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Final Report

Satellite Tracking of Western Arctic Bowhead Whales

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Satellite Tracking of Western Arctic Bowhead Whales

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Project Organization Page

Authors:
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Robert J. Small, PhD. is a Wildlife Scientist I and the Statewide Marine Mammal Program Leader within the Alaska Department of Fish and Game. His role in this project was that of Principal Investigator and his activities included coordination, contracting, permits, tagging in Canada, report and manuscript preparation.

John J. Citta, PhD. 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 management, archive, and analysis, weekly map production and distribution, assist with spring tagging at Barrow, and report and manuscript preparation.

Key Project Personnel:
John "Craig" George, PhD. is a Senior Wildlife Biologist for the North Slope Borough, 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 AEWC and Whaling Captain's Associations, and prepare manuscripts.

Mads Peter Heidi-Jørgensen, PhD. 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 with includes Mikkel and Anders Villum Jensen have developed and provided the tags 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.

Harry Brower, Jr., Lewis Brower, Billy Adams, and George Tagarook, and Eddie Arey are Alaskan Subsistence whalers who were key participants as taggers and boat drivers.

James Pokiak, Charles Pokiak, Angus Alunik, Dennis Arey, Larry Arey, Pat Kasook, Buddy Gruben, Douglas Panaktalok are Canadian hunters and trappers who were key participants as taggers and boat drivers.

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Executive Summary

The western Arctic (or Bering-Chukchi-Beaufort) stock of bowhead whales (*Balaena mysticetus*) is of high importance due to the nutritional and cultural role of bowhead whales to coastal Alaska Natives of the Bering, Chukchi, and Beaufort seas, their role in the marine ecosystem, and because their summer range overlaps with areas identified for potential oil and gas development. Movement and feeding patterns of this stock of bowhead whales, however, are not well understood. Increasing our understanding of bowhead whale movements, habitat use, and behavior will aid in resource planning and conservation. We worked with Native whalers from Alaska and marine mammal hunters from Canada to attach 46 satellite transmitters to bowhead whales during a five year period. This final report covers the time period from August 2005 to July 2010 and includes movements and behavior of 37 bowhead whales tagged near Barrow, Alaska and nine tagged in Canada. We have documented the annual distribution of western Arctic bowhead whales, including summering and wintering areas, and the migratory routes that connect these areas. At the request of the Alaska Eskimo Whaling Commission, we conducted traditional knowledge interviews in as many whaling villages as possible and report our findings. We have described how bowhead whales move through Oil and Gas Lease Sale Area 193 in the spring and fall. We have described locations and times when shipping may affect bowhead migration or feeding and have documented an interaction between a bowhead whale and a seismic vessel.

Introduction

General movements and behavior of bowhead whales (*Balaena mysticetus*) from the western Arctic stock are known from aerial surveys and from the timing of whaling in coastal villages. Some specific feeding areas have also been identified from aerial, shipboard, and shore-based surveys and the analysis of stomach contents; however, these locations are restricted to areas surveyed and areas near whaling villages. Information on the location of important feeding areas throughout bowhead range and how movements relate to currents, bathymetry, or ice cover is not currently available. Bowhead whales are known to winter in the Bering Sea, migrate through the Chukchi and Beaufort seas in spring, presumably to feed in the eastern Beaufort before returning to the Bering Sea in late fall.

However, little else is known about bowhead movement patterns and feeding areas. For example, we do not know the extent of bowhead movements or their distribution in the Bering Sea in winter, if they segregate by sex and/or age, or if they feed in wintering areas. The extent and variability of spring and fall migration corridor(s) through the Chukchi Sea are also poorly known. Although most of the stock is presumed to migrate to the eastern Beaufort Sea each spring, sightings along the Chukotka Peninsula in spring and summer and sightings near Barrow in summer question that presumption.

Bowheads leave the highly productive Bering Sea just prior to its productive period and migrate to the less productive eastern Beaufort Sea. Thus the reason(s) why bowheads migrate to the eastern Beaufort Sea remain unknown. It has been presumed that the annual spring migration is primarily for feeding during the summer months in the Beaufort Sea (Fraker and Bockstoce 1980, Lowry and Frost 1984). Studies, however, disagree on the importance of feeding in the eastern Beaufort Sea relative to the bowhead annual energy budget. Observations of feeding behavior (Ljungblad et al. 1983, 1986; Lowry and Frost 1984; Moore et al. 1989) and the analysis of stomach contents (Lowry et al. 2004) indicate that bowhead whales feed on the summer grounds in the Beaufort Sea, but feeding studies (Richardson 1987) and isotope analyses (Schell et al. 1989, Hobson and Schell 1998, Schell and Saupe 1993, Lee et al. 2005) have concluded that bowhead whales do not acquire a significant proportion of their annual nutrition from the Beaufort Sea raising the question of why bowheads migrate into the Beaufort Sea.

Bowhead whales are the most nutritionally and culturally important subsistence species for communities along the Beaufort Sea. Bowhead summer habitat also overlaps areas of interest for oil and gas development. Increased understanding of bowhead movement and feeding patterns will improve lease sale planning and increase the efficacy of mitigation measures for resource development activities. Satellite telemetry is a method well suited to the study of animals that range over large, remote areas and in 1992, 12 bowhead whales from this stock were tagged in the Beaufort Sea documenting summer movements, residence times, and dive depths, and swim speeds (Mate et al. 2000).

The objective of this study was to work with Alaska Native subsistence whalers to deploy up to 25 satellite tags each year over a five-year period. Satellite telemetry allowed individual whales to be tracked, potentially year-round, providing information on their distribution and movement, and identified migration corridors along with feeding, summering, and wintering areas. We worked with Native subsistence whalers from Alaska and marine mammal hunters in Canada to deploy satellite tags. Subsequently, through a combination of descriptive and analytical procedures, and the integration of traditional knowledge of Native subsistence whalers, we describe movement and feeding patterns of bowhead whales. We coordinated our study with the oceanographic and prey sampling components of the Bowhead Whale Feeding Ecology Study (BOWFEST), which was also funded by Minerals Management Service and conducted by the National Marine Mammal Laboratory (NOAA Fisheries). This report includes our activities from 1 August 2005 through 12 July 2010.

Goals and 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 utilization.

***Objective 1*:** The overall objective of this study was to work with subsistence whalers to deploy satellite transmitters on bowhead whales, across different sex and age cohorts, to document and describe the general pattern of year-round movements used by bowhead whales. Specific hypotheses tested include:

Hypothesis 1A: All bowhead whales of the western Arctic stock make seasonal migrations between wintering areas in the Bering Sea and summering areas in the eastern Alaskan and Canadian Beaufort Sea.

Hypothesis 1B: Occasional concentrations of bowhead whales feeding near Barrow in summer are whales returning from summering in the eastern Beaufort Sea. The alternative hypothesis to be tested was that whales feeding near Barrow summered in the eastern Chukchi Sea and only enter the southwestern Beaufort Sea periodically, and under certain oceanographic conditions.

Hypothesis 1C: Occasional concentrations of bowhead whales feeding near Barrow in summer are of mixed sex and age composition.

Hypothesis 1D: Wintering concentrations of bowhead whales are of mixed sex and age composition.

***Objective 2*:** Using satellite telemetry, document behavior during migration relative to migration routes and the environmental characteristics of those routes; i.e., polynyas, leads, bathymetry, ice conditions, industrial disturbances. Specific hypotheses include:

Hypothesis 2A: Bowheads only migrate when ice conditions are light to medium.

Hypothesis 2B: Industrial disturbances do not alter bowhead migration routes, duration, or timing.

Hypothesis 2C: During migration bowheads do not stop to feed.

Hypothesis 2D: Bowhead migration occurs along a specific isobath.

***Objective 3*:** Document the timing of migration and the rate of travel.

***Objective 4*:** Estimate residence time for individual whales relative to specific geographic locations and/or habitat types during summer. Specific hypotheses include:

Hypothesis 4A: Individual whales that comprise the occasional concentrations of bowheads feeding near Barrow are present for less than three days.

Hypothesis 4B: Individual whales feeding in the eastern Alaskan Beaufort Sea remain there for more than three days.

Methods

Coordination

Meetings, workshops, other communications. We began the study with a workshop attended by representatives of Alaska Eskimo Whaling Commission (AEWC), North Slope Borough, BP Alaska, and MMS to determine the project objectives. We gave project updates at most AEWC meetings. Between meetings, we communicated with the local whaling captains associations through their presidents and with the AEWC through its president as necessary. We prepared weekly maps of whale tracks and sent them to an extensive e-mail list and then posted them on the State of Alaska website.

We coordinated with the researchers conducting the BOWFEST study and provided updates regarding the tagging project at their annual meetings. We also provided data on tagged whale locations and movements that were relevant to their research near Barrow. We also provided maps and other information to other projects such as BWASP and COMIDA and to oil companies and their contractors.

Tagging

We used a system of deployment and attachment developed by the Greenland Institute of Natural Resources (i.e., Mads Peter Heide-Jørgensen and his assistants, Mikkel and Anders Jensen) that had been used successfully with bowhead whales in Canada and Greenland and northern right whales (*Eubalaena glacialis*) in the Bering Sea (Heide-Jørgensen et al. 2001, Heide-Jørgensen et al. 2003). We used two types of transmitters, one that recorded only the locations of whales (SPOT transmitters) and another that recorded location and diving information (SPLASH transmitters); both use the ARGOS system of satellites and are manufactured by Wildlife Computers, Inc. (Redmond, WA, USA). SPOT tags were set to transmit a maximum of 300 times per day, while SPLASH tags were set to transmit a maximum of 250 times per day. Both tags were set to transmit all hours of the day and all days of the week; there was no "duty cycle" or "dead time". Tags only send data when at the surface and more than one transmission is required by Argos satellites to calculate a location. The number of transmissions received from tags was variable and likely depends upon the position of the tag on the whale in addition to the tag settings.

The SPOT transmitter was housed inside a stainless steel cylinder (20 mm diameter) that was attached to a stainless steel anchor shaft with a cutting head and flexible barbs (5 cm long) along the shaft to impede expulsion from the blubber. The anchor shaft and cylinder was 27.5-cm long and implanted beneath the whale's skin, ~24.0 cm into the blubber, leaving ~3.5 cm of the cylinder outside of the skin and a short (15 cm) antenna extended from the top. The transmitter, housing, and anchor shaft weighed 240 g.

The SPLASH transmitter (8.5 x 5 x 2.5 cm) was deployed external to the whale's skin by a stainless steel anchor shaft with a cutting head and flexible barbs (4 cm long) along the shaft that implanted beneath the whale's skin. The total length of the transmitter and anchor shaft was 23.5 cm with 21 cm into the blubber and 2.5 cm above the skin, and a short (16 cm) antenna extended from the top. The transmitter and anchor weighed 294 g. In 2008, we used a modified shaft on all SPLASH tags. The new shaft had the same cutting head and barbs, but the transmitter was mounted to a steel plate that swiveled on the shaft allowing the transmitter to move to the position of least hydrodynamic resistance. This transmitter and anchor weighed 300 g.

We attached the SPOT tags to whales using a 2 or 4-m long fiberglass pole system (Heide-Jørgensen et al., 2003) or an airgun (ARTS, Air Rocket Transmitter System, see Heide-Jørgensen et al., 2001). The pole was used as a jab-stick to tag whales at a distance of 2–4 m. The pole system included a biopsy tip (manufactured by CETA-DART, Denmark), a 2.5 cm-long stainless steel hollow cylinder 0.6 cm diameter with internal barbs, designed to obtain a skin biopsy during tag deployment that could be analyzed to determine gender of tagged whales. When using the ARTS, the SPOT tag was placed into a plastic cylindrical projectile that was loaded into the aluminum barrel of the airgun and propelled at the whale using compressed air from a SCUBA tank (Heide-Jørgensen et al. 2001). Penetration depth was controlled by a stopper on the plastic projectile when using the airgun and by a plastic device that holds the transmitter onto the pole. SPLASH tags do not fit into the barrel of the ARTS and were deployed only by using the fiberglass pole system (Heide-Jørgensen et al. 2003).

In the fall, we deployed tags from aluminum boats (~5.5–6.1 m long) with outboard motors, whereas in spring, transmitters were deployed by standing on the nearshore ice edge near Barrow as bowhead whales passed by.

Mapping

To keep all interested parties informed of the whale's movements, maps are made on a weekly basis and sent to an extensive mailing list (~250 recipients) that includes many whalers and other subsistence hunters as well as agency personnel. ArcGIS version 9.2 (ESRI 2006) is used for all

mapping. The maps and information about the project are posted at the Alaska Department of Fish and Game's (ADF&G) website:
http://www.wildlife.alaska.gov/index.cfm?adfg=marinemammals.bowhead.

Genetic Analyses

Biopsy tips were either mounted on the deployment poles or attached to arrow shafts that were fired from crossbows. Both methods have been used successfully to attain biopsies in this and other studies (e.g., Heide-Jørgensen et al. 2003). DNA was extracted and analyzed to determine sex by genetics experts at Texas A&M University in 2006–2007. Genetic samples acquired in 2008 were sent to Purdue University in Indiana and/or to National Marine Fisheries Service, Southwest Fisheries Science Center for gender analysis and then archived. Genetic material from this archive was also used to assess stock structure within the western Arctic population of bowhead whales as requested by the International Whaling Commission.

Movement Analyses

We analyzed the movements of bowhead whales from 2006 through the spring of 2009. Data collected since the spring of 2009 are not analyzed in detail in this report. However, we used these data for qualitative comparisons in the results and discussion.

Data Management and Location Processing. Location data were collected using the ARGOS system (Harris et al. 1990) and a copy of the raw data is archived at ADF&G in Fairbanks. Transmitter locations were estimated based upon the number of times the transmitter communicated with Argos satellites when the whale was at the surface. The location error was estimated by the Argos system and characterized by "location classes" (see the Argos User's Manual for a complete description; available online from argos-system.org/manual/). Location classes are only an approximate representation of location accuracy (e.g., Vincent et al. 2002). Instead of using only the locations representing the highest accuracy (2 or 3), we chose to use all available location classes (B, A, 0, 1, 2, 3) and a filter developed by Freitas et al. (2008) in R version 2.5.1 (available online from R-project.org) to remove less accurate locations. The filter has separate velocity and angular components.

Bowhead whale locations that resulted in swim velocities of >1.94 m/s were removed unless they were within 5 km of the previous location. The threshold velocity of 1.94 m/s was based on direct measurements during spring migration and literature review indicating this velocity is the maximum observed migration speed of bowheads not fleeing vessels or assisted by currents (Zeh et al., 1993). The angular component of the filter is used to remove locations with a high degree of location error that fall far from the line of travel, but still within the threshold velocity. These locations are essentially outliers and they create "spikes" or acute deviations in the line of travel (e.g., Freitas et al. 2008, Keating 1994). For location i, this deviation is measured as the angle between locations i-1, i, and i+1. We used the default settings within the Freitas et al. (2008) filter; i.e., within 2.5 km of the track line, locations resulting in angles <15°were removed and locations between 2.5 and 5 km of the track line were removed if they resulted in angles <25° (see the manual for Package 'argosfilter' for more detail, available online at cran.R-project.org). We then removed locations that fell on land to establish the final set of locations used to determine bowhead whale migratory paths and areas of concentrated use.

Migration Paths in the Chukchi Sea. To determine where tagged whales crossed the Chukchi Sea study area (Fig. 1), we plotted whale locations in ArcGIS and used Hawth's Analysis Tools for ArcGIS developed by H. Beyer (available online from spatialecology.com/tools) to combine locations into tracks. To distinguish segments of the track that were well known (many locations) from those that were less known (few locations), we arbitrarily chose to represent segments with ≤200 km between locations by a solid line and segments with >200 km between locations with a dotted line (Fig. 2). We also report the average minimum number of days required to cross the Chukchi Sea and to enter the Bering Sea. Because not all whales migrate within close proximity to the Russian shoreline, we defined whales as having crossed the Chukchi Sea when they came within 100 km of the Chukotka Peninsula or Wrangel Island.

Areas of Concentrated Use (Kernel Density Estimation). We used kernel densities to identify geographic areas associated with a high probability of use by bowhead whales (e.g., Silverman 1986, Worton 1989, Wand and Jones 1995). Kernel density estimation is a non-parametric method for calculating the probability that an animal occurs within a defined area. Such probability distributions are also known as *utilization distributions* (e.g., Kernohan et al. 2002); however, we use the term kernel density, as it describes the methodology used to generate the probability distribution of animal locations.

When calculating a kernel density, we overlaid each whale location with a 2-dimensional probability density function (PDF), known as a *kernel* function. For example, a "normal" kernel is based upon a normal probability density function, where 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 cannot be calculated using standard formulas for variance. Therefore, the variance of the kernel, also known as the *bandwidth*, must be estimated by other means (see *Bandwidth Selection*, below). The total probability density for any location within the study area is calculated by summing the individual kernels and scaling such that the final kernel density, which includes the probability for all locations, integrates to 1. Kernel densities are often described using percent probability contours, which are the contours that contain the desired percentage of total probability within the smallest area. For example, the 10% probability contour contains 10% of the probability of use within the smallest area on the surface of the kernel density. This results in an inverse relationship between the probability of finding a whale location and the value of the contour; i.e., a 10% probability contour only contains areas with a high probability of use, while a 90% probability contour contains areas with both high and low probabilities of use. If visualized in 3-dimensions, where the height of the kernel density surface is probability of use, a 10% probability contour would surround the peak of the surface, whereas a 90% probability contour would be located lower on the surface.

When calculating kernel densities in practice, a study area is usually divided into grid cells within which individual kernels are summed. We overlaid the study area with a grid of 5 km^2 cells that was large enough (135,682 cells) to contain the complete kernel density for all whales (Fig. 1). The grid had a modified Albers projection that was shifted north and west of the standard Alaska Albers projection; our projection had a central meridian of 170.0° W and standard parallels of 65° and 75° N latitude.

The number of locations per whale varied on a daily basis. To standardize the contributions of individual whales within days, we split the day into four 6-hr periods and selected the location with the highest location class within each time period. When multiple locations within a time period had the same location class, we selected the location that was transmitted the earliest, thereby spacing the locations over time. We then generated a kernel density for each whale in each of the months of our analysis. To remove density that occurred on land, the kernel density was multiplied by a density that had cells coded 0 for land and 1 for water. We then rescaled the density for each whale so it integrated to 1.

Tags provided differing amounts of information regarding migration paths and areas of concentrated use because longevity and performance varied. We did not want tags that contributed little information to have equal weight in the kernel densities, and thus weighted the contribution of individual whales by the number of locations used to compute the kernel density for each whale within each month. Specifically, on a monthly basis the kernel density within each grid cell was multiplied by the proportion of data contributed by that whale. The cell densities for each whale were then summed to generate a single kernel density for all whales within each month.

Figure 1. Study area and outline for the grid of 5 km² cells (dotted line) used for kernel density estimation in the Chukchi Sea.

Bandwidth Selection. Kernel densities are known to be insensitive to the selection of the kernel function, but highly sensitive to the selection of bandwidth (Silverman, 1986). For wildlife studies, least squares cross-validation (LSCV) is the most common method of bandwidth selection (e.g., Seaman and Powell 1996, Seaman et al. 1999, Gitzen and Millspaugh 2003). Based upon simulation studies, LSCV is known to be unbiased, but highly variable (Park and Marron 1990). In other words, multiple realizations of the same kernel density may vary greatly. To overcome this, a number of alternative methods exist for specifying the bandwidth matrix, such as "biased least squares cross validation" and "plug-in" estimators (e.g., Wand and Jones 1995). We used Smoothed Cross-Validation (SCV) as described by Duong and Hazelton (2005).

Assume **X** is a matrix of locations (e.g., latitude and longitude), **H** is a matrix of bandwidths, and **G** is a pilot bandwidth matrix. Assuming a normal (i.e., Gaussian) kernel with a zero mean vector and identity covariance matrix (ϕ), then:

$$SCV(H) = n^{-1}(4\pi)^{-d/2}|H|^{-1/2} + n^{-2}\sum_{i=1}^{n}\sum_{j=1}^{n}\left(\phi_{2H+2G} - 2\phi_{H+2G}\right)\left(X_i - X_j\right).$$

The SCV selector of $\mathbf{H}_{SCV}$ is the minimizer of SCV(**H**). The pilot bandwidth matrix, **G**, is selected by minimizing the Asymptotic Integrated Mean Squared Error (AIMSE), which is the difference between the density of locations and the density estimated with bandwidth matrix **H**. A closed form solution for **G** is provided in Duong and Hazelton (2005). To ease computation, the pilot bandwidth matrix contains only the diagonal components of the bandwidth. As such, pre-scaling or pre-sphereing the data is recommended (Duong and Hazelton 2005).

When there are no replications of locations and the pilot bandwidth matrix (**G**) is equal to zero, SCV converges on LSCV. In effect, the pilot bandwidth matrix pre-smoothes the data to generate a less variable (and more reliable) bandwidth. Asymptotic analyses and simulation studies have shown that SCV is unbiased like LSCV, but is also less variable than LSCV for a variety of density shapes (Duong and Hazelton 2005). A bandwidth with less variability is desirable for our study, as this means the bandwidth will be less sensitive to how locations are sampled. We calculated $\mathbf{H}_{SCV}$ using package "ks" (Duong 2007) in R version 2.5.1 (available online from R-project.org). As recommended by Duong and Hazelton (2005), we pre-scaled our data before calculating bandwidth matrices.

Assumptions of Kernel Densities. Kernel density estimators are non-parametric and, therefore, make no assumptions about the statistical distribution of bowhead whale locations. However, using kernel densities to infer the importance of geographic areas for bowhead whales must be done with caution. We implicitly assume that our sample of whale locations reflects the true distribution of whales, both tagged and untagged. However, the movements of tagged whales may not represent that of untagged whales and the probability of receiving a transmission may depend upon whale behavior. For example, if dense sea ice impedes transmission or if whales spend less time at the surface while migrating, migration corridors may be under represented within the sample of locations. Even if our sample of whale locations is representative of the population, probability of use may not accurately reflect the importance of a geographic area. Geographic areas with a low probability of use might still be important; e.g., if whales spend little time in migratory corridors, the probability of use will be low within the corridor.

Habitat Use Relative to Sea Ice and Bathymetry. Locations of bowhead whales in the Bering Sea were examined relative to sea ice and bathymetry. Ice data were from NASA's Aqua satellite and were measured with the Advanced Microwave Scanning Radiometer – Earth

Observing System sensor (AMSR-E). More information about this sensor and the ice data are available on the web (http://wwwghcc.msfc.nasa.gov/AMSR/). For the Bering Sea, bathymetric data are contained within the Smith and Sandwell Global Bathymetry Chart (Smith and Sandwell 1997). We also have large amounts of depth soundings available to us at ADF&G and, if necessary, will interpolate our own bathymetric layers.

We also made qualitative comparisons for bowhead whales in the Beaufort and Chukchi seas. For these areas, we used bathymetric data from the International Bathymetric Chart of the Arctic Ocean (Jakobsson and Macnab 2006).

Seismic

In September of 2006, a satellite-tagged bowhead whale was in the vicinity of a 2D seismic operation for 17 days. This provided us with the opportunity to examine how whale behavior varied as a function of distance from the seismic ship. The survey was conducted by GX Technology Corporation using the *M/V Discoverer*, a 72 m Ice Class C vessel towing a 40 airgun array, of which a maximum of 36 airguns were firing (total discharge volume of 3,220 cubic inches).

To remove unlikely whale locations from the dataset, we filtered locations using the speed filter described by MacConnell et al. (1992) with a velocity threshold of 5.9 m/s, the maximum speed Richardson and Finley (1989) observed a bowhead whale fleeing a ship. For each whale location, we calculated distance to the seismic ship, the whale's velocity approaching the nearest location to the ship ($v_{1,2}$), the whale's velocity leaving the nearest location to the ship ($v_{2,3}$), and the whale's change in direction (q_2) relative to the ship's location. We predicted that the whale would turn away from the ship and its velocity would increase as the ship came closer to the whale. If whale movement was random, when the whale was far from the ship we expected the distribution of turn angles to be uniform with high dispersion. As the ship approached the whale, we expected the distribution of turn angles to have a mean near 180^o and a low amount of dispersion, indicating that the whale's movements were consistent with attempts to move away from the ship. We split the data into four distance categories: 1) $\leq$ 25 km; 2) 26 to 50 km; 3) 51 to 100 km; 4) > 100 km. Because the whale was located few times in close proximity to the ship, we relied on non-parametric comparisons. To compare whale velocity in the four distance categories we used a Kruskal-Wallis test in SAS 9.1 (SAS Institute 2004) using PROC NPAR1WAY. To determine if the distribution of turning angles changed in mean direction or dispersion between distance categories, we used Rao's Test for Homogeneity (Jammalamadaka and SenGupta 2001) in package CircStats in R (R Development Core Team 2007).

Traditional Knowledge

The AEWC requested a traditional knowledge component be added to this project. The whalers recognized that only a small proportion of the total bowhead population would be tagged, and were concerned that information from a relatively small sample of tagged whales would not accurately represent bowhead behavior. They wanted a formal mechanism for including their local knowledge into the assessment of bowhead behavior, and to assist in the interpretation of the information received from the tagged whales.

Traditional Knowledge interviews at Barrow and Kaktovik were funded by a grant to ADF&G from ConocoPhillips, which was used as match to fund interviews at Wainwright through the Coastal Marine Institute at the University of Alaska (funded by MMS). Interviews were conducted by Henry Huntington, a social scientist with experience in traditional knowledge studies and PI Quakenbush. We used the same methods to document traditional knowledge as those used by Noongwook et al. (2007); specifically, we used the semi-directive interview as described by Huntington (1998). Unlike Noongwook et al. (2007), however, our interviews were with one or two persons at a time, rather than with larger groups. In the semi-directive interview, researchers initiate a discussion around various topics of interest, but allow the person being interviewed to determine the order in which topics are discussed and to make connections among various topics that the researchers might not have anticipated. The interview is more fluid than would be a standardized questionnaire.

The persons interviewed were recommended by the head of the local whaling captains association or by chain referral; i.e., one participant recommending additional persons to interview. The interviews were conducted in English, as all participants were comfortable in that language. We used maps of the local areas for clarification during discussions. We drew whale movements and recorded information directly on the maps during the interviews to ensure we accurately interpreted what was being described. When information from the interviews was compiled, a draft report with annotated maps was sent to the interviewees to comment on for accuracy.

Safety

Safety plans were specific for each tagging effort. We purchased safety equipment and trained personnel in its use. Safety equipment includes Mustang floatation suits, waterproof marine VHF handheld radios, satellite phones, personal satellite-linked locator beacons, and GPS units.

Results

Coordination

We worked closely with the AEWC, the local whaling captain's associations, the North Slope Borough (NSB), the Greenland Institute of Natural Resources and MMS in all years. In 2007, we began working with the Department of Fisheries and Oceans (DFO) Canada and the local Hunters and Trappers Committees. See Table 1 for project history by month and year. We maintained a webpage on the State of Alaska, Division of Wildlife Conservation website that was updated weekly with whale movements and explained the project (http://www.wildlife.alaska.gov/index.cfm?adfg=marinemammals.bowhead). We also sent maps to an extensive list of interested entities including individual whalers and whaling captains, NOAA Fisheries biologists, NSB, MMS, and DFO.

Table 1. Project history from 1 August 2005 to 1 June 2010.

Month	Year	Event
August	2005	Kaktovik Whaling Captain's meeting. Craig George attended.
September		Ordered tags and hired tag developer/tagger. Kaktovik Whaling Captain's meeting. Lori Quakenbush and Craig George attended. Permission granted for tagging at Kaktovik, weather bad and no whales seen.
October		Contract awarded. AEWC meeting. Presented study plan. Approved with addition of Traditional Knowledge (TK).

December		Met with Wildlife Computers, Mads Peter Heide-Jørgensen in San Diego, CA.
March	2006	Presented update to AEWC. Received funding from ConocoPhillips for TK study.
May		First bowhead tagged 12 May near Barrow. Maps of bowhead track across Beaufort Sea posted on ADF&G and NSB websites.
July		AEWC meeting. Presented update of tagged whale and TK funding
September		One whale tagged at Barrow, tried tagging near Kaktovik, weather bad, whales heard but not seen.
Oct–Dec		Data analysis of bowhead speed, turn angles, and route through ice.
January	2007	Presentation at Alaska Marine Science Symposium, Anchorage (Appendix B).
February		TEK interviews in Barrow and Kaktovik
April		Two bowheads tagged near Barrow.
May		Presentation of paper to International Whaling Commission (Appendix C).
June		Two abstracts accepted to Society for Marine Mammalogy Conference.
July		AEWC meeting. Presented update of tagged whales and project.
August		Five whales tagged east of Herschel Island, Canada.
September		No whales near Barrow in September before whaling began (i.e., no opportunity for tagging whales).
October		Presentation to Whaling Captain's Mini-Convention in Fairbanks. Presentation at ConocoPhillips Arctic Environmental Knowledge Sharing Seminar in Kananaskis, Canada.
December		Presentations at Society for Marine Mammalogy Conference South Africa (Appendices D and E).
January	2008	Presentation at Alaska Marine Science Symposium (Appendix F). Met with Alex Zerbini, NMML, regarding tag performance improvement. Attended BOWFEST workshop, presented update on tagging. Met with Lois Harwood in Anchorage to discuss tagging in Canada. Traditional Knowledge interviews in Wainwright and Barrow.
February		Presentation at Whaling Captain's Convention in Barrow.
April-May		No tags deployed during spring whaling.
July		Presentation at AEWC meeting in Fairbanks (Appendix G).
August		One whale tagged at Atkinson Point, Canada.
September		14 whales tagged near Barrow.
October		Began kernel density analysis for fall movements in Chukchi Sea.
November		Presentation at MMS/ITM and O&G Meetings, Anchorage.

January	2009	Presented fall movements in Chukchi Sea at Alaska Marine Science Symposium (Appendix H). Attended BOWFEST Workshop. Worked with Dr. Okkonen on combining tag data with oceanography to test "zooplankton trap" theory. Univ. of Alaska, Inst. of Marine Science Seminar.
February		Project Update Community Presentations in Barrow, Kaktovik, and Wainwright. Science Class lectures in Kaktovik middle and high schools.
March		Began winter data analysis.
Apr-May		John Citta participated in NSB whale census at Barrow and coordinated tagging. No tags deployed due to ice conditions.
June		Presentation of paper to International Whaling Commission, Spain (Appendix I).
July		Presentation at AEWC meeting in Fairbanks.
August		Three bowheads and one gray whale tagged in Canada near Atkinson Point and five bowheads tagged near Barrow before whaling. Submitted manuscript to Arctic on fall movements in Chukchi Sea.
October		Four bowheads tagged near Barrow after whaling. Presented winter movements in Bering Sea at Society for Marine Mammalogy Conf. in Quebec City, Canada (Appendices J). Update to AEWC and presented TEK reports for approval (Appendices K and L).
January	2010	Presented seasonal movements throughout migratory range at Alaska Marine Science Symposium, Anchorage (Appendix M).
February		Presented project update to AEWC at mini-convention, Barrow.
March		Presented project update to NMFS Open Water Meeting, Anchorage.
April		Preparing winter movements in Bering Sea manuscript and final project report.
May		Three whales tagged in the lead near Barrow. Preparation of Draft Final Report

Tagged Whales, Biopsy and Tag Performance

A total of 47 satellite transmitters have been deployed during this study between 2006 and 2010; 46 on bowhead whales and one on a gray whale (Table 2). Of the 46 bowhead whales tagged, biopsies were collected from 32 and gender was been determined for 28; 20 males and 8 females. The majority (n=37, 80%) of the bowhead whales were tagged near Barrow and nine (20%) were tagged in Canada; five east of Herschel Island in Mackenzie Bay and four near Atkinson Point on the Tuktoyuktak Peninsula. The gray whale was also tagged near Atkinson Point. The sizes of the bowhead whales tagged ranged from 9 to 17 m, with the largest whales tagged near Barrow in August, October and late May.

We deployed 28 SPLASH tags and 17 SPOT tags on bowhead whales; one additional SPLASH tag was deployed on a female gray whale. Tags deployed in 2006 lasted an average of 68 days. Tags deployed in 2007, 2008, and 2009 averaged 8, 189, and 158 days, respectively. Five of the tags deployed in 2009, however, were still transmitting, therefore, we expect the 2008 and 2009 averages will be similar. Although SPLASH tags lasted longer ($\bar{x}$=130 days) than SPOT tags

($\bar{x}$=97 days), we do not think this is because SPOT tags perform less well. Rather, more SPOT tags were deployed in 2006 and 2007, while we were still developing protocols and when Wildlife Computers was improving technology. This can be seen in the proportion of tags that failed to transmit any locations. In 2006 and 2007, 33% (1/3) and 40% (4/10) of tags failed to transmit, respectively. In 2008 and 2009, only 7% of transmitters failed to transmit (1/15 in each year). All the tag failures since 2007 have been SPLASH tags.

Because of poor tag performance in 2006 and 2007 (Table 2) we developed a protocol for testing tags prior to deployment. Tags are designed to automatically turn on in salt water; we dip the tags in a salt water solution to ensure that the tag does not leak and performs properly. Through the Argos satellite network, we verify that the tags transmit properly and record their battery voltages. Tags that do not transmit or have low battery voltage are returned to the factory. We also manually activate the tags on the day of deployment; this allows us to gain information on the tag's battery voltage immediately prior to deployment and allows the tag to start transmitting on the whale without waiting for the saltwater switch to activate (which sometimes requires 24 hours). This protocol has allowed us to avoid deploying four tags that we determined were defective. Defective tags were examined by Wildlife Computers and the information was used to improve tag manufacturing. For example, tag electronics are encased in epoxy. A tag that failed in 2007 was discovered to have voids that let salt water leak into the tag and destroy the electronics. This void was likely due to a malfunction in the curing (i.e., drying) process of the epoxy, which was corrected.

Two tags have lasted more than 365 days allowing us to document the year-round movements of one male and two female bowhead whales (Table 2). Tags on another 13 whales have lasted more than 200 days.

Table 2. Bowhead whales and one gray whale tagged with satellite transmitters in Alaska and Canada between May 2006 and May 2010. Tags that were still transmitting on 31 July 2010 are denoted "+" in the Tag duration column.

Whale Id	Ptt	Date tagged	Location	Approx. length (m)	Sex	Tag type	Tag duration (days)
B06-01	60010	12-May-06	Barrow	14	M	SPOT[1]	180
B06-02	60012	12-May-06	Barrow	9	Unk	SPOT	0
B06-03	60009	21-Sep-06	Barrow	11	Unk	SPOT	24
B07-01	50685	25-Apr-07	Barrow	9	M	SPLASH[2]	1
B07-02	37280	26-Apr-07	Barrow	10	M	SPLASH	46
B07-03	60014	23-Aug-07	Canada	15	M	SPOT	0
B07-04	60015	23-Aug-07	Canada	15	M	SPOT	0
B07-05	60013	23-Aug-07	Canada	10	Unk	SPOT	0
B07-06	60016	25-Aug-07	Canada	10	M	SPOT	0
B07-07	60011	25-Aug-07	Canada	11	F	SPOT	11
B07-08	37283	29-Aug-07	Barrow	14	F	SPLASH	5
B07-09	50679	29-Aug-07	Barrow	12	F	SPLASH	16
B07-10	42522	29-Aug-07	Barrow	11	Unk	SPLASH	2

B08-01	37233	12-Aug-08	Canada	11	F	SPLASH	370
B08-02	37230	8-Sep-08	Barrow	10	Unk	SPLASH	172
B08-03	37235	9-Sep-08	Barrow	12	M	SPLASH	36
B08-04	37236	10-Sep-08	Barrow	15	Unk	SPLASH	249
B08-05	37280	10-Sep-08	Barrow	9	M	SPOT	285
B08-06	20689	20-Sep-08	Barrow	11	Unk	SPOT	1
B08-07	22854	20-Sep-08	Barrow	11	F	SPOT	2
B08-08	37234	20-Sep-08	Barrow	10	M	SPLASH	391
B08-09	37278	23-Sep-08	Barrow	10	Unk	SPLASH	282
B08-10	50679	23-Sep-08	Barrow	10	M	SPOT	0
B08-11	50685	23-Sep-08	Barrow	10	M	SPOT	203
B08-12	60009	23-Sep-08	Barrow	> 9	M	SPOT	203
B08-13	60017	23-Sep-08	Barrow	10	Unk	SPOT	341
B08-14	60018	23-Sep-08	Barrow	10	M	SPOT	169
B08-15	37277	23-Sep-08	Barrow	10	Unk	SPLASH	303
B09-01	37231	22-Aug-09	Barrow	15	F	SPLASH	120
B09-02	37232	22-Aug-09	Barrow	14	Unk	SPLASH	160
B09-03	93078	23-Aug-09	Canada	10	M	SPLASH	267+
B09-04	93090	23-Aug-09	Barrow	13	M	SPLASH	342+
B09-05	93086	23-Aug-09	Canada	10	M	SPLASH	21
B09-06	93091	23-Aug-09	Barrow	12	Unk	SPLASH	103
B09-07	93088	29-Aug-09	Barrow	11	M	SPLASH	135
B09-08	42522	29-Aug-09	Barrow	14	M	SPOT	6
B09-09	93089	29-Aug-09	Barrow	14	Unk	SPLASH	336+
B09-10	93092	29-Aug-09	Barrow	>15	Tbd	SPLASH	1
B09-11[4]	93082	3-Sep-09	Canada	10	F	SPLASH	62
B09-12	42521	2-Sep-09	Canada	12	Unk	SPOT	100
B09-13	93079	14-Oct-09	Barrow	17	F	SPLASH	290+
B09-14	93081	14-Oct-09	Barrow	4	M	SPLASH	290+
B09-15	93085	14-Oct-09	Barrow	11	F	SPLASH	0
B09-16	33001	14-Oct-09	Barrow	13	M	SPLASH	290+
B10-01	93080	24-May-10	Barrow	15	Tbd	SPLASH	68+
B10-02	93084	25-May-10	Barrow	17	Tbd	SPLASH	68+
B10-03	93083	24-May-10	Barrow	14	Tbd	SPLASH	68+

[1] SPOT = Tag that provides locations only.
[2] SPLASH = Tag that provides locations and dive data.
[3] Tbd = To be determined when DNA results are available.
[4] This is a gray whale.

Movements and Behavior by Season
Satellite telemetry is a valuable tool for tracking movements over long distances and time periods. In general, bowhead whales made long and directed movements to specific locations where they spent time before moving again. Some of these movements include classic migrations from the Bering Sea to the Canadian Beaufort in spring and from the Beaufort back to the Bering in fall and winter. Other long distance movements outside of the migration period were also documented, including a 1,400 km round trip from Amundsen Gulf to the north end of Banks Island and back by a whale in July and three whales that made round trips from the Canadian Beaufort to Barrow and back in summer. During the fall migration period several whales passed Barrow, as though migrating, only to return to Barrow for some period of time before migrating. See below for more details.

Autumn (August–December) Chukchi Sea. Locations from 15 of the 19 bowhead whales tagged between spring 2006 and fall 2008 were analyzed to determine their general movements through the Chukchi Sea; locations from the remaining four whales were insufficient for this analysis (Table 3). Most whales moved west through the Chukchi Sea between the latitudes of 71°N and 74°N (Fig. 2). Seven whales traveled to Wrangel Island before moving south to the coast of northern Chukotka and then followed that coast southeastward. The one whale that crossed farthest to the north was the only one to go west (~240 km) of Wrangel Island before heading south to the Chukotka coast.

Three whales crossed the Chukchi Sea and then returned east to Point Barrow; two after traveling ~270 km west and one after traveling ~725 km to Wrangel Island (Fig. 3). Specifically, whale B08-10 left Point Barrow for 20 days, first moving ~330 km northwest and then south ~360 km to the Alaska coast near Icy Cape, then back up the coast to Point Barrow where it stayed for 23 days before traveling southwest along the Alaska coast; this was the only whale that did not cross the Chukchi Sea to Chukotka during migration (Fig. 3). Whale B08-01 left Point Barrow for 19 days, moving west ~725 km to within ~30 km of the east coast of Wrangel Island before returning east to Point Barrow for 32 days, and then crossed the Chukchi Sea for a second time towards Cape Schmidt on the Chukotka Peninsula. Whale B08-12 left Point Barrow for 6 days, moving ~275 km west and then returned to Point Barrow for 13 days before crossing the Chukchi Sea, also towards Cape Schmidt on the Chukotka Peninsula (Fig. 3).

Twelve whales had enough locations to determine how quickly they crossed the Chukchi Sea and came within 100 km of the Chukotka Peninsula or Wrangel Island. Nine whales crossed without pausing, arriving within an average of 7.1 days after leaving Point Barrow (range = 6–9 days). These whales left Point Barrow between 29 August and 14 October (average = 18 September) and came within 100 km of Chukotka or Wrangel Island between 9 September and 31 October (average = 25 September).

