

Seasonal Movements of the Bering-Chukchi-Beaufort Stock of Bowhead Whales: 2006–2011 Satellite Telemetry Results

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ABSTRACT

Fifty-seven satellite transmitters were deployed on bowhead whales from the Bering-Chukchi-Beaufort (BCB) stock between 2006 and 2010 to study their movements and behavior. In winter, bowhead whales used the western Bering Sea in areas of heavy ice with little use of open water areas. All but one tagged whale migrated past Point Barrow in spring and went to Amundsen Gulf. The remaining whale migrated up the Chukotka coast and summered in the Chukchi Sea. While most whales summered within the Canadian Beaufort Sea, extensive summer movements included travel far to the north and northeast to overlap with bowhead whales from the Baffin Bay-Davis Strait stock. Other summer movements included trips between the Canadian Beaufort and Barrow and one whale even traveled to the northern coast of Chukotka, Russia. Fall movements coincided in space and time with oil and gas activities and potentially with shipping activities. Likely important feeding areas included Amundsen Gulf in spring and summer; Barrow in summer and fall; Wrangel Island (some years) in fall; the northern Chukotka coast in fall; and the western Bering Sea in winter.

INTRODUCTION

The Bering-Chukchi-Beaufort (BCB) stock, also known as the Western Arctic stock, is one of five recognized stocks of bowhead whales that occupy Arctic waters (Moore and Reeves 1993). The BCB stock is hunted by indigenous people of Alaska and Russia and is a species highly valued for food, materials, and cultural significance. Harvest is regulated by a strike quota determined by the International Whaling Commission and locally managed by the AEWC. Although the BCB population numbers approximately 12,631 individuals (Koski et al. 2010) and is growing by 3.4% per year (George et al. 2004, Zeh and Punt 2005), the reduction of summer sea ice and other factors associated with climate change (e.g., increased oil and gas activity, shipping, and fishing) require that we know more about BCB movements, important habitats, and behavior in order to best plan shipping lanes and develop effective mitigation measures around industrial activities.

In 2005, the Alaska Department of Fish and Game (ADF&G) began a cooperative project (with the Alaska Eskimo Whaling Commission (AEWC), the North Slope Borough, and the Greenland Institute of Natural Resources; funded by Minerals Management Service, now Bureau of Energy Management) to study the BCB stock of bowhead whales, including their movements and

behavior using satellite telemetry. The project expanded to Canada in 2007 and the Department of Fisheries and Oceans and Tuktoyaktuk Hunters and Trappers became additional cooperators. The specific objectives of the project were to work with native subsistence hunters to deploy satellite tags, use satellite telemetry to identify important habitats, and to document the timing and location of movements and behavior relative to industrial activities and physical conditions (e.g., ice, bathymetry, and distance from shore). Before we began this study, general seasonal movements and their timing were best known near the coast and during the whaling seasons. However, little was known about offshore and winter movements (Fig. 1).

