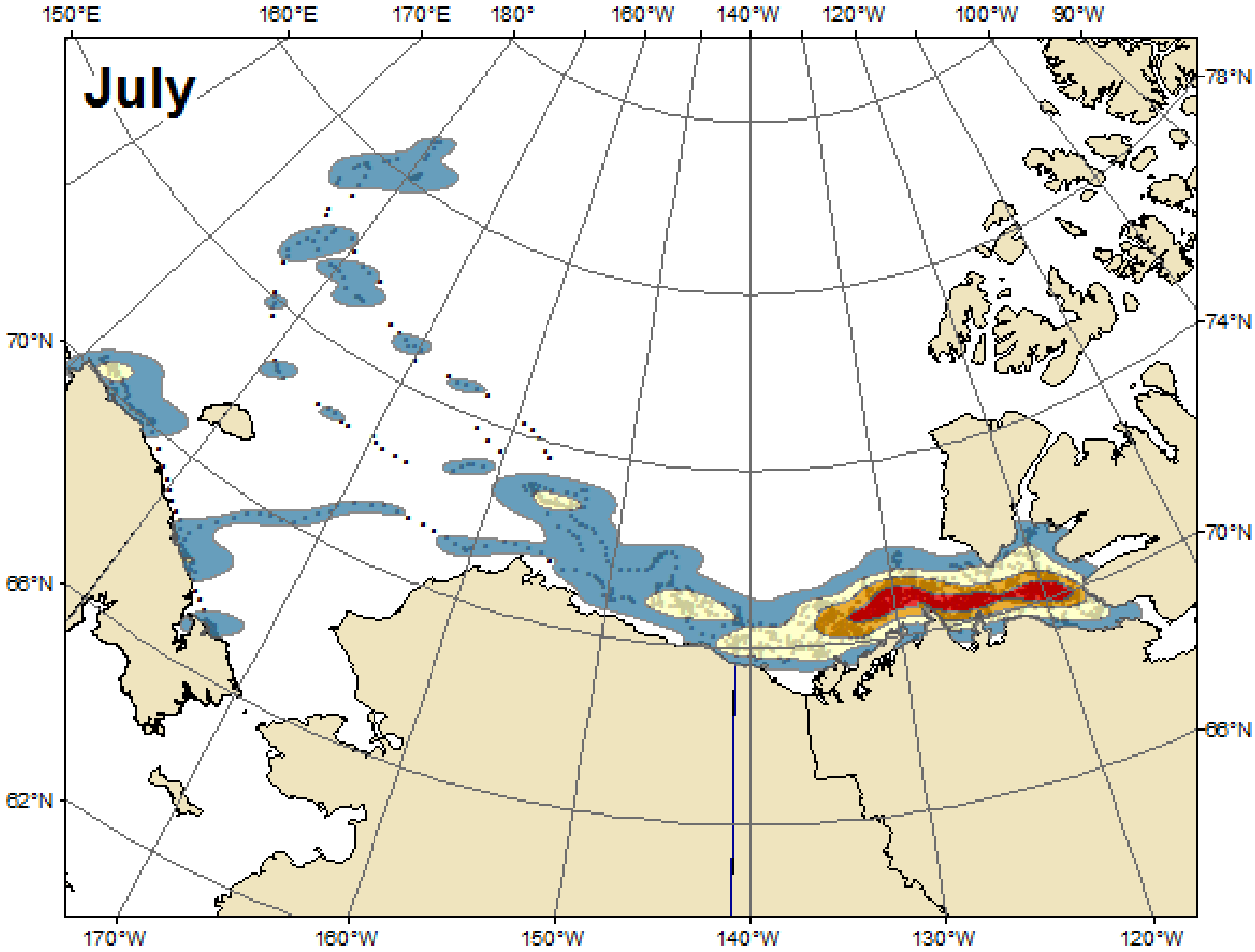
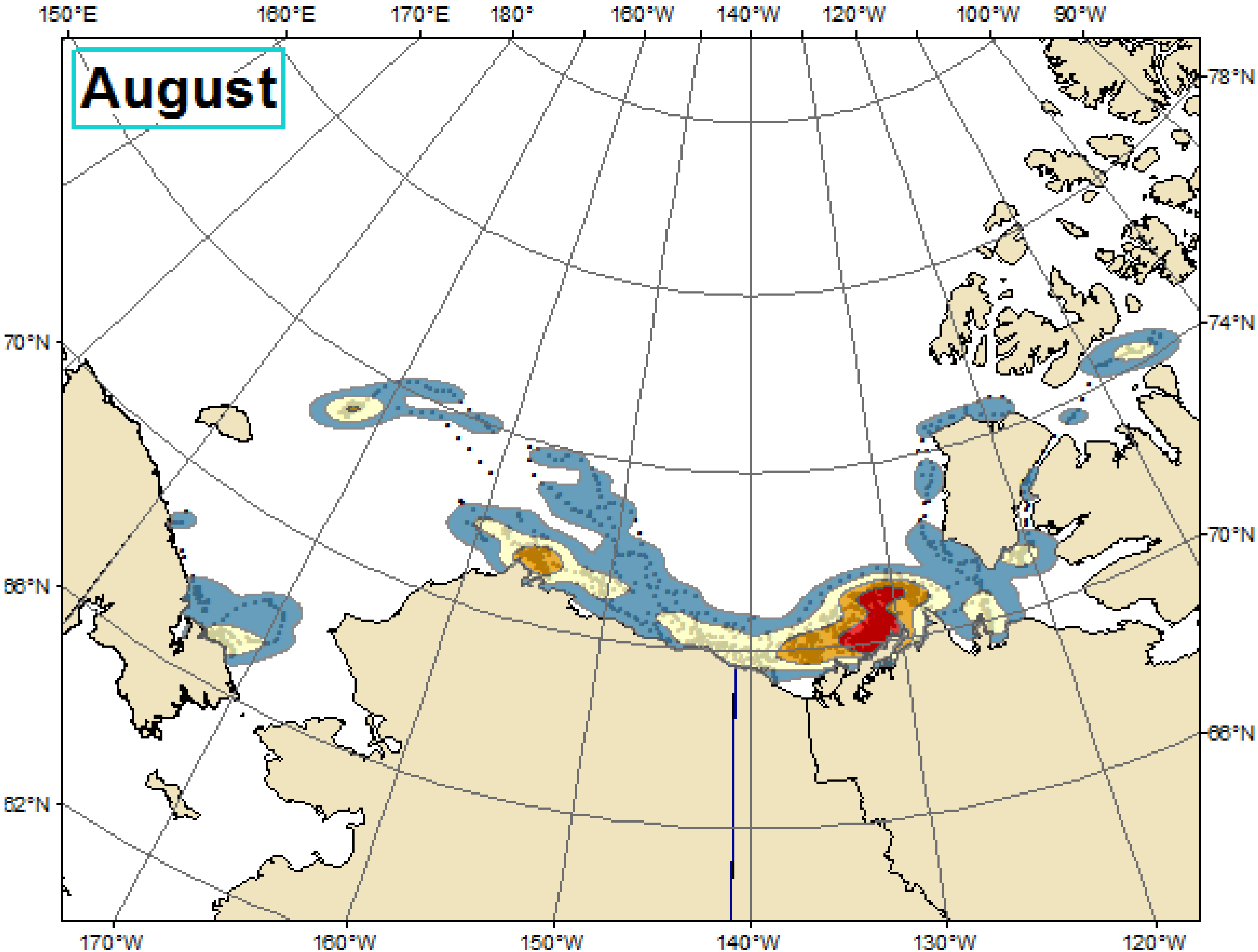
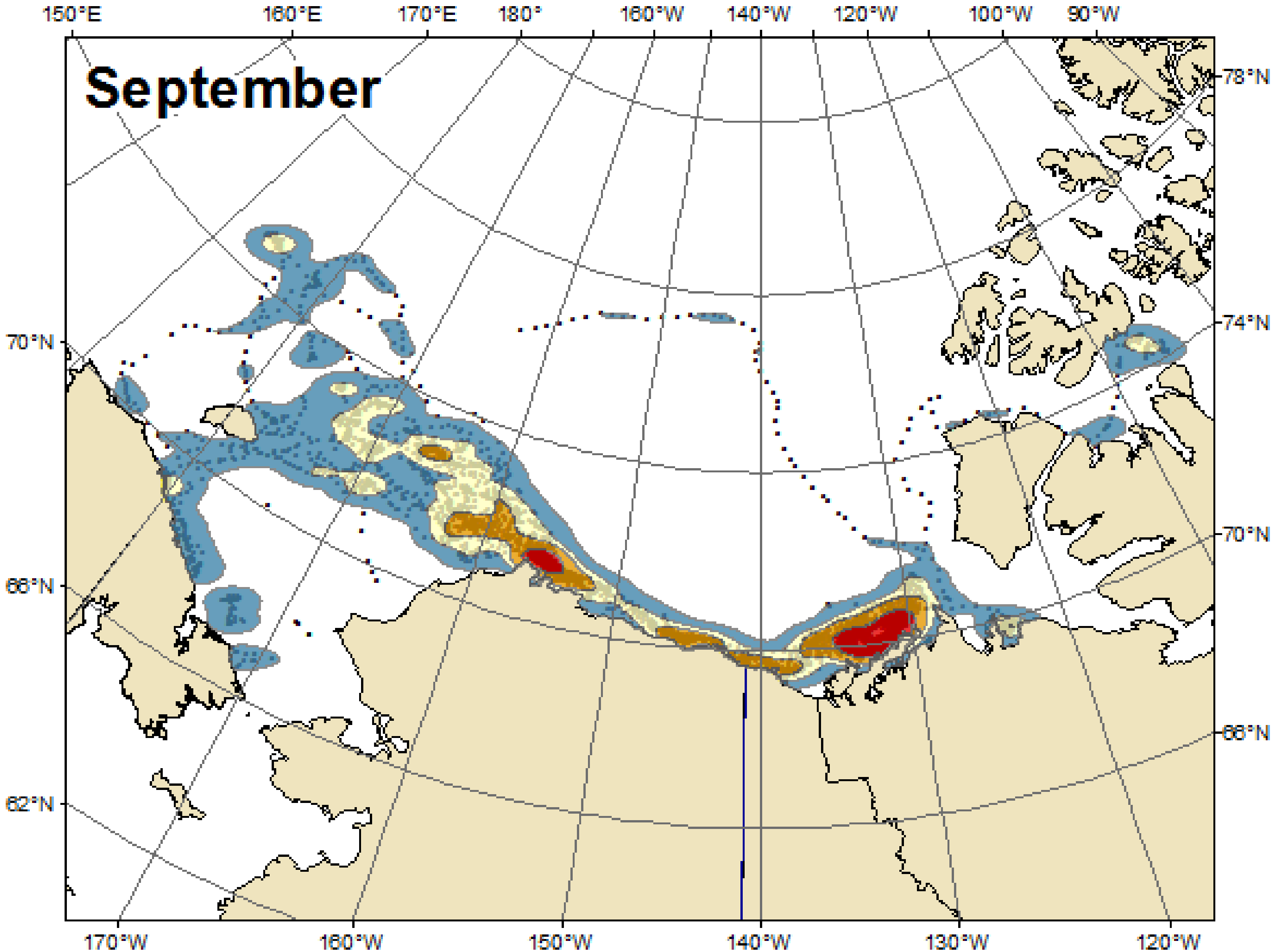