Three whales did not follow this pattern. B08-07 paused for five days over the shelf break ~120 km northwest of Point Barrow (Fig. 1) and required 14 days to cross the Chukchi Sea (25 September to 9 October). B08-01 crossed the Chukchi Sea twice; the first crossing lasted seven days. The second crossing angled southwest across the Chukchi Sea and was longer than the first (Fig. 3), requiring 14 days. B08-10 migrated down the Alaskan coast and did not come within 100 km of the Chukotka Peninsula until 29 November, 64 days after leaving Point Barrow.

Most whales that crossed the Chukchi Sea remained along the northern coast of Chukotka; whales spent an average of 59 days (range = 23–90 days) within 100 km of the coast of Chukotka, before entering the Bering Sea. The average date for entering the Bering Sea was 5 December, but it ranged from 6 November to 1 January. On 8 December 2008, the first tagged whale (B08-09) reached St. Lawrence Island ~8 days after leaving the Chukchi Sea.

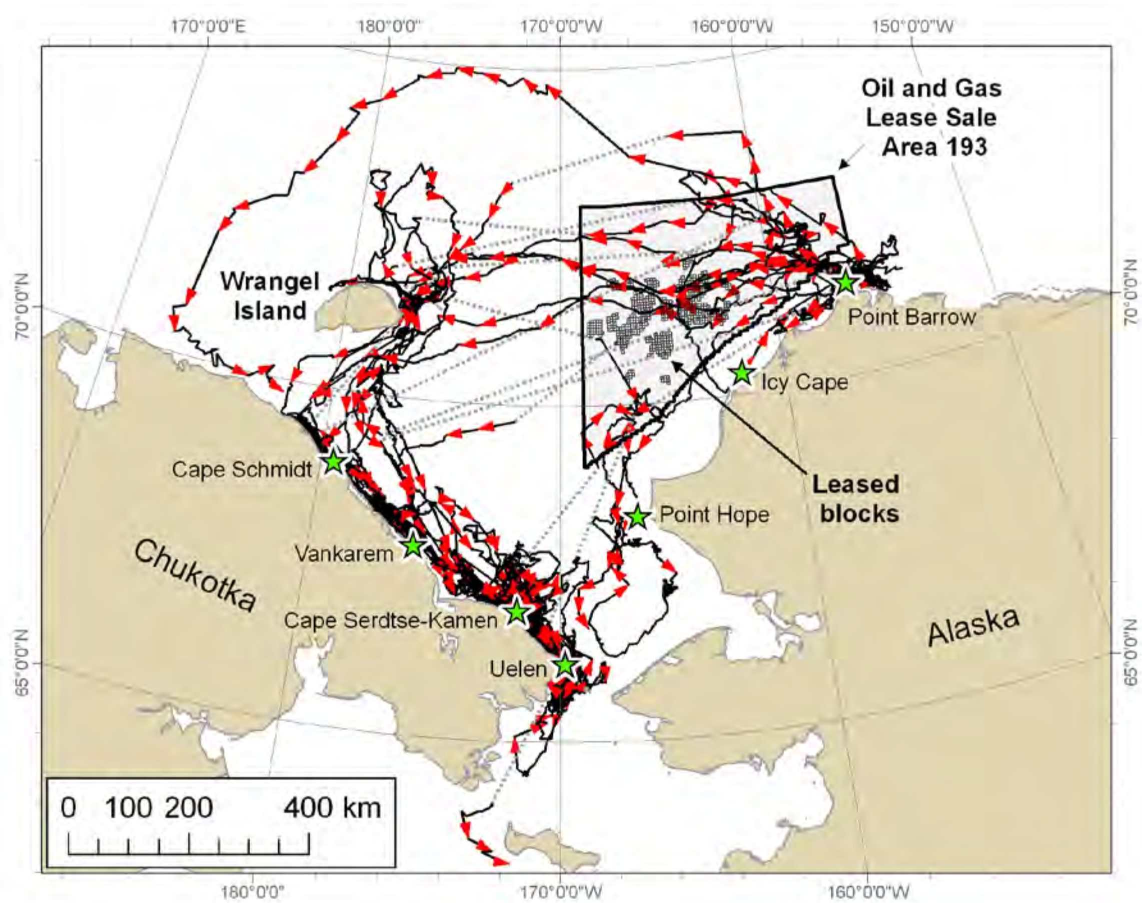

Figure 2. Tracks of 15 satellite-tagged bowhead whales in the Chukchi Sea from August through December, 2006 through 2008, estimated from a filtered set of locations. Locations >200 km apart are connected with dotted lines.

Use of Lease Sale Area and Leased Blocks. Fourteen of the 19 tagged whales transmitted positions that were located within the Lease Area indicating they crossed some portion of it (Table 3, Fig. 2). The five whales that did not transmit within the Lease Area also did not transmit from north or south of the Lease Area. Hence, there is no evidence these whales migrated around the Lease Area. Locations were recorded within both the east and west boundaries of the Lease Area for eight of the whales that crossed it, providing a minimum estimate of the duration of their crossings. Most of these eight whales crossed the lease area in <1 week (median = 5 days); however, one whale (B08-07) lingered within the Lease Area for 30 days before leaving, skewing the average duration to 7.6 days. Of the 14 whales that transmitted within the Lease Area, three (B08-12, B08-07, and B08-10) spent 34, 30, and 26 days in the area, respectively (Table 3). Time spent in the Lease Area by the other 11 whales ranged from 1 to 12 days (Table 3).

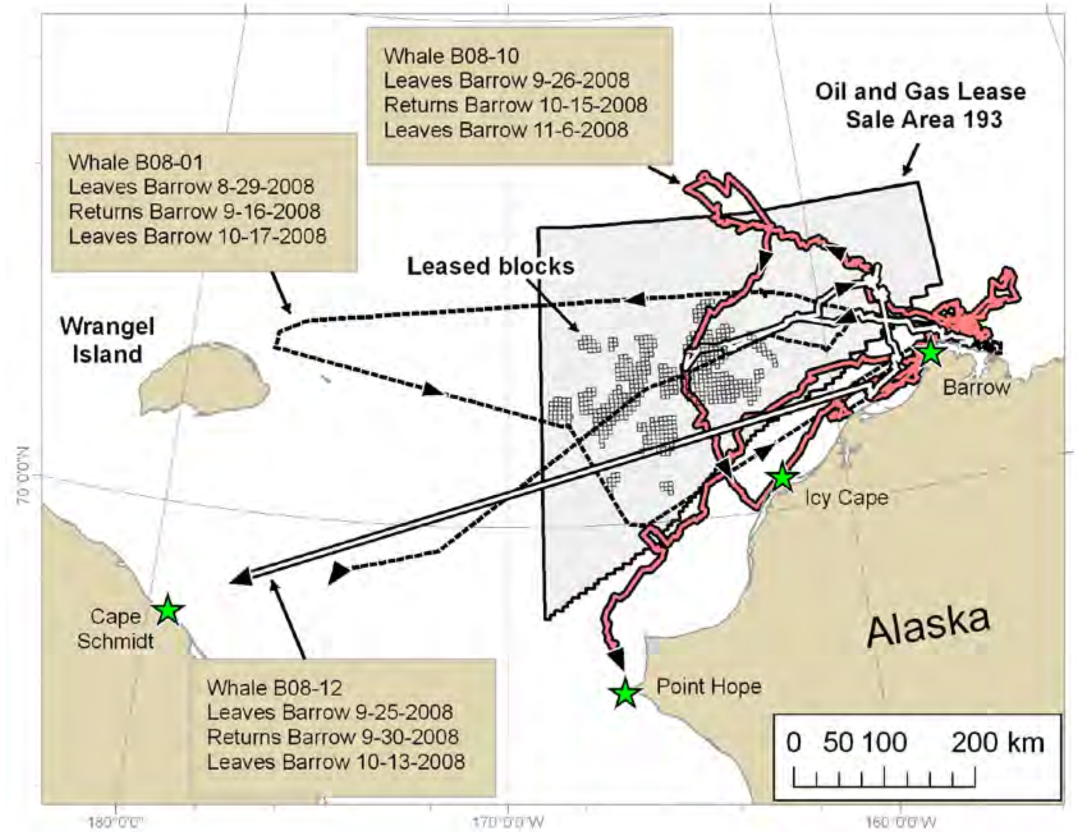

Figure 3. Tracks of three satellite-tagged bowhead whales that returned to the Barrow area after moving west into the Chukchi Sea, 2008.

Of the 14 whales that crossed some portion of the Lease Area, all but one then traveled farther west to Wrangel Island or Chukotka. The exception was whale B08-10, which first passed across the northern boundary of the Lease Area and then turned and traversed the Lease Area from north to south before returning to Point Barrow (Table 3, Fig. 2). After leaving Point Barrow on 6 November, this whale then migrated down the coast of Alaska, moving back and forth across the southwest border of the Lease Area six times (Table 3, Fig. 2) between September and December. Some whales did not provide enough locations to determine how they traversed the Lease Area; however, it is known that they spent time there. For example, B08-12 spent 31 days in the Lease Area before leaving and then re-entered for at least three more days (Table 3, Fig. 2).

Locations from five whales fell within the leased blocks of the Lease Area. The earliest date a whale was located within the leased blocks was 16 October in 2006 and 13 September in 2008; one whale (B07-04) was located in the Lease Area in 2007, yet it was only for three days and no locations fell within a leased block. The duration that whales remained within the leased blocks ranged from <1 to 4 days. These durations are negatively biased because they do not include the time within the leased blocks before the first location and after the last locations were recorded.

Kernel Density Estimation. We received 18,458 locations from the 19 tagged whales. A total of 5,369 locations were removed by filtering (Freitas et al. 2008). An additional 785 locations were removed because they fell on land. After selecting the highest location class for each 6-hr time period, we had a sample of 2,932 locations for estimating kernel densities (Table 4). A total of 20 locations, from four whales, were collected in August. These locations were insufficient to estimate a separate density for August, thus we pooled them with locations from September. Some whales contributed only a few locations (e.g., <7) and these whales contributed little to the monthly kernel densities because we weighted the contribution of each whale by their number of locations. For example, there were only three locations for whale B08-4 in September (Table 4), resulting in a weight of only 0.006 that accounted for <1% of the kernel density for all whales in September.

In September, the highest probability of use was concentrated northeast of Point Barrow and extended to the east and west, south of the shelf break and the 200-m isobath (Fig. 4). Most whales were crossing the Chukchi Sea in September, enroute to Wrangel Island and Chukotka. Because whales did not pause in the central Chukchi Sea, the migratory corridor is characterized by a low probability of use (Fig. 4). In October, probability of use was highest northeast of Point Barrow and along ~600 km of the Chukotka coast (Fig. 5). An area centered east of Wrangel Island had a moderate probability of use. In November, the probability of use continued to be highest along the Chukotka coast, but was farther south than in October (Fig. 6). Probability of use was highest near Cape Serdtse-Kamen, but stretched from ~75 km northeast of Vankarem to Bering Strait. By December, use was most concentrated along the coast of Chukotka, from Cape Serdtse-Kamen to the Bering Strait (Fig. 7).

There was a low density of bowhead whales within the Lease Area during September–December. The Lease Area was used most in September when the area contained 31% of the total probability of use for all whales. However, areas with the highest probability of use were located in the northeastern section of the Lease Area, not where the leased blocks were located. Leased blocks contained only 2% of the total probability of use (Fig. 4) by bowhead whales. In October, the entire Lease Area contained 7% of the total probability of use for all whales (Fig. 5) with only 1% of the probability of use contained within the leased blocks. In November, most of the whales were located along the coast of Chukotka; the Lease Area contained only 2% of the total probability of use and the leased blocks contained <1%. In December, the probability of use within the Lease Area increased to 5%. However, whales were located mostly south of the leased blocks, and, again, the leased blocks contained <1% of the probability of use.

Table 3. Timing and duration of locations from satellite-tagged bowhead whales within Oil and Gas Lease Sale Area 193 in the Chukchi Sea.

Whale Id	Ptt	# Locations [1]	Starting day	Ending day	Duration (d)[2]
B06-01	60010	76	15-Oct-06	19-Oct-06	5
B07-04	60015	8	31-Aug-07	2-Sep-07	3
B08-01	37233	9	31-Aug-08	31-Aug-08	1
		5	10-Sep-08	12-Sep-08	3
		14	18-Oct-08	25-Oct-08	8
B08-02	37230	44	13-Sep-08	19-Sep-08	7
B08-03	37235	55	11-Sep-08	15-Sep-08	5
B08-05[3]	37280	7	23-Sep-08	23-Sep-08	1
B08-06	20689	10	25-Sep-08	29-Sep-08	5
B08-07	22854	79	26-Sep-08	25-Oct-08	30
B08-08	37234	55	26-Sep-08	29-Sep-08	4
B08-09	37278	44	26-Sep-08	29-Sep-08	4
B08-10[4]	50679	113	26-Sep-08	1-Oct-08	6
		66	3-Oct-08	5-Oct-08	3
		17	7-Nov-08	8-Nov-08	2
		1	9-Nov-08	9-Nov-08	1
		10	12 Nov-08	14-Nov-08	3
		94	15-Dec-08	25-Dec-08	11
B08-11	50685	24	26-Sep-08	27-Sep-08	2
B08-12	60009	137	25-Sep-08	25-Oct-08	31
		5	18-Dec-08	20-Dec-08	3
B08-13[5]	60017	19	26-Sep-08	28-Sep-08	3

[1] The set of locations for distinct periods that individual whales were located in the Lease Area are listed in separate rows.
[2] Durations were calculated as the number of days between when the first and last locations were recorded within the Lease Area; because locations were not necessarily received daily, durations are minimums.
[3] This tag stopped transmitting within one day of entering the Lease Area.
[4] This whale did not travel across the Chukchi Sea to Chukotka, but rather traveled south along the Alaska coast; see Fig. 3.
[5] This tag stopped transmitting within the Lease Area and began transmitting again on 10 October 2008 off the coast of Chukotka.

Table 4. The number of bowhead whale locations, for each whale, used to estimate monthly kernel densities for September through December, 2006–2008. The year locations were recorded is indicated by the Whale ID (i.e., B06-01 represents the first whale in 2006). Twenty locations were collected between 29 and 31 August; for analysis these locations were pooled with those collected in September.

Whale Id	Ptt	Month					Total
		Aug	Sept	Oct	Nov	Dec	
B06-01	60010			55	31		86
B06-03	60009				3		3
B07-02	37280	5	11				16
B07-03	60014	5					5
B07-04	60015	5	47				52
B08-01	37233	5	49	68	54	61	237
B08-02	37230		66	64			130
B08-03	37235		76	120	69		265
B08-04	37236		3				3
B08-05	37280		7				7
B08-06	20689		22	108	79	110	319
B08-07	22854		36	92	66	94	288
B08-08	37234		23	88	86	101	298
B08-09	37278		23	56	35	11	125
B08-10	50679		27	121	110	87	345
B08-11	50685		20	114	104	102	340
B08-12	60009		22	25	25	11	83
B08-13	60017		14	54	58	71	197
B08-14	60018		7		43	83	133
Total		20	453	965	763	731	2932

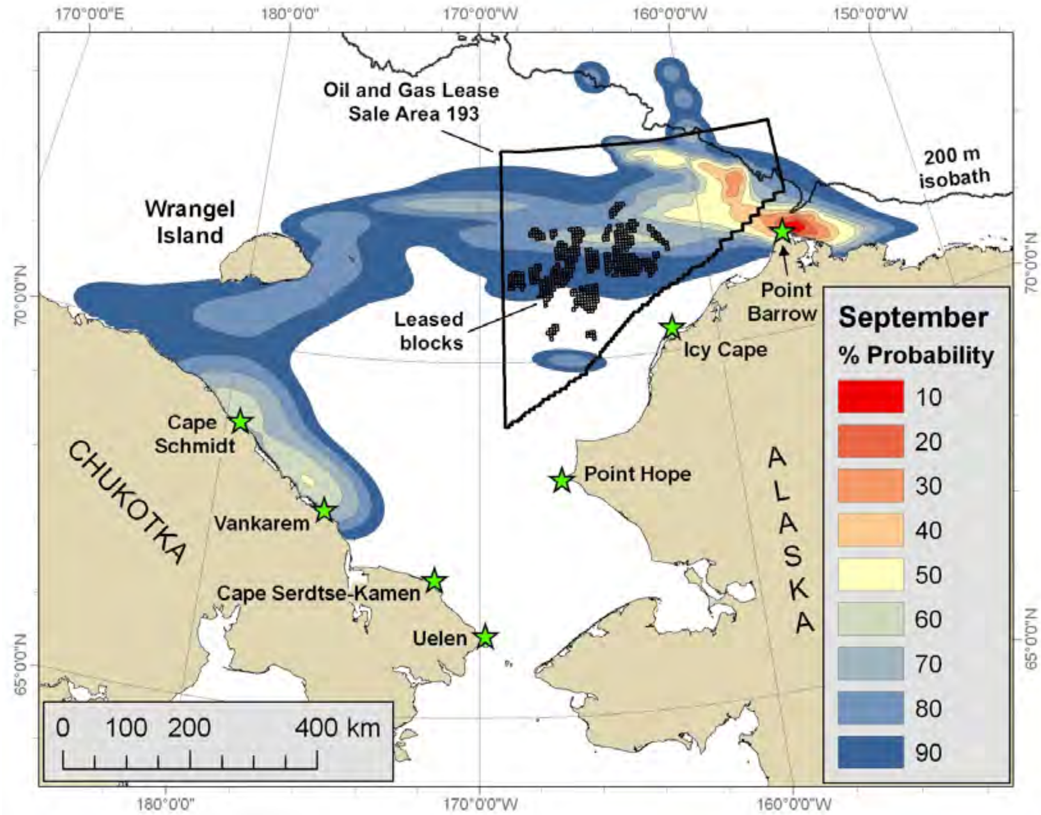

Figure 4. Contours showing the probability of use (%) by bowhead whales in September, 2006–2008.

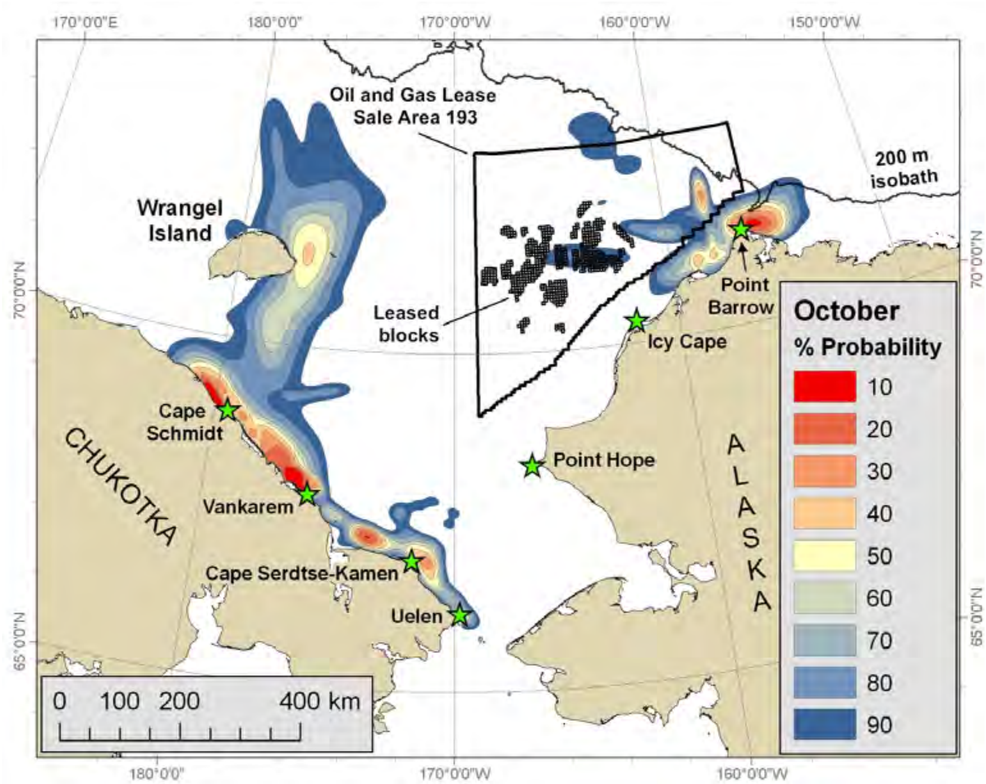

Figure 5. Contours showing the probability of use (%) by bowhead whales in October, 2006–2008.

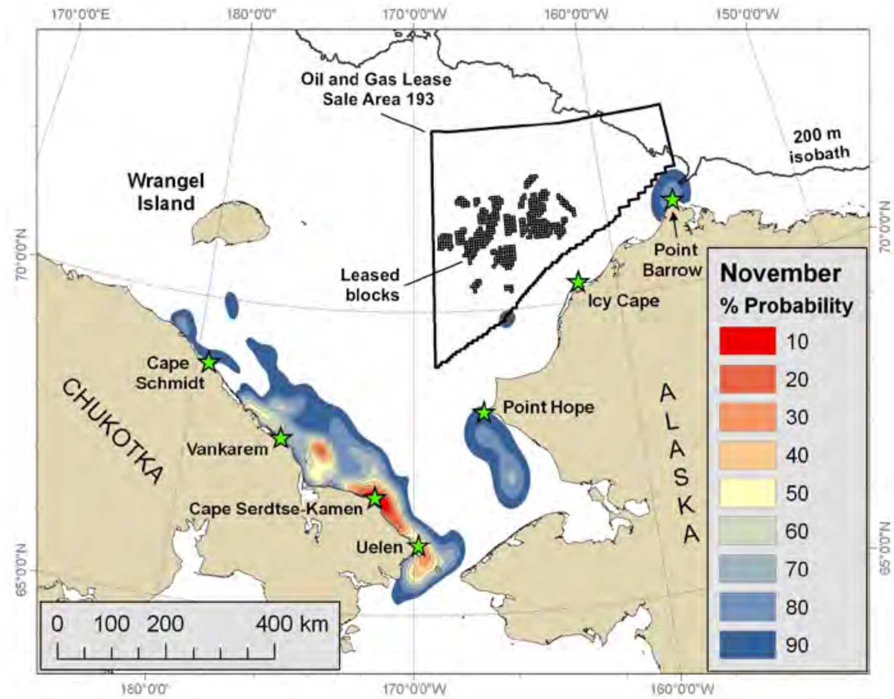

Figure 6. Contours showing the probability of use (%) by bowhead whales in November, 2006–2008.

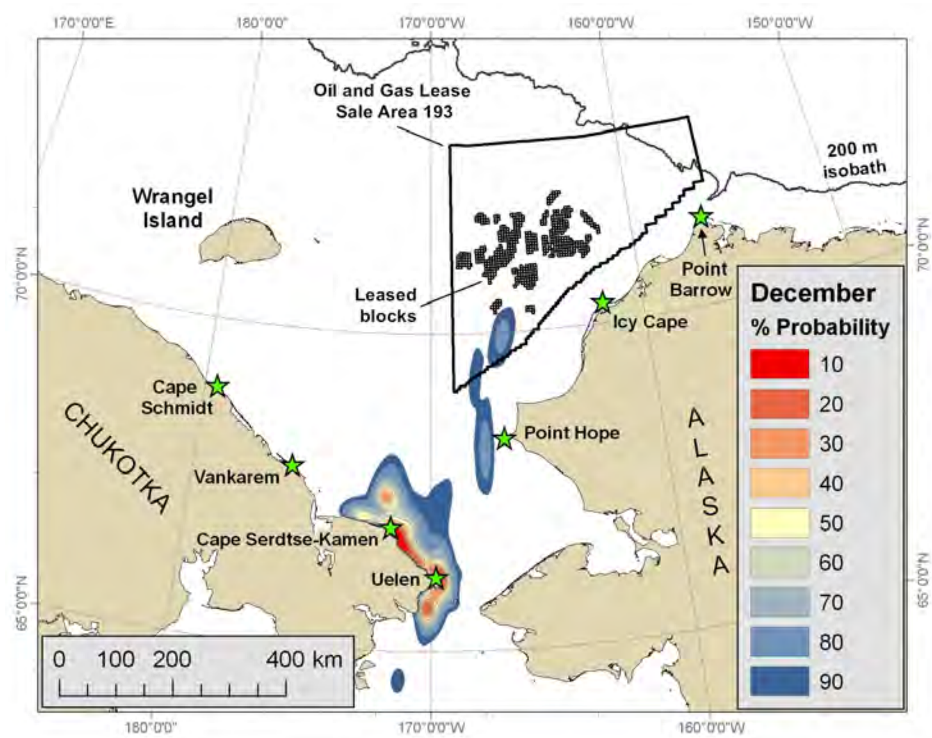

Figure 7. Contours showing the probability of use (%) by bowhead whales in December, 2006–2008.

New data from 2009/10. We also have data from whales tagged in the fall of 2009. We have yet to incorporate these data into a formal analysis, but we can present the satellite tracks for comparison with 2008. In the fall of 2009, whales followed the same general path across the Chukchi Sea. However, whales spent more time in the central Chukchi (Fig. 8) and less time within the area immediately east of Wrangel Island. As in 2008, one whale migrated down the Alaskan coast and most whales spent significant time along the coast of Chukotka, between Wrangel Island and the Bering Strait.

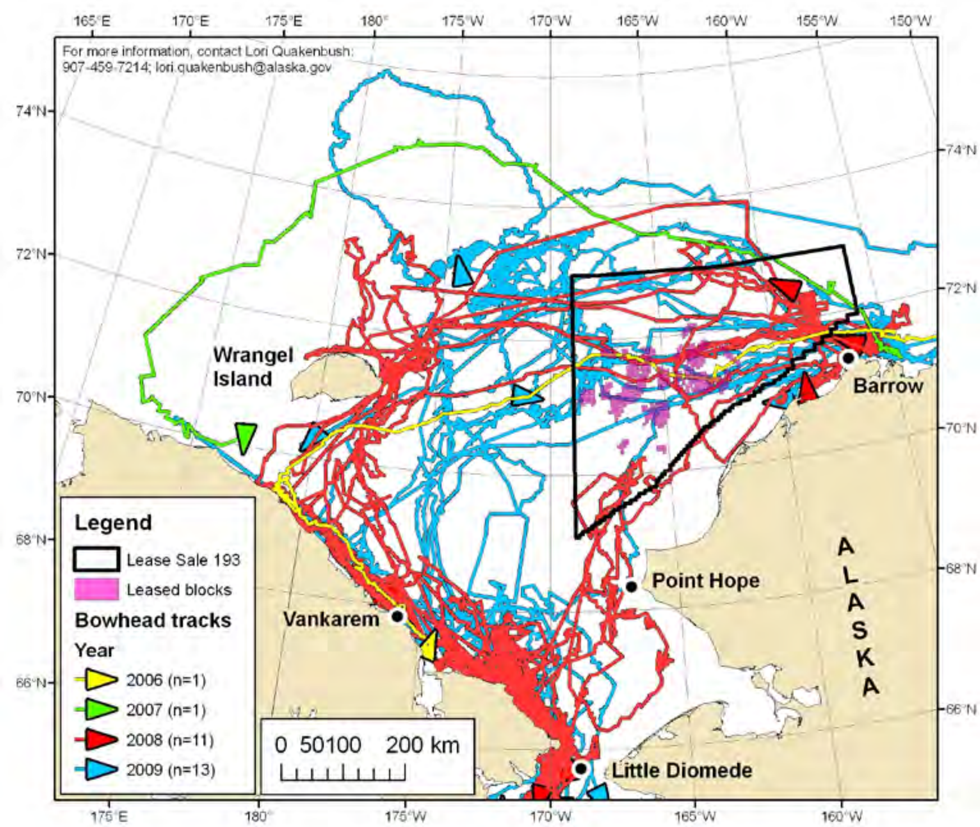

Figure 8. Tracks of 26 satellite-tagged bowhead whales during fall 2006–2009.

Diving Behavior. Three whales (B07-08, B07-09, and B07-10) tagged near Barrow in August 2007 had tags capable of measuring dive depth and duration. Near Barrow, these whales spent the majority of time between 9 and 18 m below the surface and or at the bottom, presumably feeding. Whale B07-10 crossed the Chukchi Sea far to the north along the shelf break (Fig. 9a) and traveled through areas of deep water and dove to a maximum depth of 300 m in water 600 m deep (Fig. 9a and 9b). Near the Russian coast, this whale spent the majority of time between 20 and 50 m, which was at or near the bottom ~50% of the time (Fig 9b). Dives ranged from three to over 39 minutes in duration (Fig. 10). Because the most shallow depth bin (0–3 m) might include dives where the whale was essentially at the surface, we excluded it from our analysis. Not counting the most shallow dive bin, 50% of all dives were 18 min or less in duration. Approximately 3% of the dives were longer than the maximum time limit (39 min) allowed for the tags in 2007. Therefore, we changed the time bins to be incremented by six minutes in 2008, instead of the three minute increment we used in 2007. All whales that we were able to track across the Chukchi Sea in the autumn, except two, spent time along the northern coast of Chukotka south of Wrangel Island between August and October (Fig. 2).

Winter (December–March) Bering Sea. Locations from bowhead whales tagged near Atkinson Point, Canada in August 2008 (*n*=1) and near Barrow Alaska in September 2008 (*n*=14) were analyzed to determine the timing and migration path into the Bering Sea, their general movements within the Bering Sea and the timing and migration path of eight of those whales out of the Bering Sea; transmitters on two of the 10 whales stopped transmitting prior to the spring migration (Table 2).

Bowhead whales entered the Bering Sea between 6 November 2008 and 9 January 2009, with an average date of entry of 9 December. Movement into the Bering Sea was not abrupt; rather, whales lingered along the coast of Chukotka before entering the Bering Strait and then lingered within the Bering Strait. All whales passed west of both Little and Big Diomede Islands (Fig. 11). On 8 December 2008, the first tagged whale (B08-09) reached St. Lawrence Island ~8 days after leaving the Chukchi Sea. All whales passed west of St. Lawrence Island, both in the fall and the following spring.

Kernel Density Estimation. We received 15,946 locations from 10 tagged whales during the winter of 2008-2009. A total of 5,966 locations were removed by filtering, leaving 9,980 locations. After selecting the highest location class for each 6-hr time period, we had a sample of 2,713 locations for estimating kernel densities.

In general, densities were spread out along an axis extending from the Bering Strait, through the Anadyr Strait, to Navarin Canyon (Figs. 12–15). In January, the kernel density extended from the southern Chukchi Sea to Cape Navarin (Fig. 12). In February, the density shifted south of the Bering Strait and the areas of highest use were in Anadyr Strait and east of Cape Navarin, at the entrance to the Gulf of Anadyr (Fig. 13). In March, two whales moved north into the Chukchi Sea. In the Bering Sea, however, March densities were characterized by three distinct areas of use: the Bering Strait, the Anadyr Strait, and the area east of Cape Navarin, at the entrance to the Gulf of Anadyr (Fig. 14). By mid-April, whales were beginning to migrate north. Again, April densities extended from Navarin Canyon, north into the Bering Strait (Fig. 15).

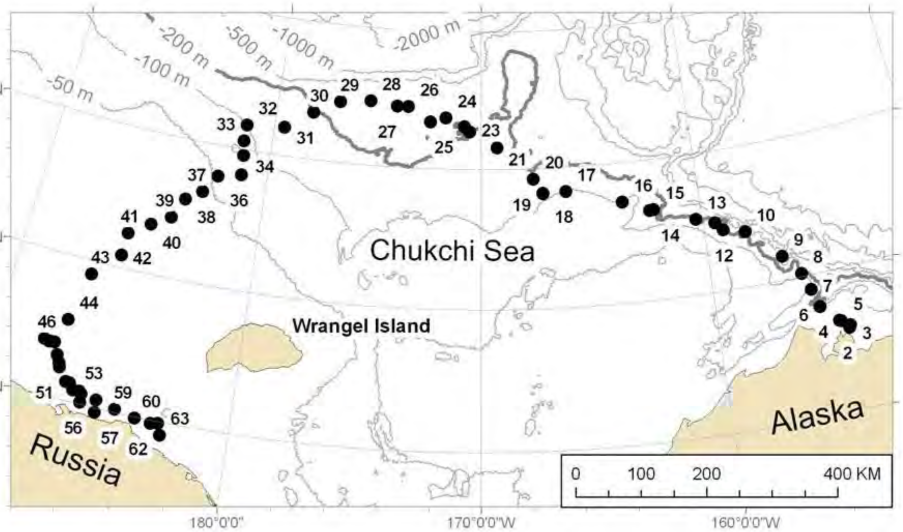

Figure 9a. Interpolated locations where dive data were collected for whale B07-10. Numbers correspond to interval numbers in (b) below. For example, the deepest area, Barrow Canyon occurs at approximately interval 8and the coast of Russia (interval 50–63) is shallow.

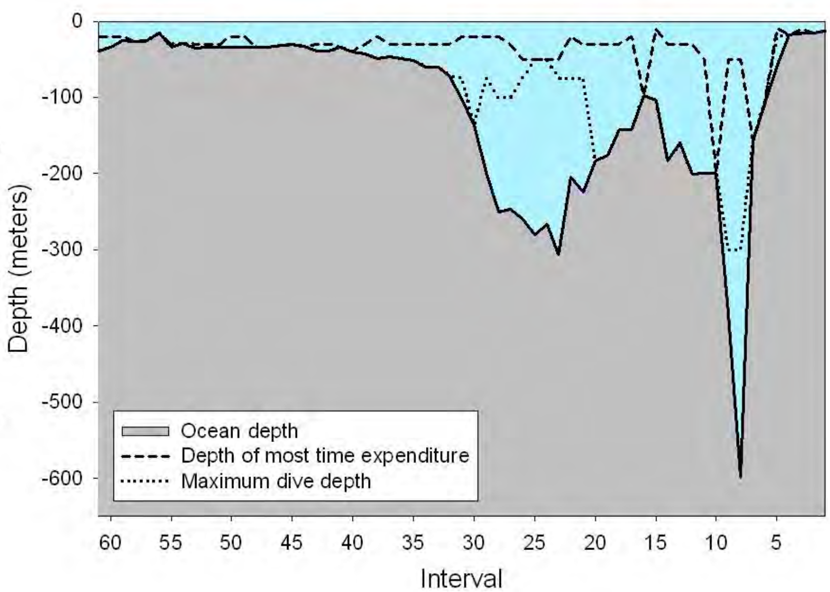

Figure 9b. Ocean depth and dive histogram summaries associated with each interval location. The interval numbers associated with locations in (a) correspond to the intervals on the x-axis in (b).

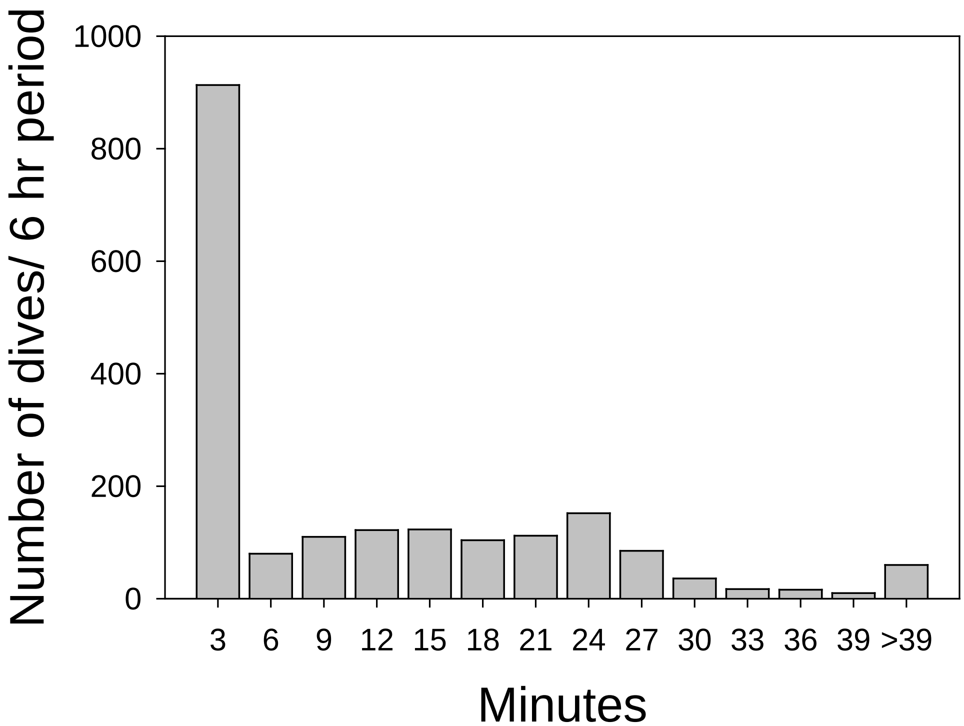

Figure 10. Number of dives (n = 2543) that fall into different time bins for whale B07-10, tagged in 2007. Approximately 3% of the dives were longer than the maximum time limit (39 minutes). Therefore, we changed our time bins to six minute increments in 2008, instead of the three minute increment we used in 2007 to accommodate longer dives.

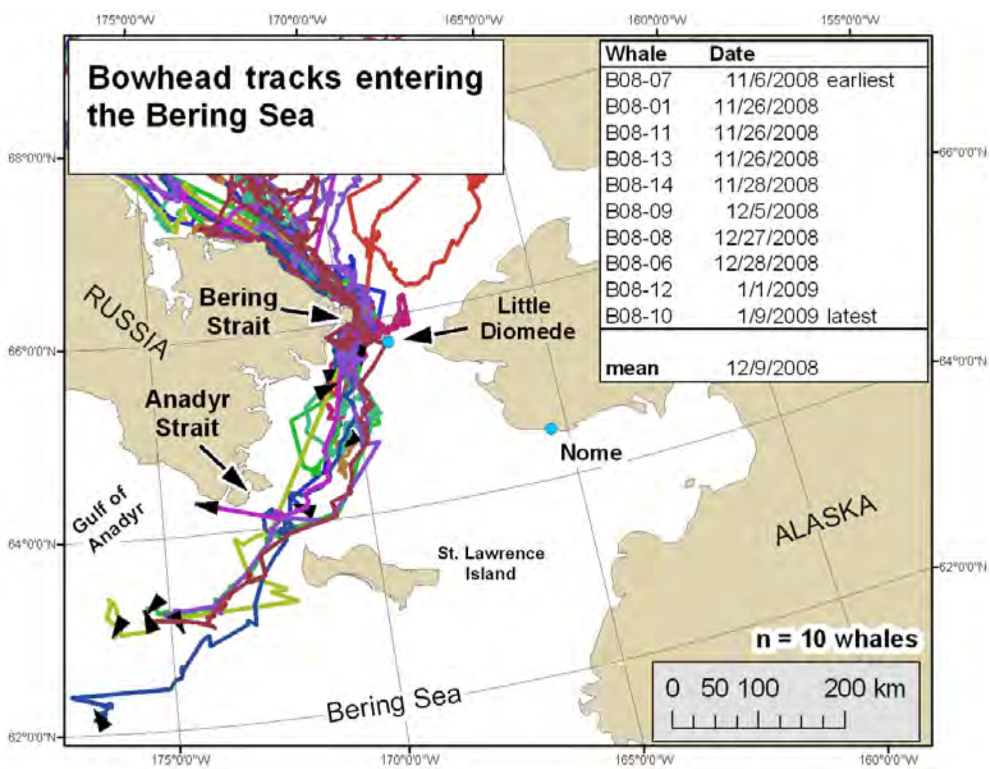

Figure 11. Tracks of 10 satellite-tagged bowhead whales entering the Bering Sea wintering area between 6 November 2008 and 9 January 2009.

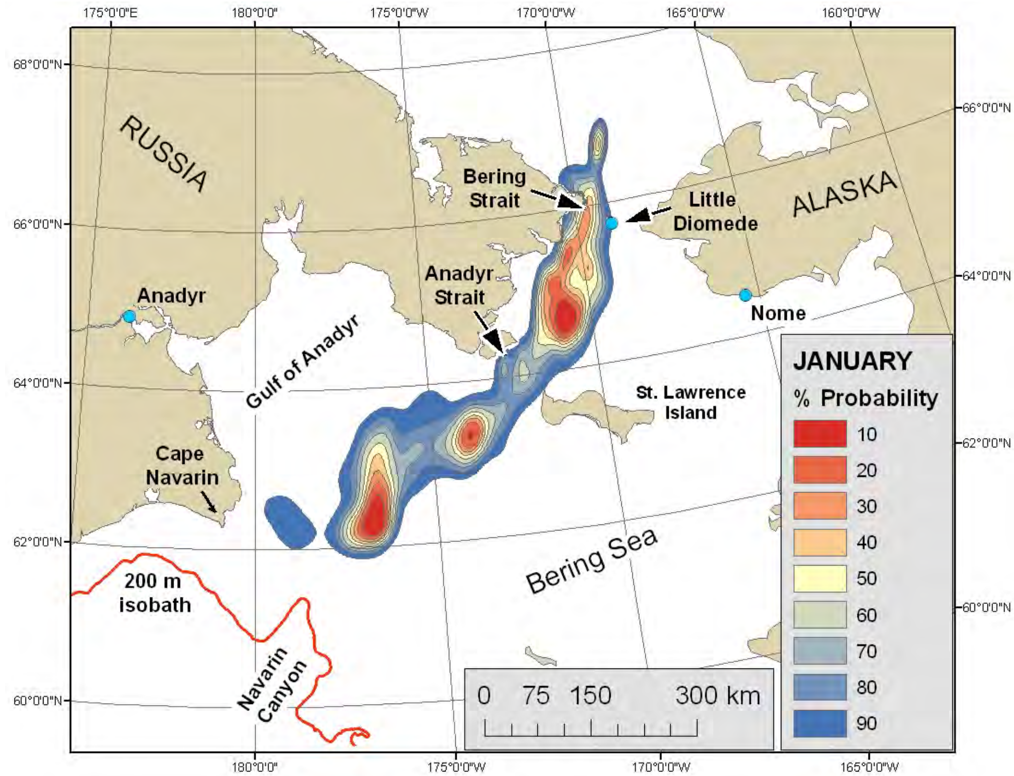

Figure 12. Contours showing the probability of use (%) by bowhead whales in January, 2009.