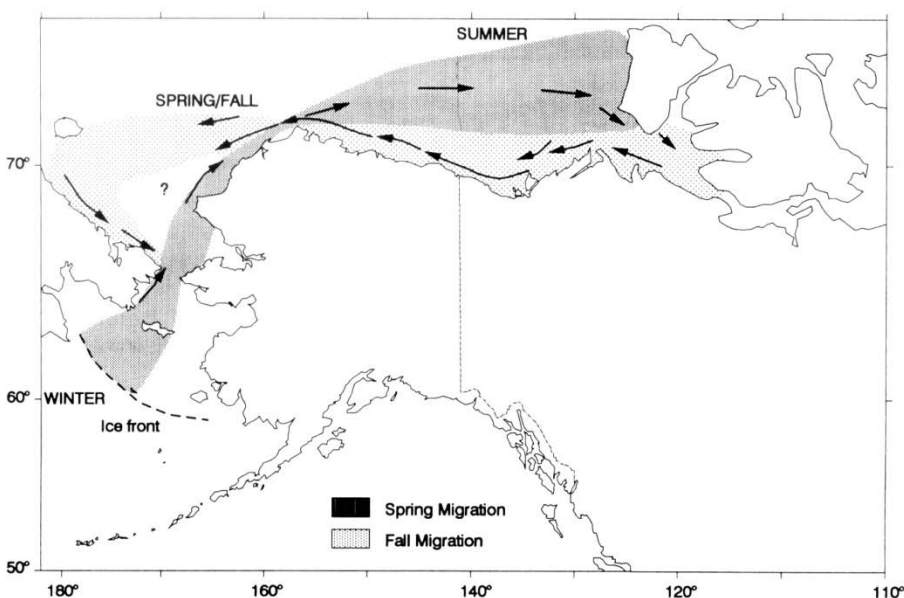


Figure 1. Generalized seasonal occurrence and migration corridor for the BCB bowhead stock depicting spring and fall pathway (Fig. 9.7, pg 337 from Moore and Reeves (1993)).

METHODS

We used satellite transmitters manufactured by Wildlife Computers (Redmond, Washington, USA) and the attachment and deployment system was developed by the Greenland Institute of Natural Resources (Heide-Jørgensen et al. 2001, 2003; Quakenbush et al. 2010a). Transmitters were placed on bowhead whales in Alaska and Canada in 2006–2010. Most of the tags were deployed by Alaskan and Canadian Native subsistence hunters and their boat drivers. Two types of tags were deployed; one that transmitted location only and one that transmitted location and diving information (Quakenbush et al. 2010a). Skin biopsies were collected either by crossbow or by a biopsy rod on the tagging pole. DNA in the skin was used to determine sex of tagged whales (Citta et al. 2012). Transmitter locations acquired from the Argos satellite system were processed using a filter developed by Freitas et al. (2008). Bowhead whale locations that resulted in swim velocities of over 1.94 m/s were removed unless they were within 5 km of the previous location. The threshold velocity of 1.94 m/s is the maximum observed migration speed of bowheads not fleeing vessels or assisted by currents (e.g., Zeh et al., 1993). The filter also has an angular component to account for locations with a high degree of location error that often fall far from the line of travel, forming acute angles between adjacent locations. We used default

settings to define the angular components of the filter; within 2.5 km of the track line, locations resulting in angles less than 15° were removed and locations between 2.5 and 5 km of the track line were removed if they resulted in angles under 25°. We then removed locations that fell on land to establish the final set of locations used in our analyses. In order to show areas of concentrated use we used kernel density estimation (Worton 1989, Wand and Jones 1995). Following Quakenbush et al. (2010a), we selected a bandwidth matrix for each whale using Smoothed Cross-Validation (SCV; Duong and Hazelton 2005, Duong 2007).

RESULTS AND DISCUSSION

Fifty-seven satellite transmitters were deployed between 2006 and 2010. Thirty-seven were deployed near Point Barrow, Alaska (7 in spring, 30 in fall), and 20 were deployed near the Mackenzie River Delta, Canada in fall. Twenty of the tags transmitted location only and 37 also transmitted dive information. Sex was determined for 37 of the 57 tagged whales; 15 females and 22 males.

Satellite transmitters have allowed us to track bowhead whale movements and identify high use areas throughout their annual cycle. We have documented variability among years and observed unexpected movements; these data indicate that the summer range of BCB bowhead whales is larger than previously believed. We have also documented movements and behavior within the Bering Sea, where the range of bowhead whales was least understood (Citta et al. 2012). Here we provide details about the distribution and movements of tagged bowhead whales during the winter, spring, summer, and fall.

Winter. Tagged bowhead whales moved south from the Chukchi Sea into the Bering Sea between November and mid-January (Citta et al. 2012). All but one tagged whale passed west of Big Diomed Island, Russia (Fig. 2), and St. Lawrence Island, Alaska (Fig. 3) as they migrated southward. In 2008/2009 most whales remained offshore of the Gulf of Anadyr until the end of March (Fig. 3). During the winter of 2009/2010, bowheads also used the area between Saint Lawrence Island and Saint Matthew Island and areas northwest and southwest of Saint Matthew Island (Citta et al. 2012). During both winters there was no use of the eastern Bering Sea (Fig. 3).