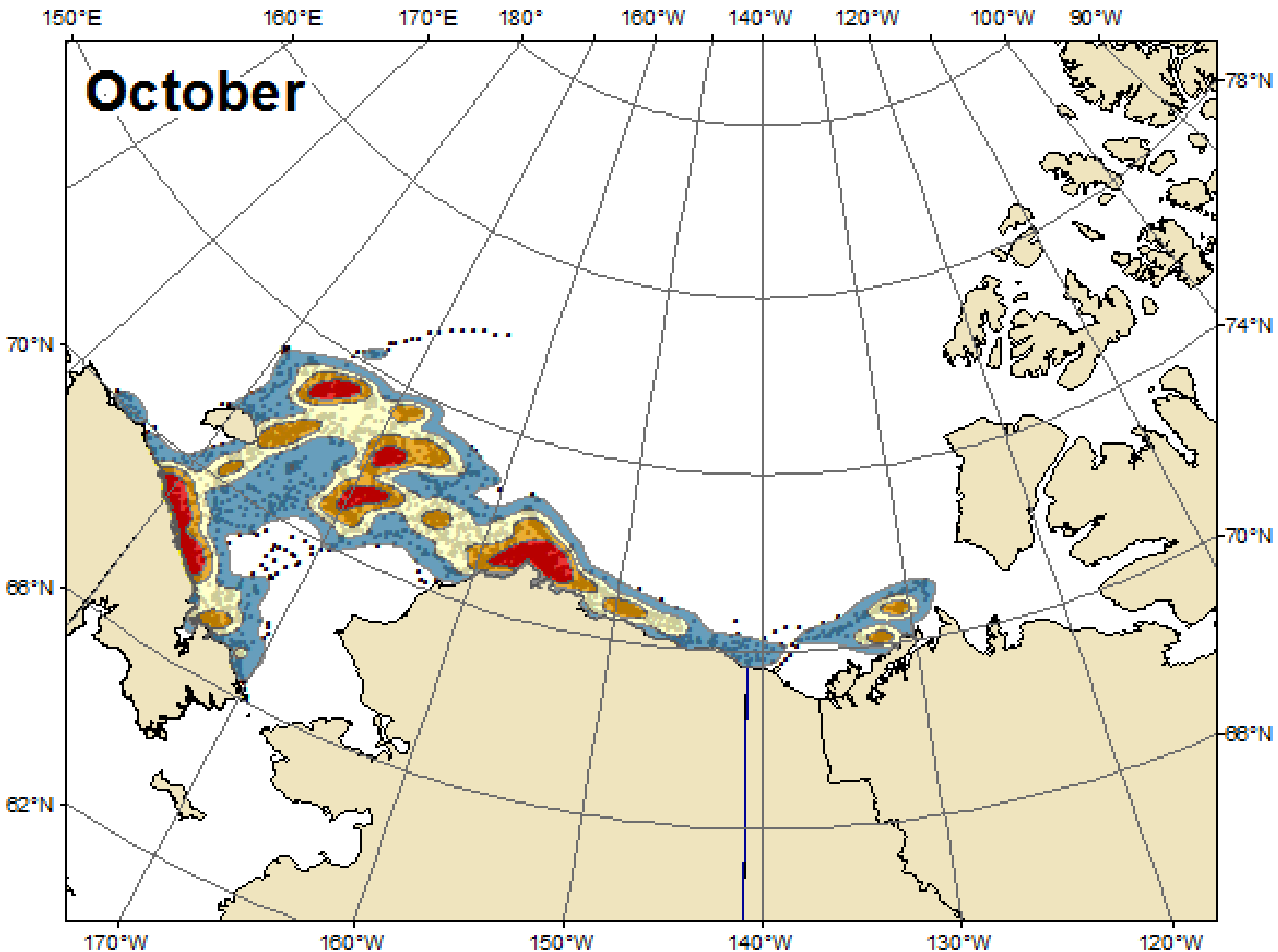
66°N
70°N
66°N
62°N
170°W
160°W
150°W
140°W
130°W
120°W