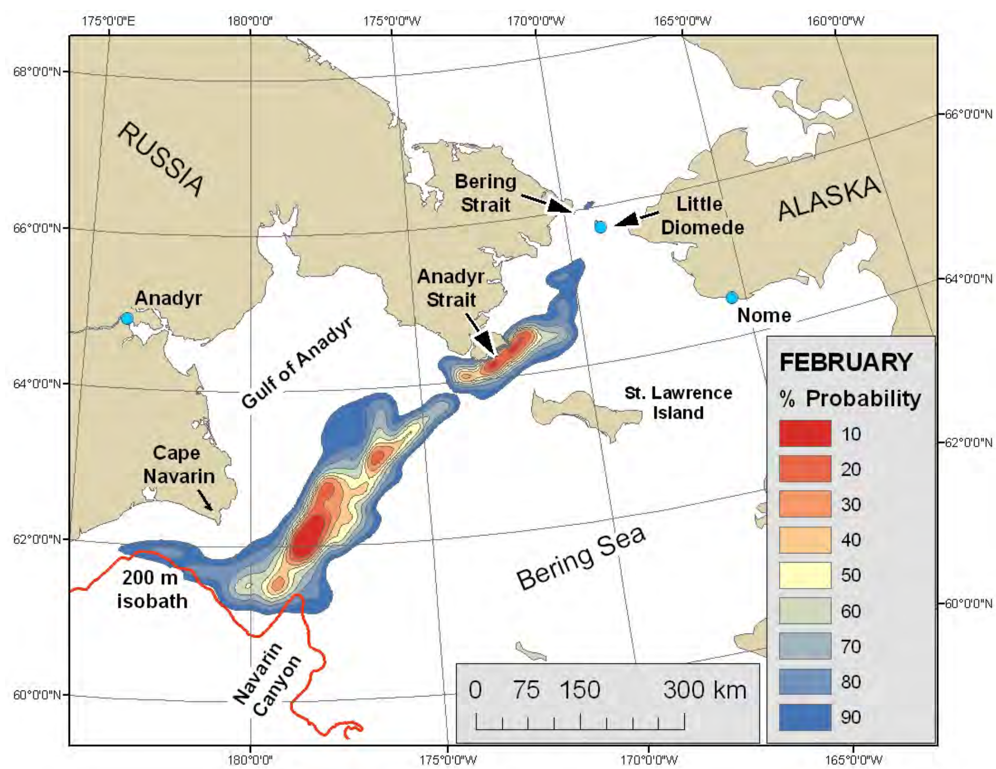

Figure 13. Contours showing the probability of use (%) by bowhead whales in February, 2009.

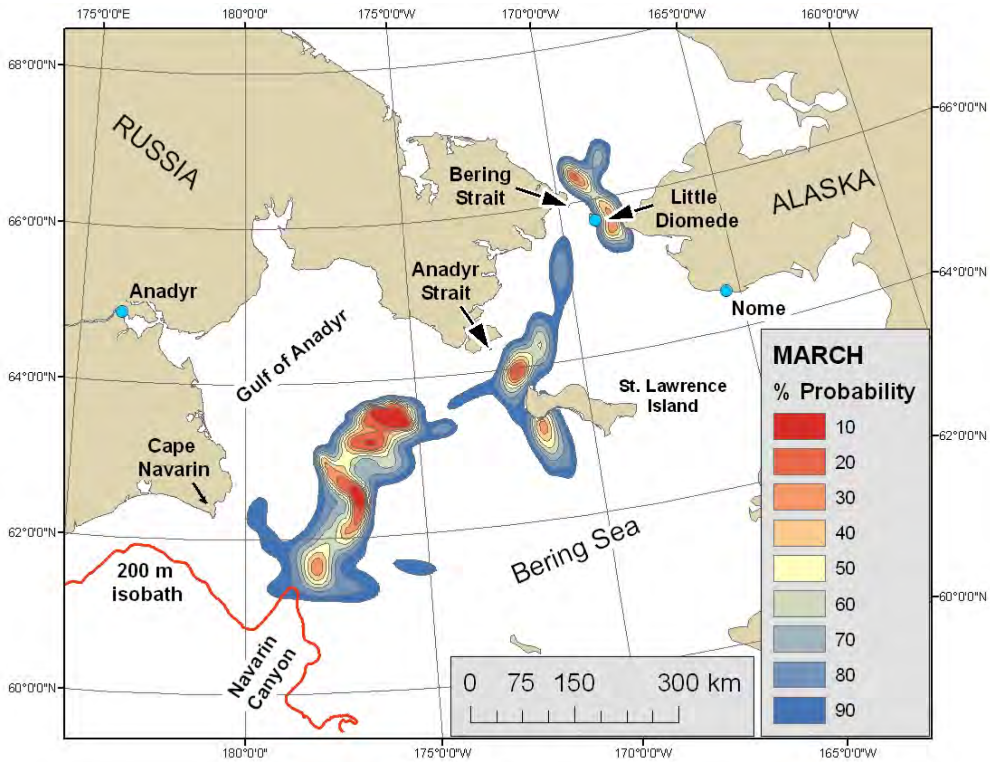

Figure 14. Contours showing the probability of use (%) by bowhead whales in March, 2009.

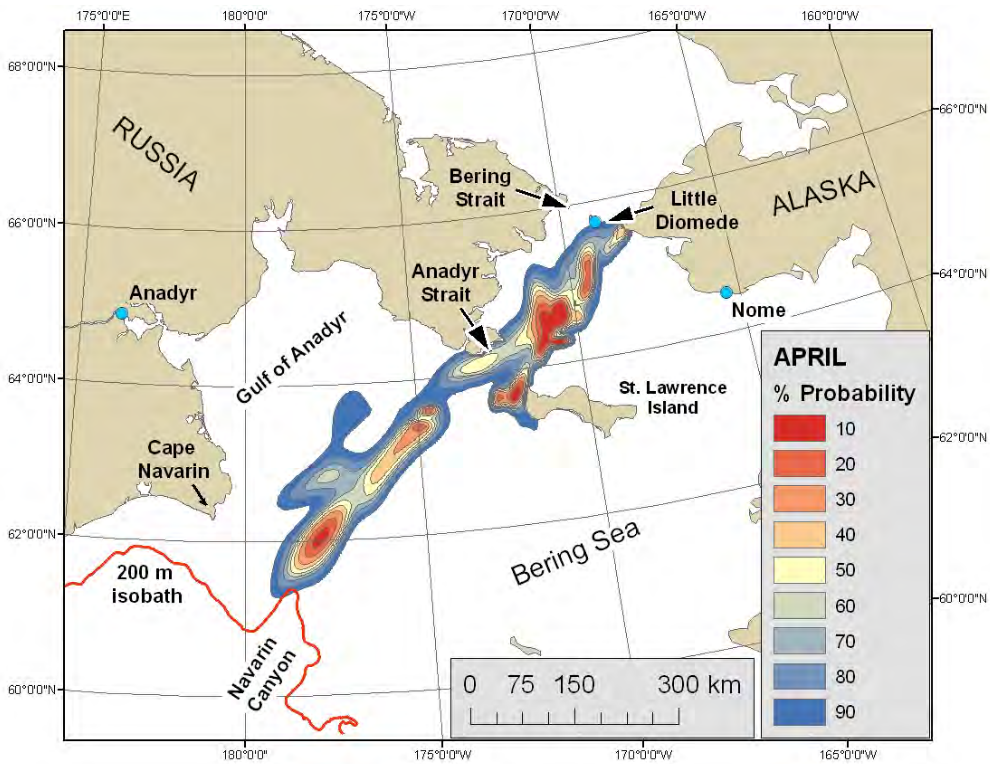

Figure 15. Contours showing the probability of use (%) by bowhead whales in April, 2009.

Winter density was generally restricted to the Bering Shelf, north of the 200 m isobath, which corresponds with the southernmost extent of winter sea ice. There was also very little use of areas within the Gulf of Anadyr.

Diving Behavior. We analyzed 889 dive intervals (6-hr) and in all but five intervals (99.4%) tagged whales dove to the bottom at least once (Fig. 16). Water depth in the area ranged from 25 to 300 m.

Habitat Use Relative to Sea Ice. When ice conditions at bowhead locations were compared with ice conditions at random locations, whale use of 90–100% ice cover was significantly greater than random (P<0.01). Although open water areas (polynyas) were available for use, tagged bowheads only used areas of 50% or greater ice coverage and the majority of use was in the 90–100% ice cover (Figs. 17 and 18). Whales mostly remained over the Bering Shelf, north of Navarin Canyon.

We have not completed an analysis of movements, habitat use or dive behavior for the winter of 2009–2010, however we can make a general comparison of movements and areas used by examining the tracks of tagged bowhead whales in the Bering Sea during the winters of 2008–2009 and 2009–2010 (Fig. 19). Movements of tagged whales in the winter of 2009–2010 overlapped completely with those of 2008–2009 in the western Bering Sea from the Bering Strait to the 200 m isoboath; however, more use of the central Bering Sea between St. Lawrence Island and St. Matthew Island occurred in 2009–2010.

Spring (April–June) Chukchi and Beaufort Seas. Whales began migrating north in early-April and passed into the Chukchi Sea between 1 and 27 April 2009, with an average date of 12 April (n=7). Five of seven whales transmitted locations adjacent to the Diomede Islands; four whales passed east of Little and Big Diomede Islands, while one whale (B08-12) passed west of Big Diomede. B08-12 was also the last tagged whale to begin migration and pass into the Chukchi Sea.

In the spring, beginning in late March, eight of the 10 tagged whales that entered the Bering Sea during November 2008 through January 2009 began to migrate northward. All whales passed west of St. Lawrence Island. Five of the eight whales passed east of Little Diomede when leaving the Bering Sea (Fig. 20), whereas all of them entered on the west side (Fig. 11). Whales migrated north through the Bering Strait between 1 and 27 April (average date = 14 April). We calculated the travel time between villages for whales that had transmissions near villages. On average, whales took 11 days to travel from St. Lawrence Island to Point Hope (sd=2.3, n=6), six days to travel from Point Hope to Wainwright (sd=0.4, n=5), and one day to travel from Wainwright to Barrow (sd=0.5, n=5). Bowhead whales traveled mostly parallel and within 40 km of the Alaskan coast during the spring migration. There was little use of Chukchi Sea Lease Sale Area 193 during spring migration with only one of the six tracks skirting the eastern boundary (Fig. 21). Six whales were tracked past Barrow, the earliest passing ~16 April and the latest was ~6 May.

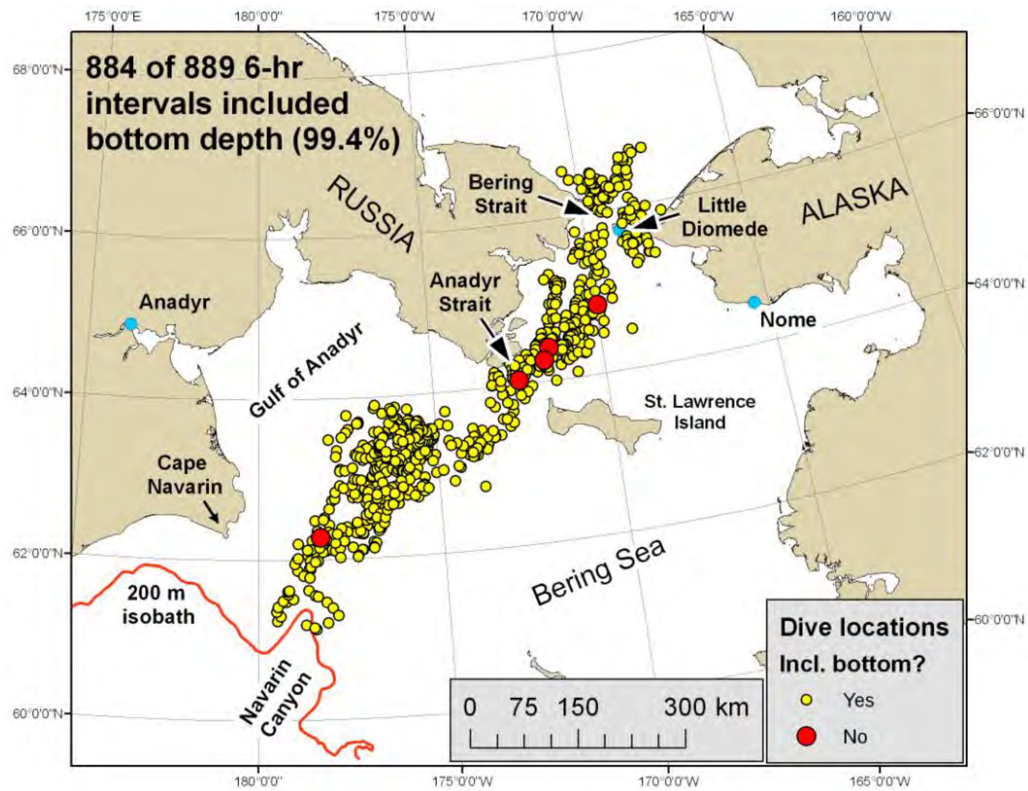

Figure 16. Tagged bowhead whale locations in the Bering Sea between January and April 2009 for which there are dive data. Red circles represent the only locations where a bowhead whale did not dive to the bottom during a 6-hr period. Nearly all dive intervals (99.4%) included the bottom.

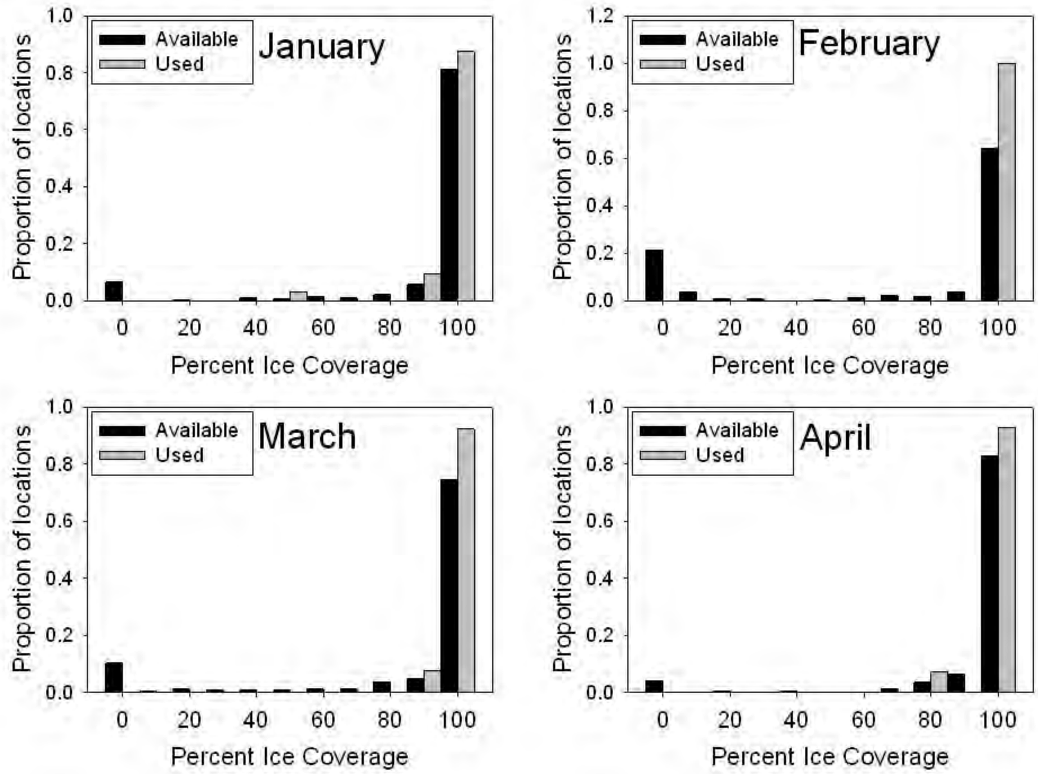

Figure 17. Comparison of ice concentrations of areas used by tagged bowhead whales compared to areas available to be used within the Bering Sea in the winter of 2009. Whales showed no attraction to open water and were found in locations associated with a high percentage of sea ice coverage.

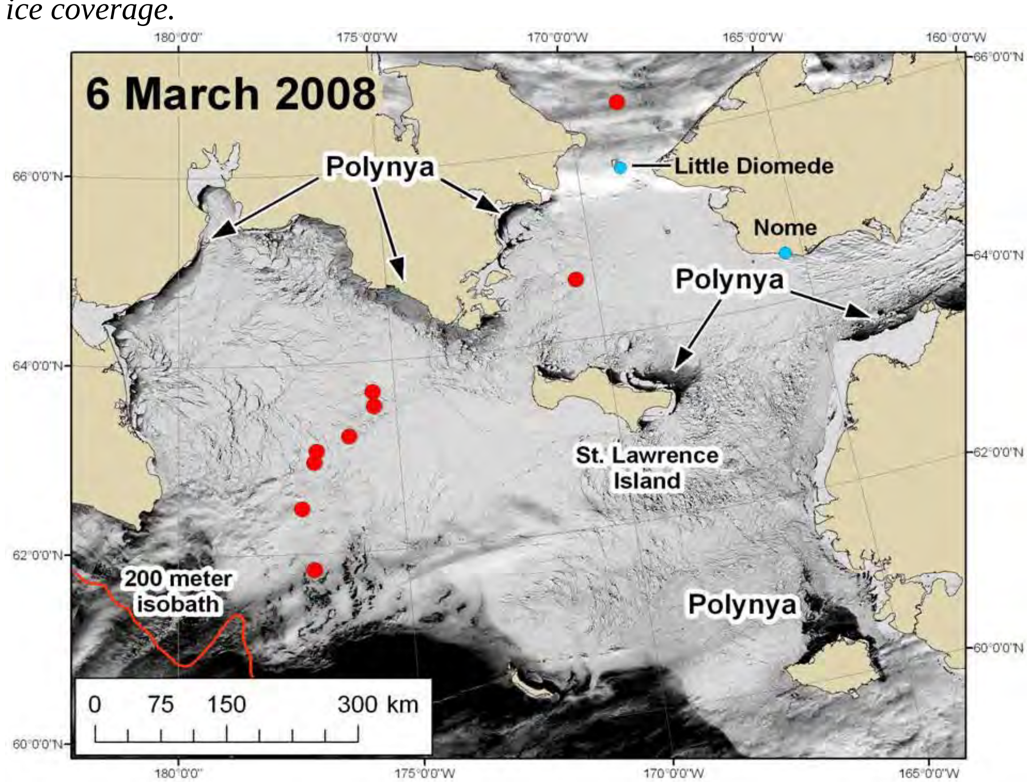

Figure 18. Locations of satellite-tagged bowhead whales (red circles) in March 2008 relative to open water areas (polynyas).

Once past Point Barrow in spring, all tagged whales traveled northeast before turning east and traveling 100–200 km offshore of the Beaufort Sea coast (Fig. 21). All whales stayed between 71 and 72^o N latitude. In 2006, whale B06-01 traveled ~200 km northeast before turning east; in 2009, five whales traveled ~80–120 km before turning. In spring, all tagged whales traveled relatively directly to the Amundsen Gulf polynya, arriving there by 26 May in 2006 and by 3 May in 2008. The six whales tracked across the Beaufort Sea in spring 2009 followed virtually the same path (Fig. 22), yet they did not travel together. These whales passed by Barrow over a period of 21 days and no two whales passed on the same day. In 2006, whale B06-01 traveled to ~72^o N latitude before turning and traversed the Alaskan Beaufort Sea farther north than the others; however, by the time it reached the Canadian Beaufort Sea it was also at 71^o N latitude and entered Amundsen Gulf south of where the whales did in 2009 (Fig. 23). Inspection of sea ice data during this migration showed near 100% ice cover throughout the migration and did not reveal any apparent leads that tagged whales were following. Contrarily, a distinctive east-west lead was present in 2006 that the whale passed by and remained north of while traveling east (Fig. 23).

Although bowhead whales are capable of migrating under sea ice, it appears that they may not travel far under land fast ice. In the spring of 2009, six bowheads migrated to Amundsen Gulf, which was still filled with land-fast ice. The whales lingered at the ice edge until the gulf cleared of land-fast ice (Fig. 24).

Summer (June–Early October) Beaufort Sea. In 2006, a tagged bowhead arrived in Amundsen Gulf on 25 May. This whale traveled to the northern tip of Banks Island between 31 July and 15 August, a trip of approximately 1,400 km in 15 days. Upon returning to Amundsen Gulf on 15 August, the whale remained there until 17 September. In 2009, the first whale arrived in Amundsen Gulf on 2 May and the last whale left the Gulf on approximately 23 July. However, whales tagged near Atkinson Point in late August and early September 2009 remained near the entrance to Amundsen Gulf until approximately 12 September. Hence it appears that Amundsen Gulf is used by bowhead whales from May until mid-September. In 2009, two other whales made long distance movements during this time period after leaving Amundsen Gulf; both traversed the Beaufort Sea from east to west to an area north of Point Barrow before returning to the eastern Beaufort Sea (Fig. 25).

Whale Behavior Near a Seismic Operation. One tagged whale was located 160 times during a seismic survey conducted from the *M/V Discoverer* between 31 August and 4 October 2006 in the Canadian Beaufort Sea, north of the Tuktoyaktuk Peninsula (Citta et al. 2008; Fig. 26; Appendix D). The minimum distance between the whale and the seismic ship was 9.2 km. The whale was located eight times in the closest distance category ($\leq$25 km), 10 times in the second category (26 to 50 km), 10 times in the third category (51 to 100 km), and 132 times in the fourth category (> 100 km). Whale velocity did not differ by distance category (p=0.67 for $v_{1,2}$; p=0.85 for $v_{2,3}$) and the distance categories did not differ in either their mean direction (p=0.16) nor dispersion (p=0.52). Mitigation measures used by the *M/V Discoverer* included: 1) shutting down airguns when whales were observed within designated safety zones (~1 km where noise levels were predicted to be > 180 dB) and 2) following shutdowns, activating one airgun at a time to allow whales to move away as the sound levels increased slowly (Harris et al. 2007).

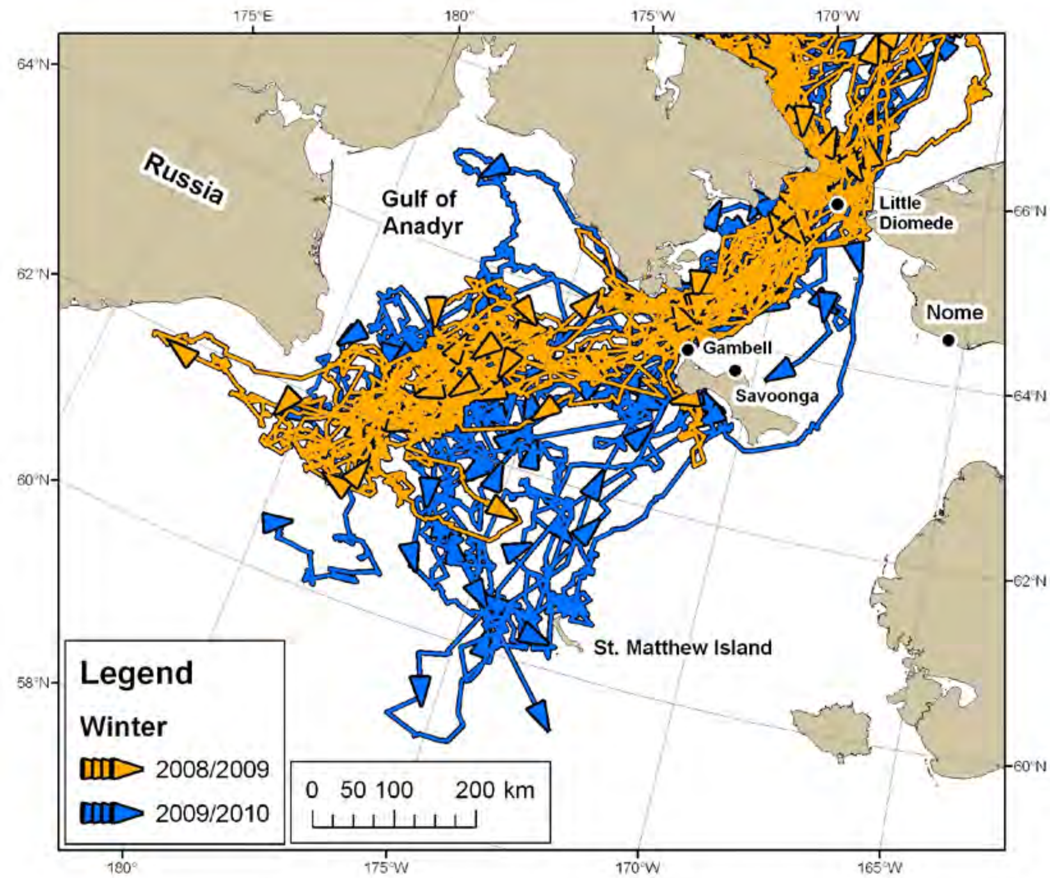

Figure 19. Winter 2008–2009 and 2009–2010 movements of satellite-tagged bowhead whales in the Bering Sea.

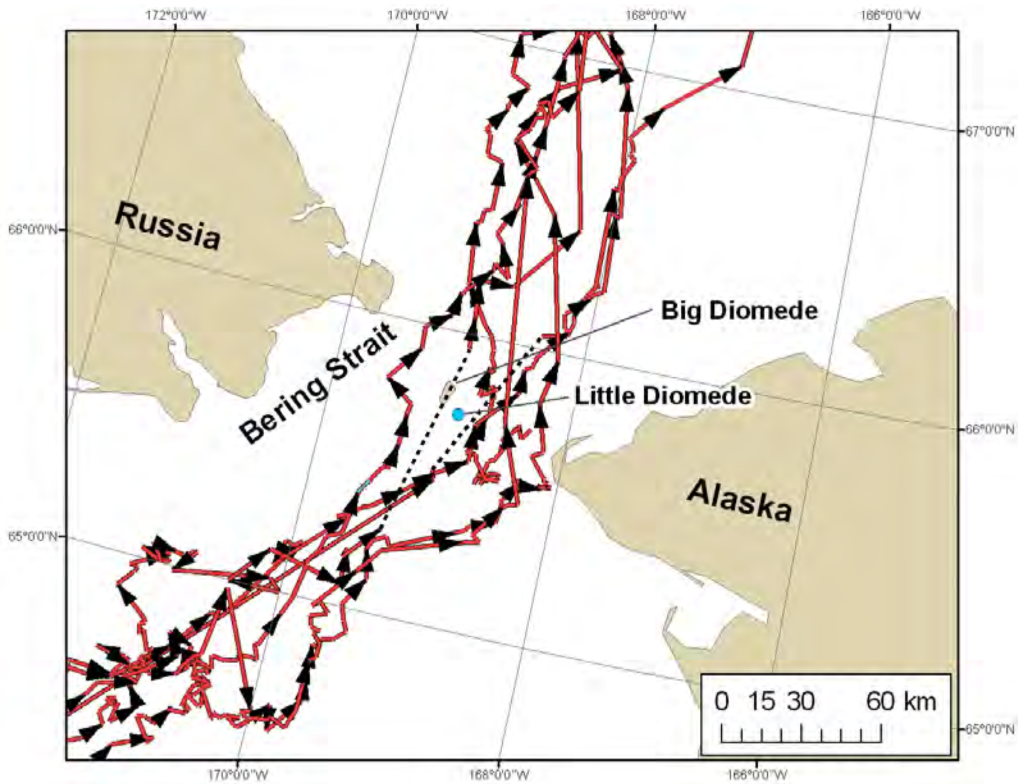

Figure 20. Tracks of satellite-tagged bowhead whales on spring migration through the Bering Strait in 2009. Dotted lines indicate tracks without enough locations to determine if whales passed east or west of the Diomede Islands.

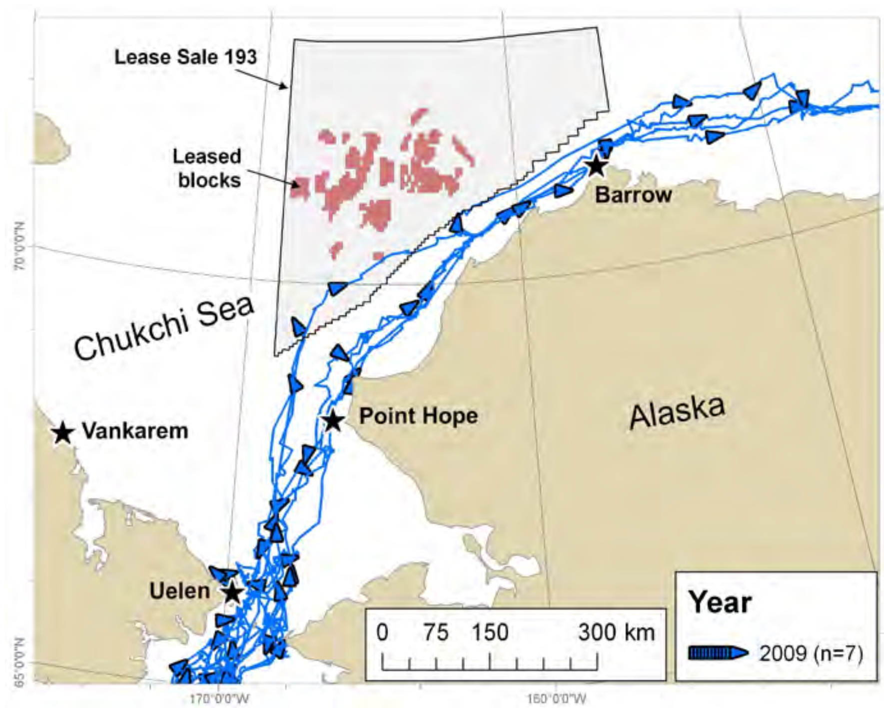

Figure 21. Tracks of satellite-tagged bowhead whales on spring migration through the Chukchi Sea and past Point Barrow in 2009.

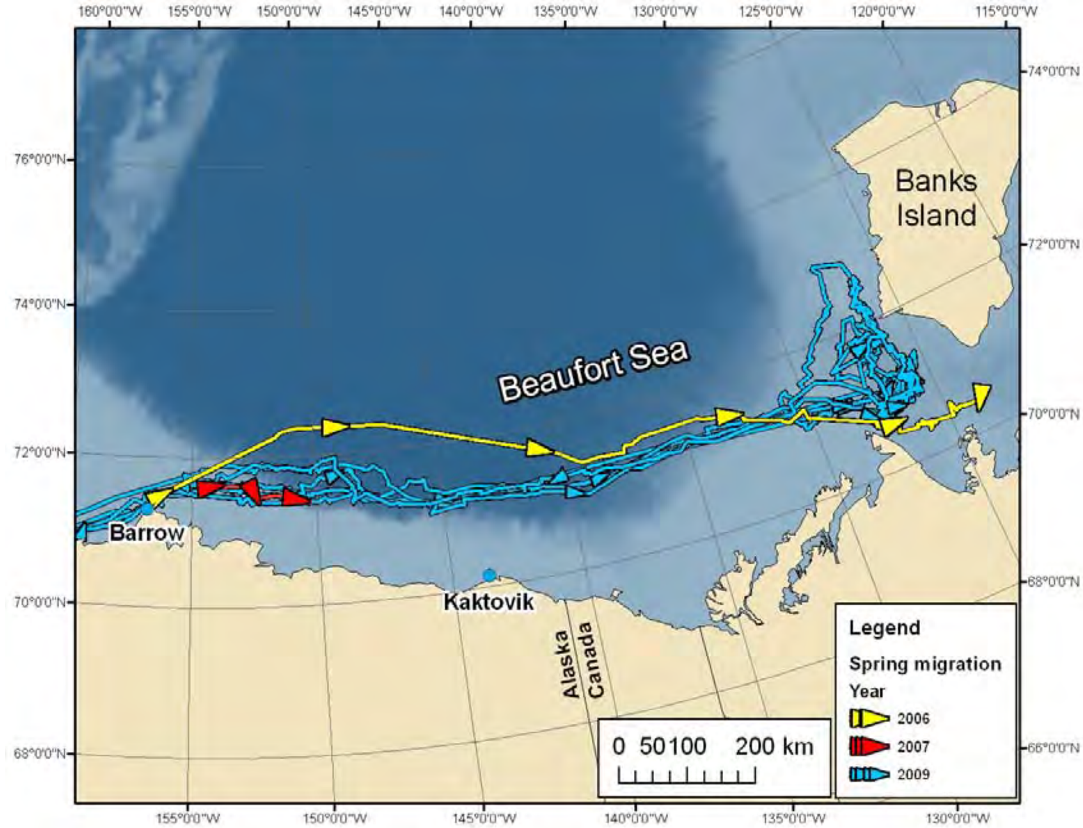

Figure 22. Tracks of satellite-tagged bowhead whales during spring migration in the Beaufort Sea in 2006, 2007, and 2009.

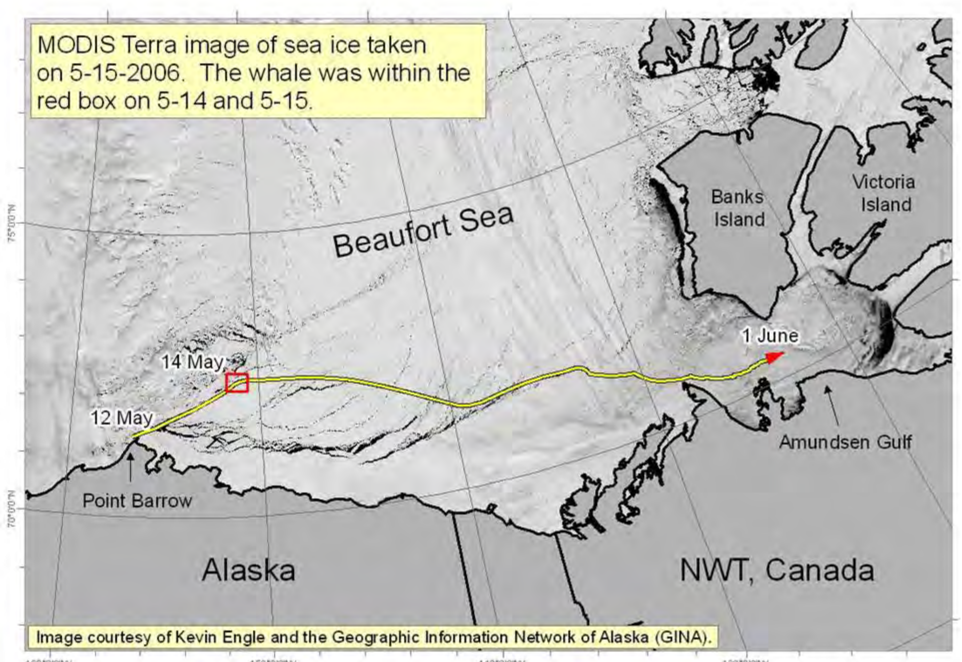

Figure 23. Track of a satellite-tagged bowhead whale relative to ice conditions in May 2006 during spring migration across the Beaufort Sea.

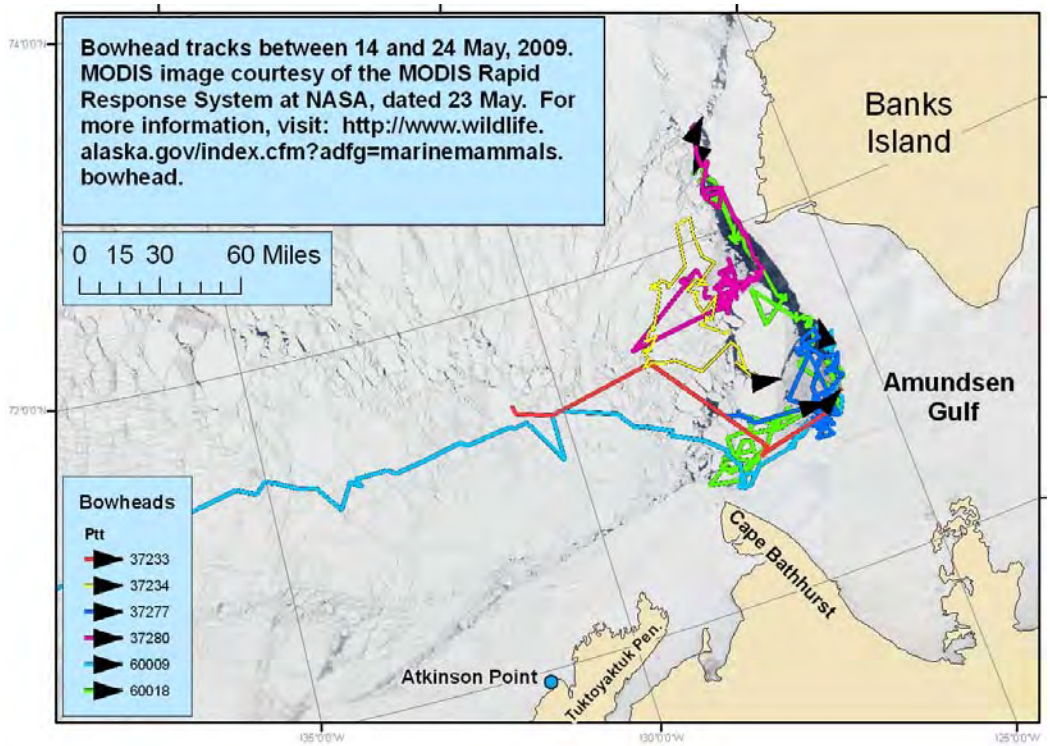

Figure 24. Tracks of six satellite-tagged bowhead whales in May of 2009. Amundsen Gulf has land-fast ice (no cracks), while the Beaufort Sea has fragmented ice. All whales previously migrated through the fragmented ice.

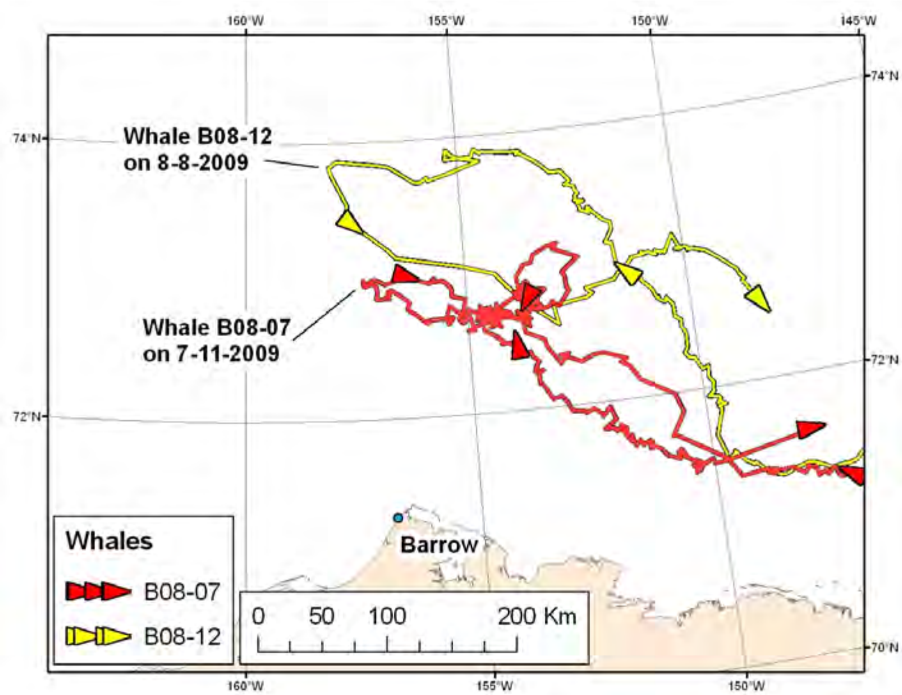

Figure 25. Tracks of two satellite-tagged bowhead whales that made two trips across the Beaufort Sea in summer 2009.