Tagged whales used offshore areas of heavier, yet fractured, ice despite the availability of areas with open water near shore (Figs. 4 and 5). Within a random sample of bowhead locations, only 1 of 102 locations (i.e., ~1%) fell within an open water area (polynya) during the winter of 2009/08 (Citta et al. 2012). Only 3 of 53 locations (~6%) fell within polynyas during the winter of 2009/10. Figure 6 shows the locations of seven tagged bowhead whales relative to ice and open water areas on 6 March 2009.

We analysed 889 dive intervals (6-hr) and in all but five intervals (99.4%) tagged whales dove to the bottom at least once (Fig. 7). Water depths in the area ranged from 25 to 300 m (Quakenbush et al. 2010b). Such frequent use of the bottom may indicate feeding on an overwintering layer of copepods or euphausiids.

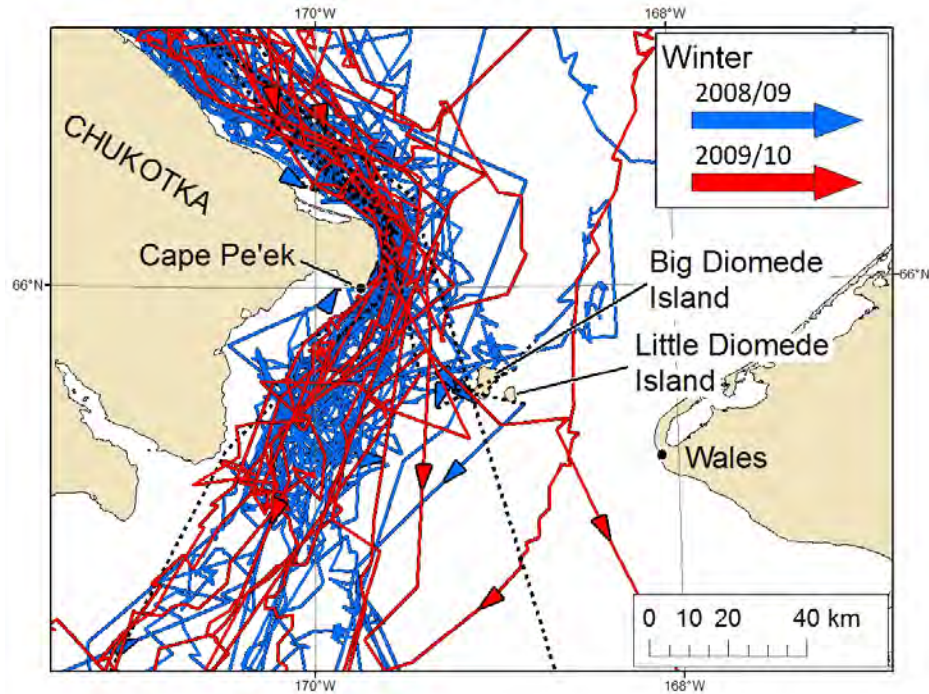


Figure 2. Tracks of tagged bowhead whales moving south through Bering Strait into the Bering Sea during the winters of 2008/09 ($n=11$) and 2009/10 ($n=10$). Dotted lines indicate connected locations that crossed landforms.