July
150°E
160°E
170°E
180°
160°W
140°W
120°W
100°W
90°W
78°N
74°N
70°N
66°N
70°N
66°N
62°N
170°W
160°W
150°W
140°W
130°W
120°W



August
150°E
160°E
170°E
180°
160°W
140°W
120°W
100°W
90°W
78°N
74°N
70°N
66°N
70°N
66°N
62°N
170°W
160°W
150°W
140°W
130°W
120°W


September
150°E
160°E
170°E
180°
160°W
140°W
120°W
100°W
90°W
78°N
74°N
70°N
66°N
62°N
170°W
150°W
130°W
120°W


October
150°E
160°E
170°E
180°
160°W
140°W
120°W
100°W
90°W
78°N
74°N
70°N
66°N
70°N
66°N
62°N
170°W
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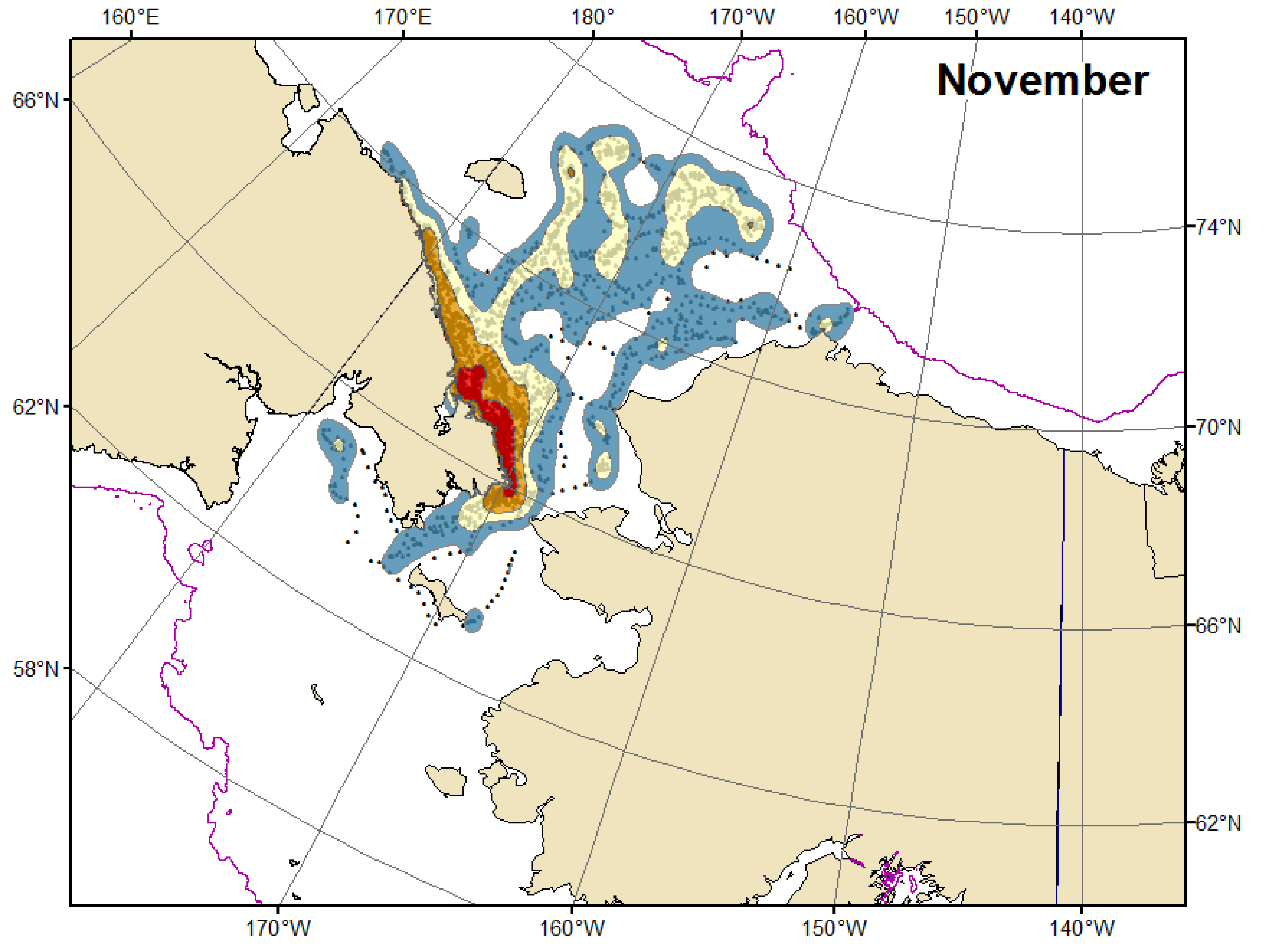
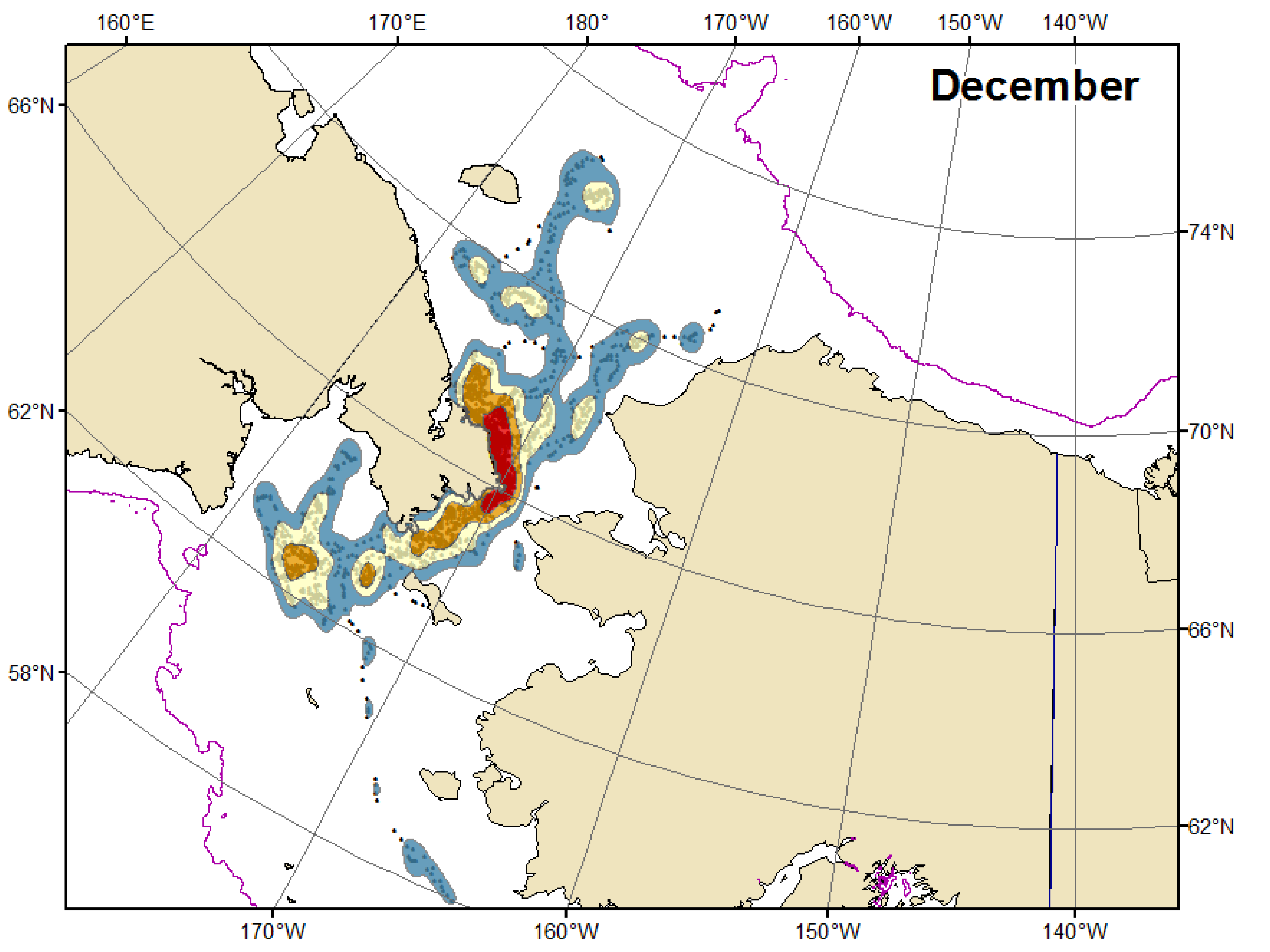
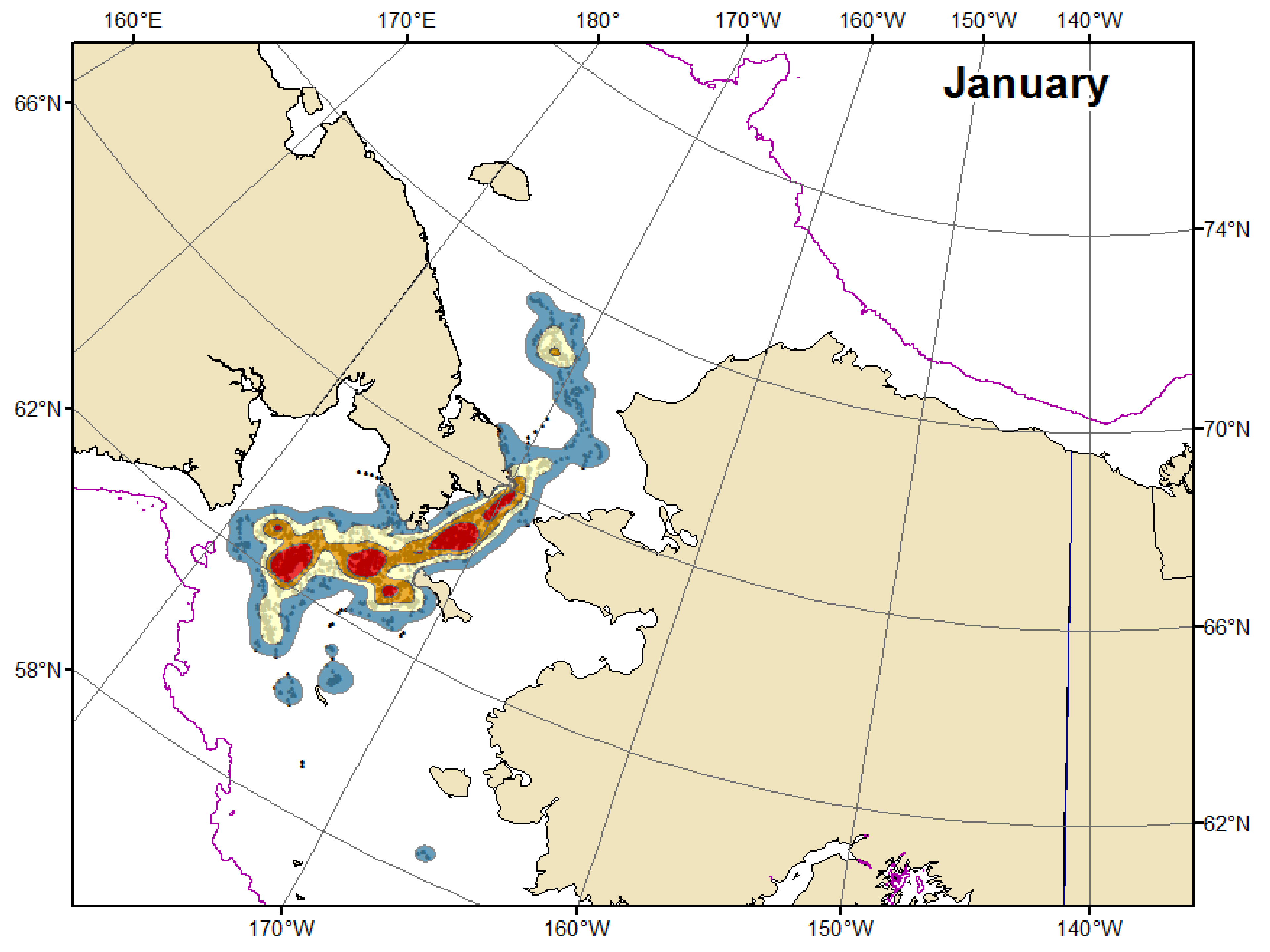
150°W
140°W
130°W
120°W