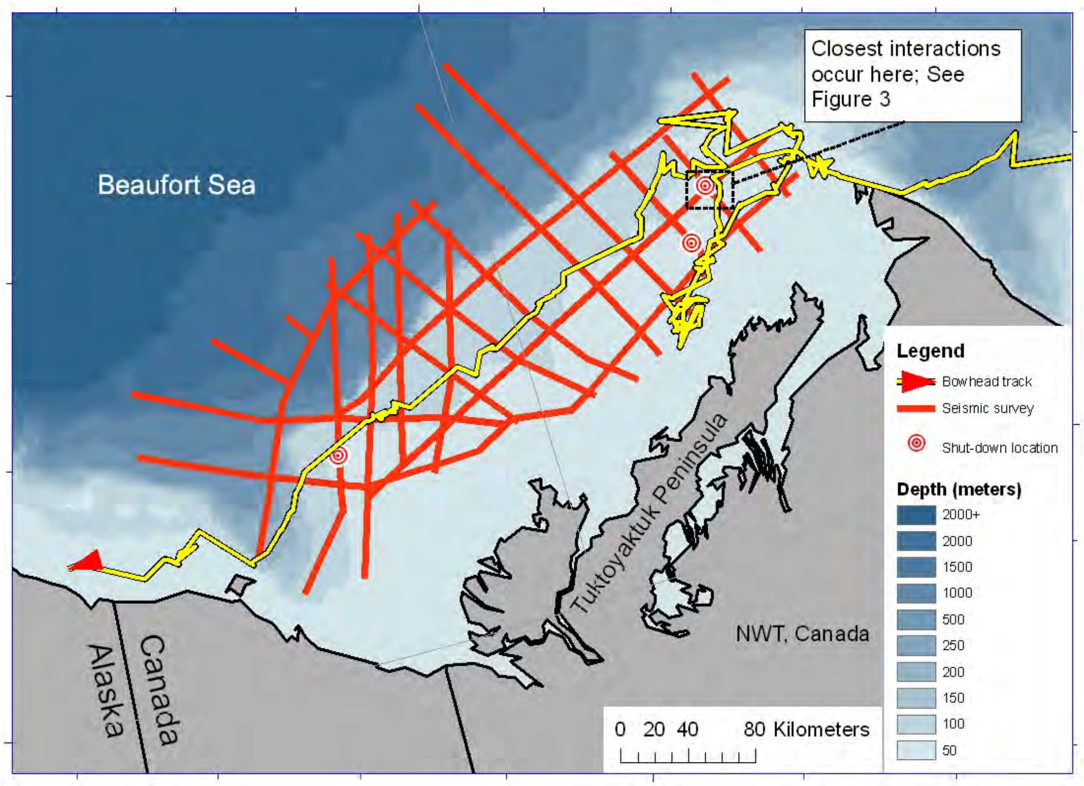

Figure 26a. Track of a tagged bowhead whale (yellow) relative to the tracks of a seismic ship (red) in fall 2006.

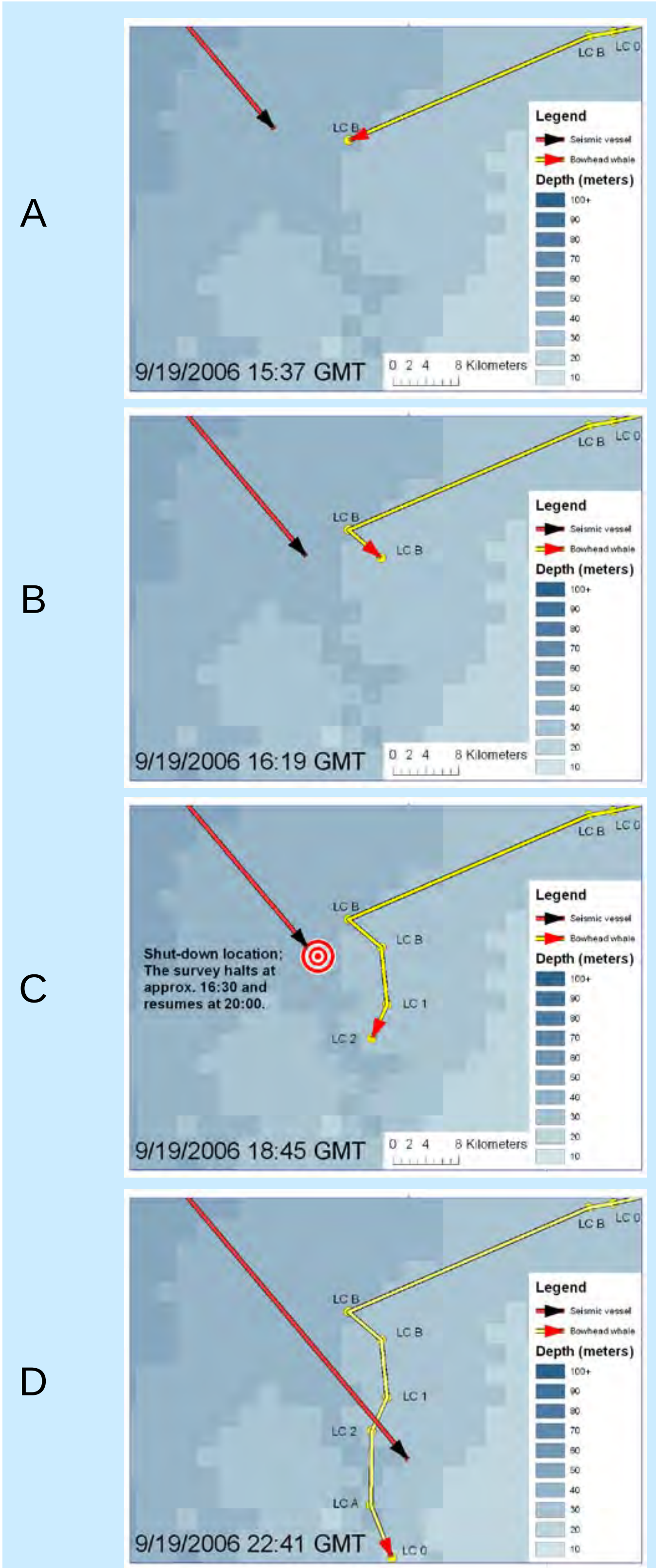

Figure 26b. Detailed interaction of a tagged bowhead whale (yellow) relative to the tracks of a seismic ship (red).

We found evidence that the tagged whale avoided the seismic ship on 19 September at a much greater distance than the whale would be visible by the observers. On this day, marine mammal observers on the ship sighted a mother-calf pair of bowhead whales ~500 m from the ship; consequently the airguns were shut-down and the ship and the operation were halted for ~3.5 hours. The tagged whale maintained a distance of ~9.2 km from the ship and then crossed in front of it during the shut-down (Fig. 26). The seismic program was completed and the ship left on 4 October. The tagged whale remained in the area for four days after the survey was complete.

Dive Behavior. Whale B08-01 tagged near Atkinson Point, Canada on 12 August 2008 moved west after tagging. By 31 August 2008, this whale had passed west of Barrow, Alaska along a route closer to shore but similar to that used by B06-01 in 2006 (Fig. 27). This whale often dove to the sea floor, between 30 to 200 m below the surface (Fig. 28a and 28b). However, the most common dive depths ranged from 10 to 40 m. Dives ranged from 6 to 24 min in duration. Similar to whale B07-10, 50% of all dives were 18 min or less in duration, not counting the most shallow dive bin (Fig. 29).

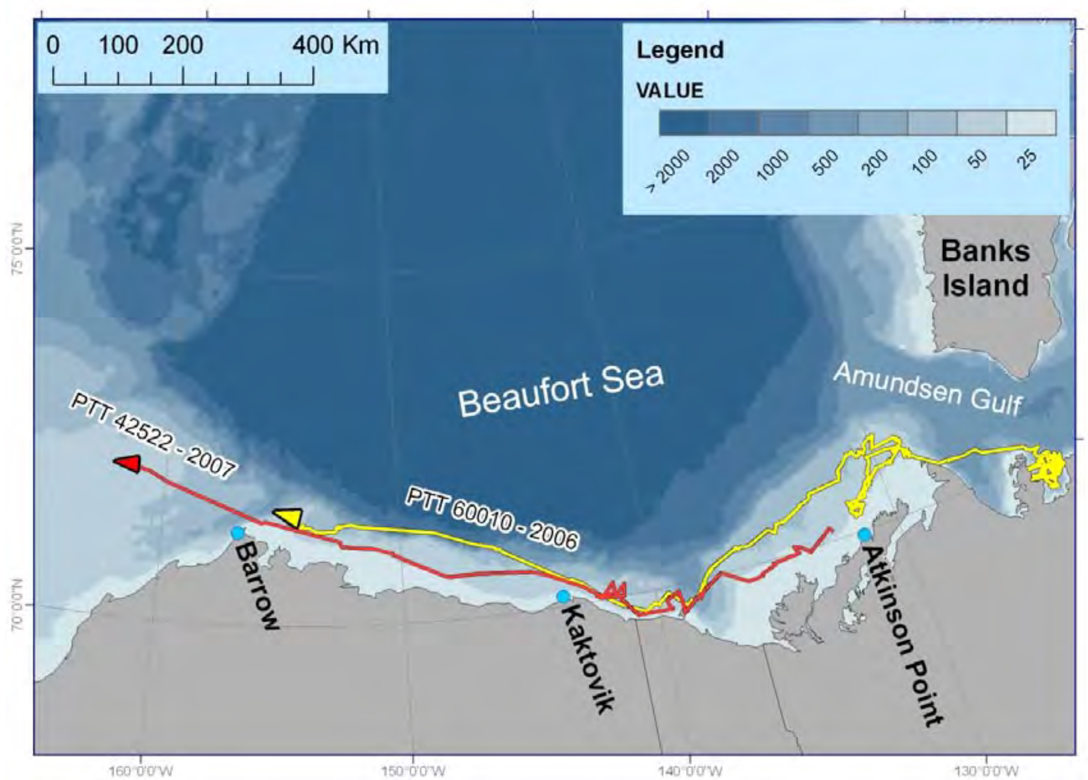

Figure 27. August movements of bowhead B07-10 (red) tagged near Atkinson Point, Canada on 12 August 2008 juxtaposed with September 2006 movements of bowhead B06-01 (yellow) for comparison. Bathymetry is in meters.

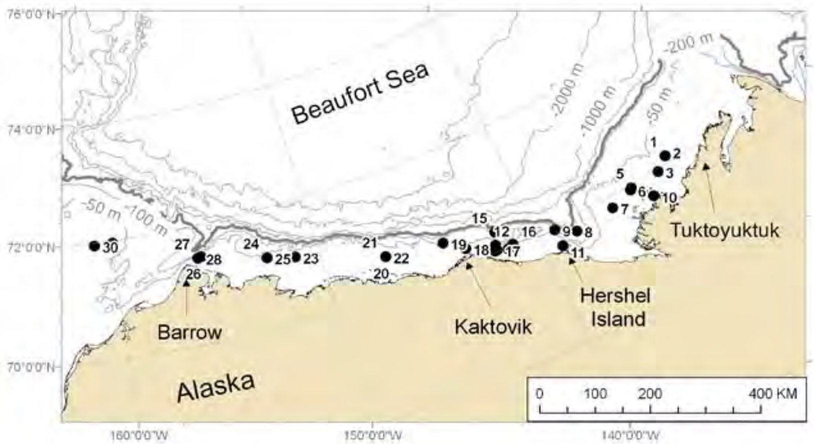

Figure 28a. Interpolated locations where dive data were collected for whale B08-01.

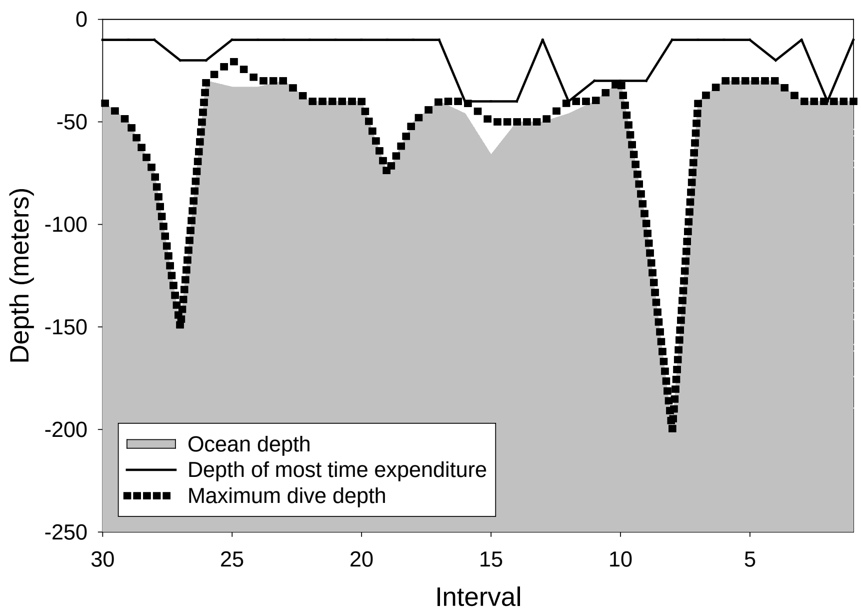

Figure 28b. Ocean depth and dive histogram summaries associated with each interval location. The interval numbers associated with locations in (a) correspond to the intervals on the x-axis in (b).

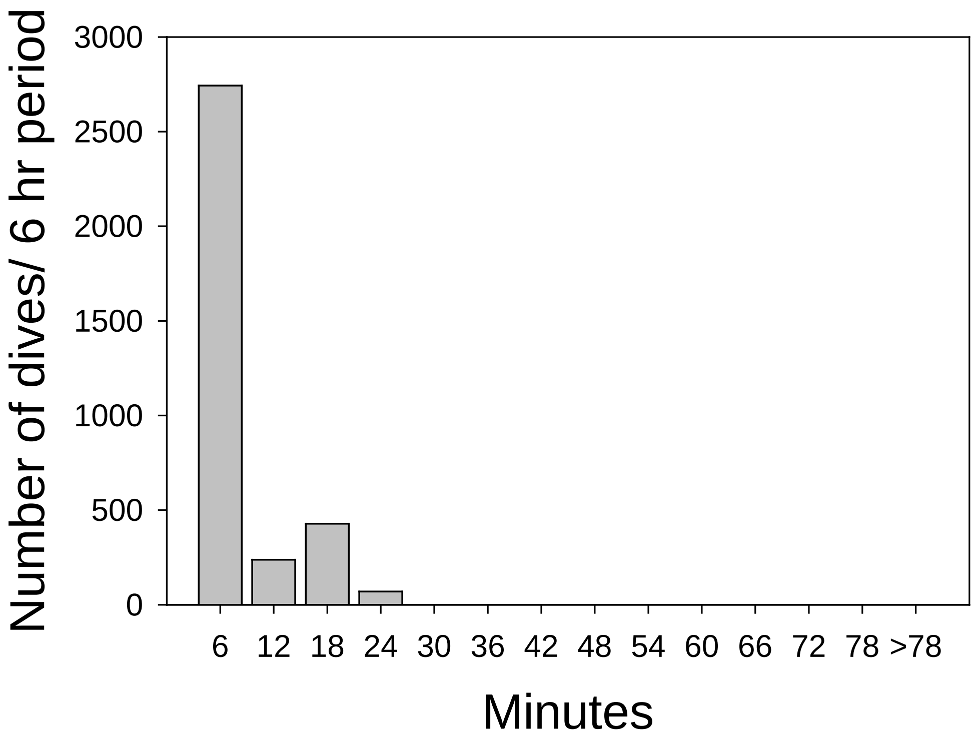

Figure 29. Number of dives (n = 3483) that fall into different time bins for whale B08-01, from 12 to 21 August 2008 in the Beaufort Sea.

Tag development and deployment

Tags transmitted for as few as 0 days to as many as 391 days (Table 2). We began using a newly designed SPLASH tag in 2007 to minimize drag and increase retention time. The transmitter was mounted on a plate and the transmitter and plate were allowed to swivel on the attachment shaft to align itself in the most hydrodynamic position.

Traditional Knowledge

The collection and incorporation of traditional knowledge was not part of our contract with MMS for this project. At the request of AEWC, however, we agreed to conduct interviews in as many whaling villages as possible, provide the information as reports for the villages and the AEWC, and incorporate the information into our reports to MMS. ConocoPhillips provided funding for the interviews in Barrow and Kaktovik and this funding was used as match for a Coastal Marine Institute (CMI) project to conduct interviews in Wainwright. The traditional knowledge project produced three reports; two to the AEWC and local whaling captains associations (Huntington and Quakenbush 2009a and b; Appendix K and L) and one to CMI (Quakenbush and Huntington 2010). The traditional knowledge project used the same approach that the Native Village of Savoonga used when documenting traditional knowledge about bowhead whales on St. Lawrence Island (Noongwook et al. 2007).

Traditional knowledge is an important component of understanding the movements and behavior of bowhead whales. The whalers were justifiably concerned that the tagged whales might not represent their knowledge of what bowhead whales do near shore where they observe and hunt them. Tags can only be placed on a small number of whales compared to the number in the population. In addition to collecting and compiling bowhead movement and behavior information, the interviews allowed us to share results of the tagging project with the whalers and their communities in real time.

Specific information collected from Barrow whaling captains includes that in spring whales may pass by not only in the nearshore lead but also 75 miles offshore. The spring migration occurs in waves of similar sized whales. Small numbers of medium sized whales come first, followed by a larger number of small whales, the biggest whales, including cows with calves, come through last (Huntington and Quakenbush 2009a). Some whales migrate by quickly and others feed by diving under the ice returning to the lead to breathe. Some calving occurs near Barrow in the spring.

Whalers in Wainwright know that bowheads will reach them in spring about one week after whales are seen at Point Hope depending on ice conditions (Huntington and Quakenbush 2009b, Quakenbush and Huntington 2010). Wainwright also sees the same sized whales travelling together with small and medium-sized whales passing before the biggest whales including the cows with calves. Mating, calving, and feeding have been seen near Wainwright. Feeding occurs with whales swimming parallel to the ice edge with their mouths open.

Bowhead whales are not seen near Kaktovik in spring. Whales are sometimes seen in July and early August, however the main migration begins in late August, when large whales lead the westward migration (Huntington and Quakenbush 2009a). The leaders are left alone to establish the migration path. In some, but not all years, some whales (usually the smaller ones) travel close to shore pausing to feed at the passes between barrier islands, while other whales travel westward offshore without pausing (Fig. 30). Kaktovik whalers do not see size groupings of whales relative to the timing of migration, although large whales tend to come earlier, but whales of all sizes are seen throughout the migration. Whalers do not see the very big whales near Kaktovik and believe these must pass by farther offshore than the whalers go in their boats.

Barrow whalers see bowheads near Barrow again in late August, although some large whales have been seen earlier but 20–30 miles north of Barrow. Although there is a lot of hunting activity for seals and walruses west of Barrow in July, bowhead whales are usually not seen at this time. Barrow whalers see a pattern in the size of whales migrating in the fall too, although it is less distinct than in the spring. The large whales come first, followed by medium and then small whales. Barrow whalers also sometimes see bowheads feeding near the barrier islands (Fig. 31).

Hunters occasionally see bowhead whales near Wainwright in summer; these whales are thought to be late spring migrants. Few whales are seen in the fall and Wainwright depends on spring whaling for the needs of their community (Huntington and Quakenbush 2009a, Quakenbush and Huntington 2010).

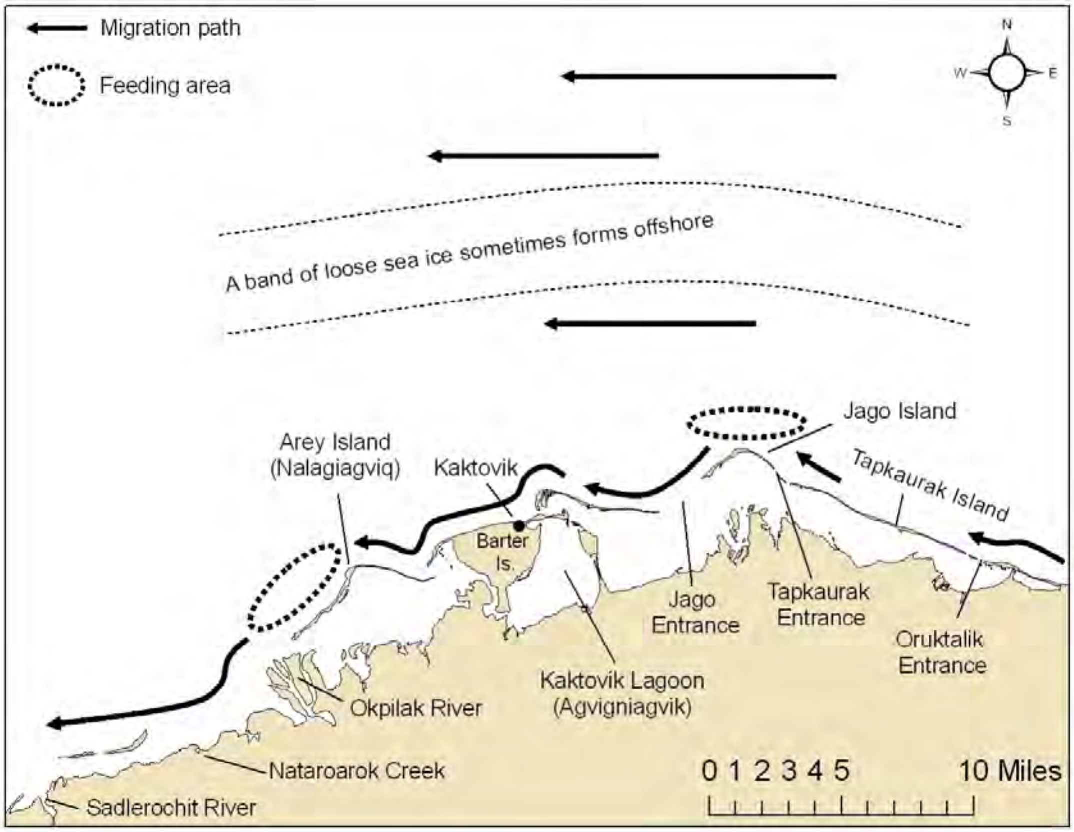

Figure 30. Movements and behavior of bowhead whales near Kaktovik, Alaska in August–September, based upon traditional knowledge. Figure from Huntington and Quakenbush 2009a.

Several things that were related to us through the traditional knowledge project have been useful for exploring interpretations of the tracks of tagged whales. For example, that Wainwright sees few whales in fall fits well with the tracks of all but one of the tagged whales heading west, not south, from Barrow (Fig. 2). The three tagged whales that looped back to Barrow traveled along the coast to get there and occasional sightings of bowheads near Wainwright may be whales returning to Barrow. In 2009, two tagged whales traveled from the eastern Beaufort Sea to an area north of Barrow in mid-July and early August before returning to the eastern Beaufort Sea. That Barrow whalers know about whales north of Barrow in summer indicates this was probably not an unusual occurrence that only happened in 2009. The size segregation that is consistently seen during spring migration means we need to be aware of when we put our tags out and what segment of the population the tags may represent.

Accomplishment of Goals and 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 utilization.

***Objective 1*:** The overall objective of this study was to work with the subsistence whalers to deploy satellite transmitters on bowhead whales to document and describe the general pattern of year-round movements used by bowhead whales representing different sex and age categories.

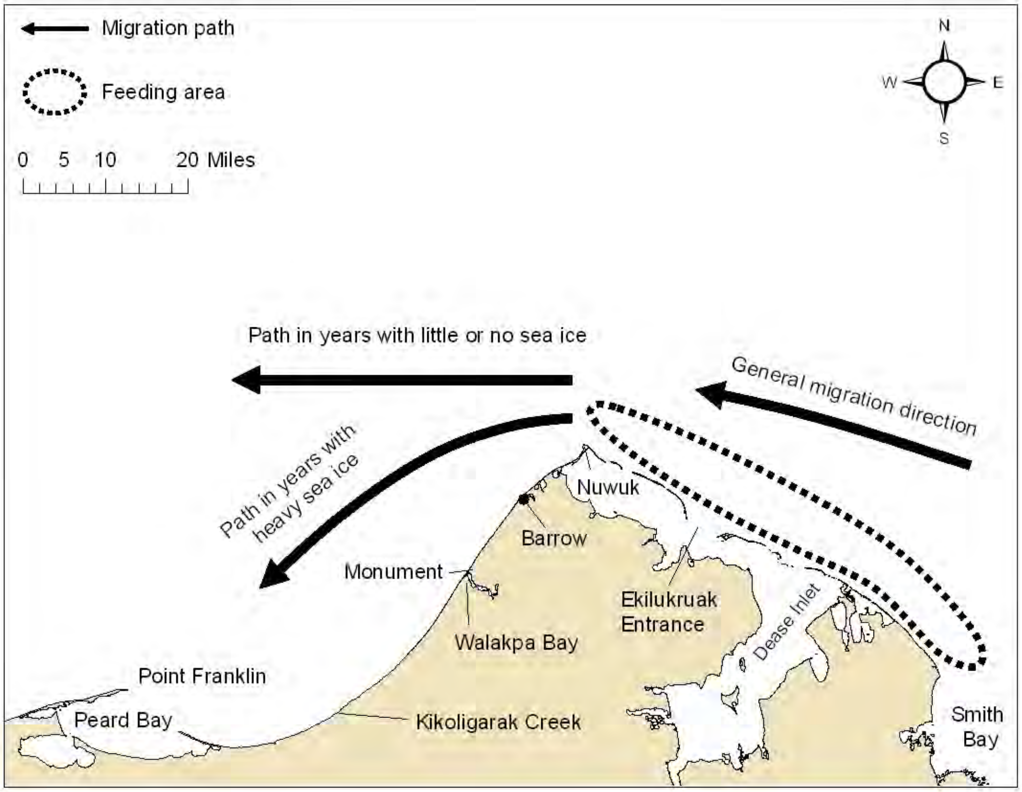

Figure 31. Movements and behavior of bowhead whales in fall near Barrow, Alaska, based upon traditional knowledge. Figure from Huntington and Quakenbush 2009a.

We accomplished Objective 1 by working with subsistence whalers from Barrow, Kaktovik, Point Hope, Gambell, and Savoonga, in Alaska and marine mammal hunters from Aklavik and Tuktoyaktuk, Canada to deploy 46 satellite transmitters on bowhead whales. Tags were deployed on bowhead whales representing both sexes and several sizes representing several age classes. Tracking the movements of those tagged whales provided documentation of potential feeding areas, wintering areas, interactions with a seismic operation, and the pattern of year-round movements including some indication of inter-annual variability.

Hypothesis 1A: All bowhead whales of the western Arctic stock make seasonal migrations between wintering areas in the Bering Sea and summering areas in the eastern Alaskan and Canadian Beaufort Sea.

To date, all tagged whales have wintered in the Bering Sea. Except for one, all whales migrated from the Bering Sea, directly to the Canadian Beaufort Sea. Whale B09-09 (Fig. 32) migrated into the Chukchi Sea on 25 March 2010 and followed the coast of Chukotka north. This whale is currently located south of Wrangel Island (as of 31 July). At this time, we do not know how common this pattern is.

Hypothesis1B: Occasional concentrations of bowhead whales feeding near Barrow in summer are whales returning from summering in the eastern Beaufort Sea. The alternative hypothesis to be tested is that whales feeding near Barrow summered in the eastern Chukchi Sea and only enter the southwestern Beaufort Sea periodically, and under certain oceanographic conditions.

Most whales were tagged near Barrow in the fall and we do not know where those whales were prior to being tagged. We have not yet had an opportunity to tag whales at Barrow in the summer and none of our tagged whales have gone to Barrow in the summer. However, two whales tagged near Barrow migrated to Amundsen Gulf in 2009 and then returned to an offshore area, north of Barrow, in July. B08-07 traveled to within 140 km north of Barrow between 20 June and 15 July, 2009. B08-12 traveled to within 190 km north of Barrow between 4 and 13 August, 2009 (Fig. 25). Although these two whales traveled to the area north of Barrow after visiting Amundsen Gulf, we still do not know if whales observed near Barrow in the summer are from Amundsen Gulf or Chukotka or both.

Hypothesis 1C: Occasional concentrations of bowhead whales feeding near Barrow in summer are of mixed sex and age composition.

As mentioned above, none of the tagged whales have traveled to Barrow in the summer. Both of the whales that initially went to Amundsen Gulf and then returned to the offshore area north of Barrow were small to medium sized (~ 10 m) males. However, sample sizes are insufficient to make any conclusions.

Of the 11 whales tagged near Barrow in August, all were in the 11–15 m size range. We collected biopsies on eight of these, however, we currently only have results for six; three females and three males. Although the samples size is small it does not appear that bowheads near Barrow in August are sexually segregated.

Hypothesis 1D: Wintering concentrations of bowhead whales are of mixed sex and age composition.

We do not yet have sufficient data to address this hypothesis. During the winter of 2008–2009, we tracked six whales of known sex, all males, and nine whales of known length, all nine or ten meters long. There is not enough variability in the sex and size of the whales tagged to examine the sex or age composition of groups in the winter of 2008–2009. During the winter of 2009–2010, however, there were five whales of known sex, three males and two females, and six whales of known length, varying from 10 to 17 meters. Using the data from the winter of 2009–2010, we examined the data by month and found no partitioning by sex or length. Although we have yet to identify partitioning by sex or age, our sample size is still very limited for the winter season.

***Objective 2*:** Using satellite telemetry we will document behavior during migration relative to migration routes and the environmental characteristics of those routes; i.e., polynyas, leads, bathymetry, ice conditions, industrial disturbances. Specific hypotheses include:

Hypothesis 2A: Bowheads only migrate when ice conditions are light to medium.

After passing Point Barrow in spring, bowhead whales migrated through ice that was quantified as 100% cover by satellite images (Fig. 23). In the Bering Sea, in winter, bowhead whales concentrated in areas of 90–100% ice cover, even though lighter ice and polynyas were available (Figs. 17 and 18).

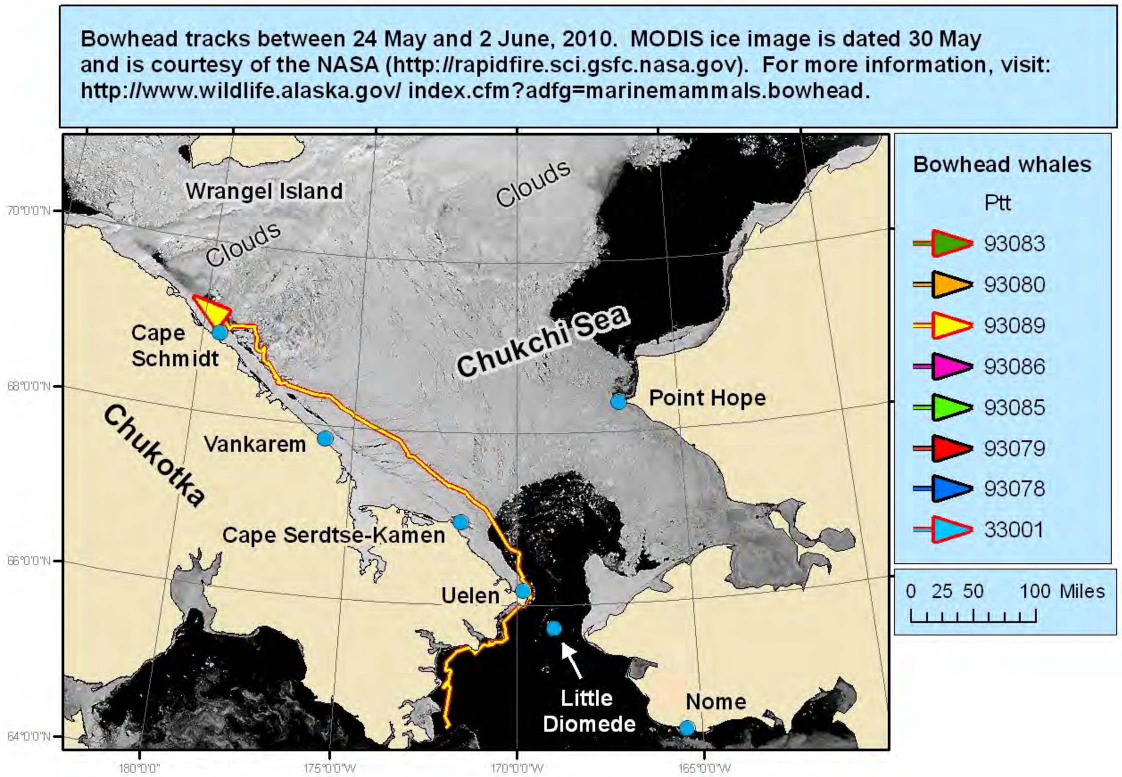

Figure 32. Track of the only satellite-tagged whale that had not migrated to the Canadian Beaufort Sea in spring.

Hypothesis 2B: Industrial disturbances do not alter bowhead migration routes, duration, or timing.

Our opportunities to study bowhead interactions with industry were limited, partly due to the limited number of tagged whales that were in the vicinity of activity while it was occurring and partly due to the difficulty in acquiring seismic ship location and number of guns firing by minute from industry. During one seismic operation in the fall in the Canadian Beaufort Sea, a tagged bowhead whale was in an area known to be a recurring feeding area. This whale appeared to alter its behavior due to the approach of a ship towing an active seismic array (Fig. 26; Appendix D). This whale, however, did not leave the area until after the seismic operation was over.

Hypothesis 2C: During migration bowheads do not stop to feed.

In general, based upon data collected to date, it does not appear that whales stop to feed during the spring migration, between the Bering Sea and Amundsen Gulf or during the fall migration until they reach the Barrow area. During the fall migration, whales lingered at Barrow, east of Wrangel Island, and along the northern coast of Chukotka, presumably feeding (Figs. 4–7; Quakenbush et al. 2010).

Although tagged whales did not stop in the Beaufort Sea during the fall migration, their dive behavior did include diving to the bottom. So although they did not stop to feed, they could have engaged in some feeding without stopping.

Hypothesis 2D: Bowhead migration occurs along a specific isobath.

Bowhead migration does not follow specific isobaths. In the spring, most bowheads loosely followed the coast to Barrow and then continued north before crossing the Arctic Basin to Amundsen Gulf (Figs. 21-23). In the fall, during the migration back to Barrow, whales were closer inshore than in the spring (Fig. 27), but they did not follow a specific isobath.

***Objective 3*:** Document the timing of migration and the rate of travel.

Spring Migration. We defined spring migration as the date bowhead whales left the Bering Sea. In 2009, whales passed north of Little Diomede and into the Chukchi Sea between 31 March and 27 April. The average date of passage was 12 April (n=7). In 2010, the average date of passage was 22 April (n=6), but this was because one whale (B09-09) remained in the Bering Sea until 26 May. Not including this whale, the average date of passage for 2010 was 15 April and ranged from 10 to 22 April. We defined the summering area to be east of Hershel Island in the Canadian Beaufort Sea (139.1˚ W longitude). We observed 11 tagged whales as they passed into the summering area, one in 2006, six in 2009, and four in 2010. The average date of arrival was 11 May and ranged from 1 May to 1 June. By examining the maximum spread of dates between when whales left the Bering Sea and arrived in the Canadian Beaufort, we calculated the maximum duration of migration as 62 days, from 31 March to 1 June.

Individual whales, however, do not require this much time for spring migration. We have enough locations to determine the duration of migration for seven individual whales. For these whales, migration between the Bering Sea and the Canadian Beaufort required an average of 19 days (range = 17–24).

Fall Migration. The fall migration, from the Canadian Beaufort Sea to the Bering Sea, takes place over a longer period of time and is much more variable than the spring migration. The period over which tagged whales were migrating extended from 17 August to 12 January (i.e., 148 days). We observed six whales as they began to migrate west in the fall. The average date of passage west of Hershel Island was 17 September and ranged from 17 August to 7 October.

Seventeen whales were tagged at Barrow and tracked to the Bering Sea. Upon leaving the Barrow area (the area within 100 km of Barrow), these whales entered the Bering Sea an average of 69 days later (range = 32–102). The great range in variation is likely due to whales stopping to feed in the Chukchi Sea in the fall. Two whales tagged in Canada allowed us to calculate the number of days individual whales took to migrate from the Canadian Beaufort to the Bering Sea. Interestingly, these two whales only required 61 and 62 days. Although our sample size is limited, tagged whales did not spend much time in the Alaskan Beaufort Sea (i.e., between Hershel Island and the Barrow area). Four whales tracked from Hershel Island to within 100 km of Barrow required an average of 7.75 days to complete the journey (range = 4–12). The only whale that paused during its migration was B08-01; this whale lingered in an area 75 km east of Kaktovik for five days between 18 and 23 August 2008 (this was the whale that took 12 days to migrate from Hershel Island to Barrow).

***Objective 4*:** Estimate residence time for individual whales relative to specific geographic locations and/or habitat types during summer. Specific hypotheses include:

Hypothesis 4A: Individual whales that comprise the occasional concentrations of bowheads feeding near Barrow are present for less than three days.

We defined residence time for the Barrow area as the sum of days individual whales were within 100 km of Barrow within each season. We categorized whales by those tagged at Barrow and those tagged elsewhere. Whales tagged at Barrow likely have residence times that are biased low because these whales were present for an unknown length of time before tagging. The sample for whales tagged at Barrow also includes six tags that failed before the whale left the Barrow area.

In the spring, whales tagged at Barrow (n=4) had a shorter residence time (1–3 days) than whales tagged elsewhere (2–5 days). In the fall, whales tagged at Barrow (n = 29) within the same season were present within the Barrow area for an average of 6.69 days (range = 1–34) before migrating. Whales tagged elsewhere or in a different season (n = 6) were present for an average of 6.60 days (range = 1–14) (Table 5).

Residence time for whales in the fall is highly variable. Although it is clear that whales spend more time near Barrow in the fall than in the spring, we suggest that averages are not very useful for determining how important the Barrow area is for bowhead whales. If we examine the residence times of individual whales we find that the distribution is greatly skewed. Most commonly, whales spend two to four days near Barrow, but some whales spend up to 34 days within the Barrow area. Residence time is likely a function of food availability; when food is available, whales probably stay near Barrow longer.

Table 5. Residence time of tagged bowhead whales in the Barrow area for spring and fall.

	Spring			**Fall**		
	n	**Average (d)**	**Range (d)**	**n**	**Average (d)**	**Range (d)**
Tagged at Barrow	4	1.75	1–3	29	6.69	1–34
Tagged elsewhere	10	3.10	2–5	6	6.60	1–14

Hypothesis 4B: Individual whales feeding in the eastern Alaskan Beaufort Sea remain there for more than three days.

We tracked four whales from Hershel Island to within 100 km of Barrow. These whales required an average of 7.75 days to complete the journey (range = 4–12). The only whale that paused during migration was B08-01; this whale lingered in an area 75 km east of Kaktovik for five days between 18 and 23 August 2008 (this was the whale that took 12 days to migrate from Hershel Island to Barrow). Hence, we believe that only one of four tagged whales stopped to feed in the Alaskan Beaufort Sea.

Regarding residence time in other locations, 13 whales had transmitters that lasted long enough to document residence time in the Bering Sea; seven in 2008–2009 and six in 2009–2010. Whales spent an average of 130 days in the Bering Sea, south of Little Diomede (range = 88–182).

Only three whales have been tracked for the entire summer season. One whale (B06-01) remained in the Canadian Beaufort Sea all summer, a total of 148 days. The other two whales (B08-07 and B08-10) initially migrated to the Canadian Beaufort (Amundsen Gulf) in 2009 and then returned to an offshore area, north of Barrow, in July. B08-07 was in the Canadian Beaufort for 34 days and B08-10 was in the Canadian Beaufort for 74 days. Three whales were tagged near Barrow in spring 2010 and we hope these will increase our sample size for summer and fall migration.

Discussion

Coordination

The combination of the AEWC, NSB, Captain's associations, individual whalers, Canadian hunters, DFO, and MMS personnel made an excellent framework for conducting tagging and for exchanging information. The study was designed, modified, approved, and conducted by the partners. Decisions about where and when to tag were made with 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 objectives was that tagging would not interfere with subsistence whaling and in order to achieve that we were ready to avoid the whaling season and plan tagging for other times or places. 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 Barrow 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 order to keep AEWC informed of the study progress and to see what questions and concerns they had we made regular oral presentations at AEWC meetings and provided handouts for the commissioners. In order 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 contains >250 addresses; many people also forward our maps to their own list of addresses.

Often when the maps are sent out recipients will reply to the list with their thoughts, questions, or other information about what whales are doing. We have received valuable real time information that has provided perspective on the movements of the tagged whales relative to the population. For example, when we sent out a map showing when the first tagged whales were entering the Bering Sea, hunters on St. Lawrence Island informed us that they were already observing whales and were whaling. Hence, when whales were first spotted from St. Lawrence Island, the closest tagged whales were still 250 km to the north. This type of information is extremely valuable in helping us interpret how representative the tagged whales are and serves as in important reminder that the tagged whales do not represent all whales. This is what the whalers told us and why we added the traditional knowledge component to the study.