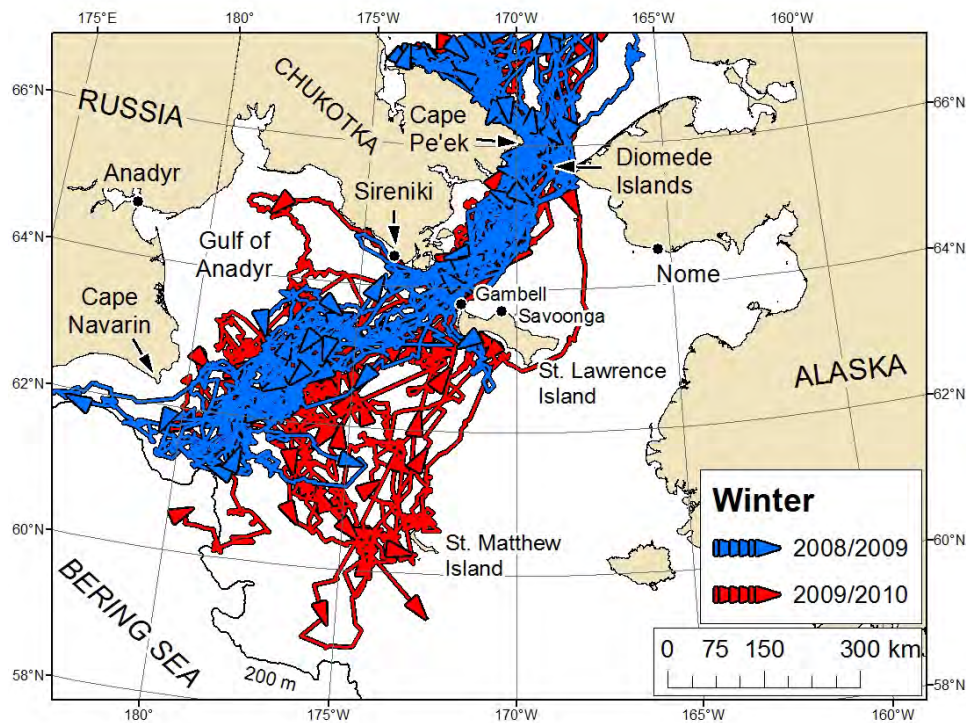


Figure 3. Tracks of tagged bowhead whales within the Bering Sea during the winters of 2008/09 ($n=11$) and 2009/10 ($n=10$).