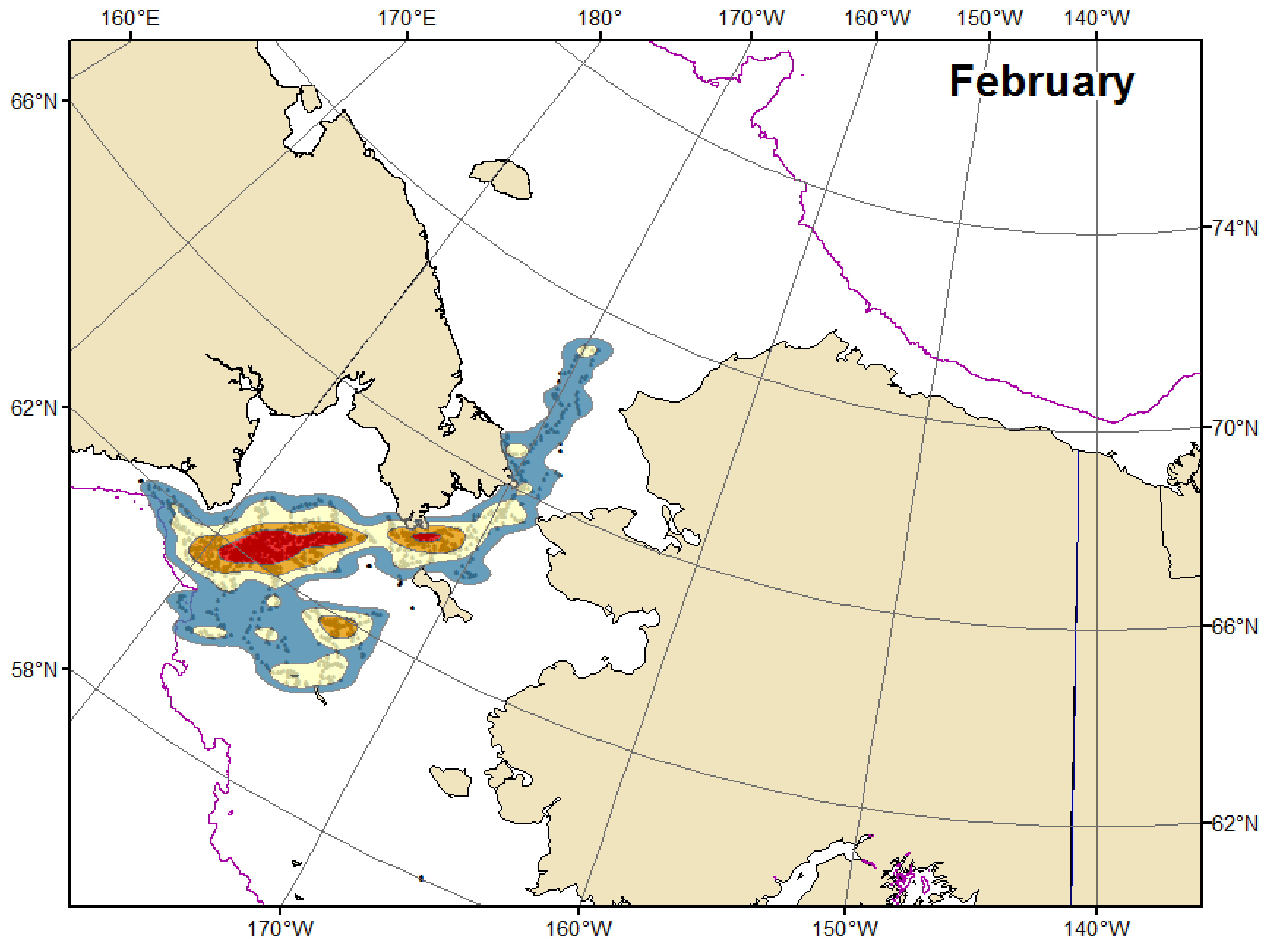

November
160°E
170°E
180°
170°W
160°W
150°W
140°W
66°N
62°N
58°N
74°N
70°N
66°N
62°N
170°W
160°W
150°W
140°W



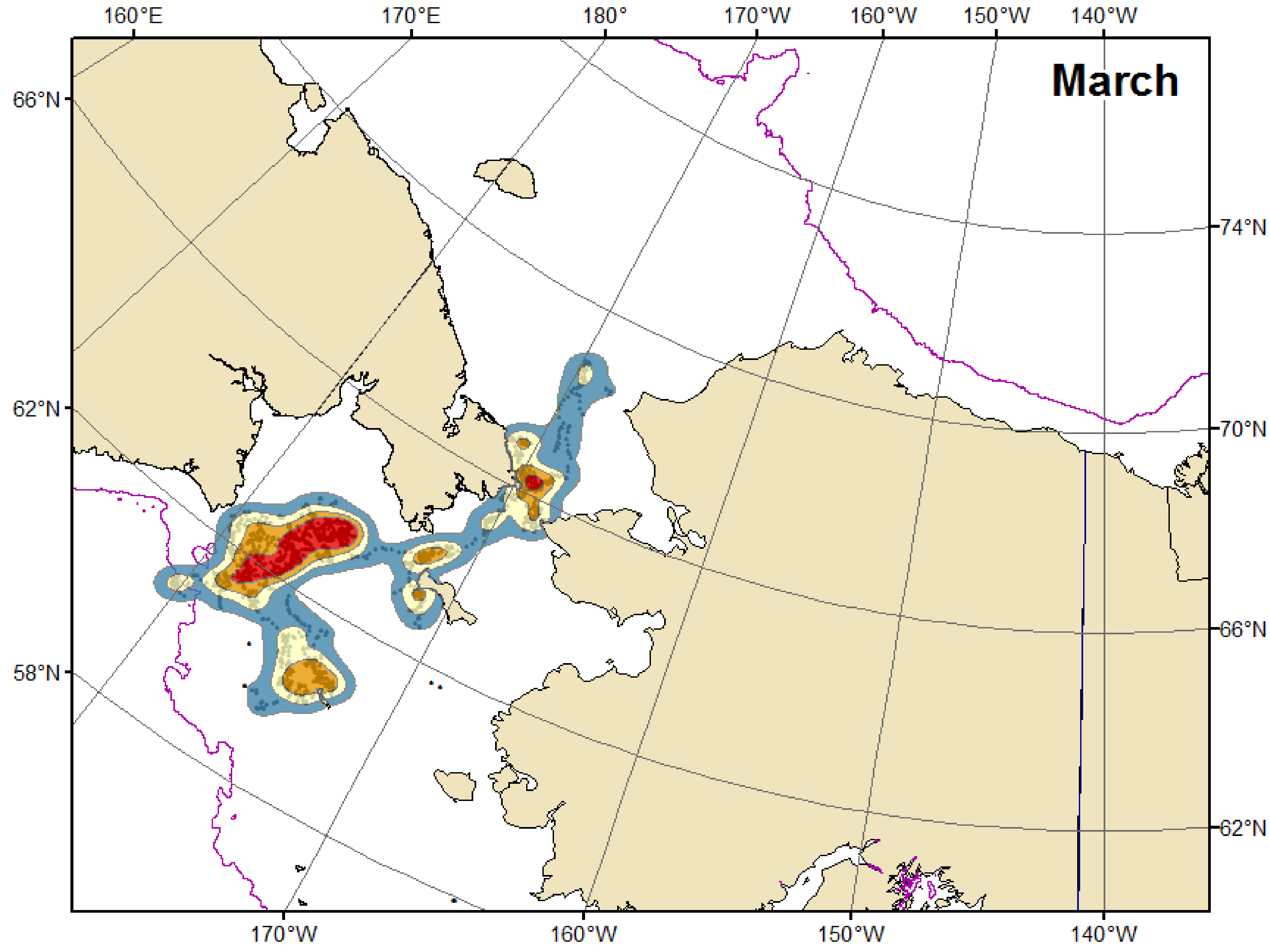
December
160°E
170°E
180°
170°W
160°W
150°W
140°W
66°N
62°N
58°N
74°N
70°N
66°N
62°N
170°W
160°W
150°W
140°W