After the maps are e-mailed they are placed on the ADF&G website for people without e-mail to access. We know that the website is checked regularly because if we are late posting a map we receive inquiries. We also post analyses, posters, and other products there as well. These products are used by many entities as we have seen our maps and figures in oil company reports, agency products, and in nonprofit products such as habitat maps.

We coordinated with the research conducted by BOWFEST and provided updates regarding the tagging project at their annual meetings. We also provide data on tagged whale locations and movements that were relevant to their research near Barrow.

Tagged Whales, Biopsy and Tag Performance
The amount of data collected from each tag varies greatly and is dependent on many factors some of which are impossible to identify with certainty. In 2007, we believe that we deployed some tags that were defective. For example, four out of five tags deployed in Canada failed to transmit at all, and one transmitted for only 11 days (Table 2). Two of those tag deployments, however, were not ideal and could have resulted in poor attachments that also could explain the lack of transmissions. One tag that failed was never deployed; it fell into the ocean and was retrieved. The failure was traced back to curing of the epoxy that the tags were housed in. Quick curing, under high heat, caused a void to form in the epoxy that allowed water to leak into the electronics.

Since 2008 we have had better success with tag longevity and performance. There are many reasons why tag performance has improved. First, fewer defective tags are deployed. The tag company (Wildlife Computers) fixed the epoxy curing process and we developed a protocol to detect defective or marginal tags. This protocol included dunking tags in buckets of salt water and then testing them to ensure that they transmitted to satellites. We also checked the battery voltage for each tag upon arrival and immediately prior to deployment. Second, tag placement and attachment likely improved as taggers gained more experience placing tags.

To date, we have deployed 46 transmitters, and the success of this program is largely due to cooperation with native whalers. Whalers are familiar with how best to approach and harpoon bowhead whales and are able to place tags at the highest point on the whale's back and seat the anchors completely and perpendicular to the surface of the whale. We think that high, perpendicular tag placement leads to good rates of transmission and full seating of the anchors leads to long tag attachment.

DNA from skin biopsies collected during tagging has allowed us to determine gender for 28 of 47 whales tagged. Although most (71%) of these were males, females were also tagged during each tagging event, therefore none of the groups in which whales were tagged were exclusively male.

Movements and Behavior by Season
Although general routes and timing for bowhead whale migration were known from subsistence whaling activities and from aerial surveys, satellite telemetry from this study has provided behavior and habitat use of several individuals year-round. We have also been able to compare the inter-annual variability in use of specific areas by season.

Autumn (August–December) Chukchi Sea. Once west of Barrow in the fall, little was known about bowhead movements or habitat use in the central Chukchi Sea (Fig. 33). The Chukchi Sea has important potential for oil and gas development in both U.S. and Russian waters. It may also become important for major shipping lanes as sea ice diminishes. Therefore understanding how and when bowhead whales use the area is important to avoid conflicts with development.

In addition to the detailed analyses conducted on the 15 tagged whales in 2008 depicted in Figure 2, we have tracks for an additional 13 whales tagged in 2009 that provide even more information about the use of the Chukchi Sea in fall, including variability among years (Fig. 8). From these tracks it is evident that the area near Barrow and the northern portion of the lease sale area received a lot of use, while the eastern Chukchi Sea, especially nearshore, from Wainwright to the Bering Strait was not used much by bowhead whales in the fall. The western Chukchi Sea, however, received extensive use in both years and included use of nearshore habitats by many individuals for long periods of time (average 59 days in 2008). Although more detailed analysis using kernel density methods will show this more clearly, the use of the area east of Wrangel Island was different between 2008 and 2009. In 2008, bowheads spent time closer to the island (Fig. 8, red tracks); while in 2009 activity was concentrated to the northeast of the island (Fig. 8, blue tracks).

Winter (December–March) Bering Sea. Prior to this study, winter sightings of bowheads were limited to areas of open water near shore (Ainana et al. 1997, Noongwook et al. 2007) and from helicopter surveys from an icebreaker (Brueggeman 1982) giving the general impression that bowhead whales wintered in nearshore polynyas and near the ice edge. Our data showed that in the winter of 2008–2009 bowheads spent most of their time offshore (Figs. 12–15) in relatively heavy ice (Figs. 16 and 17) with little use of open water areas or the ice edge. Although there was complete overlap in the area used by bowheads during the winter of 2008–2009 and 2009–2010, bowheads used a larger area in 2009–2010 that included use of habitats near St. Lawrence and St. Matthew islands and more use of the central Bering Sea (Fig. 19).

Spring (April – May) Chukchi and Beaufort seas. Based upon sightings of bowhead whales near villages and from limited aerial surveys (Braham et al. 1980, 1984) bowheads pass Little Diomede on their way up the coast of Alaska to Point Barrow and then to follow leads east into the Canadian Beaufort Sea (Fig. 33). We found that most tagged whales passed to the east of Little Diomede Island (Fig. 20) and then traveled up the coast of Alaska to Point Barrow (Fig. 21). However, upon leaving Point Barrow, whales generally headed straight for Amundsen Gulf (Fig. 22), regardless of where leads were located (e.g., Fig. 23).

All whales but one followed this pattern. Whale B09-09 (#93089) migrated late in May and followed the Russian coast north into the Chukchi Sea (Fig. 32). This whale then continued to follow the Chukota coast to an area west of Wrangel Island, where the whale was located as of 31 July 2010. Bowhead whales were counted migrating past Cape Deshnev (near Uelen) in May and June 1999–2001 and were known to be passing by later than whales counted at Barrow (Melnikov and Zeh 2006, Melnikov et al. 2004). Although whales are sighted along the Chukotka Peninsula in the summer and fall (Bogoslovskaya et al. 1982, Moore et al. 1995, Melnikov et al. 1998), it was not known if those whales had followed the normal migratory route to the Canadian Beaufort and then migrated to Chukotka or if some whales migrated directly to the Chukotka area in the spring. We now have documented that some whales will migrate directly along the Chukotka Peninsula to the area west of Wrangel Island in the spring. Whale B09-09 (#93089) was tagged near Barrow in late August 2009 (Table 2); the movements of this whale will continue to be of interest.

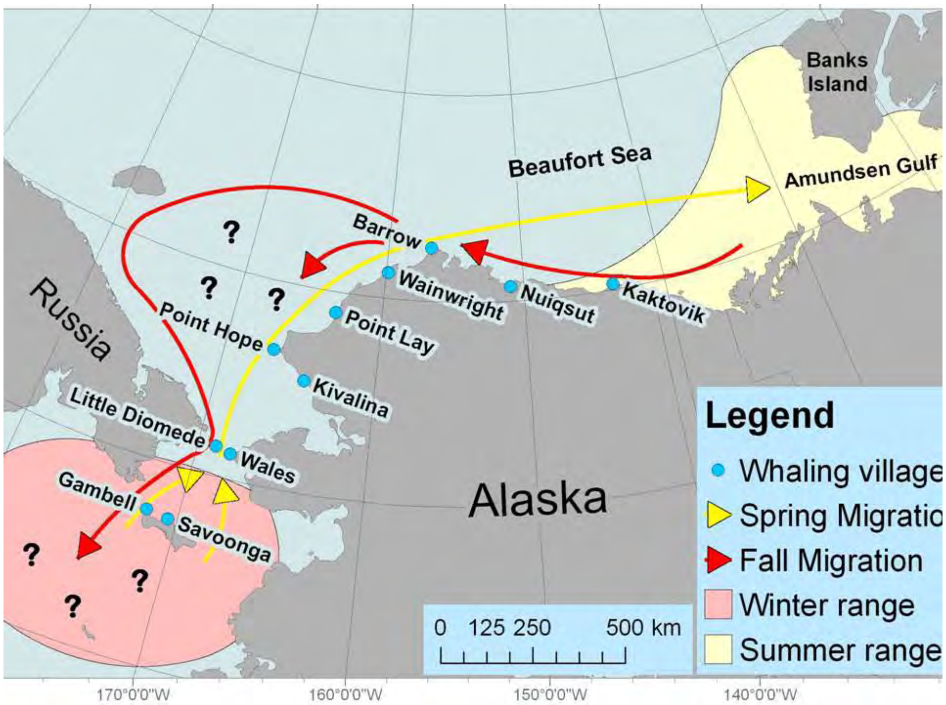

Figure 33. General migration routes and general summer and winter ranges of bowhead whales prior to this study. Figure based on Moore and Laidre 2006.

Summer (June-August) Beaufort Sea. Bowhead whales are known to summer in the eastern Beaufort Sea, with concentrations of whales near Cape Bathurst, Tuktoyaktuk, the Mackenzie River Delta, and in Amundsen Gulf (e.g., Hazard and Cubbage 1982, Braham et al. 1984, Harwood and Borstad 1985, Richardson et al. 1987, Moore and Reeves 1993). In the fall, whales then begin to migrate towards Barrow.

Tagged whales generally followed this pattern; however, we observed some long distance movements outside of the migration period. In 2006, one whale traveled from Amundsen Gulf to the northern end of Banks Island and then returned to Amundsen Gulf, a 1,400 km round trip (Fig. 34). In 2009, two whales left Canadian Beaufort and traveled to an area north of Barrow, before returning to the Canadian Beaufort (Fig. 25).

Habitat use

Feeding areas. Identification of feeding areas was based upon where bowhead whales spent significant amounts of time. Bowhead movements are generally characterized by long directed movements (presumably migration) and long periods where whales move back and forth within a restricted spatial area (presumably feeding). We do not get direct evidence of feeding from the tags. However, dive records indicate when whales visit the bottom often and this might be also evidence of feeding.

Concentrations of zooplankton are likely necessary for bowheads and other large baleen whales to feed efficiently in order to meet their energy requirements (Kenney et al., 1986; Lowry, 1993). Euphausiids are not thought to be produced in the Chukchi Sea but are advected from the Bering Sea (Siegel, 2000). Because euphausiids and other zooplankton are carried on currents they can be concentrated by physical factors such as wind, bathymetry, upwelling, and oceanographic factors such as temperature and salinity (Berline et al., 2008). Feeding areas may have the physical and oceanographic factors necessary to concentrate prey each year; however, the timing of prey concentration within years may be sporadic due to variability in some of these factors. Based on stomach contents of harvested bowhead whales, Point Barrow is known to be a fall feeding area (Lowry and Frost, 1984; Lowry et al., 2004, Moore et al. 2010) and euphausiids (mostly *Thysanoessa raschii*) are the most common prey item (Lowry, 1993; Lowry et al., 2004). Physical and oceanographic factors near Point Barrow apparently concentrate zooplankton and develop favorable feeding conditions for bowhead whales intermittently from July through October Ashjian et al. 2010). These factors include persistent winds from the east that push the Alaska Coastal Current offshore from Barrow Canyon bringing zooplankton onto the shelf from upwelling northeast of Point Barrow. If winds lessen or shift south or southwest, the Alaska Coastal Current returns, trapping and concentrating zooplankton northeast of Point Barrow on the Beaufort Sea shelf (Ashjian et al. 2010).

Physical and oceanographic factors may concentrate zooplankton along the Chukotka coast as they do near Point Barrow. There is independent evidence that Chukotka coastal areas are also important for feeding. Bowhead whales have been observed in many years along the northern coast of Chukotka during mid September to mid October (Johnson et al., 1981; Marquette et al., 1982; Melnikov and Bobkov, 1993; Moore et al., 1995; Ainana et al., 1997; Melnikov et al., 1997; Bogoslovskaya, 2003). In October of 1992 and 1993, Moore et al. (1995) encountered a large number of bowhead whales feeding between Cape Schmidt and Vankarem. In 1993, they conducted a net tow for plankton and found abundant euphausiids (*T. raschii*) associated with a sharp salinity gradient where bowhead whales appeared to be feeding.

Areas where we suspect tagged whales spent time feeding included Amundsen Gulf, Barrow, the area surrounding Wrangel Island, the northern coast of Chukotka, and the western Bering Sea. We did not identify the Alaskan Beaufort Sea as an important feeding area, possibly because our sample size for that area was small; only one of five tagged whales paused to feed in the Alaskan Beaufort Sea, near Kaktovik. We also suspect that whales were feeding during winter in the Bering Sea because of the amount of time whales spent near the seafloor (Fig. 15).

Migratory corridors. Migratory corridors were variable in width and connected areas where whales lingered. In the spring, the migratory corridor used by tagged whales from the Bering Strait, to Barrow, and across the Beaufort Sea to Amundsen Gulf was well defined (Figs. 20 and 21). The migratory corridor from Amundsen Gulf back to Barrow was less defined with some whales traveling inshore and some traveling offshore (Fig. 34). The fall migratory corridor across the Chukchi Sea, from Barrow to Chukotka, was the least defined (Fig. 8). Most tagged whales crossed the Chukchi Sea in a wide band between 70^{o} and 74^{o} north latitude. However, some whales crossed farther north and some migrated down the Alaskan coast. Hence, the fall migration from Barrow to the Bering Sea covered much of the Chukchi Sea and all tagged whales traveled through the lease sale area in the fall (Fig. 8), while only one did so in the spring (Fig. 21).

We suspect that variability in migratory paths is linked to variability in forage conditions. Because krill concentrates due to oceanographic factors that are variable, areas with good foraging conditions can vary greatly with time. In the fall, whales arrive at feeding areas at different times. Individuals may bypass a particular area if local foraging conditions are poor at that moment. Whale movements become asynchronous as individuals visit different feeding areas at different times. This results in a complex pattern of movement that is not clearly migratory. Upon leaving Barrow, whales may find foraging areas that cause them to remain along the shelf break, near Wrangel Island, or along the coast of Chukotka, from Wrangel Island to the Bering Strait. In general, whales that remain near Barrow later in the fall do not migrate to Wrangel Island. These whales either cross the Chukchi Sea farther to the south or migrate down the Alaskan coast. For example, consider the three whales in 2008 that bypassed Barrow and then returned (Fig. 3). These whales left Barrow relatively late in the fall (mid-October to mid-November). None of these whales went to Wrangel Island and one migrated down the Alaskan coast.

During the spring migration, tagged whales generally did not stop between the Bering Strait and Amundsen Gulf suggesting limited feeding opportunities or obstructions caused by ice. Hence, the migratory path was more predictable and consistent. Likewise, most tagged whales did not linger between Barter Island and Barrow during the fall migration. This migratory path was also more predictable and consistent.

Feeding within the water column. It appears that whales typically spend a high proportion of time on or near the ocean floor (e.g., Figs. 8 and 25). Even when traveling, whales visit the bottom on a regular basis (Figs. 8 and 25). A number of studies have identified krill concentrated near the bottom (e.g., Laidre et al. 2007) and bowheads have been observed with mud on their head and body and streaming from their mouths (Mocklin 2009) and we suspect that the tagged whales are feeding on such krill concentrations. Traveling whales might be searching for or feeding on krill when they visit the bottom.

Sea ice. Sea ice is generally assumed to limit the distribution of bowhead whales. However, even though the Beaufort Sea has virtually 100% ice cover when bowhead whales migrate through in the spring, ice does not seem to limit the movements of tagged whales between Barrow and Amundsen Gulf (e.g., Fig. 23). There must be enough openings and thin ice to allow whales to travel straight from Barrow to Amundsen Gulf without lingering and waiting for leads to open. Likewise, sea ice within the Bering Sea does not seem to limit the movements of tagged whales.

Bowhead whales wintering in the Bering Sea were believed to be restricted to polynas or the ice edge (Ainana et al. 1997, Brueggeman 1982). We found that whales used areas with 100% ice cover, even when polynas were available (Figs. 17 and 18). However, land-fast ice does seem to limit the distribution of bowhead whales. For example, in the spring of 2009, six bowheads migrated to Amundsen Gulf, which was filled with land-fast ice. The whales remained at the ice edge until the gulf cleared of land-fast ice (Fig. 24).

Anthropogenic effects/mitigation

Oil and Gas Lease Sale Area 193. The potential for anthopogenic disturbances within the Lease Area is much greater in the fall (Fig. 8) than in the spring (Fig. 21). In the fall, it is likely that all 19 tagged bowhead whales that were tracked leaving Point Barrow traveled through some portion of the Lease Area (Fig. 21). During the winter of 2008-2009, fourteen bowhead whales transmitted enough locations to determine how they passed through the Lease Area and five transmitted locations within the leased blocks, where oil exploration activity has occurred or is likely to occur. We used the kernel densities (Figs. 4–7) to calculate a probability of use by grid cell. Generally, the Lease Area contained a low percent probability of use by bowhead whales (2–31%) during all months examined with the highest percent probability of use occurring in September. The pattern was similar for leased blocks, although the percent probability of use within the leased blocks was much lower (<1–1%) than that for the entire Lease Area. Based on

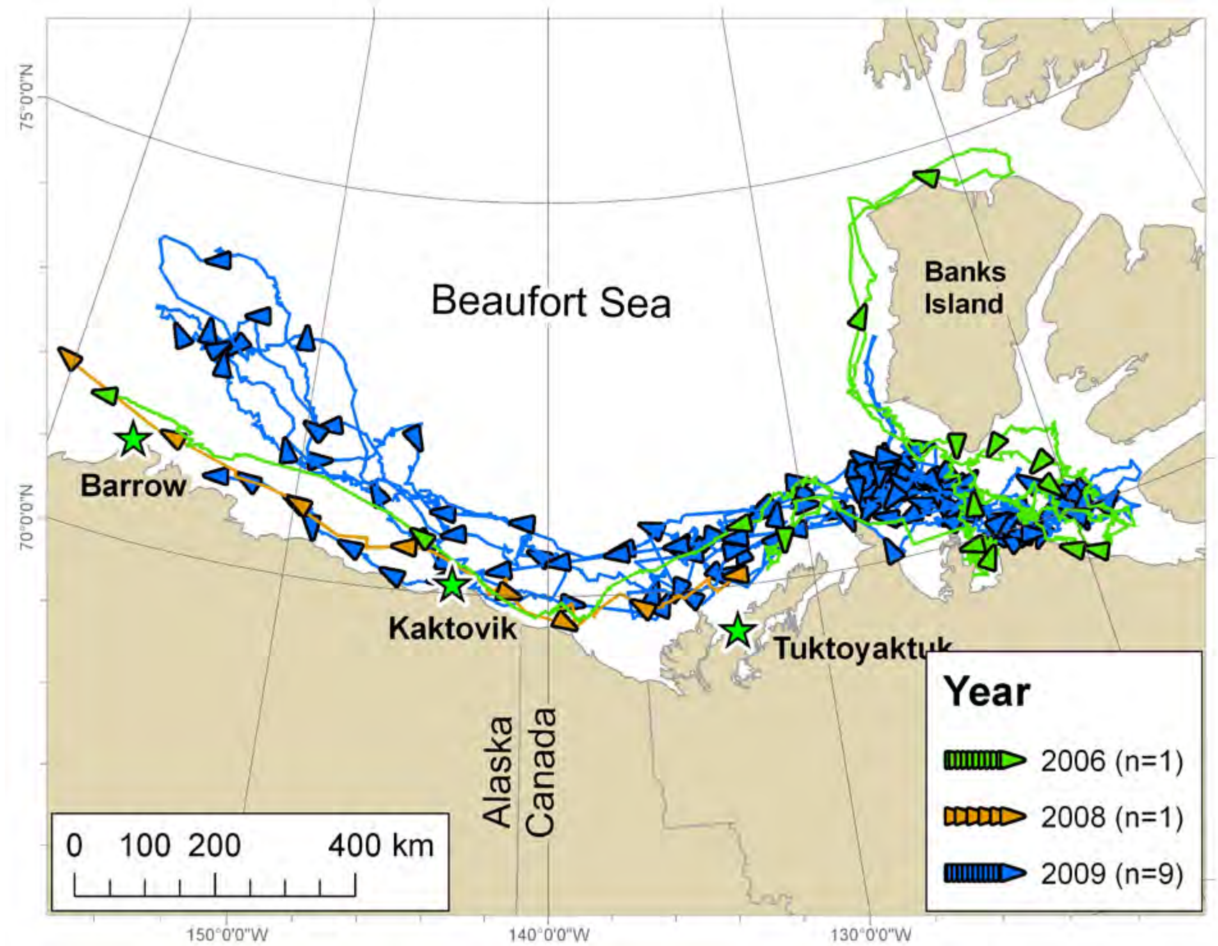

Figure 34. Tracks of 11 satellite-tagged bowhead whales in the Beaufort Sea in summer/fall 2006–2009.

movements and behavior of tagged bowhead whales tagged in 2008, the greatest potential for anthropogenic disturbances from industrial activities is near Point Barrow in September and October and in the Lease Area in September.

Shipping lanes. The reduction of sea ice is increasing the potential for the opening of arctic shipping lanes. Shipping activities related to oil and general shipping and tourism are also expected to increase as the ice-free season lengthens (ACIA 2004). Increased ship traffic has the potential to cause further disturbances to bowhead whales in the form of noise and ship strikes. Areas of high importance for bowhead whales (i.e., Point Barrow and Chukotka) during September through December generally fell within 75 km of shore (Figs. 4–7). As such, shipping traffic within 75 km offshore of Point Barrow or Chukotka during this time period could cause significant disturbance. Similarly, in fall, in the western Bering Strait, near Uelen, the highest probability of use by bowhead whales was along the Chukotka coast (Figs. 6 and 7). Ships traveling through the narrow area west of Little Diomede Island in November and December would have high potential for encountering bowhead whales. North Atlantic right whales (*Eubalaena glacialis*), a close relative to bowhead whales, migrate and feed along the east coast of the U.S. within busy commercial shipping lanes. Ship collisions and propeller wounds are a significant source of mortality to North Atlantic right whales in these areas (Moore et al, 2004). Similarly bowheads will likely be susceptible to ship-related injuries should vessel traffic increase along the Chukotka coast.

Seismic. We documented one interaction between a seismic vessel and a tagged whale. We found evidence that this whale maintained a minimum distance of 9.2 km from the seismic ship (Fig. 23), which is a much greater distance than the designated 1 km 'safety zone' used to trigger shut-downs. However, this is considerably less than the 20 km deflections noted for migrating bowheads in the mid-Beaufort Sea (Richardson 1999). The difference between the behavior of whales in Richardson's study and our study appears to be that our tagged whale was feeding. Based upon our statistical analyses, it does not appear the seismic survey affected overall whale behavior, as the whale remained in the area after the seismic survey ended, presumably feeding, and then migrated through the Chukchi Sea to the coast of Chukotka, Russia. Hence, we conclude that the seismic operation did not permanently disrupt the feeding or migratory behavior of this whale.

We believe there have been other interactions with seismic operations and tagged whales during this study that could be analyzed to learn more about the effects of seismic activities on bowhead whales. Due to the proprietary nature of seismic data, however, such analyses remain challenging.

Conclusions

To date, our project has been extremely successful. Our success can be directly attributed to how we worked with Native subsistence whalers to develop study objectives and to deploy tags. We have also worked with the tag designers and developed protocols to improve tag performance. We have shared our results with the scientific community and subsistence whalers. We send weekly maps of tagged whale movements to an extensive e-mail list including whalers, agencies, biologists, oil companies, and other interested parties has been effective at share data in real time and getting immediate feedback on whale movements and behavior. We also maintain an active website that is valuable for allowing immediate access to data and products that are used by many people with diverse objectives. For example, our maps and other products were used to develop species and habitat maps, environmental assessments, biological opinions, and incidental harassment applications and authorizations. One of our maps was even used in a text book for Canadian school children.

We have also learned much about the distribution, movements, and biology of bowhead whales. These include, but are not limited to:

1. We have documented the annual distribution of western Arctic bowhead whales, including summering and wintering areas and the migratory routes that connect these areas.

2. We have identified areas where whales spend time, and are likely feeding. These areas include Amundsen Gulf; Barrow; Wrangel Island; the coast of Chukotka, between Wrangel Island and the Bering Strait; and the western Bering Sea. We have documented duration times and kernel densities for these areas (see Results and Discussion).

3. Although we did not identify important feeding locations within the Alaskan Beaufort Sea our sample size of tagged whales was smaller for this region than for other areas and the oceanographic factors that concentrate krill may not have been favorable within the study period. Therefore our results for this area were not conclusive.

4. We have identified migratory corridors that whales use to travel between feeding areas. Both the spring migratory corridor between the Bering Strait and Amundsen Gulf and the fall migratory corridor between Hershel Island and Barrow are distinct and consistent between years. However, the fall migratory corridor between Barrow and the Bering Strait is poorly defined. We think this is related to variability in forage quality and the timing of whale movements. Krill is concentrated by oceanographic factors and vary in space and time. This results in complex movement patterns as individual whales travel to different feeding areas at different times.

5. The whalers were concerned that the tagged whales might not represent their knowledge of what bowhead whales do near shore where they observe and hunt them. At the request of AEWC, we conducted traditional knowledge interviews in as many whaling villages as possible and reported our findings to the AEWC, the whaling villages, and to MMS through the Coastal Marine Institute. Several contributions from traditional knowledge have been useful interpreting the tracks of tagged whales. For example, Wainwright sees few whales in fall, which fit well with the pattern we observed as few whales migrated down the Alaskan coast in the fall.

6. We have described how bowhead whales move through Oil and Gas Lease Sale Area 193. Based on movements and behavior of tagged bowhead whales in 2008, the greatest potential for anthropogenic disturbances from industrial activities are near Point Barrow in September and October and in the Lease Area in September.

7. We have described locations and times when shipping may affect bowhead migration or feeding. In the fall and summer, shipping traffic within 75 km offshore of Point Barrow or Chukotka could cause significant disturbance. Ships traveling through the narrow area west of Little Diomede Island in November and December would have high potential for encountering bowhead whales.

8. We have documented an interaction between a bowhead whale and a seismic vessel. We found evidence that this whale maintained a minimum distance of 9.2 km from the seismic ship (Fig. 23), which is a much greater distance than the designated 1 km ‘safety zone’ used to trigger shut-downs.

9. We have a manuscript in preparation describing the winter movements and dive behavior of bowhead whales in the Bering Sea.

Recommendations

1. In order to increase the likelihood that tagged whales represent the population as a whole, and in order to gain a year-round understanding of bowhead whale movements and distribution, tagging should continue from as many locations and during as many different times of year as possible. Specifically:

    a. Increasing the sample size of tagged whales at all tagging locations will make identifying separate concentrations of whales more likely. For example, whale B09-09 was tagged in Barrow in late August of 2009, but migrated to Chukotka in the spring of 2010. More summering areas may be identified as more tags are deployed.

    b. More information is needed regarding bowhead whale movements and feeding behavior for the Alaskan Beaufort Sea. There is great interest in oil and gas exploration in this region and we expect an increase in industrial activity. However, we have deployed few tags in Canada in the fall and have had few tags that were deployed in other locations last long enough to provide data for the Alaskan Beaufort Sea in the fall. Hence, we have only observed four whales cross the Alaskan Beaufort Sea in the fall when most industrial activity occurs. Tagging more whales near Barrow in the spring and tagging more whales in Canada in the fall will address this need.

    c. Deploy tags near St. Lawrence Island to determine if whales tagged there are similar in their movements and behavior to those tagged near Barrow and in Canada. To target whales summering in Chukotka, we suspect it is more efficient to tag whales migrating past St. Lawrence Island in the spring than from Barrow in the fall.

2. Conduct a comprehensive analysis of bowhead whale interactions with seismic activities. Bowhead whale tracks that spatially and temporally overlap with seismic operations need to be analyzed to learn about bowhead whale behavior near seismic activities. Oil and seismic companies need to be forthcoming with their seismic information in order for this analysis to occur.

3. Deploy tags that are capable of measuring temperature and salinity, important factors that relate to how krill concentrate.

4. Investigate combining satellite telemetry and acoustic technology to directly monitor the noise levels that bowhead whales are exposed to.

5. Conduct a comprehensive analysis of how whale movements and feeding areas shift by year. Understanding annual variability is important for understanding the full range of bowhead movements, behavior, and habitat use. Furthermore, we cannot predict how whales will respond to climate change and changing ice conditions until we know what influences their current distribution.

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Literature Cited

ACIA. 2004. Impacts of a warming Arctic: Arctic Climate Impact Assessment. Cambridge University Press [online]. Available from acia.uaf.edu.

Ainana, L., N. Mymrin, L. Bogoslovskaya, and O. Veter. 1997. Role of the Eskimo Society of Chukotka in encouraging traditional native use of wildlife resources by Chukotka natives and in conducting shore based observations in the study of migration patterns of the bowhead whale, *Balaena mysticetus*, in the waters of the Bering Sea and Chukchi Sea adjacent to the Chukotka Peninsula (Russia) during January to September, 1996. Report to North Slope Borough from Eskimo Society of Chukotka, Provideniya, Russia. Available from the Alaska Dept. of Fish and Game, 1300 College Rd., Fairbanks, AK 99701. 122 p.

Ashjian, C. J., S. R. Braund, R. G. Campbell, J. C. George, J. Druse, W. Maslowski, S. E. Moore, C. R., Nicolson, S. R. Okkonen, B. F. Sherr, E. B. Sherr, and Y. H. Spitz. 2010. Climate variability, oceanography, bowhead whale distribution, and Inupiat subsistence whaling near Barrow, Alaska. Arctic 63 (2):179–194.

Berline, L., Spitz, Y.H., Ashjian, C.J., Campbell, R.G., Maslowski, W., and Moore, S.E. 2008. Euphausiid transport in the Western Arctic Ocean. Marine Ecology Progress Series 360:163–178. doi:10.3354/meps07387.

Bogoslovskaya, L. S., L. M. Votrogov, and I. I. Krupnik. 1982. The bowhead whale off Chukotka: migrations and aboriginal whaling. Report of the International Whaling Commission 32:391–399.

Braham, H.W., Fraker, M.A. and Krogman, B.D. 1980. Spring migration of the western Arctic population of bowhead whales. *Mar. Fish. Rev.* 42(9-10):36-46.

Braham, H. W., B. D. Krogman, and G. M. Carroll. 1984. Bowhead and white whale migration, distribution and abundance in the Bering, Chukchi and Beaufort Seas, 1975-78. NOAA Tech. Rep. SSRF-778, 39pp. [Available from: www.nmfs.gov].

Brueggeman, J. J. 1982. Early spring distribution of bowhead whales in the Bering Sea. Journal of Wildlife Management 46:1036–1044.

Brueggeman, J. J., B. Webster, R. Grotefendt, and D. Chapman. 1987. Monitoring the winter presence of bowhead whales in the Navarin Basin through association with sea ice. Report by Envirosphere Co. to the US Minerals Management Service, NTIS No. PB88-101258. 179pp. [Available from: *http://www.mms.gov*].

Carroll, G. M., J. C. George, L. F. Lowry, and K. O. Coyle. 1987. Bowhead whale (*Balaena mysticetus*) feeding near Point Barrow, Alaska, during the 1985 spring migration. Arctic 40(2):105–110.

Duong, T. 2007. ks: kernel density estimation and kernel discriminant analysis for multivariate data in R. Journal of Statistical Software 21:1–16.

Duong, T. and M. L. Hazelton. 2005. Cross-validation bandwidth matrices for multivariate kernel density estimation. Scandinavian Journal of Statistics 32:485–506.

ESRI. 2006. ArcMap 9.2, build 1380. ESRI, Redlands, CA, USA.

Fraker, M. A., and J. R. Bockstoce. 1980. Summer distribution of bowhead whales in the eastern Beaufort Sea. Marine Fisheries Review 42(9–10):57–64.

Freitas, C., C. Lydersen, M. A. Fedak, and K. M. Kovacs. 2008. A simple new algorithm to filter marine mammal Argos locations. Marine Mammal Science 24:315–325.

Harris, R. B., S. G. Fancy, D. C. Douglas, G. W. Garner, S. C. Amstrup, T. R. McCabe, and L. F. Pank. 1990. Tracking wildlife by satellite: Current systems and performance. U.S. Department of the Interior, Fish and Wildlife Service, Fish and Wildlife Technical Report No. 30. 52 pp.

Harris, R. E., T. Elliot, and R. A. Davis. 2007. Results of mitigation and monitoring program, Beaufort Span 2-D marine seismic program. LGL Ltd. LGL Project TA4319-1.

Harwood, L. A., and G. A. Borstad. 1985. Bowhead whale monitoring study in the southeast Beaufort Sea, July–September 1984. Environmental Studies Revolving Fund Report No. 009. Ottawa, Canada. 99 pp.

Hazard, K.W. and Cubbage, J.C. 1982. Bowhead whale distribution in the southeastern Beaufort Sea and Amundsen Gulf, Summer 1979. Arctic 35(4):519-23.

Heide-Jørgensen, M. P., L. Kleivane, N. Øien, K. L. Laidre, and M. V. Jensen. 2001. A new technique for deploying satellite transmitters on baleen whales: Tracking a blue whale (*Balaenoptera musculus*) in the North Atlantic. Marine Mammal Science 17:949–954.

Heide-Jørgensen, M. P., K. L. Laidre, Ø. Wiig, M. V. Jensen, L. Dueck, L. D. Maiers, H. C. Schmidt, and R. C. Hobbs. 2003. From Greenland to Canada in ten days: tracks of bowhead whales, *Balaena mysticetus*, across Baffin Bay. Arctic 56(1):21–31.

Hobson, K. A., and D. M. Schell. 1998. Stable carbon and nitrogen isotope patterns in baleen from eastern Arctic bowhead whales (*Balaena mysticetus*). Canadian Journal of Fisheries and Aquatic Sciences 55:2601–2607.

Huntington, H. 1998. Observations on the utility of the semi-directive interview for documenting traditional ecological knowledge. Arctic 51(3):237–242.

Huntington, H. P., and L. T. Quakenbush. 2009a. Traditional knowledge of bowhead whale migratory patterns near Kaktovik and Barrow, Alaska. Report to the Alaska Eskimo Whaling Commission and the Barrow and Kaktovik Whaling Captains. 14 pp.

Huntington, H. P., and L. T. Quakenbush. 2009b. Traditional knowledge of bowhead whale migratory patterns near Wainwright, Alaska. Report to the Alaska Eskimo Whaling Commission and the Wainwright Whaling Captains. 9 pp.

Gitzen, R.A., and J. J. Millspaugh. 2003. Comparison of least-squares cross-validation bandwidth options for kernel home-range estimation. Wildlife Society Bulletin 31:823–831.

Jakobsson, M., and R. Macnab. 2006. A comparison between GEBCO sheet 5.17 and the International Bathymetric Chart of the Arctic Ocean (IBCAO) version 1.0. Marine Geophysical Researches 27:35–48.

Jammalamadaka, S. Rao and A. SenGupta. 2001. Topics in circular statistics. World Scientific Publishing Company Pte. Ltd., Singapore.

Keating, K.A. 1994. An alternative index of satellite telemetry location error. Journal of Wildlife Management 58:414–421.

Kenney, R.D., Hyman, M.A.M, Owen, R.E., Scott, G.P., and Winn, H. E. 1986. Estimation of prey densities required by western North Atlantic right whales. Marine Mammal Science 2:1–13.

Kernohan, B.J., R. A. Gitzen, and J. J. Millspaugh. 2002. Analysis of animal space use and movements. Pages 125–166 *in:* Radio tracking and animal populations. J.J. Millspaugh and J.M. Marzluff, eds. Academic Press, San Diego, California.

Krutzikowsky, G.K. and Mate, B.R. 2000. Dive and surfacing characteristics of bowhead whales (*Balaena mysticetus*) in the Beaufort and Chukchi seas. Canadian Journal of Zoology 78:1182-98.

Laidre, K. L., M. P. Heide-Jorgensen, and T. G. Nielsen. 2007. Role of the bowhead whale as a predator in West Greenland. Marine Ecology Progress Series 346:285–297.

Lee, S. H., D. M. Schell, T. L. McDonald, and W. J. Richardson. 2005. Regional and seasonal feeding by bowhead whales (*Balaena mysticetus*) as indicated by stable isotope ratios. Marine Ecology Progress Series 285:271–287.

Ljungblad, D. K., S. E. Moore, and D. R. Van Schoik. 1983. Aerial surveys of endangered whales in the Beaufort, eastern Chukchi, and northern Bering Seas, 1982. Report from Naval Ocean systems Center, San Diego, CA, for the U.S. Minerals Management Service, by the Naval Ocean Systems Center. NTIS No. AD-A 134772. 382 pp.

Ljungblad, D. K., S. E. Moore, J. T. Clarke, and J. C. Bennett. 1986. Aerial surveys of endangered whales in the northern Bering, eastern Chukchi and Alaskan Beaufort Seas, 1985: with a seven-year review, 1979–1985. Report from Naval Ocean systems Center, San Diego, CA, for the U.S. Minerals Management Service. NTIS No. PB 87 115929/AS. 443 pp.

Lowry, L. F., and K. J. Frost. 1984. Foods and feeding of bowhead whales in western and northern Alaska. Scientific Reports of the Whale Research Institute, Tokyo 35:1–16.

Lowry, L. F., G. Sheffield, and J. C. George. 2004. Bowhead whale feeding in the Alaskan Beaufort Sea, based on stomach contents analysis. Journal of Cetacean Research

Management 6(3):215–223.

Mate, B. R., G. K. Krutzikowsky and M. H. Winsor. 2000. Satellite-monitored movements of radio-tagged bowhead whales in the Beaufort and Chukchi seas during the late-summer feeding season and fall migration. Canadian Journal of Zoology 78:1168–1181.

Melnikov, V.V., and Bobkov, A.V. 1993. Bowhead whale migration in the Chuckchee Sea. Russian Journal of Marine Biology 19(3):180–185. Translated from Russian by Biologya Morya 1993 (3):60–67.

Melnikov, V., and J. Zeh. 2006. Chukotka Peninsula counts and estimates of the number of migrating bowhead whales. SC/58/BRG15. Report to the International Whaling Commission.

Melnikov, V. V., D. I.Litovka, I. A. Zagrebin, G. M. Zelensky, and L. I. Ainana. 2004. Shore-based counts of bowhead whales along the Chukotka Peninsula in May and June 1999–2001. Arctic 57(3):290–298.

McConnell, B. J., C. Chambers, and M. A. Fedak. 1992. Foraging ecology of southern elephant seals in relation to the bathymetry and productivity of the Southern Ocean. Antarctic Science 4:393–398.

Mocklin, J. 2009. Evidence of feeding by bowhead whales from aerial photography. Master's Thesis, Univ. Washington. 67 pp.

Moore, S. E., and K. L. Laidre. 2006. Trends in sea ice cover within habitats used by bowhead whales in the western Arctic. Ecological Applications 16(3):932–944.

Moore, S.E., and R. R. Reeves, 1993. Distribution and movement. pp. 313-86. In: J.J. Burns, J.J. Montague and C.J. Cowles (eds.) Special Publication. No. 2. The Bowhead Whale. Society for Marine Mammalogy, Lawrence, Kansas. 787pp.

Moore, M. J., A. R. Knowlton, S. D. Kraus, W. A. McLellan, and R. K. Bonde. 2004. Morphometry, gross morphology and available histopathology in North Atlantic right whale (*Eubalaena glacialis*) mortalities (1970–2002). Journal of Cetacean Research Management 6(3):199–214.

Moore, S. E., J. T. Clarke, and D. K. Ljungblad. 1989. Bowhead whale (*Balaena mysticetus*) spatial and temporal distribution in the central Beaufort Sea during late summer and early fall 1979–86. Report of the International Whaling Commission 39:283–290.

Moore, S. E., J. C. George, K. O. Coyle, and T. J. Weingartner. 1995. Bowhead whales along the Chukotka coast in autumn. Arctic 48:155–160.

Moore, S. E., J. C. George, G. Sheffield, J. Bacon, and C. J. Ashjian. 2010. Bowhead whale distribution and feeding near Barrow, Alaska, in late summer 2005–06. Arctic 63(2):195–205.

Noongwook, G., the Native Village of Savoonga, the Native Village of Gambell, H. Huntington, and J. C. George. 2007. Traditional knowledge of the bowhead whale (*Balaena mysticetus*) around St. Lawrence Island, Alaska. Arctic 60(1):47–54.

Park, B. U., and J. S. Marron. 1990. Comparison of data-driven bandwidth selectors. Journal of the American Statistical Association 85:65–78.

Quakenbush, L. T., and H. P. Huntington. 2010. Traditional knowledge regarding bowhead whales in the Chukchi Sea near Wainwright, Alaska. OCS Study MMS 2009-063.

Quakenbush, L. T., J. J. Citta, J. C. George, R. J. Small, and M. P. Heide-Jørgensen. 2010. Fall and winter movements of bowhead whales in the Chukchi Sea and within a potential petroleum development area. Arctic 63(3).

R Development Core Team. 2007. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org.

Richardson, W. J. (ed.). 1987. Importance of the Eastern Alaskan Beaufort Sea to Feeding Bowhead Whales, 1985-86. Report to the US Minerals Management Service by LGL Inc., NTIS No. PB88-150271. 547pp. [Available from: http://www.mms.gov].