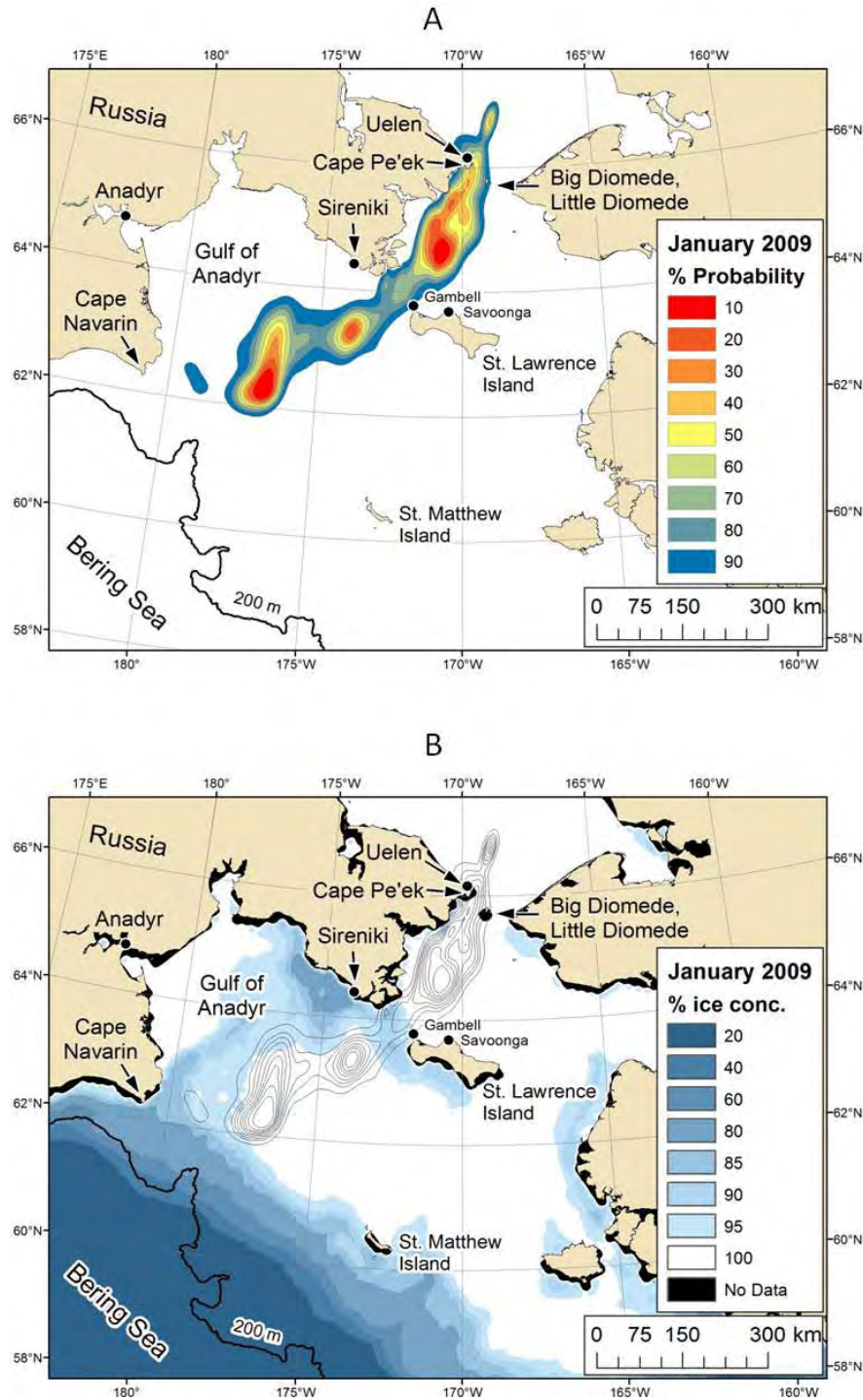


Figure 4. Contours showing probability of use (%) by bowhead whales and average AMSR-E ice concentration in January 2009. The ice concentration maps include non-shaded contours for probability of use, illustrating how probability of use overlaps ice concentration.