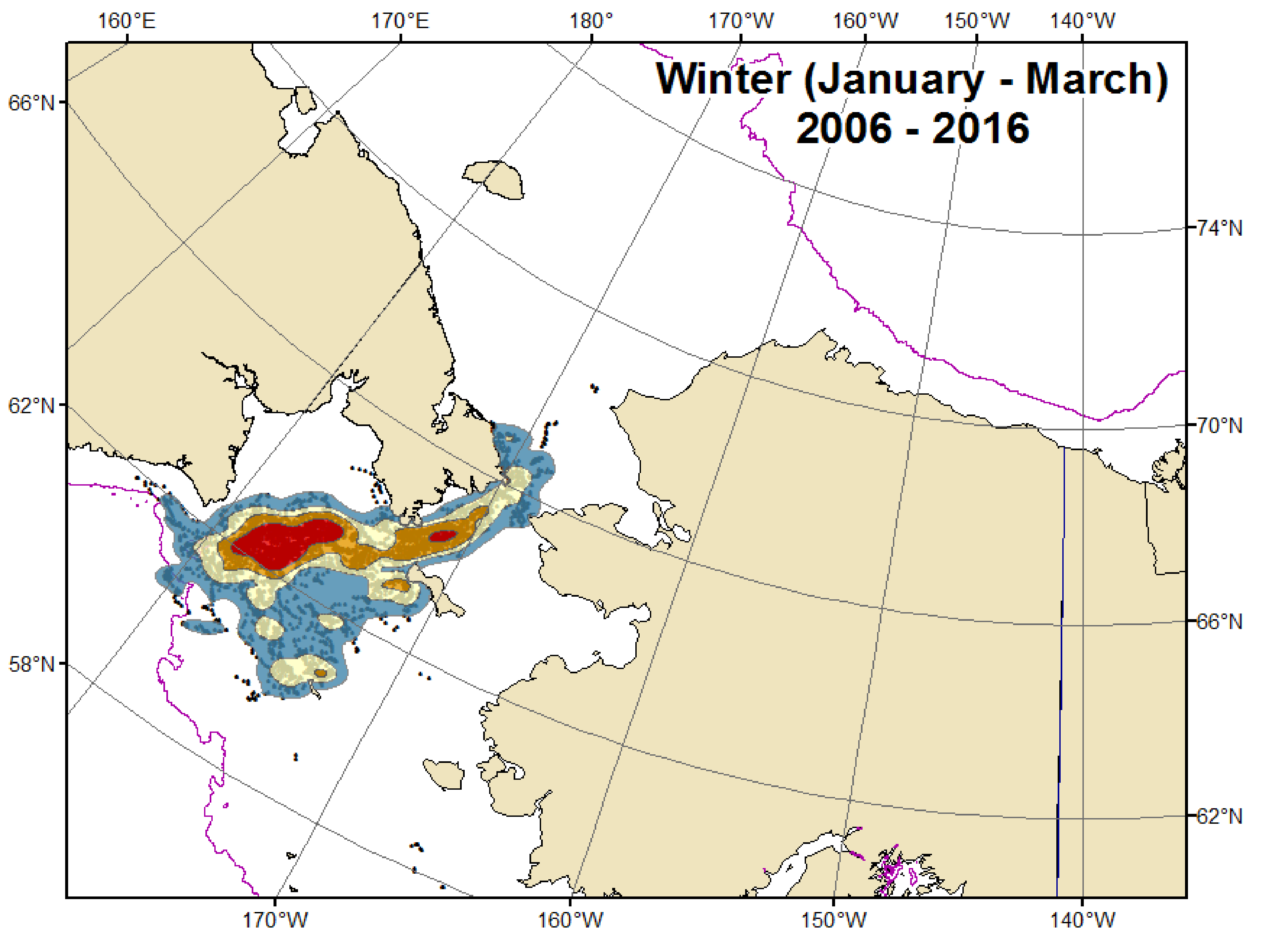
January
160°E
170°E
180°
170°W
160°W
150°W
140°W
66°N
62°N
58°N
74°N
70°N
66°N
62°N
170°W
160°W
150°W
140°W