Richardson, W. J., R. A. Davis, C. R. Evans, D. K. Ljungblad, and P. Norton, 1987. Summer distribution of bowhead whales, *Balaena mysticetus*, relative to oil industry activities in the Canadian Beaufort Sea, 1980-84. Arctic 40(2):93-104.

Richardson, W.J. (ed.). 1999. Marine mammal and acoustical monitoring of Western Geophysical's open-water seismic program in the Alaskan Beaufort Sea, 1998. LGL Rep. TA2230-3. Rep. from LGL Ltd., King City, Ont., and Greenridge Sciences Inc., Santa Barbara, CA, for Western Geophysical, Houston, TX, and National Marine Fisheries Service, Anchorage, AK., and Silver Spring, MD. 390 pp.

Richardson, W. J., and K. J. Finley. 1989. Comparison of behavior of bowhead whales of the Davis Strait and Bering/Beaufort stocks. Report for U. S. Minerals Management Service by LGL Ltd. NTIS No. PB89 195556/AS. 131pp.

SAS Institute. 2004. SAS/STAT Version 9.1. SAS Institute, Inc., Cary, NC.

Seaman, D.E., J. J. Millspaugh, B. J. Kernohan, G. C. Brundige, K. J. Raedeke, and R. A. Gitzen. 1999. Effects of sample size on kernel home range estimates. Journal of Wildlife Management 63:739–747.

Seaman, D.E., and R. A. Powell. 1996. An evaluation of the accuracy of kernel density estimators for home range analysis. Ecology 77:2075–2085.

Schell, D. M., and S. M. Saupe. 1993. Feeding and growth as indicated by stable isotopes. Pages 491–509 *in* The bowhead whale. J. J. Burns, J. J. Montague, and C. J. Cowles, eds. Special Publication No. 2, The Society for Marine Mammalogy, Lawrence, KS.

Schell, D. M., S. M. Saupe, and N. Haubenstock. 1989. Bowhead whale (*Balaena mysticetus*) growth and feeding as estimated by $\delta^{13}C$ techniques. Marine Biology (Berl.) 103:433-443.

Siegel. V. 2000. Krill (Euphausiacea) life history and aspects of population dynamics. Canadian Journal of Fisheries and Aquatic Sciences (Supplement 3):130–150.

Silverman, B.W. 1986. Density estimation for statistics and data analysis. Chapman and Hall, London, England.

Smith, W. H. F., and D. T. Sandwell. 1997. Global seafloor topography from satellite altimetry and ship depth soundings. Science 277:1957–1962.

Vincent, C., B. J. McConnell, V. Ridoux, and M. A. Fedak, M.A. 2002. Assessment of Argos location accuracy from satellite tags deployed on captive gray seals. Marine Mammal Science 18:156–166.

Wand, M., and M. Jones. 1995. Kernel smoothing. Chapman and Hall, London, England.

Worton, B.J. 1989. Kernel methods for estimating the utilization distribution in home-range studies. Ecology 70:164–168.

Zeh, J.E., C. W. Clark, J. C. George, D. Withrow, G. M. Carroll, and W. R. Koski. 1993. Current population size and dynamics. Pages 409–489 *in:* The bowhead whale. J.J. Burns, J.J. Montague, and C.J. Cowles, eds. Special Publication. No. 2. Society for Marine Mammalogy, Lawrence Kansas.

Appendix A. Chronological List of Project Publications, Reports, and Presentations

2005

AEWC, October 2005. Presented study plan, received approval.

2006

AEWC Update, March 2006.

AEWC Update, July 2006.

2007

Quakenbush, L. T., R. J. Small, J. J. Citta, J. C. George. 2007. Satellite tracking of western arctic bowhead whales. Alaska Marine Science Symposium, 21–24 January, Anchorage, AK. (Abstract and oral presentation) (Appendix B).

Quakenbush, L. 2007. Preliminary satellite telemetry results for Bering-Chukchi-Beaufort bowhead whales. Report to the Bowhead/ Right/Gray Whale Committee of the International Whaling Commission, Anchorage, Alaska. SC/59/BRG12 (Appendix C).

AEWC Update, 25 October 2007, Fairbanks.

Quakenbush, L. T., R. J. Small, J. J. Citta, J. C. George, L. Harwood, M.P. Heide-Jørgensen, and M. Jensen. 2007. Satellite tracking of western Arctic bowhead whales. ConocoPhillips Arctic Environmental Knowledge Sharing Seminar, 16–20 October, Kananaskis, Alberta, Canada. (Oral presentation)

Citta, J. J., L. T. Quakenbush, R. J. Small, and J. C. George. 2007. Movements of a tagged bowhead whale in the vicinity of a seismic survey in the Beaufort Sea. 17th Biennial Conference on the Biology of Marine Mammals, 29 November – 4 December 2007, Cape Town, South Africa. (Abstract and poster) (Appendix D).

Quakenbush, L. T., J. J. Citta, J. C. George, and R. J. Small. 2007. Satellite tracking of western arctic bowhead whales. 17th Biennial Conference on the Biology of Marine Mammals, 29 November – 4 December 2007, Cape Town, South Africa. (Abstract and poster) (Appendix E).

2008

Quakenbush, L. T., J. J. Citta, J. C. George, R. J. Small, and M.P. Heide-Jørgensen. 2008. Satellite tracking of the western Arctic stock of bowhead whales. Alaska Marine Science Symposium, 20–23 January, Anchorage, AK. (Abstract and poster) (Appendix F).

Project update to BOWFEST at Workshop at Alaska Marine Science Symposium, January 2008, Anchorage, AK.

AEWC Update, February 2008.

AEWC Update, July 2008 (Appendix G).

Quakenbush, L. R. Small, J. J. Citta, J.C. George, H. Brower, Jr., L. Harwood, and M.P. Heide-Jørgensen. 2008. Satellite tracking of the Western Arctic Stock of bowhead whales. MMS/ITM and O&G meetings, Anchorage. (Oral presentation).

2009

Quakenbush, L. T., J. J. Citta, J. C. George, R. J. Small, and M. P. Heide-Jørgensen.. 2009. Fall movements of bowhead whales in the Chukchi Sea. Alaska Marine Science Symposium, January 2009, Anchorage, AK. (Abstract, Poster) (Appendix H)

Project update to BOWFEST at Workshop at Alaska Marine Science Symposium, January 2009, Anchorage, AK.

Quakenbush, L. 2009. Satellite tracking bowhead whales. UAF Institute of Marine Science Seminar. January, Fairbanks. (Oral presentation).

Community and school presentations in Barrow, Kaktovik, and Wainwright. February 2009.

AEWC Update, July 2009, Fairbanks

AEWC Update, October 2009, Anchorage.

Quakenbush, L., H. Brower, Jr., J. J. Citta, M. P. Heide-Jørgensen, J. C. George, and R. Small. 2009. Some satellite telemetry results on BCB bowhead whales, 2006–2009. Report to the Bowhead/ Right/Gray Whale Committee of the International Whaling Commission, 22–25 June, Madeira, Portugal. (Appendix I).

Quakenbush, L., J. J. Citta, J. C. George, R. J. Small, and M. P. Heide-Jørgensen. 2009. Winter behavior of bowhead whales in the Bering Sea. 18^{th} Biennial Conference on the Biology of Marine Mammals, 12–16 October, Quebec, Canada. (Abstract, Oral Presentation) (Appendix J).

AEWC Update, October 2009, Barrow.

Huntington, H. P., and L. T. Quakenbush. 2009a. Traditional knowledge of bowhead whale migratory patterns near Kaktovik and Barrow, Alaska. Report to the Alaska Eskimo Whaling Commission and the Barrow and Kaktovik Whaling Captains. 14 pp. (Appendix K).

Huntington, H. P., and L. T. Quakenbush. 2009b. Traditional knowledge of bowhead whale migratory patterns near Wainwright, Alaska. Report to the Alaska Eskimo Whaling Commission and the Wainwright Whaling Captains. 9 pp. (Appendix L).

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Quakenbush, L., J. J. Citta, J. C. George, R. J. Small, M. P. Heide-Jørgensen, Lois Harwood, and Harry Brower, Jr. 2010. Western Arctic bowhead whale movements and habitat use throughout their migratory range: 2006–2009 satellite telemetry results. Alaska Marine Science Symposium, 18–22 January, Anchorage, AK (Appendix M).

Project update to BOWFEST at Workshop at Alaska Marine Science Symposium, January 2010, Anchorage, AK.

AEWC Update, February 2010, Barrow.

Quakenbush, L. T. 2010. State of Alaska, Arctic Marine Mammal Program Projects (Bowheads, Belugas and Ice Seals). Presentation to NMFS Open water meeting. Anchorage. (Oral presentation).

Quakenbush, L. T., J. J. Citta, J. C. George, R. J. Small, and M. P. Heide-Jørgensen. 2010. Fall and winter movements of bowhead whales in the Chukchi Sea and within a potential petroleum development area. Arctic 63(3).

Quakenbush, L. T., J. J. Citta, J.C. George, R. J. Small, M.P. Heide-Jørgensen. *In prep*. Winter movements and dive behavior of bowhead whales in the Bering Sea.

Weekly maps and updates sent to extensive e-mail list (>250) of whalers, agency, industry and other interested individuals prior to being posted on the website.

Website for project: http://www.wildlife.alaska.gov/index.cfm?adfg=marinemammals.bowhead

Appendix B. Quakenbush, L. T., R. J. Small, J. J. Citta, J. C. George. 2007. Satellite tracking of western arctic bowhead whales. Alaska Marine Science Symposium, 21–24 January, Anchorage, AK. (Abstract)

Satellite Tracking of Western Arctic Bowhead Whales

Quakenbush, Lori T.[1]; Small, Robert J.[1]; Citta, John J.[1]; and George, John C.[2]
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The western Arctic stock of bowhead whales (*Balaena mysticetus*) are of high importance due to their nutritional and cultural role in Alaska Native subsistence lifestyle, their role in the marine ecosystem, and because their summer range overlaps areas with the potential for oil and gas development. Movement patterns and feeding areas of this stock of bowhead whales, however, are not well understood in some regions. Increasing our understanding of bowhead whale behavior will aid in planning and resource conservation. This study will attempt to attach up to 25 satellite transmitters to bowhead whales each year for the next five years. The study was designed cooperatively with subsistence whalers and with local, state, and federal agencies. Alaska Native subsistence whalers have been important in the field component of this project during tagging efforts. Six Barrow whalers have been trained to deploy tags, which will greatly expand our opportunities for tagging. Two transmitters are reporting locations and one whale has been tracked over 2,500 km from Barrow east to Amundsen Gulf, Canada and then west beyond Barrow into the Chukchi Sea. As of 1 November 2006 both whales were near the northern coast of Chukotka, west of 179 degrees W longitude. Several areas appear to have been used for feeding based on movement patterns and residence times. We will report the most recent movements of the tagged whales in our presentation.

Appendix C. Quakenbush, L. 2007. Preliminary satellite telemetry results for Bering-Chukchi Beaufort bowhead whales. Report to the Bowhead/ Right/Gray Whale Committee of the International Whaling Commission, Anchorage, Alaska. SC/59/BRG12

SC/59/BRG12

Preliminary Satellite Telemetry Results for Bering-Chukchi-Beaufort Bowhead Whales

LORI QUAKENBUSH
Alaska Department of Fish and Game, Fairbanks, AK

INTRODUCTION

The Alaska Department of Fish and Game (ADF&G) has begun a cooperative project (with the AEWC and the NSB and funded by the US Minerals Management Service (MMS) to study bowhead whale movements and behavior using satellite telemetry.

METHODS

Two satellite transmitters designed by M.P. Heide-Jorgensen were placed on bowhead whales near Barrow, Alaska in 2006. One was deployed in May and a second in September 2006.

RESULTS AND DISCUSSION

A approximately 13.7 m (45 ft) male bowhead (#60010) was tagged on 12 May near Barrow and behaved in a manner consistent with our understanding of bowhead migratory behavior based on aerial and ship-based surveys, and harvest monitoring (Moore and Reeves, 1993). The whale travelled directly across the Beaufort Sea and arrived in Amundsen Gulf (east of 127° W Longitude) in early June and stayed there until early August when he travelled directly to the northwest end of Banks Island and back. While unexpected, this behavior is not unprecedented. This whale began his westward migration in early October when he moved rapidly across the Alaskan Beaufort Sea to arrive at Barrow on 14 October (Figure 1).

Another whale (#60009), tagged near Barrow on 21 September gave fewer locations but showed that both whales occurred together along the northern Chukotka coast in November (Figure 1).

The movements of the two whales described here are consistent with published literature regarding migratory behavior (Moore *et al.* 1995, Mate *et al*. 2000; Moore and Reeves, 1993). However, important new information on swimming speeds, probable feeding areas, precise migratory routes and migration timing are provided by these data (ADFG, unpublished data).

ACKNOWLEDGEMENTS

This project would not be possible without the following cooperators: the North Slope Borough, the Alaska Eskimo Whaling Commission, the Barrow and Kaktovik Whaling Captains' Associations, and the Greenland Institute of Natural Resources, who developed and deployed the transmitters. This is a 5-year study funded by the Minerals Management Service.

REFERENCES

Moore, S.E. and Reeves, R.R. 1993. Distribution and movement. In: J.J. Burns, J.J. Montague and Cowles, C.J. (eds.) The Bowhead Whale. Special publication No. 2 of the Society for Marine Mammalogy. 787 pp.

Mate, B.R., Krutzikowsky, G.K., Winsor, M.H. 2000. Satellite-monitored movements of radio-tagged bowhead whales in the Beaufort and Chukchi seas during the late-summer feeding season and fall migration Can J. Zool. 78 1168-1181.

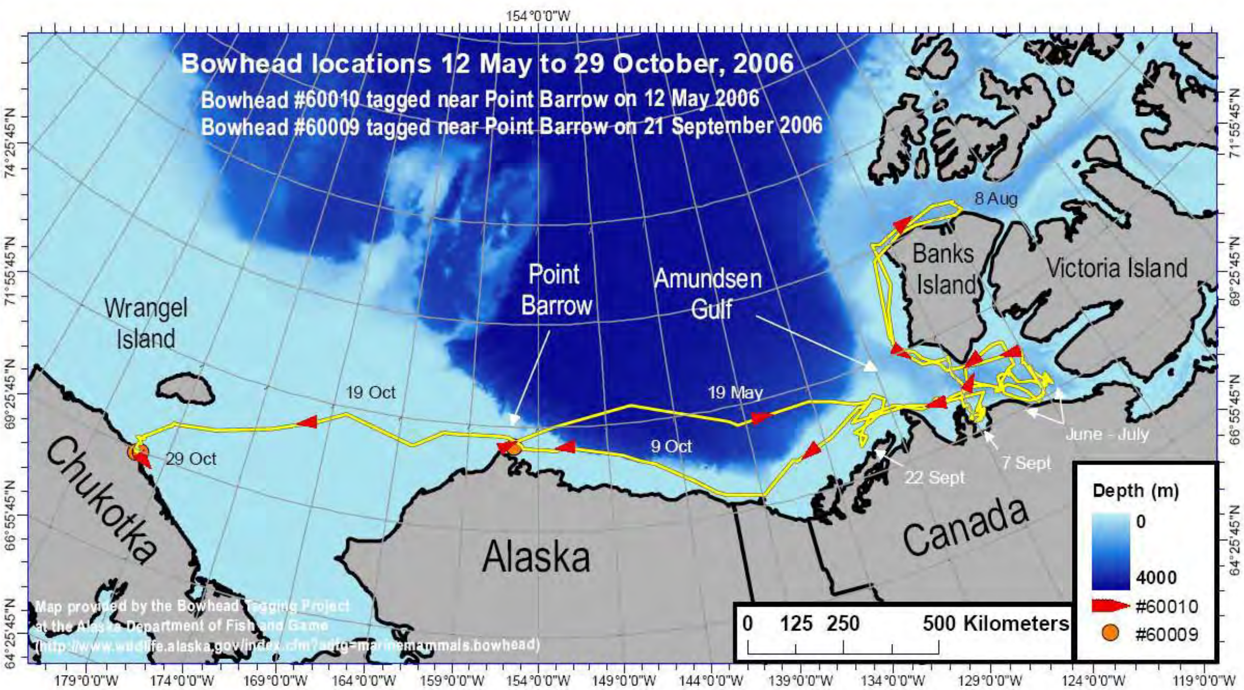

Figure1. Bowhead locations 12 May to 29 October 2006 from satellite telemetry. Arrows show track for whale 60010. The tag for whale 60009 only transmitted intermittently at Barrow and several weeks later along the Chukotka coast.

Appendix D. Citta, J. J., L. T. Quakenbush, R. J. Small, and J. C. George. 2007. Movements of a tagged bowhead whale in the vicinity of a seismic survey in the Beaufort Sea. 17th Biennial Conference on the Biology of Marine Mammals, 29 November – 4 December 2007, Cape Town, South Africa. (Abstract and poster)

ABSTRACT: The western Arctic stock of bowhead whales (*Balaena mysticetus*) is critical for the nutritional and cultural health of Alaska Natives and it is important in the marine ecosystem as a consumer of zooplankton. Most bowheads winter in the Bering Sea and summer in the eastern Beaufort Sea where they are vulnerable to possible effects from oil and gas exploration, development, and production. Marine seismic surveys are commonly used during oil and gas exploration and have the potential to disrupt bowhead communication, feeding, and migration. Such surveys often include mitigation measures intended to minimize potential effects of seismic activity on marine mammals; however, the efficacy of such measures is unknown. In 2006, we documented movements of a satellite-tagged bowhead whale in the vicinity of an active seismic survey, north of the Mackenzie River Delta, Canada. We examined how the whale's velocity, turn angle relative to the seismic ship, and the dispersion in turn angles were related to distance from the seismic ship. We found no statistical relationship between whale behavior and distance from the seismic ship and suspect this is largely due to the ship shutting down seismic operations when the whale came closest. On 19 September, when the whale was closest (9.2 km) to the ship, the whale deviated course. Marine observers aboard the ship then halted the survey and shutdown the airguns in response to sighting other closer bowhead whales, during which time the satellite-tagged whale crossed the projected path of the seismic ship.

Movements of a Tagged Bowhead Whale in the Vicinity of a Seismic Survey in the Beaufort Sea

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ABSTRACT: The western Arctic stock of bowhead whales (*Balaena mysticetus*) is critical for the nutritional and cultural health of Alaska Natives and it is important in the marine ecosystem as a consumer of zooplankton. Most bowheads winter in the Bering Sea and summer in the eastern Beaufort Sea where they are vulnerable to possible effects from oil and gas exploration, development, and production. Marine seismic surveys are commonly used during oil and gas exploration and have the potential to disrupt bowhead communication, feeding, and migration. Such surveys often include mitigation measures intended to minimize potential effects of seismic activity on marine mammals; however, the efficacy of such measures is unknown. In 2006, we documented movements of a satellite-tagged bowhead whale in the vicinity of an active seismic survey, north of the Mackenzie River Delta, Canada. We examined how the whale's velocity, turn angle relative to the seismic ship, and the dispersion in turn angles were related to distance from the seismic ship. We found no statistical relationship between whale behavior and distance from the seismic ship and suspect this is largely due to the ship shutting down seismic operations when the whale came closest. On 19 September, when the whale was closest (9.2 km) to the ship, the whale deviated course. Marine observers aboard the ship then halted the survey and shutdown the airguns in response to sighting other closer bowhead whales, during which time the satellite-tagged whale crossed the projected path of the seismic ship.

INTRODUCTION: In September of 2006, a satellite-tagged bowhead whale was in the vicinity of a 2D seismic operation for 17 days (Fig. 1). The survey was conducted by GX Technology Corporation using the *M/V Discoverer*, a 72 m Ice Class C vessel towing a 40 airgun array, of which a maximum of 36 airguns were firing (total discharge volume of 3,220 cubic inches). On this survey, specific mitigation measures included: 1) shutting down airguns when bowhead whales were observed within designated safety zones (~ 1 km where noise levels were predicted to be > 180 dB) and 2) following shutdowns, activating one airgun at a time to allow whales to move away as the sound levels increased slowly (Harris et al. 2007). The purpose of this project was to examine how whale behavior varied as a function of distance from the seismic ship.

METHODS: To remove unlikely whale locations from the dataset, we filtered locations using the speed filter described by MacConnell et al. (1992) with a velocity threshold of 5.9 m/s, the maximum speed Richardson and Finley (1989) observed a bowhead whale fleeing a ship. For each whale location, we calculated distance to the seismic ship, the whale's velocity approaching the nearest location to the ship ($v_{1,2}$), the whale's velocity leaving the nearest location to the ship ($v_{2,3}$), and the whale's change in direction (θ_2) relative to the ship's location (Fig. 2). We predicted that the whale would turn away from the ship and its velocity would increase as the ship came closer to the whale. If whale movement was random, when the whale was far from the ship we expected the distribution of turn angles to be uniform with high dispersion. As the ship approached the whale, we expected the distribution of turn angles to have a mean near 180^o and a low amount of dispersion, indicating that the whale's movements were consistent with attempts to move away from the ship. We split the data into four distance categories: 1) $\leq$ 25 km; 2) 26 to 50 km; 3) 51 to 100 km; 4) > 100 km. Because the whale was located few times in close proximity to the ship, we relied on non-parametric comparisons. To compare whale velocity in the four distance categories we used a Kruskal-Wallis test in SAS 9.1 (SAS Institute 2004) using PROC NPAR1WAY. To determine if the distribution of turning angles changed in mean direction or dispersion between distance categories, we used Rao's Test for Homogeneity (Jammalamadaka and SenGupta 2001) in package CircStats in R (R Development Core Team 2007).

The M/V Discoverer towing a seismic array.

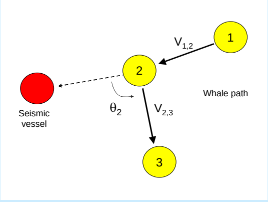

Figure 2. Example of velocity and angular statistics calculated for whale location number 2.

REFERENCES:

Harris, R. E., T. Elliot, and R. A. Davis. 2007. Results of mitigation and monitoring program, Beaufort Span 2-D marine seismic program. LGL Ltd. LGL Project TA4319-1.

Jammalamadaka, S. Rao and A. SenGupta. 2001. Topics in circular statistics. World Scientific Publishing Company Pte. Ltd., Singapore.

McConnell, B. J., C. Chambers, and M. A. Fedak. 1992. Foraging ecology of southern elephant seals in relation to the bathymetry and productivity of the Southern Ocean. Antarctic Science 4:393-398.

R Development Core Team. 2007. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org.

Richardson, W.J. (ed.) 1999. Marine mammal and acoustical monitoring of Western Geophysical's open-water seismic program in the Alaskan Beaufort Sea, 1998. LGL Rep. TA2230-3. Rep. from LGL Ltd., King City, Ont., and Greenridge Sciences Inc., Santa Barbara, CA, for Western Geophysical, Huston, TX, and Nat. Mar. Fish. Serv. , Anchorage, AK., and Silver Spring, MD.

Richardson, W. J., and K. J. Finley. 1989. Comparison of behavior of bowhead whales of the Davis Strait and Bering/Beaufort stocks. Report for U. S. Minerals Management Service by LGL Ltd. NTIS No. PB89 195556/AS. 131pp.

SAS Institute. 2004. SAS/STAT Version 9.1. SAS Institute, Inc., Cary, NC.

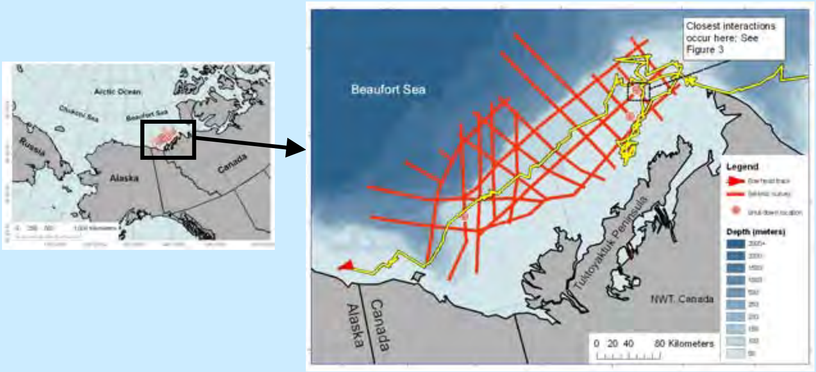

Figure 1. Overlay of the bowhead whale and seismic survey tracks.

RESULTS: The whale was located 160 times during the seismic survey. The minimum distance between the whale and the seismic ship was 9.2 km. The whale was located eight times in the first distance category ($\leq$25 km), 10 times in the second category (26 to 50 km), 10 times in the third category (51 to 100 km), and 132 times in the fourth category (> 100 km). Neither metric of whale velocity differed by distance category (p=0.67 for $v_{1,2}$; p=0.85 for $v_{2,3}$) and the distance categories did not differ in either their mean direction (p=0.16) nor dispersion (p=0.52).

We found visual evidence, however, that the whale avoided the seismic ship on 19 September. On this day, marine mammal observers on the ship sighted a mother-calf pair of bowhead whales ~ 500 m from the ship; consequently the airguns were shut-down and the survey was halted for ~ 3.5 hours. The whale maintained a distance of ~ 9.2 km from the ship and then crossed in front of the ship during the shut-down (Fig. 3). Animations of the whale and the seismic survey can be viewed at: ftp://ftpr3.adfg.state.ak.us/JCitta/.

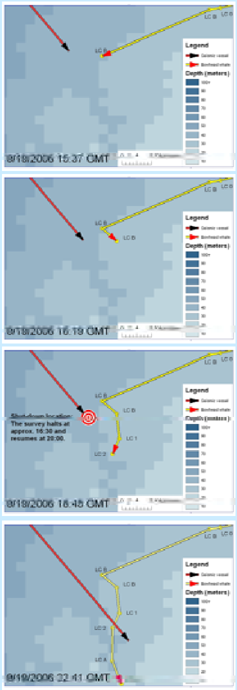

Figure 3. Sequential maps depicting the closest interaction between the whale and the seismic survey.

DISCUSSION: This is the first documented interaction between a satellite-tagged bowhead whale and a seismic ship. We found evidence that this whale maintained a minimum distance of 9.2 km from the seismic ship, which is a much greater distance than the designated 1 km 'safety zone' used to trigger shut-downs. However, this is considerably less than the 20 km deflections noted for migrating bowheads in the mid-Beaufort Sea (Richardson 1999). Based upon our statistical analyses, it does not appear the seismic survey affected overall whale behavior, as the whale remained in the area after the seismic survey ended, presumably feeding, and then migrated into the Chukchi Sea, off the coast of Chukotka, Russia. Hence, we conclude that the seismic operation did not permanently disrupt the feeding or migratory behavior of this whale.

ACKNOWLEDGEMENTS: Cooperators include the Alaska Department of Fish and Game, the North Slope Borough, the Alaska Eskimo Whaling Commission, the Barrow and Kaktovik Whaling Captains Association, the Greenland Institute of Natural Resources, the Aklavik Hunters and Trappers Committee, and the Department of Fisheries and Oceans Canada. Information on the seismic survey was provided by, GX Technology. This project is funded by the U.S. Department of the Interior, Minerals Management Service. Bowhead tagging was conducted under NFMS permit number 782-1719-04.

Appendix E. Quakenbush, L. T., J. J. Citta, J. C. George, and R. J. Small. 2007. Satellite tracking of western arctic bowhead whales. 17th Biennial Conference on the Biology of Marine Mammals, 29 November – 4 December 2007, Cape Town, South Africa. (Abstract and poster)

ABSTRACT: The western Arctic stock of bowhead whales (*Balaena mysticetus*) has been the focus of considerable research because they: 1) are critical to the nutritional and cultural health of Alaska Natives, 2) likely play a significant role as zooplankton grazers in the ecosystems of the Bering, Chukchi and Beaufort seas, and 3) are vulnerable to possible effects from oil and gas exploration, development, and production in their summer range. General movements are known from aerial surveys and from the timing of whaling in coastal villages, yet knowledge of movements during migration relative to bathymetry and ice cover is limited. Working with other researchers and subsistence whalers we have attached satellite transmitters to bowhead whales and during the 2006 spring and fall migratory periods we tracked a 45-foot (13.7 m) male bowhead over 2,500 km, from Point Barrow, Alaska, to Amundsen Gulf, Canada, and then to Chukotka, Russia. During the spring migration, between Point Barrow and Amundsen Gulf, this whale passed through seas with 90-100% sea ice cover. Using raw ARGOS location data and Bayesian state-space modeling, we interpolated whale locations and classified movements as migration (high speed and small turning angles), foraging (low speed and large turning angles), and a mixture of migration and foraging (low speed and small turning angles). Two other whales tagged at Barrow were also tracked to the Chukotka coast in fall. These data indicate that some bowhead whales are probably feeding in Amundsen Gulf, along the coast of Chukotka, and also near Point Barrow.

Satellite Tracking of Western Arctic Bowhead Whales

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INTRODUCTION: Knowledge of movements and feeding patterns of the western Arctic stock of bowhead whales are limited. Bowhead whales are known to winter somewhere in the Bering Sea and migrate through the Chukchi and Beaufort seas in spring, presumably to feed in the eastern Beaufort before returning to the Bering Sea in late fall. It is not known if bowhead whales feed in wintering areas or if other important feeding areas exist. Because activities related to oil and gas exploration and development are increasing in the Chukchi and Beaufort seas, effective management requires a better understanding of which habitats are important for bowhead whales and where migration corridors are located. The purpose of this project is to use satellite telemetry to identify feeding areas and migration corridors.

METHODS: Bowhead whales were tagged with satellite transmitters manufactured by Wildlife Computers and adapted and deployed using an airgun or pole developed by Mads Peter Heide-Jorgensen and Mikkel Jensen. Location data were collected using the ARGOS system (Harris et al. 1990). Location qualities provided by ARGOS included B, A, 0, 1, 2, and 3 with 3 representing the highest quality and most accurate position. To determine which locations to use for analyses we used Bayesian state-space models to estimate the true locations (Jonsen 2005). In effect, the true location is treated as an unknown variable and can be statistically estimated. This technique has the advantage of being able to use all locations and the resulting track is generally more accurate than what filtering methods provide. Where possible, we also used Jonsen's (2005) model to estimate the state-space of the whale. States included movements consistent with feeding, migration, or intermediate state (i.e., likely a mixture of feeding and migration). For sea ice data we used Moderate-resolution Imaging Spectroradiometer (MODIS) imagery available through the National Snow and Ice Data Center.

Figure 1. Track of bowhead whale #60010 during eastward spring migration through 90-100% sea ice cover.

Figure 2. Entire track of bowhead whale #60010 showing migration route and feeding areas.

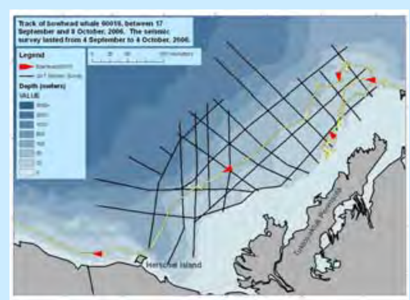

Figure 3. Map of seismic survey lines and track of feeding bowhead in Canada near Tuktoyaktuk.

Figure 4. Tracks and locations of three bowhead whales (#s 60010, 60009, and 42522) in fall showing routes across to Russia and feeding areas along the Chukotka Peninsula.

RESULTS: Bowhead #60010 was tagged near Barrow on 12 May 2006 and arrived in ice-covered Amundsen Gulf, Canada, 14 days later, **(Fig. 1)**. A major east-west lead system visible from ice imagery was not used as a migration route and the whale traveled northeast beyond the lead to ~72 degrees North latitude before turning east to travel 1,100 km at ~78 km/day through 90–100% ice cover.

The whale remained in Amundsen Gulf for 68 days where its low swim speed and large turning angles indicated that he was likely feeding (**Fig. 2**). High swim speeds and small turning angles indicate that this whale transitioned into a 'migratory state' and traveled to the north end of Banks Island and returned (**Fig. 2**). This whale left Amundsen Gulf on 15 September and spent 17 days in the vicinity of a 2D seismic operation near Tuktoyaktuk, Canada (**Fig. 3**; see Citta et al. poster, this session) prior to migrating westward on 3 October. The whale passed Point Barrow 11 days later on 14 October, after covering 1,191 km in 270 hours. Although the whale averaged 4.41 km/hr during this time, the maximum sustained speed was 10.9 km/hr between Kaktovik and Barrow, which was probably assisted by the westerly current along the Beaufort Shelf. After leaving Barrow this whale crossed the Chukchi Sea at approximately latitude 71 ° N and spent time along the Chukotka coast near Vankarem before following the coast southward.

Two other whales tagged while feeding near Barrow in the fall also spent time along the Chukotka coast (**Fig. 4**).

CONCLUSIONS:

1) Bowhead whales can migrate 78 km/day through 90–100% ice cover and do not appear to require major lead systems.

2) Likely feeding areas include Amundsen Gulf and Tuktoyaktuk in Canada, Barrow in Alaska, and the northern coastline of the Chukotka Peninsula in Russia.

Other maps and information about this project can be viewed at:
http://www.wildlife.alaska.gov/index.cfm?adfg=marinemammals.bowhead.

ACKNOWLEDGEMENTS: Cooperators include Alaska Department of Fish and Game, North Slope Borough, Alaska Eskimo Whaling Commission, Barrow and Kaktovik Whaling Captain's Associations, Greenland Institute of Natural Resources, Department of Fisheries and Oceans Canada, and the Aklavik Hunters and Trappers Committee. Special thanks to taggers Mikkel Jensen, Harry Brower, Lewis Brower, George Tagarook, and Eddie Arey. This project is funded by the U.S. Dept. of Interior, Minerals Management Service. Bowhead tagging was conducted under NFMS permit number 782-1719-04.

REFERENCES:

Harris, R. B., S. G. Fancy, D. C. Douglas, G. W. Garner, S. C. Amstrup, T. R. McCabe, and L. F. Pank. 1990. Tracking wildlife by satellite: Current systems and performance. U.S. Department of the Interior, Fish and Wildlife Service, Fish and Wildlife Technical Report No. 30. 52 pp.
Jonsen, I. D. 2005. Robust state-space modeling of animal movement data. Ecology 86:2874-2880.

Appendix F. Quakenbush, L. T., J. J. Citta, J. C. George, R. J. Small, and M.P. Heide-Jørgensen. 2008. Satellite tracking of the western Arctic stock of bowhead whales. Alaska Marine Science Symposium, 20–23 January, Anchorage, AK. (Abstract and poster)

Satellite Tracking of the Western Arctic Stock of Bowhead Whales

Bowhead whales (*Balaena mysticetus*) from the western Arctic stock have been the focus of considerable research because they: 1) are critical to the nutritional and cultural health of Alaska Natives, 2) likely play a significant role as zooplankton grazers in the Bering, Chukchi and Beaufort seas, and 3) are vulnerable to possible effects of oil and gas activities during migration and in their summer range. General movements are known from aerial surveys and from the timing of whaling in coastal villages, yet knowledge of movements during migration relative to bathymetry, ice cover, and where important feeding areas are is limited. Working with other researchers and subsistence whalers we have attached satellite transmitters to bowhead whales. During the 2006 spring and fall migratory periods we tracked a 45-foot (13.7 m) male bowhead (#60010) over 2,500 km, from Point Barrow, Alaska, to Amundsen Gulf, Canada, and then to Chukotka, Russia. Two other whales tagged at Barrow were also tracked to the Chukotka coast in fall. These data indicate that Amundsen Gulf, Chukotka, and Point Barrow may be important feeding areas. During the spring migration, between Point Barrow and Amundsen Gulf, #60010 passed through seas with 90–100% sea ice cover. Using raw ARGOS location data and Bayesian state-space modeling along with swim speed and turn angles, we interpolated whale locations and classified movements as being associated with migration, foraging, or a mixture of migration and foraging behaviors. We also documented the movements of this whale during an active seismic survey, north of the Mackenzie River Delta, Canada. As the ship and the whale converged, the whale deviated course and maintained a minimum of 9.2 km from the ship. We examined how the whale's velocity, turn angle relative to the seismic ship, and the dispersion in turn angles were related to distance from the seismic ship. We found no statistical relationship between whale behavior and distance from the seismic ship and suspect this is largely due to the ship shutting down seismic operations when the whale came closest.

Satellite Tracking of the Western Arctic Stock of Bowhead Whales

Lori T. Quakenbush[1], John J. Citta[1], John C. George[2], Robert J. Small[1], Mads Peter Heide-Jørgensen[3]

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INTRODUCTION: The western Arctic stock of Bowhead whales is known to winter somewhere in the Bering Sea and migrate through the Chukchi and Beaufort seas in spring, presumably to feed in the eastern Beaufort before returning to the Bering Sea in late fall. It is not known if bowhead whales feed in wintering areas or if other important feeding areas exist. Because activities related to oil and gas exploration and development are increasing in the Chukchi and Beaufort seas, effective management requires a better understanding of which habitats are important for bowhead whales and where migration corridors are located. The purpose of this project is to use satellite telemetry to identify feeding areas and migration corridors.

Figure 1. Track of bowhead whale #60010 during eastward spring migration through 90-100% sea ice cover.

Figure 2. Entire track of bowhead whale #60010 showing migration route and feeding areas.

METHODS: Bowhead whales were **tagged** with satellite transmitters manufactured by Wildlife Computers as described by (Heide-Jørgensen et al. 2001). Location data were collected using the ARGOS system (Harris et al. 1990). We used Bayesian state-space models to estimate the true locations and the state-space (i.e., feeding, migration, or an intermediate state) (Jonsen 2005). For **sea ice data** we used Moderate-resolution Imaging Spectroradiometer (MODIS) imagery available through the National Snow and Ice Data Center. For analysis of whale **movements relative to the seismic ship**, we filtered the data by speed (MacConnell et al. 1992) using a maximum speed of 5.9 m/s reported by Richardson and Finley (1989) for a bowhead fleeing a ship. For each whale location, we calculated distance to the seismic ship, the whale's velocity approaching the nearest location to the ship ($v_{1,2}$), the whale's velocity leaving the nearest location to the ship ($v_{2,3}$), and the whale's change in direction (θ_2) relative to the ship's location (**Fig. 3a**). If whale movement was random, when the whale was far from the ship we expected the distribution of turn angles to be uniform with high dispersion. As the ship approached the whale, we expected the distribution of turn angles to have a mean near 180° and a low amount of dispersion, indicating that the whale's movements were consistent with attempts to move away from the ship. We split the data into four distance categories: 1) $\leq$ 25 km; 2) 26 to 50 km; 3) 51 to 100 km; 4) > 100 km. Because the whale was located few times in close proximity to the ship, we relied on non-parametric comparisons. To compare whale velocity in the four distance categories we used a Kruskal-Wallis test in SAS 9.1 (SAS Institute 2004) using PROC NPAR1WAY. To determine if the distribution of turning angles changed in mean direction or dispersion between distance categories, we used Rao's Test for Homogeneity (Jammalamadaka and SenGupta 2001) in package CircStats in R (R Development Core Team 2007).

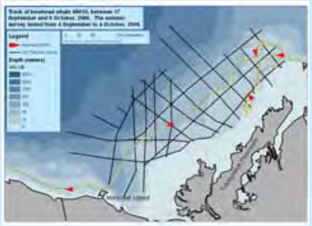

Figure 3. Area of inset in Fig. 2. Map of seismic survey lines and track of feeding bowhead in Canada near Tuktoyaktuk.

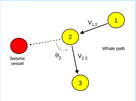

Figure 3a. Example of velocity and angular statistics calculated for whale location #2.

A

B

C

D

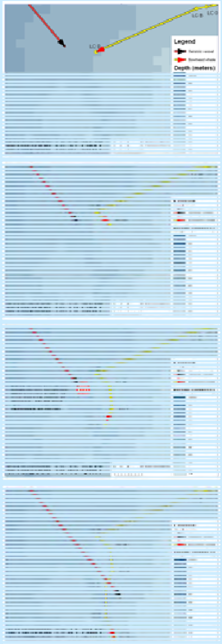

Figure 3b. Sequential maps depicting the closest interaction between the whale and the seismic survey.

Figure 4. Tracks and locations of three bowhead whales (#s 60010, 60009, and 42522) in fall showing routes across to Russia and feeding areas along the Chukotka Peninsula.

RESULTS: Bowhead #60010 was tagged near Barrow on 12 May 2006 and arrived in Amundsen Gulf, Canada, 14 days later **(Fig. 1)**. A major east-west lead system visible from ice imagery (**Fig. 1**) was not used as a migration route and the whale traveled northeast beyond the lead to ~72 degrees North latitude before turning east to travel 1,100 km at ~78 km/day through 90–100% ice cover.

The whale remained in Amundsen Gulf for 68 days where its low swim speed and large turning angles indicated that he was likely feeding (**Fig. 2**). High swim speeds and small turning angles indicate that this whale transitioned into a 'migratory state' and traveled to the north end of Banks Island and returned (**Fig. 2**).