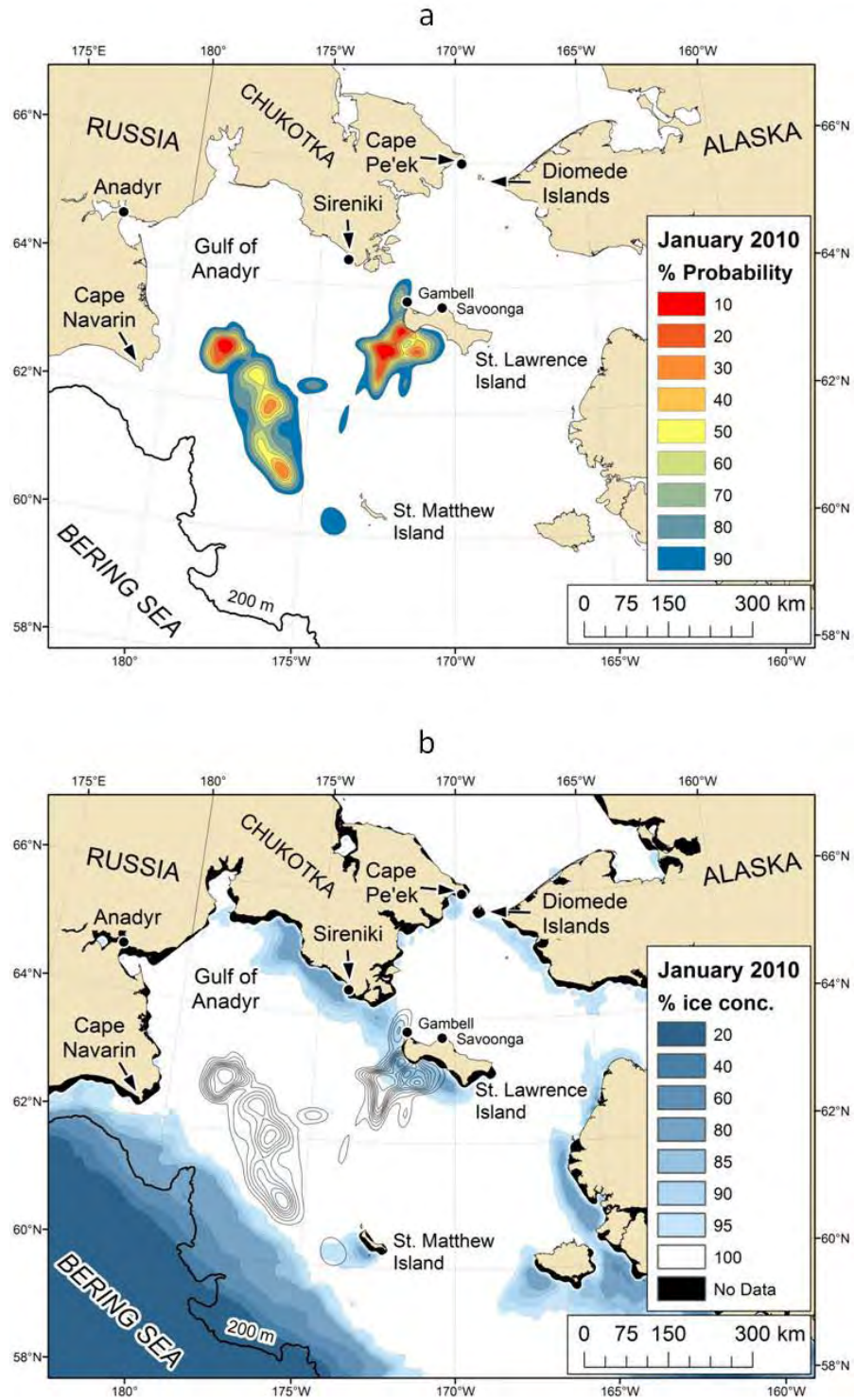


Figure 5. Contours showing probability of use (%) by bowhead whales and average AMSR-E ice concentration in January 2010. The ice concentration maps include non-shaded contours for probability of use, illustrating how probability of use overlaps ice concentration.

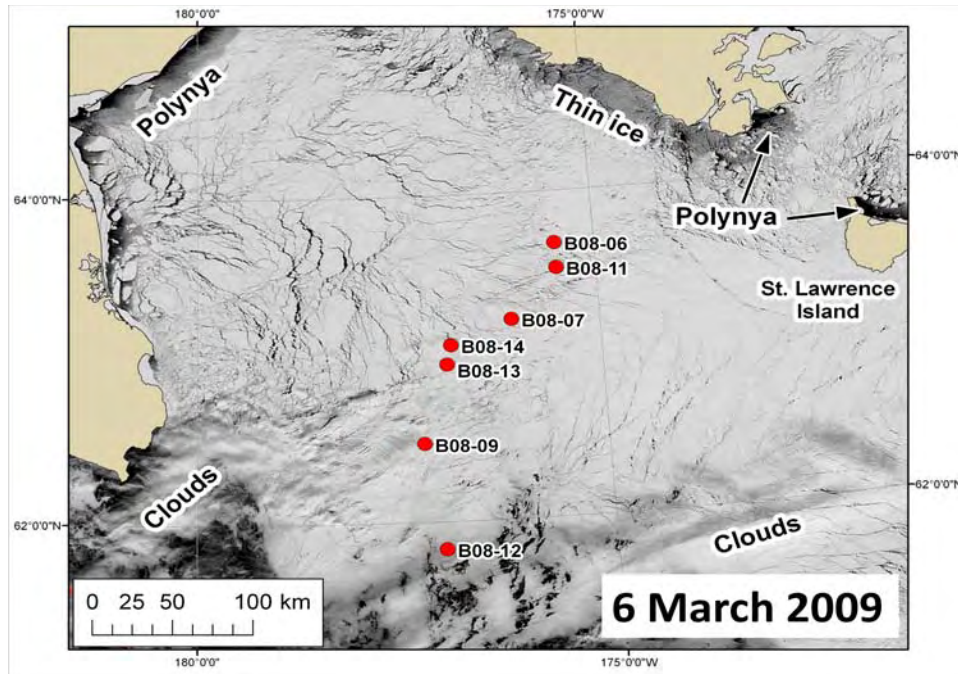


Figure 6. Locations of satellite-tagged bowhead whales (red circles) in March 2009 relative to open water areas (polynyas).