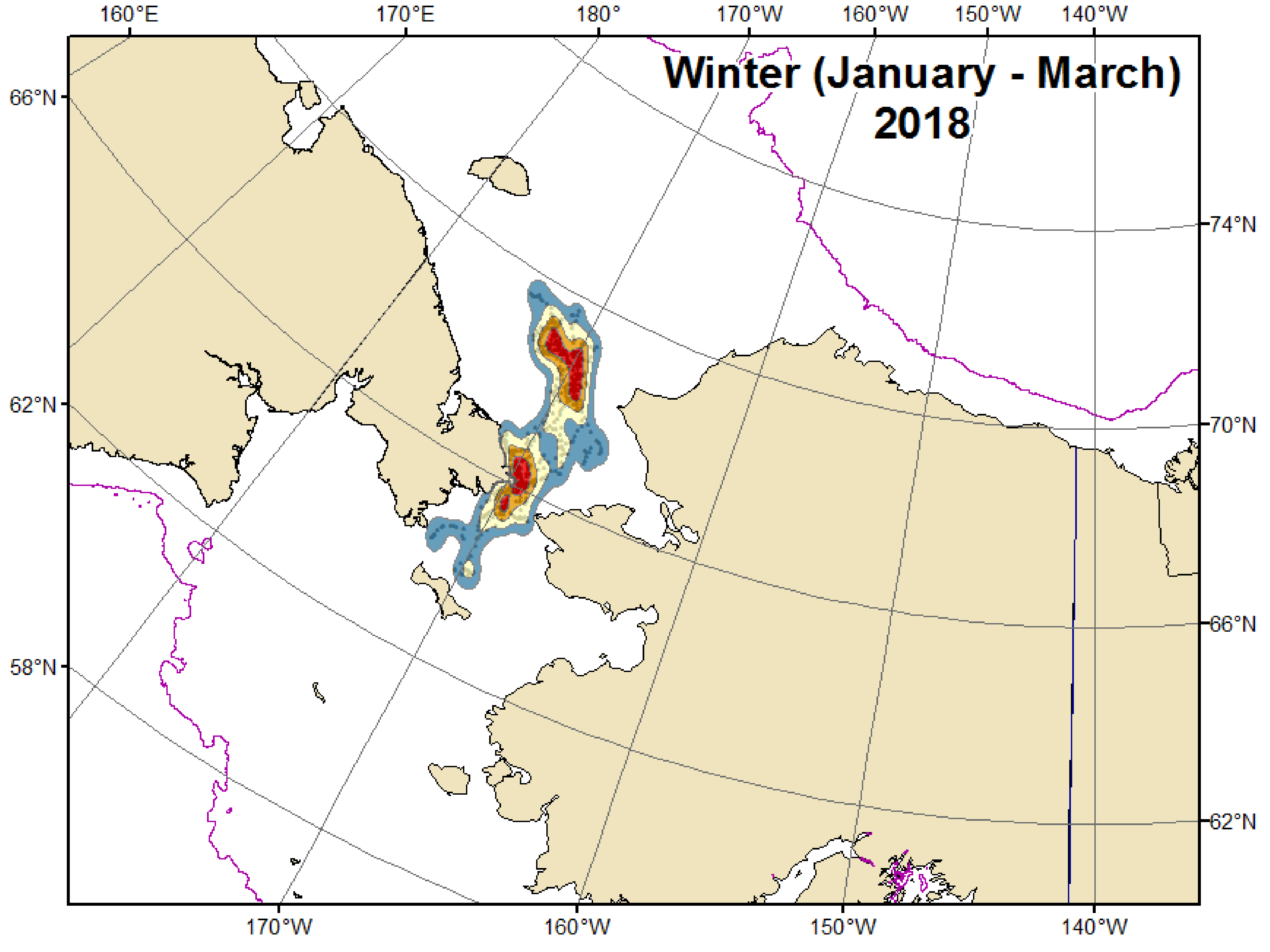


February
160°E
170°E
180°
170°W
160°W
150°W
140°W
66°N
62°N
58°N
74°N
70°N
66°N
62°N
170°W
160°W
150°W
140°W