This whale left Amundsen Gulf on 15 September and spent 17 days in the vicinity of a 2D seismic operation near Tuktoyaktuk, Canada (**Fig. 3**) prior to migrating westward on 3 October. The whale was located 160 times during the seismic survey. The minimum distance between the whale and the seismic ship was 9.2 km (**Fig. 3b**). The whale was located eight times in the first distance category ($\leq$25 km), 10 times in the second category (26 to 50 km), 10 times in the third category (51 to 100 km), and 132 times in the fourth category (> 100 km). Neither metric of whale velocity differed by distance category (p=0.67 for v1,2; p=0.85 for v2,3) and the distance categories did not differ in either their mean direction (p=0.16) nor dispersion (p=0.52).

We found visual evidence, however, that the whale avoided the seismic ship on 19 September. On this day, marine mammal observers on the ship sighted a mother-calf pair of bowhead whales ~ 500 m from the ship; consequently the airguns were shut-down and the survey was halted for ~ 3.5 hours. The whale maintained a distance of ~ 9.2 km from the ship and then crossed in front of the ship during the shut-down (**Fig. 3b**). Animations of the whale and the seismic survey can be viewed at: ftp://ftpr3.adfg.state.ak.us/JCitta/.

The whale passed Point Barrow 11 days after leaving Tuktoyaktuk on 14 October. After leaving Barrow this whale crossed the Chukchi Sea at approximately latitude 71 ° N and spent time along the Chukotka coast near Vankarem before following the coast southward.

Two other whales tagged while feeding near Barrow in the fall also spent time along the Chukotka coast (**Fig. 4**) indicating that this area may be an important fall feeding area.

CONCLUSIONS:

1) Bowhead whales can migrate 78 km/day through 90–100% ice cover and do not appear to require major lead systems.
2) Feeding bowhead whales may be found in the vicinity of active marine seismic operations.
3) Likely feeding areas include Amundsen Gulf and Tuktoyaktuk in Canada, Barrow in Alaska, and the northern coastline of the Chukotka Peninsula in Russia.

ACKNOWLEDGEMENTS: Cooperators include Alaska Department of Fish and Game, North Slope Borough, Alaska Eskimo Whaling Commission, Barrow and Kaktovik Whaling Captain's Associations, Greenland Institute of Natural Resources, Department of Fisheries and Oceans Canada, and the Aklavik Hunters and Trappers Committee. Special thanks to taggers Mikkel Jensen, Harry Brower, Lewis Brower, George Tagarook, and Eddie Arey. Information on the seismic survey was provided by GX Technology. This project is funded by the U.S. Dept. of Interior, Minerals Management Service. Bowhead tagging was conducted under NFMS permit number 782-1719-04.

References are available on request. More about this project can be found at: http://www.wildlife.alaska.gov/index.cfm?adfg= marinemammals.bowhead.

Appendix G. Handout prepared for AEWC, July 2008 Meeting in Fairbanks.

Satellite Tracking of Bowhead Whales
Project Update to AEWC – 16 July 2008

Accomplished – Seven tags have been deployed near Barrow (3 in spring and 4 in fall). Six of seven tags have been deployed by whalers (Harry Brower, Jr. and Lewis Brower). Five tags have been deployed in Canada. Three of those five were tagged by whalers (George Tagarook and Eddie Arey).

Traditional Knowledge Interviews with whaling captains and crew members have been completed in Kaktovik, Barrow, and Wainwright. We need approval of the TK report from the Whaling Captains Associations of Barrow and Kaktovik and from the AEWC before we share it with others. We are working on a map for the Wainwright report and then it will be reviewed by the whalers that were interviewed.

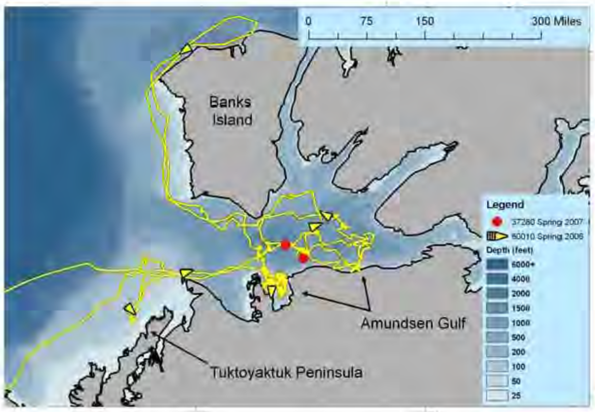

Figure 1. Areas important for bowheads in the spring and summer include Amundsen Gulf and the Tuktoyaktuk Peninsula.

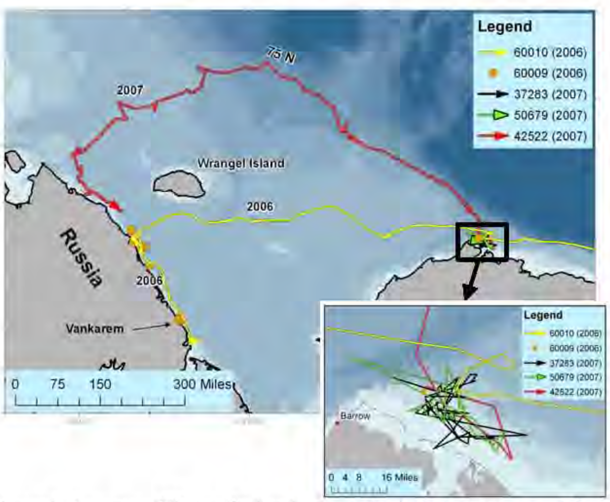

Figure 2. Important fall area for bowhead whales includes Barrow and the Russian coast.

What we are finding – So far, Amundsen Gulf and the area north of the Tuktoyaktuk Peninsula appear to be important in the spring and summer (Fig. 1). In the fall, the nearshore areas of Barrow and the Russian coast between Wrangel Island and Vankarem appear to be important (Fig. 2). Near Barrow, three whales with tags capable of measuring dive depth spent the majority of time between 30 and 65 feet below the surface, presumably feeding. This was at or very near the bottom. Near the Russian coast, one whale spent the majority of time between 65 and 165 feet, which was at or near the bottom approximately half of the time.

In 2006, we observed a whale passing through an active seismic survey (Fig. 3). This whale came within 5.7 miles of the seismic ship, at which point it deflected (Fig. 4). The ship shut-down the survey when they observed other whales nearby. During this shut-down, the tagged whale swam around the ship and then continued to spend time in the area.

Coming up – The Canadians are conducting aerial surveys again this August offshore of the Mackenzie Delta and in Amundsen Gulf to document feeding concentrations of bowheads so that feeding areas can be better protected during seismic operations. This year we will be tagging northeast of Tuktoyaktuk with hunters from the Tuktoyaktuk Hunters and Trappers Committee, Canadian and Alaskan biologists, hunters from Aklavik, and George Tagarook from Kaktovik. We hope to find another Alaskan whaler to be part of this tagging crew. We plan to tag up to 10 bowheads during the first half of August to obtain information on their activity in the Canadian Beaufort and then during their westward migration.

Because we have had more tag failure than expected we have expanded our procedure to test and monitor tag performance. In the past we relied on the saltwater switch to turn the tag on. We will now manually activate the tags and test battery strength and performance in the field before the tags are deployed.

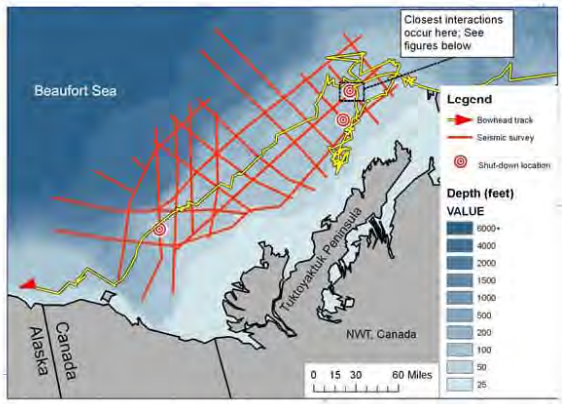

Figure 3. Map of seismic survey area and bowhead whale track in 2006.

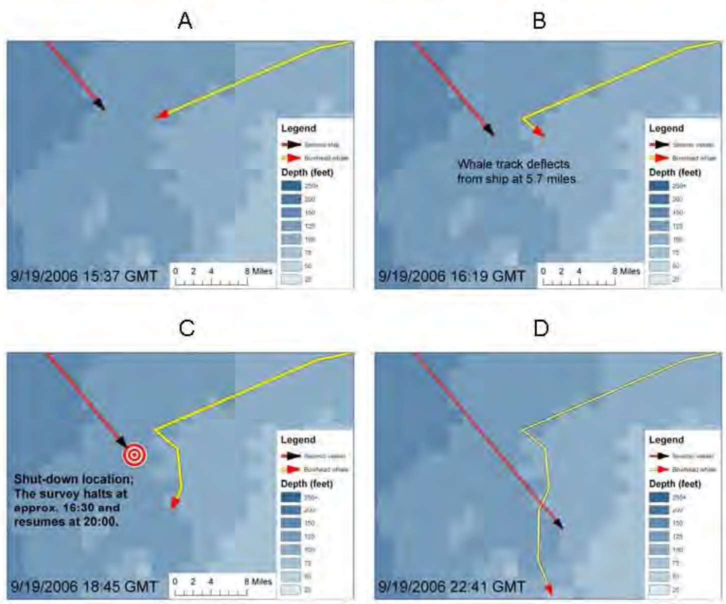

Figure 4. Detail of the closest interaction between bowhead #60010 and the seismic vessel. The whale deflects from the ship when 5.7 miles away and then skirts the ship after the survey is shut down. The survey was shut-down when whales closer to the ship were sighted by ship-board observers.

Website – We post maps and information about the tagged whales on the Alaska Department of Fish and Game: http://www.wildlife.alaska.gov/index.cfm?adfg=marinemammals.bowhead

Contacts – Lori Quakenbush, 459-7214, e-mail: lori.quakenbush@alaska.gov; Craig George, 852-0350, e-mail: craig.george@north-slope.org.

Appendix H. Quakenbush, L. T., J. J. Citta, J. C. George, R. J. Small, and M. P. Heide-Jørgensen. 2009. Fall movements of bowhead whales in the Chukchi Sea. Alaska Marine Science Symposium, 19–23 January 2009, Anchorage, AK. (Abstract, oral presentation)

Fall Movements of Bowhead Whales in the Chukchi Sea

Lori T. Quakenbush, John J. Citta, John "Craig" George, Robert J. Small, and Mads Peter Heide-Jørgensen

Bowhead whales (*Balaena mysticetus*) from the western Arctic stock have been the focus of considerable research because they: 1) are critical to the nutritional and cultural health of Alaska Natives, 2) likely play a significant role as zooplankton grazers in the Bering, Chukchi and Beaufort seas, and 3) are vulnerable to possible effects of oil and gas activities during migration and in their summer range. General movements and behavior are known from aerial surveys and from the timing of whaling in coastal villages. Some specific feeding areas have also been identified from aerial surveys and the analysis of stomach contents; however, these locations are restricted to areas surveyed and near whaling villages. Information on the location of important feeding areas throughout bowhead range and how movements relate to currents, bathymetry, or ice cover is unknown. Working with other researchers and subsistence whalers we have attached satellite transmitters to bowhead whales. Here we describe the fall migration of 18 bowhead whales in the Chukchi Sea in 2006–2008. Using a Bayesian kernel density estimator, we also describe areas that might be important for feeding and calculate residence times. The earliest date any whale passed west of Barrow was 31 August. Most whales moved through the Chukchi Sea between 71 and 74°N. Seven whales spent time along the eastern side of Wrangel Island before going to the coast of northern Chukotka and following the coast southward. Three whales returned to Barrow; two whales returned after travelling 300 km west and one returned after travelling to Wrangel Island. Only one whale travelled south along the Alaskan coast. All whales that crossed the Chukchi Sea before transmitter failure (13 of 18) travelled through Oil and Gas Lease Sale Area 193. Of 11 whales still transmitting in late November 2008, one whale had passed through the Bering Strait while 10 others were still in the Chukchi Sea. The kernel density estimator identified Point Barrow, the east side of Wrangel Island, and the northern coast of Chukotka as areas of importance.

Appendix I. Quakenbush, L., H. Brower, Jr., J. Citta, M. P. Heide-Jørgensen, J. C. George, and R. Small. 2009. Some satellite telemetry results on BCB bowhead whales, 2006–2009. Report to the Bowhead/ Right/Gray Whale Committee of the International Whaling Commission, 22–25 June, Madeira, Portugal.

Some Satellite Telemetry Results on BCB Bowhead Whales, 2006–2009

Lori Quakenbush[1], Harry Brower[2], Jr., John Citta[1], Mads Peter Heide-Jørgensen[3], John C. George[2], and Robert Small[1]

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[2]North Slope Borough, Barrow AK, USA; [3]Greenland Institute of Natural Resources, Copenhagen Denmark

INTRODUCTION

In 2005, the Alaska Department of Fish and Game (ADF&G) began a cooperative project (with the Alaska Eskimo Whaling Commission and the North Slope Borough, funded by Minerals Management Service) to study Bering-Chukchi-Beaufort (BCB) bowhead whale movements and behavior using satellite telemetry.

METHODS

Twenty-eight satellite transmitters designed by M.P. Heide-Jorgensen were placed on bowhead whales in Alaska and Canada in 2006, 2007, and 2008. Twenty-two transmitters were deployed near Point Barrow, Alaska, and six transmitters were deployed near the Mackenzie River Delta, Canada. In 2008, 14 of 15 tags were deployed by Alaska Native subsistence whalers and their boat drivers.

RESULTS AND DISCUSSION

Satellite transmitters have allowed us to track bowhead whale movements and identify high use areas throughout an annual cycle. In fall, tagged bowhead whales travelled from the Barrow area across the Chukchi Sea to Wrangel Island, and then south to the Chukotka coast where most remained until December when they entered the Bering Sea (Fig. 1). Bowhead whales spent the most time near Point Barrow, Wrangel Island, and along the northern coast of Chukotka, from Cape Schmidt to Uelen, during the fall migration indicating these areas may be important habitats, probably for feeding.

During winter, tagged bowhead whales entered the Bering Sea between November 2008 and mid-January 2009 by travelling west of Big Diomede Island, Russia. All tagged whales passed west of Saint Lawrence Island, Alaska as they migrated southward; most whales remained offshore of the Gulf of Anadyr until the end of March (Fig. 2). Throughout the winter, tagged whales used offshore areas of heavier, yet fractured, ice despite the availability of areas with thin ice or open water near shore.

Spring migration began as tagged bowhead whales left the Bering Sea between 31 March and 27 April 2009 by travelling north, again passing west of Saint Lawrence Island. The tracks northward to Point Barrow varied in distance from shore but most travelled on the U.S. side of the International Dateline (Fig 2). Bowhead whales travelled 6–18 km north of Point Barrow before turning east to cross the Beaufort Sea. All tagged whales migrated to Amundsen Gulf, Canada. The route used by a whale in 2006 was farther north than that used by whales in 2009

(Fig. 3). In 2009, all whales used a similar route, despite not travelling together. In 2006, the tagged whale arrived in Amundsen Gulf on 26 May, and in 2009, tagged whales arrived in Amundsen Gulf between 3 and 20 May.

In summer, one whale remained within Amundsen Gulf from 26 May until 3 August and then again from 14 August to 17 September (Fig. 4). Between 3 and 14 August, this whale left Amundsen Gulf and travelled to the north end of Banks Island before returning. This whale also spent time along the Tuktoyaktuk Peninsula where it interacted with an active marine seismic ship prior to fall migration (Citta et al. 2007).

Data from two tagged whales show that the timing of the westward fall migration across the Beaufort Sea varied. In 2006, the tagged whale left the Canadian Beaufort Sea on 8 October and arrived at Point Barrow on 14 October; in 2008, the tagged whale migrated much earlier on 18 August and arrived at Point Barrow on 30 August. Their tracks across the Alaskan Beaufort Sea were similar as both travelled over the shelf within 100 km of shore (Fig. 4). Fall tracks were much closer to shore than spring tracks (Fig. 3 and Fig 4).

The movements of the 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, important new information on probable feeding areas, precise migratory routes, migration timing, wintering areas, habitat use, and behavior near seismic activity are provided by these data (ADF&G, unpublished data).

ACKNOWLEDGMENTS

This project would not be possible without 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, and Billy Adams. Mikkel and Anders Villum Jensen built the tag anchors and assisted with tagging. Funding was provided by the Minerals Management Service with excellent assistance from Charles Monnett. The research was conducted under the following permits: NMFS 782-1719, ADF&G ACUC 06-16, and in Canada AUP FWI-ACC-2007-2008-027.

REFERENCES

Braham, H., B. Krogman, S. Leatherwood, W. Marquette, D. Rugh, M Tillman, J. Johnson, and G. Carroll. 1979. Preliminary report of the 1978 spring bowhead whale research program results. Report of the International Whaling Commission 29:291–306.

Citta, J. J., L. T. Quakenbush, R. J. Small, and J. C. George. 2007. Movements of a tagged bowhead whale in the vicinity of a seismic survey in the Beaufort Sea. 17th Biennial Conference on the Biology of Marine Mammals, 29 November – 4 December 2007, Cape Town, South Africa. (Abstract and poster)

Moore, S.E. and Reeves, R.R. 1993. Distribution and movement. Pages 313–386 *in:* J.J. Burns, J.J. Montague and Cowles, C.J. (eds.). The Bowhead Whale. Special Publication No. 2, Society for Marine Mammalogy.

Moore, S.E., J.C. George, K.O. Coyle, and T.J. Weingartner. 1995. Bowhead whales along the Chukotka coast in autumn. Arctic 48(2):155–160.

Mate, B.R., Krutzikowsky, G.K., Winsor, M.H. 2000. Satellite-monitored movements of radio-tagged bowhead whales in the Beaufort and Chukchi seas during the late-summer feeding season and fall migration Canadian Journal of Zoology 78:1168–1181.

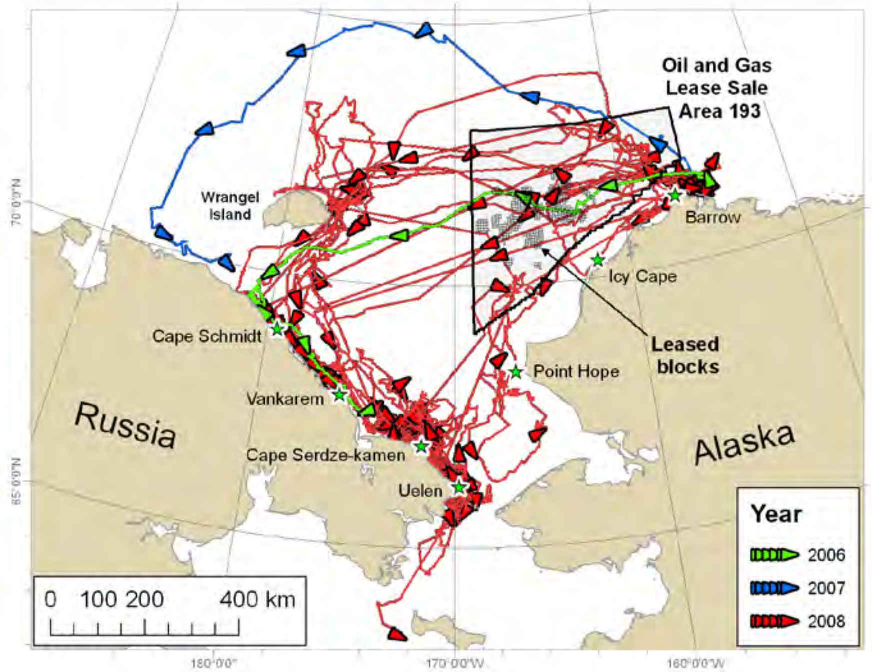


Figure 1. Fall (late August–December) tracks of 19 bowhead whales tagged near Pt. Barrow, Alaska and near the Mackenzie River Delta, Canada between 2006 and 2008.

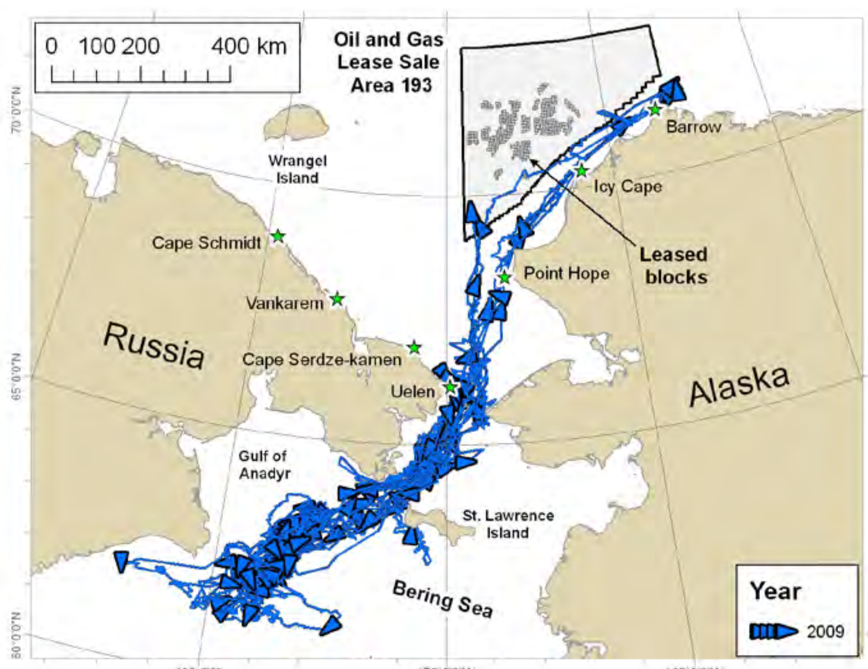


Figure 2. Winter and spring (December 2008– May 2009) tracks of 6 to 14 bowhead whales tagged near Pt. Barrow, Alaska and near the Mackenzie River Delta, Canada in August and September 2008.

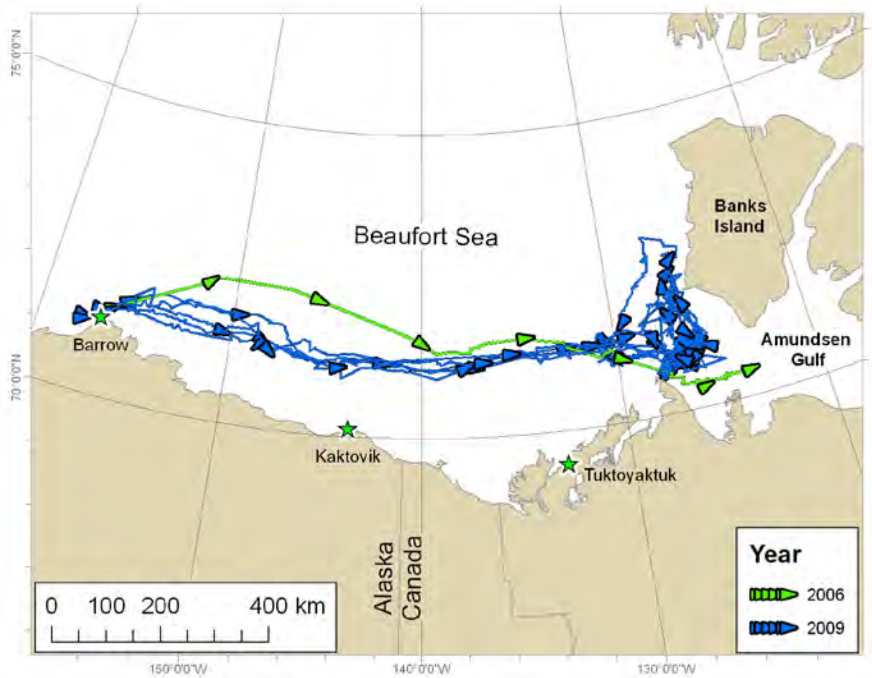


Figure 3. Spring (April–June) tracks of bowhead whales (tagged near Pt. Barrow, Alaska in May 2006 and September 2008 and near the Mackenzie River Delta, Canada in August 2008) from Barrow to Amundsen Gulf in the Alaskan and Canadian Beaufort Sea.

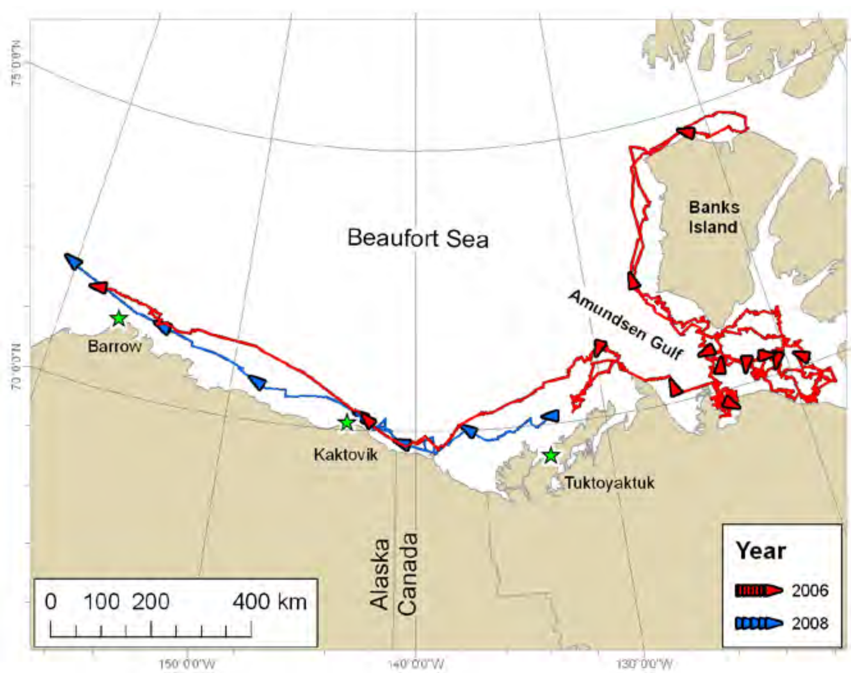


Figure 4. Summer and fall (June–October) tracks of a bowhead whale tagged near Barrow, Alaska in 2006 (red) and one tagged near Tuktoyaktuk, Canada in 2008 (blue).

Appendix J. Quakenbush, L., Citta, J. C. George, R. J. Small, and M. P. Heide-Jørgensen. 2009. Winter behavior of bowhead whales in the Bering Sea. 18th Biennial Conference on the Biology of Marine Mammals, 12–16 October, Quebec, Canada. (Abstract and oral presentation)

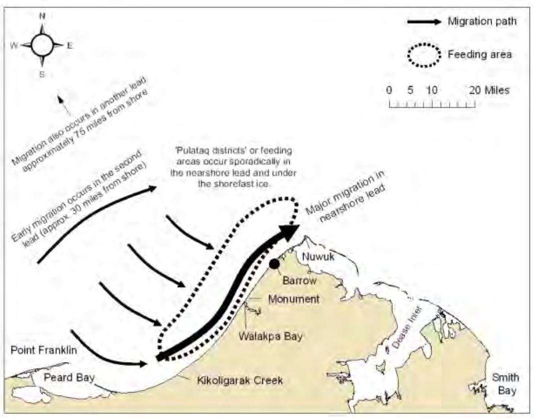
Winter Movements and Dive Behavior of Bowhead Whales in the Bering Sea

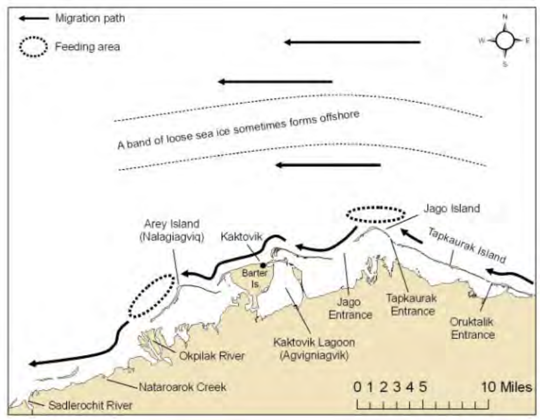
The movements and dive behavior of bowhead whales (*Balaena mysticetus*) from the Western Arctic stock are poorly understood within their ice-covered wintering grounds in the Bering Sea. Working with subsistence whalers from Alaska and hunters from Canada, we attached satellite-linked transmitters to bowhead whales near Tuktoyaktuk, Canada and Point Barrow in August and September 2008. We describe the movements of 11 bowhead whales in the Bering Sea from November 2008 to May 2009. All tagged bowheads entered the Bering Sea between early November 2008 and mid-January 2009 by traveling between Cape Deshnev and Big Diomede Island, Russia. All whales passed west of St. Lawrence Island, Alaska as they migrated southward. We identify areas of potential importance for wintering bowhead whales based on a kernel density estimator that determined where whales were located for longer periods of time. Although a few whales spent time near Big Diomede, Little Diomede, and St. Lawrence islands, the majority of whales remained near the entrance of the Gulf of Anadyr, near the Anadyr front and Navarin Canyon, until the end of March. Five whales with depth recorders ranged over water from 5 to 300 meters deep. The maximum depth a bowhead dived was approximately 250 meters and whales dove to depths near the seafloor in 99% of all 6-hour intervals. We used a discrete choice model of habitat selection to determine that whale movements were largely independent of ice conditions. Specifically, whales remained in areas of heavier, yet fractured, ice despite the availability of areas with thin ice or open water. The first tagged whale left the Bering Sea on 31 March, and the last one left on 27 April. The timing of early northward migrants is consistent with observations by Eskimo whale hunters in the Bering Strait region.

Appendix K. Huntington, H. P., and L. T. Quakenbush. 2009a. Traditional knowledge of bowhead whale migratory patterns near Kaktovik and Barrow, Alaska. Report to the Alaska Eskimo Whaling Commission and the Barrow and Kaktovik Whaling Captains. 14 pp.

Traditional Knowledge of Bowhead Whale Migratory Patterns near Kaktovik and Barrow, Alaska

Report to:
The Barrow and Kaktovik Whaling Captains Associations
and
The Alaska Eskimo Whaling Commission





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October 2009

Traditional Knowledge of Bowhead Whale Migratory Patterns near Kaktovik and Barrow, Alaska

Henry P. Huntington and Lori T. Quakenbush

Introduction

The general migratory patterns of bowhead whales in the Bering, Chukchi, and Beaufort Seas are well documented. The details of whale movements and activity throughout the migratory range are not as well known. Offshore industrial activity in the region is increasing, including seismic exploration, oil and gas development, and ship traffic. A better understanding of bowhead movements and activity is needed to help determine how to minimize the impacts of industrial activity on whales and those who hunt them. The Alaska Department of Fish and Game (ADF&G), in cooperation with the Alaska Eskimo Whaling Commission (AEWC), is conducting two related projects to learn and document more about bowhead whale movements and activities.

First, ADF&G is placing satellite transmitters on a small number of whales to learn more about the movements and behavior of individual whales over large portions of the migratory range. To date, 40 transmitters have been deployed; 31 in Alaska and 9 in Canada. Thirty-one were placed on whales near Barrow; five in spring and 26 in fall, and most were tagged by Barrow whalers. Efforts to place transmitters on whales near Kaktovik have not yet been successful due to weather conditions. In 2007, ADF&G and whalers from Kaktovik and Point Hope, Alaska, have worked with the Canadian communities of Aklavik and Tuktoyaktak to tag nine bowheads in August. George Tagarook and Eddie Arey from Kaktovik assisted with this tagging effort at Shingle Point. In 2008, ADF&G worked with the Canadian community of Tuktoyaktuk to tag one bowhead in August. George Tagarook from Kaktovik and Ray Koonuk from Point Hope assisted with this tagging effort near Atkinson Point. In Alaska, ADF&G plans to continue its efforts in Barrow and also to work with whaling captains on St. Lawrence Island to extend its work to the Bering Sea. The satellite transmitter work has been funded by the Minerals Management Service (MMS) and tagging efforts in Canada are supported by the Department of Fisheries and Oceans Canada.

Second, at the request of the AEWC, ADF&G has interviewed whaling captains and crew members in Kaktovik and Barrow to document traditional knowledge of bowhead movements and behavior near those communities. This information will provide details about the patterns of large numbers of whales in more localized areas, complementing the information gathered by satellite telemetry about patterns of a few whales over larger areas. The traditional knowledge project uses the same approach that the Native Village of Savoonga used when documenting traditional knowledge about bowhead whales on St. Lawrence Island (Noongwook et al. 2007). This study was funded by a grant from ConocoPhillips. This report presents the results of the interviews.

Kaktovik

Bowhead whales have occasionally been seen in the Kaktovik area in July and early August, for example in Camden Bay or 8–10 miles offshore from Kaktovik. The main migration begins in late August, with whales moving westwards (Figure 1). The first whales in the migration are typically large ones that establish the route of the migration. Whalers do not hunt these whales, allowing the migratory pattern to be established in the expectation that later whales will follow regardless of whaling activity. This behavior is also recognized in migrating caribou and other animals. The migration continues through September and into October, but Kaktovik whalers stop whaling before the migration ends and so are not sure how late in the fall the whales continue to come by.

Some whales travel close to the shore, pausing to feed in the passes between barrier islands or just off of the islands where water flowing from the lagoons mixes with ocean water. In these areas, bowheads leave depressions in the sea floor that can be seen by whalers when the water is calm. Whales have been seen with mud on their stomachs when feeding in these areas. Other whales travel farther offshore, generally swimming steadily westward. “Traveling” whales can be distinguished from feeding whales because traveling whales surface to blow once and then continue, whereas feeding whales surface many times and stay in the same area. When the leader of a group of feeding whales shows its flukes during a dive, it signals to the other whales that it is time to leave. Whales are not seen close to shore every year. That whales have long been found nearshore is indicated by Arey Island's Iñupiaq name, Nalagiagviq, which means "place to listen for whales."

In some years, there is a band of loose pack ice (it is possible to boat through without difficulty) a few miles wide between 5 and 15 miles offshore. Bowheads are known to migrate on both sides of the ice and also among the ice floes. When being hunted, whales may hide or seek refuge in the ice. In years with ice, bowheads are generally closer to shore than in years without ice. Sometimes whalers go as far as 20 miles offshore to find whales.

Kaktovik whalers have seen few patterns in whale size or other characteristics during the bowhead migration. Large whales may tend to come earlier (not counting the first few whales that set the migratory path), but whales of all sizes are seen throughout the migratory period. Whalers noted that they do not see the "super-big" whales that are sometimes taken at Barrow. They speculated that those whales may be farther offshore than the whalers go (i.e., more than 20 miles). Cows and calves start coming by in mid-September, later than the earliest whales to migrate past Kaktovik. Small whales may be more common close to shore, but large whales and even cow-calf pairs are seen close to shore, too. Calves may be separate from their mothers, making it difficult for whalers to tell if a small whale is a calf or not.

Since whaling resumed in Kaktovik in the early 1960s, whalers have noticed more whales and a decrease in sea ice during whaling season. Whalers used to be able to climb onto ice floes and use high ice as a lookout for whales. Other aspects of whale behavior, such as the timing of the migration or feeding behavior near shore, have not changed. There has been considerable change in the barrier islands, with both erosion and build-up seen. Some passes have become shallower. Until the 1950s, the lagoon now called Kaktovik Lagoon was known as Agvigniagvik, or "place to hunt whales," from an earlier period of whaling in the region. Today, beluga whales occasionally enter this lagoon, but it is too shallow for bowheads.

Bowhead whales are known to be sensitive to noise. When a thermos was accidentally knocked over in one whaling boat, a nearby bowhead whale immediately dove and was not seen again. Kaktovik whalers are thus worried about offshore oil activity in their area, fearing that the noise may deflect bowhead whales away from shore.

In the fall of 2006, whalers noticed millions of jellyfish in the waters off Kaktovik. This has been seen in other years, too. A Bering wolfish was caught near Kaktovik in the summer of 2006, the first time one had been seen in the area. Overall, fishing success has declined in recent years. Dolly varden and cisco were the most common fish. Today, there are more salmon than formerly.

Kaktovik whalers generally do not begin whaling until early September, when the air temperature is cool enough to preserve the meat during butchering. They typically finish whaling in September, having reached their allocation of whales before the migration ends and before the weather deteriorates. Prior to and after whaling, Kaktovik residents are typically hunting on land or fishing in rivers or the nearshore, and thus have limited opportunities to see whales when they are not actively whaling.

<u>Barrow</u>

Bowhead whales have been seen near Barrow as early as February, but the main migration begins in mid-April. Offshore from Barrow, there are three lead systems in the spring sea ice. Moving outwards from shore, the first lead begins at the edge of the shorefast ice. Beyond this lead, there is pack ice out to another lead about 30 miles offshore. The third lead is about 75 miles offshore, but is narrow. There are also different current movements in the different leads with the farthest lead having the strongest current. Whalers who flew planes while guiding polar bear hunts in the 1960s have noticed these patterns. When the second lead is long, a few large bowhead whales have been seen there in early April, but beluga whales are more common in that lead than are bowheads.

The main migration in the nearshore lead begins with a small number of mid-sized whales (“qairaliq”), followed by larger numbers of small whales in mid- to late April (Figure 2). The whales are plentiful during the three to four days the first wave lasts. The whalers let the first 50–100 whales of the first wave go past to establish the path. A second wave, consisting of mid-sized whales, typically arrives in early May after a gap of two or three days from the first wave.

The second wave has many whales, and lasts about a week. After another period of fewer whales, the final wave of large whales, including cows and calves, arrives in mid-May and continues into June.

One whaling crew has noticed a recognizable whale appearing year after year, always on April 23, indicating that perhaps some individual whales follow their own annual patterns.

Whale behavior is the same during all three waves, although whales in the first wave may spend more time in the area, feeding or playing. While many bowheads migrate quickly through the Barrow area (perhaps aware of the presence of whalers), some stop and feed under the shorefast ice. Feeding whales may circle many times under the ice, returning to open water to breathe. This behavior is termed “pulataq” in Iñupiaq, and the whalers recognize “pulataq districts” along the edge of the shorefast ice. Whaling camps may be located at places where bowheads are expected to emerge from under the shorefast ice. Whales migrating quickly through the area tend to be farther from the edge of the shorefast ice.

A cow with a calf may leave the calf in bays in the shorefast ice while the cow travels ahead to scout conditions along the route. The cow will then retrieve the calf and continue the migration. Some females give birth in the Barrow area.

Barrow residents often hunt walrus and seals offshore, west of Barrow in July. During the interviews, respondents did not report seeing bowhead whales west of Barrow in July. During the review of a draft of this report by the AEWC, however, it was remarked that bowhead whales have been seen west of Barrow in July in recent years. The difference may reflect the intentional selection of older respondents, many of whom are less active now and who therefore may not have observed recent changes in distribution, timing or behavior. Occasionally bowhead whales are seen north of Barrow in summer. Many gray whales are seen in this season. Gray whales may enter Dease Inlet, as do belugas, but bowhead whales require deeper water.

In the 1940s, when one respondent was growing up at Cape Halkett, bowhead whales were not seen in that area.

Bowhead whales return to the area near Point Barrow in late August, though some large whales were seen 20–30 miles offshore in open water in early August one year. Generally, the large whales come first in the fall migration, followed by mid-sized whales, with small whales coming last (Figure 3). This pattern is less distinct in fall than is the three-wave pattern in spring. Bowhead whales may feed near the barrier islands east of Point Barrow. Whales are heavier in fall than in spring. In years with heavy pack ice in fall, whales will head southwest from Point Barrow. In years with light or no pack ice in fall, whales may stay near Point Barrow longer before heading west. The migration tends to occur later in years with little or no ice than in years with heavy ice, with whales in the area through late October. Small whales that stay close to shore may encounter gray whales southwest of Barrow.

Barrow whalers have noticed an increase in the number of whales over the past several decades. At the same time, changes in ice conditions and an increase in noise from snowmachine travel on the shorefast ice have led to noticeable changes in the spring migration pattern near Barrow. Fewer bowheads travel next to the edge of the shorefast ice, and fewer bowheads are seen southwest of Barrow. Whaling crews that used to set up camps near the Monument (approximately 12 miles southwest of Barrow) have had to move farther north along the shorefast ice. This shift may be the result of thinner ice conditions and less multi-year ice, which is associated with feeding opportunities for bowhead whales, thus reducing the attraction of the shorefast ice southwest of Barrow. Bowhead whales are also arriving earlier in spring now than they did in the past.

The shorefast ice has become thinner in spring and more susceptible to breaking off and being blown away from shore. The shore-fast ice breaks apart earlier than it used to. In fall, there is more open water and the ice forms later. In November 1964, a 28-foot bowhead whale was landed at Barrow and hauled up onto sea ice for butchering. In more recent years, no shorefast ice has been present in November, at least not of sufficient thickness to bear the weight of a bowhead whale and allow butchering to take place on the ice.

When a test well was drilled offshore near Point Barrow, whales diverted their migration around the area, even though no drilling occurred during the migration. The noise from the idle drill ship was still sufficient to affect the whales. After the drilling ceased and the rig was removed, the whales reverted to normal behavior in the area within a couple of years.