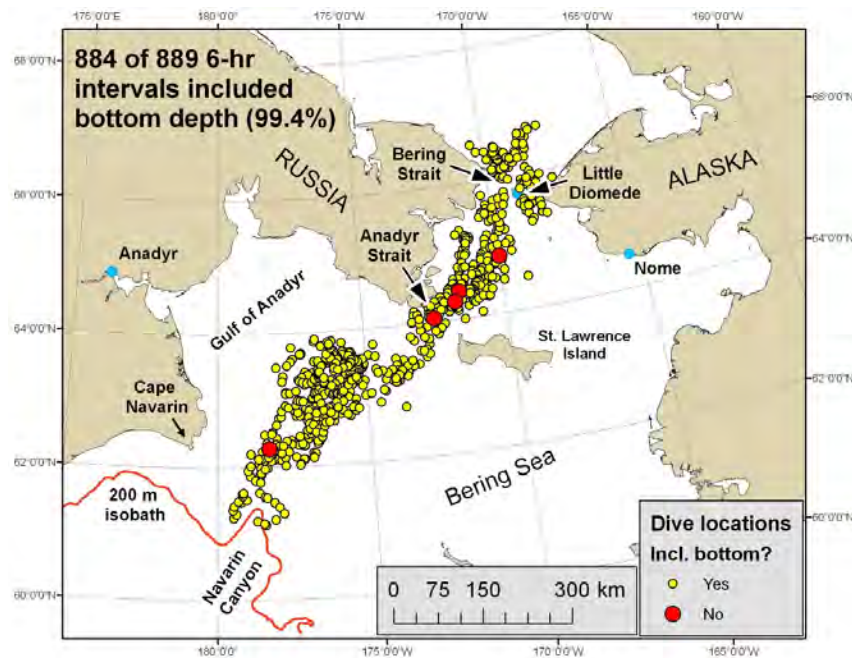


Figure 7. Tagged bowhead whale locations in the Bering Sea between January and April 2009 for which there are dive data. Red circles represent the only locations where a bowhead whale did not dive to the bottom during a 6-hr period. Nearly all dive intervals (99.4%) included the bottom.

Entanglements in fishing gear are a potential source of mortality for large whales. Commercial pot fisheries occur in the Bering Sea in winter. Direct overlap with fishing rarely occurs currently; however, 10% of the bowhead whales harvested at Barrow have rope scars indicating that some whales do encounter and entangle in gear, possibly lost gear (Reeves et al. 2012, Citta et al. 2011, North Slope Borough, unpublished data).

Spring. Tagged bowhead whales left the Bering Sea between 31 March and 27 April in 2009 ($n=7$). In 2010, 5 of 6 tagged bowhead whales left the Bering Sea between 10 and 22 April. One whale (B09-09) migrated much later (26 May). Prior to reaching the strait all tagged whales traveled north by passing west of Saint Lawrence Island. In the Bering Strait whales passed by both to the east ($n=8$) and to the west ($n=3$) of the Diomedede Islands (Fig. 8) and three whales did not transmit often enough when passing to determine where they passed the Diomedes (Citta et al. 2012).