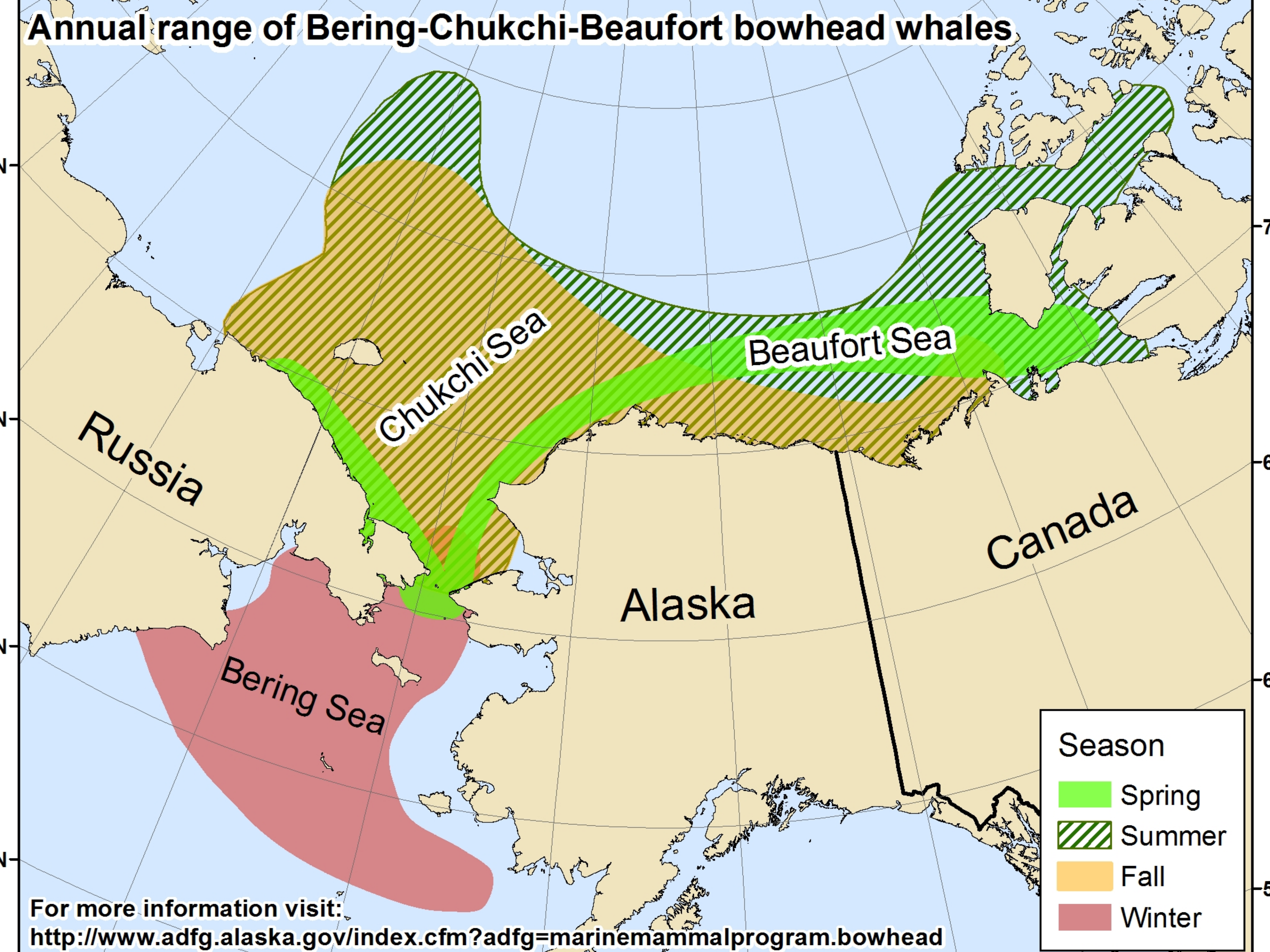


March
160°E
170°E
180°
170°W
160°W
150°W
140°W
66°N
62°N
58°N
74°N
70°N
66°N
62°N
170°W
160°W
150°W
140°W

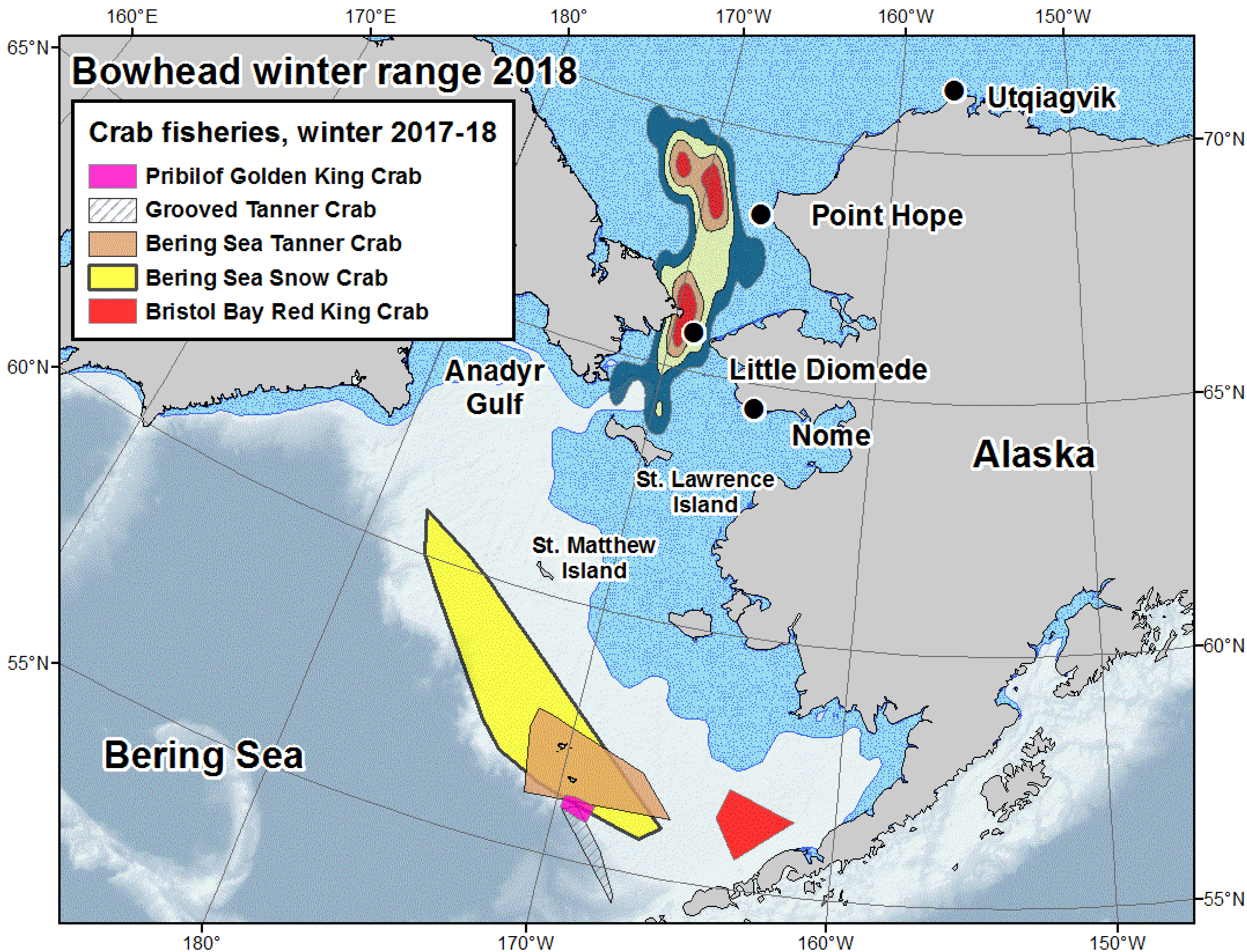

Winter (January - March)
2006 - 2016
160°E
170°E
180°
170°W
160°W
150°W
140°W
66°N
62°N
58°N
74°N
70°N
66°N
62°N
170°W
160°W
150°W
140°W



Winter (January - March)
2018
160°E
170°E
180°
170°W
160°W
150°W
140°W
66°N
62°N
58°N
74°N
70°N
66°N
62°N
170°W
160°W
150°W
140°W


Annual range of Bering-Chukchi-Beaufort bowhead whales
Chukchi Sea
Beaufort Sea
Russia
Alaska
Canada
Bering Sea
Season
Spring
Summer
Fall
Winter
For more information visit:
http://www.adfg.alaska.gov/index.cfm?adfg=marinemammalprogram.bowhead

Appendix W.



160°E
170°E
180°
170°W
160°W
150°W
65°N
60°N
55°N
70°N
65°N
60°N
55°N
Bowhead winter range 2018
Crab fisheries, winter 2017-18
Pribilof Golden King Crab
Grooved Tanner Crab
Bering Sea Tanner Crab
Bering Sea Snow Crab
Bristol Bay Red King Crab
Utqiagvik
Point Hope
Little Diomede
Nome
Alaska
Anadyr Gulf
St. Lawrence Island
St. Matthew Island
Bering Sea
180°
170°W
160°W
150°W

Appendix X.

Declining winter sea ice is associated with a northward shift of bowhead whale winter range

John J. Citta, Lori T. Quakenbush, Stephen R. Okkonen, Lois A. Harwood, Matthew L. Druckenmiller, John "Craig" George, Billy Adams, Ellen Lea, Mads Peter Heide-Jørgensen, James Pokiak, Charles Pokiak.

Since 2006, satellite-linked transmitters (tags) have been attached to bowhead whales (*Balaena mysticetus*) of the Bering-Chukchi-Beaufort (BCB) stock. During 2006-2016, tagged whales never travelled south of the ice margin in winter (January-March) and the primary wintering area was located east of Anadyr Gulf in the Bering Sea. This wintering area was ice-free during 2017 and 2018 and it was unknown if whales would travel south of the ice margin to return to this area or if they would remain under sea ice and shift their distribution northwards. No tags were transmitting in 2017, however, four tags transmitted during the winter (January-March) of 2018, allowing us to compare the distribution and behavior of whales in two time periods, 2006-2016 and 2018. In 2018, tagged whales remained under sea ice and shifted their distribution northwards. During 2006-2016, less than 6% of all tag locations (*n*=4,793) were in the Chukchi Sea in winter. In contrast, during 2018, 86% of all tag locations (*n*=576) were in the Chukchi Sea. The proportion of square- and U-shaped dives, dives where ≥50% time is spent at a specific depth and are thought to be associated with feeding behavior, did not change between the two time periods (~90% of all dives). The average percentage of time spent at or near the seafloor was less during the winter of 2018 (21%) than during 2006-2016 (30%), but within the range of variation observed in individual whales. These dive data suggest whales were feeding during both time periods. Why bowhead whales do not venture south of the ice margin in winter, when they are only weakly associated with ice concentration in summer, is unknown. Bowhead whales may remain north of the ice margin to avoid killer whales which are known to frequent the ice edge in winter but are rarely observed in BCB bowhead summer ranges. The fall and early winter of 2017-18 were also characterized by southerly winds that are inferred to have promoted northward transport of krill through Bering Strait, possibly improving feeding conditions in the Chukchi Sea.

Alaska Marine Science Symposium 28 January–1 February 2019, oral presentation.

The Department of the Interior (DOI)

The Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors the Nation's trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities.

The Bureau of Ocean Energy Management (BOEM)

The mission of the Bureau of Ocean Energy Management is to manage development of U.S. Outer Continental Shelf energy and mineral resources in an environmentally and economically responsible way.

BOEM Environmental Studies Program

The mission of the Environmental Studies Program is to provide the information needed to predict, assess, and manage impacts from offshore energy and marine mineral exploration, development, and production activities on human, marine, and coastal environments. The proposal, selection, research, review, collaboration, production, and dissemination of each of BOEM's Environmental Studies follows the DOI Code of Scientific and Scholarly Conduct, in support of a culture of scientific and professional integrity, as set out in the DOI Departmental Manual (305 DM 3).