Barrow whalers have seen whales much larger than those that have been landed. Some whalers believe that the very large whales would have tough meat and maktak, and so might not be worth hunting.

Methods

This study used the same basic methods to document traditional knowledge as those used by Noongwook et al. (2007), and described in detail there. (That paper also describes the ways that traditional knowledge is acquired among Yupik whalers. The description is generally applicable to Barrow and Kaktovik as well.) Specifically, we used the semi-directive interview (Huntington 1998). Unlike Noongwook et al., however, our interviews were with one or two persons at a time, rather than with larger groups. In the semi-directive interview, researchers initiate a discussion around various topics of interest, but allow the person being interviewed to determine the order in which topics are discussed and to make connections between various topics that the researchers might not have anticipated. The interview is thus more fluid than would be a standardized questionnaire. The interviews were conducted in English, as all participants were comfortable in that language.

The research trip took place in early February 2007. In Kaktovik, we interviewed six whalers or whaling captains. They had an average of about 30 years of whaling experience, ranging from 18 to 45 years. In Barrow, we interviewed five whalers or whaling captains plus one locally resident scientist who had over 25 years of experience working with and learning from the whalers. The Barrow whalers and whaling captains had an average of over 50 years of whaling experience, ranging from 40 to 64 years. In both cases, the persons being interviewed were recommended by the head of the local whaling captains association or by chain referral (one participant recommending additional persons to interview). This report includes the information told to us by the whaling captains and whalers that participated in interviews in each village. As noted earlier, there may be additional information known by others that is not included here, particularly concerning recent changes. Because the environment continues to change, there may be merit in developing a mechanism for recording and reporting ongoing observations made by whalers and hunters.

The researchers included a marine mammalogist (LTQ) who is also the principal investigator of the satellite transmitter study, and a social scientist (HPH) with experience in traditional knowledge studies (and who also took part in the St. Lawrence Island study mentioned earlier). Having both forms of expertise helped in the conduct of the interviews and in asking appropriate follow-up questions. The interviews also allowed LTQ to share preliminary results of the satellite transmitter study, specifically the movements of two tagged whales. This information was in most cases shared at the end of the interview, the exceptions occurring when one respondent arrived as the previous interview was ending.

Following the trip, LTQ and HPH prepared a draft report, which was provided to the individuals who were interviewed and the presidents of the Barrow and Kaktovik whaling captains associations for corrections and comments. The corrections and comments were incorporated into a final report, which was approved by the AEWC.

Acknowledgments

We are grateful to ConocoPhillips for funding the traditional knowledge project. We are particularly grateful to the Alaska Eskimo Whaling Commission for its support and encouragement, and to the Barrow Whaling Captains Association and the Kaktovik Whaling Captains Association for helping set up interviews, plan the research trip, and review the draft report. Eugene Brower and Fenton Rexford were extremely helpful as our primary local contacts. John “Craig” George in Barrow helped identify participants and also agreed to be interviewed himself. In Kaktovik, we interviewed Charles M. Brower, Eddie Rexford, and four others who preferred to remain anonymous. In Barrow, we interviewed Ben Itta, David U. Leavitt, Warren Matumeak, Johnnie Brower, John “Craig” George, and one individual who preferred to remain anonymous. Although Harry Brower, Jr. was not interviewed, he assisted in developing the project and he reviewed the draft report and provided valuable comments. John Citta prepared the maps used during interviews and the figures in this report. Minerals Management Service is funding the satellite telemetry project that prompted the traditional knowledge interviews.

References

Huntington, H.P. 1998. Observations on the utility of the semi-directive interview for documenting traditional ecological knowledge. Arctic 51(3):237-242.

Noongwook, G., the Native Village of Gambell, the Native Village of Savoonga, H.P. Huntington, and J.C. George. 2007. Traditional knowledge of the bowhead whale (*Balaena mysticetus*) around St. Lawrence Island, Alaska. Arctic 60(1):47–54.

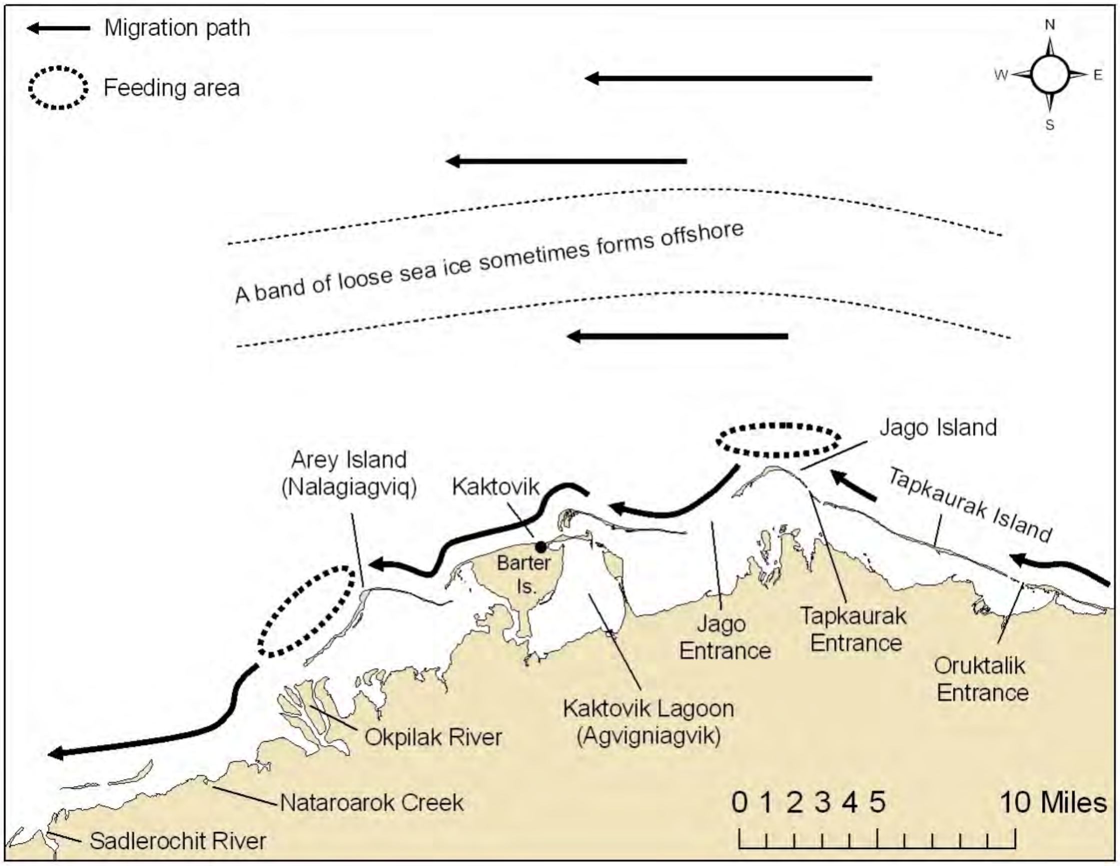


Figure 1. Movements and behavior of bowhead whales near Kaktovik, Alaska in August–September. Some whales travel close to shore, feeding in the passes between barrier islands and outside of Jago and Arey islands, however they may feed also feed at other places along the coast in this area. Whales also pass farther offshore and whalers may go as far as 20 miles from shore to find whales. Sometimes there is a band of loose ice 5–15 miles offshore. Whales travel to the north and south of this ice and through it. In years with more ice whales tend to travel closer to shore.

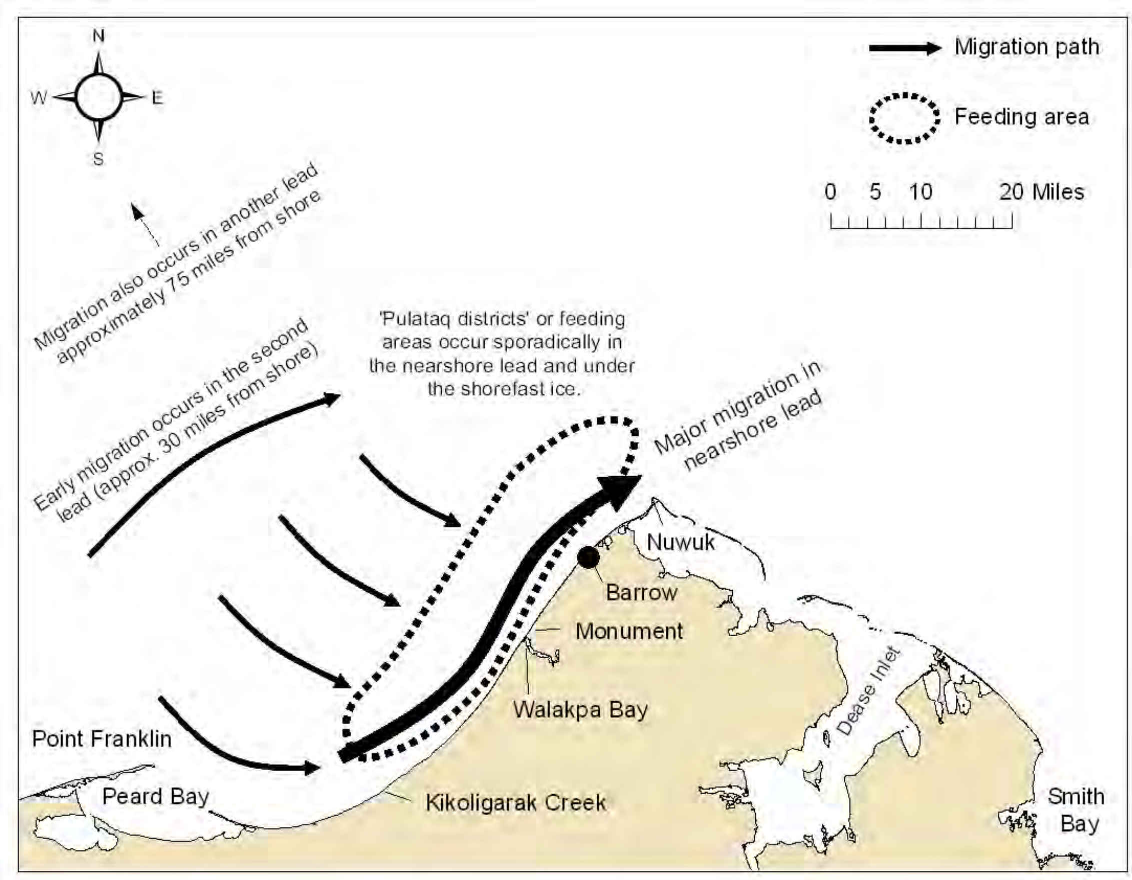


Figure 2. Movements of bowhead whales in spring near Barrow, Alaska. There are three lead systems in the spring sea ice. The closest one begins at the edge of the shorefast ice and is where the main migration occurs. The second lead occurs about 30 miles out and a third occurs about 75 miles out. Some whales move through quickly and some circle under the ice to feed. These feeding areas are called “pulataq districts”.

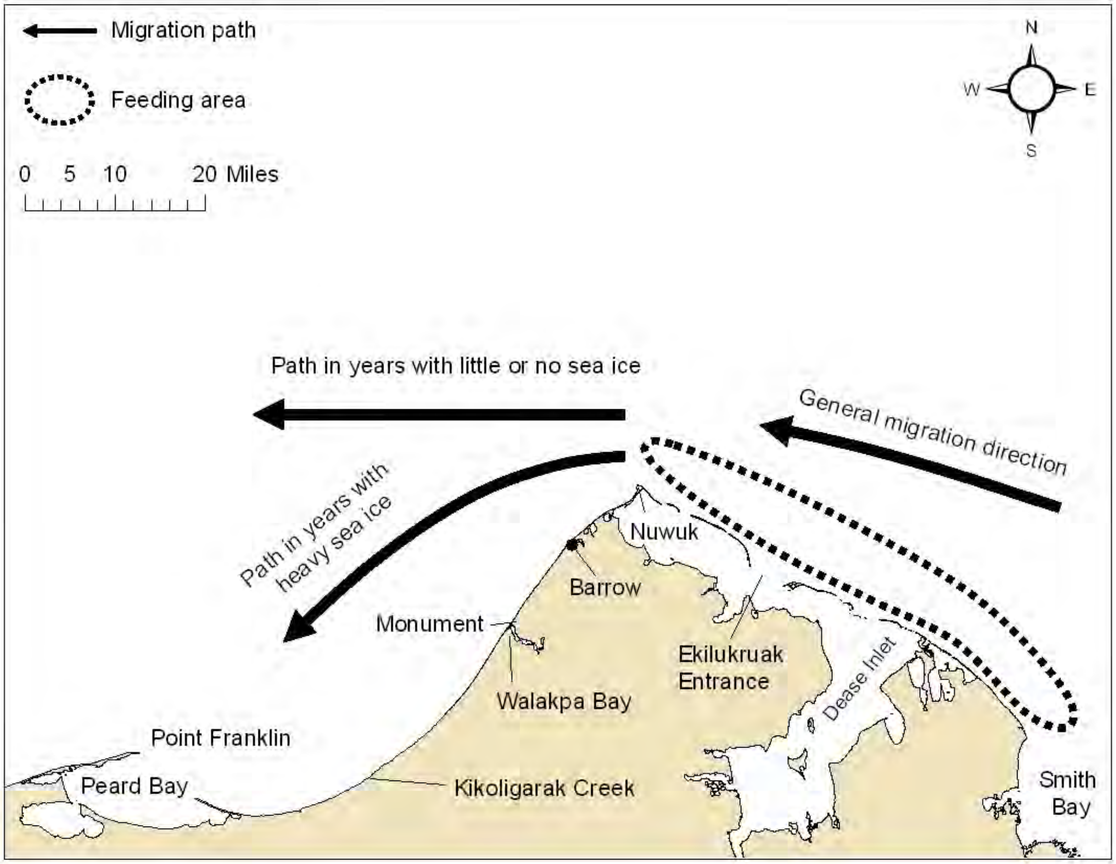


Figure 3. Movements and behavior of bowhead whales in fall near Barrow, Alaska. Bowhead whales may feed near the barrier islands between Nuwuk and Dease Inlet. In years with little or no ice, whales may stay longer near Barrow and head more west when they leave. In years with heavy ice, the whales head more southwest and they leave earlier.

Appendix L. Huntington, H. P., and L. T. Quakenbush. 2009b. Traditional knowledge of bowhead whale migratory patterns near Wainwright, Alaska. Report to the Alaska Eskimo Whaling Commission and the Wainwright Whaling Captains. 9 pp.

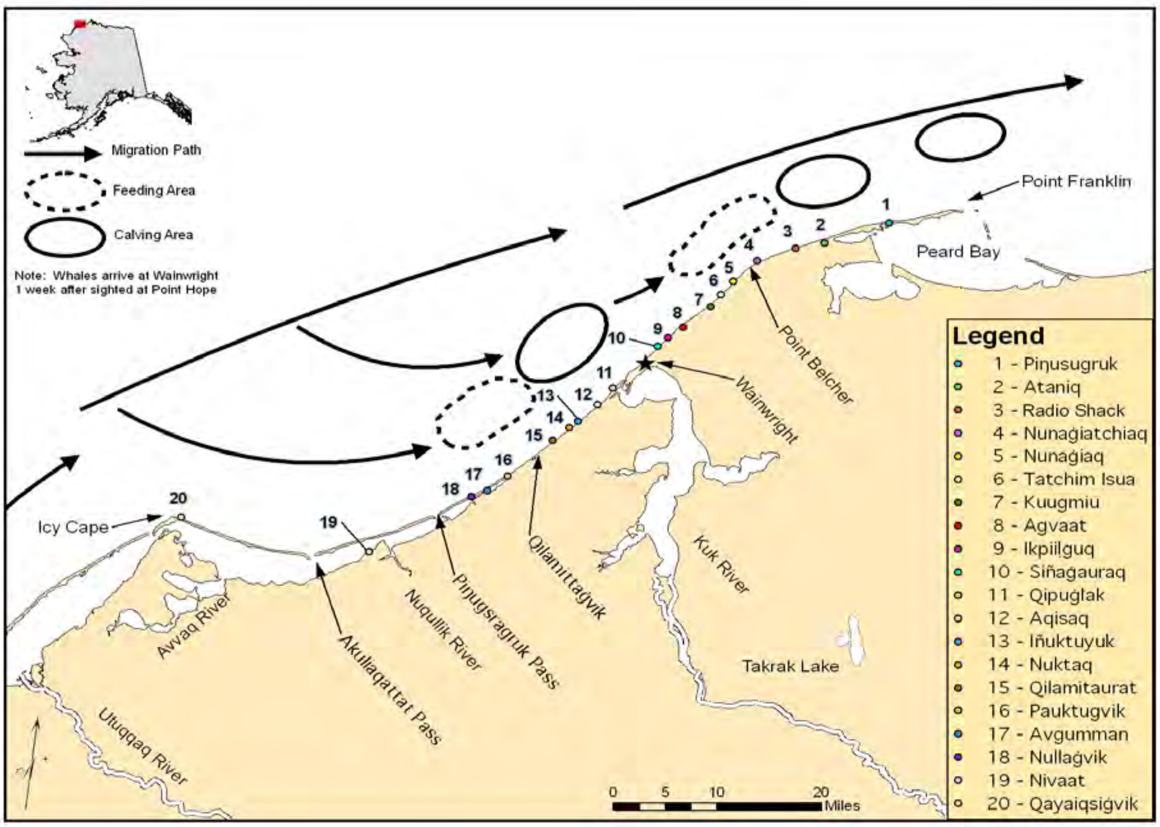
Traditional Knowledge of Bowhead Whale Migratory Patterns near Wainwright, Alaska

Report to:

The Alaska Eskimo Whaling Commission

and

The Wainwright Whaling Captains Association



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Introduction

The general migratory patterns of bowhead whales in the Bering, Chukchi, and Beaufort seas are well documented. The details of whale movements and activity throughout the migratory range are not as well known. Offshore industrial activity in the region is increasing, including seismic exploration, oil and gas development, and ship traffic. A better understanding of bowhead movements and activity is needed to help determine how to minimize the impacts of industrial activity on whales and those who hunt them. The Alaska Department of Fish and Game (ADF&G), in cooperation with the Alaska Eskimo Whaling Commission (AEWC), is conducting two related projects to learn and document more about bowhead whale movements and activities.

First, satellite transmitters are being placed on a small number of whales to learn more about the movements and behavior of individual whales over large portions of the migratory range. To date, 40 transmitters have been deployed; 31 in Alaska and 9 in Canada. Thirty-one were placed on whales near Barrow, five in spring and 26 in fall, and most were tagged by Barrow whalers. Efforts to place transmitters on whales near Kaktovik have not yet been successful due to weather conditions. Since 2007, ADF&G and whalers from Kaktovik and Point Hope, Alaska, have worked with the Canadian communities of Aklavik and Tuktoyaktuk to tag nine bowheads in August. In Alaska, ADF&G plans to continue its efforts in Barrow during spring and fall and also to work with whaling captains on St. Lawrence Island to increase knowledge of bowhead movements in the Bering Sea. The satellite transmitter work has been funded by the Minerals Management Service (MMS) and tagging efforts in Canada are supported by the Department of Fisheries and Oceans Canada.

Second, at the request of the AEWC, ADF&G has interviewed whaling captains and crew members in Kaktovik, Barrow, and Wainwright to document traditional knowledge of bowhead movements and behavior near those communities. This information will provide details about the patterns of large numbers of whales in more localized areas, complementing the information gathered by satellite telemetry about patterns of a few whales over larger areas. The traditional knowledge project uses the same approach that the Native Village of Savoonga used when documenting traditional knowledge about bowhead whales on St. Lawrence Island (Noongwook et al. 2007). Traditional knowledge research in Kaktovik and Barrow was funded by a grant from ConocoPhillips (Huntington and Quakenbush 2009) and this funding was used as match by the Coastal Marine Institute (CMI) for research in Wainwright. This report presents the results of the interviews in Wainwright.

Wainwright

The movements of bowhead whales near Wainwright are determined primarily by ice conditions. Leads in the local area affect local distribution, whereas the condition of leads to the south influences the timing of the migration as a whole. The prevailing east-northeast winds tend to open the leads near Wainwright, with currents playing a role, too. West winds tend to close the lead, making whaling impossible. When the lead is closed, the whales travel farther from the shorefast ice. Currents are stronger by Point Belcher, and there is a strong current near the Kuk River mouth by Wainwright in late May and early June.

Wainwright whalers hear from St. Lawrence Island and from Point Hope that bowheads are migrating. They expect bowheads to reach the Wainwright area about a week after they reach Point Hope, depending on ice conditions in between. Before whaling, Wainwright whalers wait for the leads to be open wide, to help reduce the struck-and-lost rate. The pattern of leads varies from year to year in the Wainwright area. In some years, the lead has remained open all spring, whereas in other years there has been hardly any open water during whaling season. When nearshore leads do not open, whalers may have to travel farther offshore, either across young ice or on un-grounded ice susceptible to breaking off, both of which are dangerous.

In spring, whalers recognize three waves (sometimes called schools, runs, or pulses) of whales. The first wave is primarily small, young whales, and occurs when the leads first open. Formerly, this would occur in late April, but in recent years has been taking place earlier so that bowhead whales now appear in the area in early April and at times even in March. The whales in the first wave migrate past Wainwright through open leads or ponds of open water. The second wave of whales, comprised of mid-sized whales, also requires open leads or ponds. For both waves, if the lead closes or if leads are not available to the south, the whales may delay their migration to await more favorable conditions. The whales may congregate in open pools while waiting for the leads to open up.

The third wave of whales, which includes the largest whales and also most of the mother-and-calf pairs, takes place in the second half of May and early June. These whales are capable of pushing up through young ice (up to approximately 18” or 45 cm thick) to create breathing holes. Subsequent whales will use the same breathing holes, which can be dangerous to people on the ice if the holes are covered with snow and thus invisible from above. Elders used to tell the young boys at whaling camps to keep quiet so that blows could be heard even when the lead was closed and so that the whales would not be disturbed while setting the migratory path. Later whales follow the pattern set by the first animals. Bowheads can also find cracks in thicker ice through which they can breathe. They are thus able to migrate even when the main lead system is closed. Whales in the third run may also be found in cracks and openings far out in the pack ice.

Wainwright whalers seek open leads closest to shore. The whalers will have been on the ice throughout the winter, watching where the ice breaks off and assessing where it is likely to do so in spring, which helps them plan. In most years, whaling starts near Point Belcher to the north of the village (Fig. 1), where the currents and ice conditions tend to create leads closer to shore. The ice is typically rough in this area. A key concern is finding a suitable location for hauling a whale onto the ice for butchering. The ice needs to be thick enough to support a whale, with a large enough flat area for the whale and the cutting-up activities. The whalers begin by seeking such a spot, often traveling the lead edge by boat and then cutting a trail to the suitable location. (Searching on the shorefast ice would be much more difficult due to the difficulty of traveling over rough ice.) In recent years, the ice has been thinner, making it harder to find a good spot.

As the season progresses, leads may open up closer to Wainwright, and the whalers may move to the southwest from Point Belcher, seeking other locations to set up whaling camps. In some years, the whalers may go as far south as Icy Cape, though that is not as common. (One year, migrating ducks at Icy Cape were so numerous that the whalers’ camps and gear were covered in duck droppings, reducing the appeal of returning to that particular location.) The whales often follow the ice edge, but may also travel directly from the Icy Cape area to the Point Belcher area, staying farther offshore as they pass the village.

During the spring migration, whales have been observed calving, mating, and feeding. Calving has been seen in a few locations (Fig. 1). Calves are occasionally seen in late April, but more typically in late May and June. Calves are small and gray, rather than the black of an older whale. Elders emphasized the need to look carefully when whaling to make sure that an adult whale was not accompanied by a calf. Whales with calves should not be taken. Mating behavior consists of several males and one female. The female and one male will stay in one location, rolling slowly over and over so that each has the opportunity to breathe without disengaging. The other males will slowly circle the mating pair. Whalers once asked elders about the advisability of hunting a mating pair. The elders discouraged this, saying that first the whales were making more whales, and second that they might become violent if disturbed at this time and thus would be hazardous to the whalers. For these reasons, mating whales are left alone.

Feeding is often seen along the edge of the shorefast ice (Fig. 1). Whales will swim parallel to the edge with their mouths open. They may have trouble closing their mouths, sometimes using the ice by pushing their lower jaw against the ice to help shut their mouths. Whales are also known to swim under the shorefast ice to feed, circling under a particular area or traversing the area by breathing through cracks in the shorefast ice or pushing up through young ice to create breathing holes. Whalers have seen and heard whales surfacing between their camps at the ice edge and land, as the whales migrate under the shorefast ice. In one case, the whalers had cut a hole in the ice behind their camp, and found a whale breathing in that hole. In another case, where whales were repeatedly circling under the shorefast ice, the whalers approached and the whales quickly moved away from the area. Whales also feed under young ice, where food can often be found.

Bowhead whales have been seen occasionally after the shorefast ice has broken up and also in fall near Wainwright. After the whaling season, hunters often seek bearded seals in the pack ice. At these times they may see bowhead whales still migrating. One such whale was seen near Point Franklin in June of 2007. Many large whales were seen in July 2007 while hunters were out after bearded seals. These are believed to be part of the third run, the large whales that come last. Whales have been seen later in July on a few occasions, near Wainwright and Icy Cape. Three very large bowheads were seen by the Kuk River mouth one July about 35 years ago. In October, whales have been seen a few times near Wainwright, but they do not generally follow the coast southwards from Barrow.

Whalers have seen other species of whales in the region. Identifying which species is difficult, but characteristics such as a small dorsal fin make it clear that they are not bowhead or gray whales. Fin and minke whales are likely candidates, and there is a possibility that sperm and blue whales have been seen in the area, too. The sperm whale was seen during bearded seal hunting about 30 years ago, recognized by its blunt head (whalers being familiar with Moby Dick). Beluga whales are common during the spring migration, typically migrating ahead of one or more bowheads. In summer, belugas congregate near Icy Cape. In some years, they come close to Wainwright and are hunted, whereas in other years they do not come past Icy Cape along the coast.

In recent years, the ice has been changing. The ice used to start forming in October, but now may not form until December or even until after Christmas. The resulting thinner ice can be blown offshore more easily during winter storms, further reducing the time it has to thicken and become anchored to provide safe locations for whaling camps. Break-up of the shorefast ice used to occur in late June and July, but now the ice may start to rot in May (both from sun on top and from currents underneath), making travel on the ice dangerous and limiting the season that the whalers can be out whaling. The lack of multi-year ice and other large, thick floes has allowed the whales to begin their migration earlier in the spring.

Wainwright whalers are very concerned about offshore oil and gas activities in the Chukchi Sea. In 1968, there was seismic testing offshore during the spring migration. The whalers saw no whales, not even a blow, that spring. Barrow provided whale meat and maktak to Wainwright for Thanksgiving and Christmas. The whalers were supposed to have been compensated for the loss of whaling that year, but never were. For planned activities in the Chukchi, the whalers believe stringent conditions should be imposed. They also have seen impacts from the activity near

Prudhoe Bay, recognizing that Barrow and Nuiqsut whalers report that the whales now migrate farther offshore in fall than before. In Wainwright, this means that the whales will not travel southwest near the Chukchi coast, but will stay offshore to the north as they migrate across to the Russian coast.

Methods

This study used the same basic methods to document traditional knowledge as those used by Noongwook et al. (2007), and described in detail there. (That paper also describes the ways that traditional knowledge is acquired among Yupik whalers. The description is generally applicable to Iñupiat whalers of Wainwright as well.) Specifically, we used the semi-directive interview (Huntington 1998). As was the case in Noongwook et al. (2007), we conducted a single group interview with seven whaling captains, who were identified and invited to the interview by the head of the Wainwright Whaling Captains Association. The captains had an average of 35 years of whaling experience ranging from 15 to 45. The research took place in Wainwright in late February 2008.

In the semi-directive interview, researchers initiate a discussion around various topics of interest, but allow the person(s) being interviewed to determine the order in which topics are discussed and to make connections between various topics that the researchers might not have anticipated. The interview is thus more fluid than would be a standardized questionnaire. The interviews were conducted in English, as all participants were comfortable in that language, though the participants occasionally discussed a particular point in Iñupiaq before providing us with a summary in English.

The researchers included a marine mammalogist (LTQ) who is also the principal investigator of the satellite transmitter study, and a social scientist (HPH) with experience in traditional knowledge studies (and who also took part in the St. Lawrence Island study mentioned earlier). Having both forms of expertise helped in the conduct of the interviews and in asking appropriate follow-up questions. The interview also allowed LTQ to share preliminary results of the satellite transmitter study, specifically the movements of two tagged whales, at the end of the interview.

Following the trip, LTQ and HPH prepared a draft report, which was made available to the individuals who were interviewed for their review and comments. Comments and changes, if any, were incorporated into the final report.

Acknowledgments

We are particularly grateful to the Alaska Eskimo Whaling Commission for its support and encouragement, and to the Wainwright Whaling Captains Association for helping set up the interviews, plan the research trip, and review the draft report. Jack Panik was extremely helpful as our primary local contact. We appreciate the participation of Terry Tagarook and the other whaling captains, who chose to remain anonymous, to share their knowledge of bowhead whale behavior and whaling near Wainwright for this project. We thank the Coastal Marine Institute for funding the interviews, with funds originally from the Minerals Management Service and the matching funds by ConocoPhillips. We thank Caryn Rea for her role in providing the funds from ConocoPhillips. John Citta prepared the maps used during interviews and Justin Crawford made the figure in this report. Minerals Management Service is funding the satellite telemetry project that prompted the traditional knowledge interviews.

References

Huntington, H.P. 1998. Observations on the utility of the semi-directive interview for documenting traditional ecological knowledge. Arctic 51(3):237–242.

Huntington, H.P., and L.T. Quakenbush. 2009. Traditional knowledge of bowhead whale migratory patterns near Kaktovik and Barrow, Alaska. Report to the Barrow and Kaktovik Whaling Captains Associations and the Alaska Eskimo Whaling Commission.

Noongwook, G., the Native Village of Gambell, the Native Village of Savoonga, H.P. Huntington, and J.C. George. 2007. Traditional knowledge of the bowhead whale (*Balaena mysticetus*) around St. Lawrence Island, Alaska. Arctic 60(1):47–54.

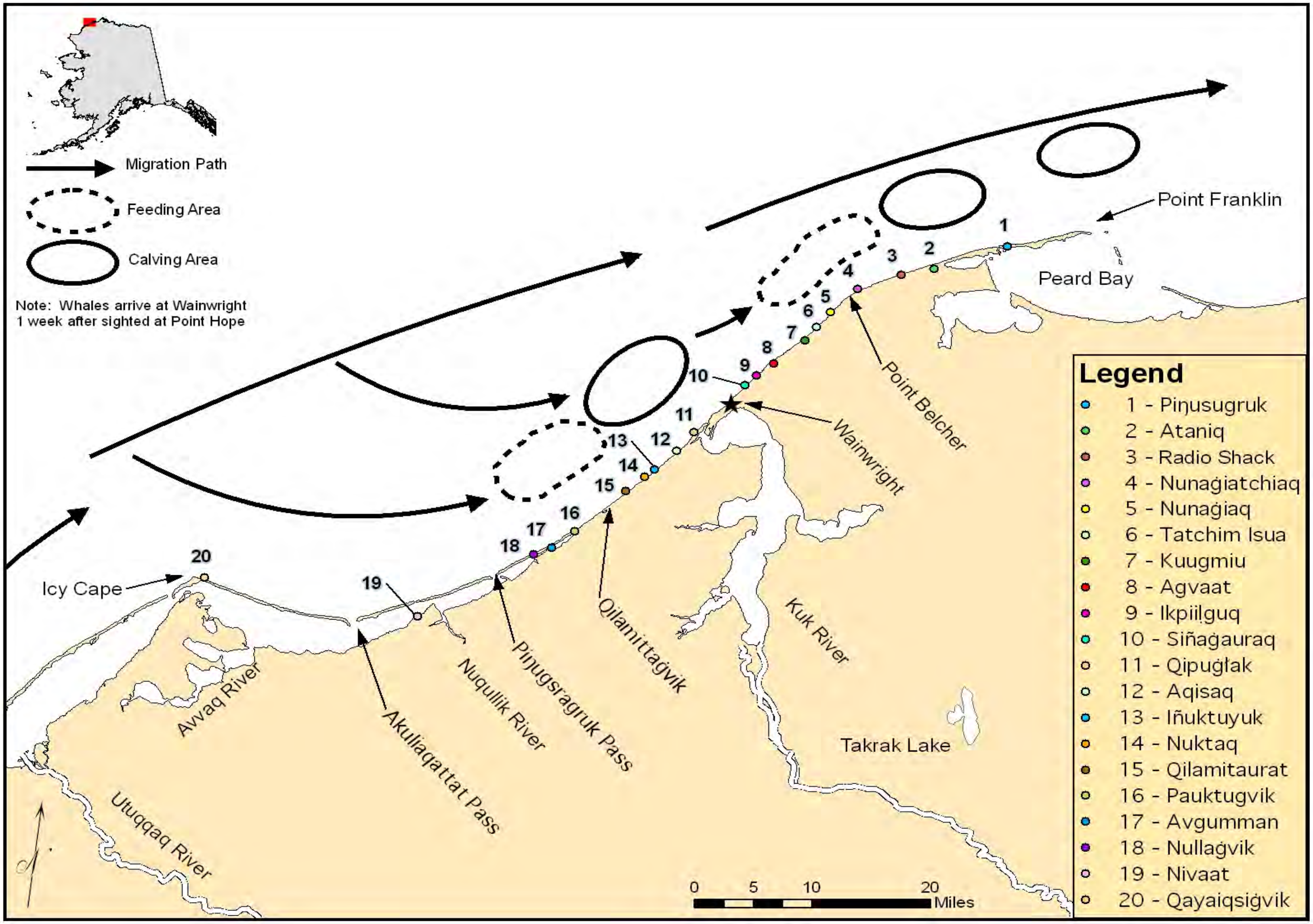

Figure 1. Movements and behavior of bowhead whales in spring near Wainwright, Alaska relative to local landmarks and other coastal features. Whales have been observed calving, mating, and feeding in the nearshore lead near Wainwright. Calves are occasionally seen in late April, but more typically in late May and June.

Appendix M. Quakenbush, L., Citta, J. C. George, R. J. Small, M. P. Heide-Jørgensen, Lois Harwood, and Harry Brower, Jr. 2010. Western Arctic bowhead whale movements and habitat use throughout their migratory range: 2006–2009 satellite telemetry results. Alaska Marine Science Symposium, 18–22 January, Anchorage, AK (Abstract and poster).

Western Arctic Bowhead Whale Movements and Habitat Use throughout their Migratory Range: 2006–2009 Satellite Telemetry Results

Lori Quakenbush[1], John Citta[1], John C. George[2], Robert Small[3], Mads Peter Heide-Jørgensen[4], Lois Harwood[5], and Harry Brower, Jr.[2]

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In 2005, the Alaska Department of Fish and Game began a cooperative research project to study movements and habitat use of the western Arctic stock of bowhead whales (*Balaena mysticetus*). An important goal of the study is to describe how bowhead whale behavior is affected by industrial activity. In collaboration with the Alaska Eskimo Whaling Commission, the North Slope Borough, the Greenland Institute of Natural Resources, and the Department of Fisheries and Oceans Canada with funding from the Minerals Management Service, 44 satellite transmitters were placed on bowhead whales in Alaska and Canada between 2006 and 2009. The majority of the tags were deployed in waters near Point Barrow by Alaska Native subsistence whalers. A few tags have transmitted ~12 months allowing us to track individual bowhead whales throughout their complete annual migration in the Bering, Chukchi, and Beaufort seas. Tagging in consecutive years has allowed us to look at the variability in movements and the timing of migration among years. We have identified several areas of concentrated use throughout the range of bowhead whales, and have documented interactions with industrial activities. We plan to continue tagging in order to better understand annual variability in movements and to document additional behaviour relative to industrial activities. We will also consider oceanographic factors to better understand what influences the movements and foraging behavior of his stock of bowhead whales.

Western Arctic Bowhead Whale Movements Throughout Their Migratory Range 2006–2009 Satellite Telemetry Results

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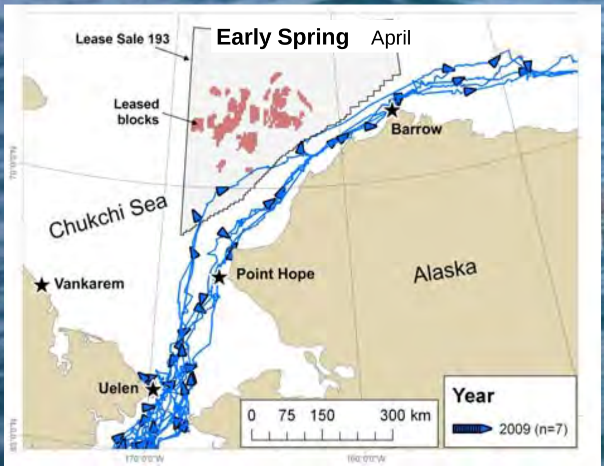
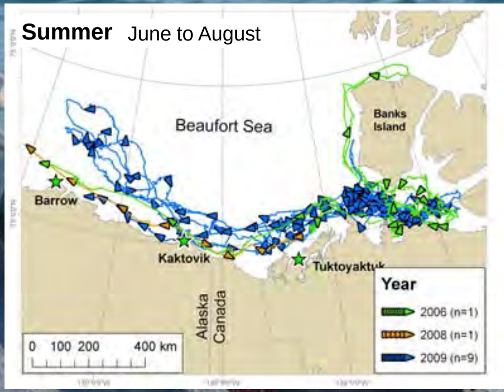
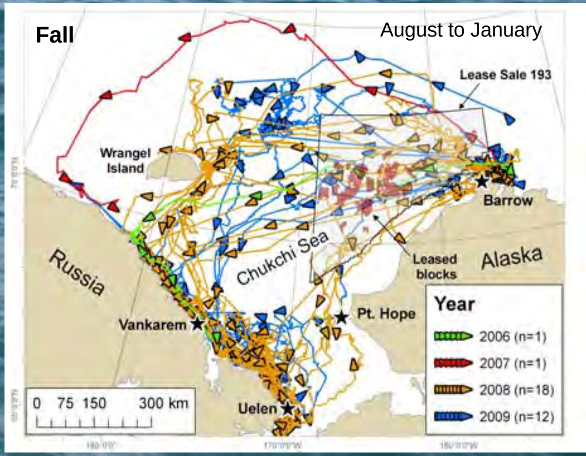
INTRODUCTION. In 2005, the Alaska Department of Fish and Game began a cooperative research project with the Alaska Eskimo Whaling Commission and others to study movements and habitat use of the western Arctic stock of bowhead whales (*Balaena mysticetus*).

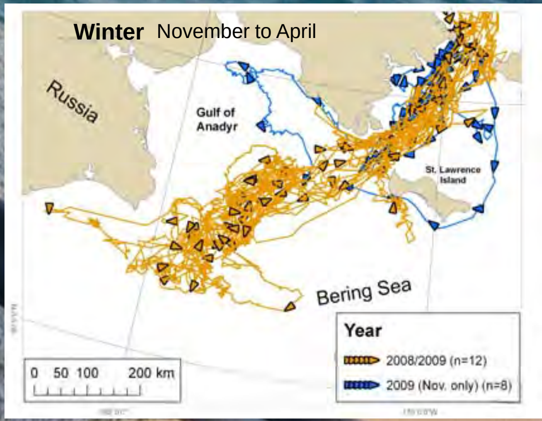
RESULTS. Tags have lasted an average of >6 months. Two tags lasted >12 months, and two others ~10 months, allowing us to track individual bowhead whales throughout their complete annual migration in the Bering, Chukchi, and Beaufort seas. Tagging in consecutive years has allowed us to look at the variability in movements and the timing of migration among years.

METHODS. Between 2006 and 2009, 44 satellite transmitters were placed on bowhead whales in Alaska (n=35) and Canada (n=9). The majority of the tags were deployed in waters near Pt. Barrow by Alaska Native subsistence whalers and the others were deployed near Tuktoyaktuk Canada and near the Alaska-Canada border.









SUMMARY. Once the ***Early spring*** migration began, tagged whales travelled almost directly through the Chukchi Sea mostly between the southern boundary of oil and gas lease sale area 193 and shore. Once past Point Barrow (***Late Spring***) they travelled directly through the Beaufort Sea to Amundsen Gulf, Canada. ***Summer*** movements occurred across the entire Beaufort Sea and included two whales that traversed the Beaufort Sea four times in the same season instead of the usual two. All tagged whales passed through lease sale area 193 after leaving Barrow in the ***Fall*** and most spent weeks along the northern Chukotka coast before entering the Bering Sea. ***Winter*** movements were concentrated in the western Bering Sea from Bering Strait to the ice edge. The success of this project demonstrates what can be accomplished when Alaska Native subsistence hunters and scientists work together.

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