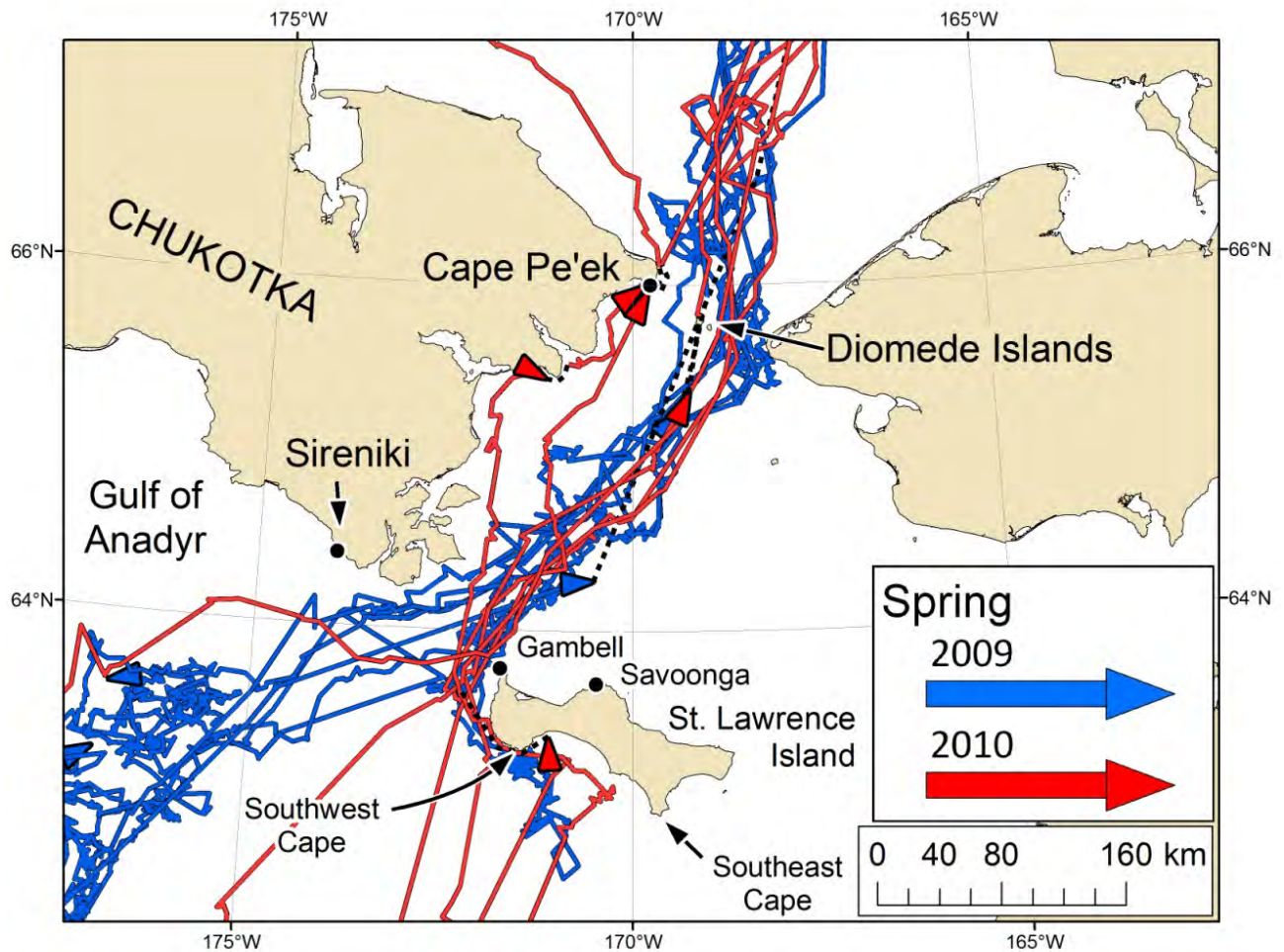


Figure 8. Tracks of tagged bowhead whales moving north through Bering Strait into the Chukchi Sea in April 2009 ($n=8$) and 2010 ($n=6$).

The tracks northward to Point Barrow varied in distance from shore but most traveled on the U.S. side of the International Dateline (Fig. 9). A total of 12 tagged bowhead whales passed the spring bowhead survey station (i.e., “the observation perch”) near Point Barrow; five bowhead whales passed between 16 April and 7 May in 2009, four passed between 23 April and 1 May in 2010, and three passed between 19 April and 5 May in 2011. Half of the tagged whales (6 of 12) passed the observation perch when leads were closed and whales could not be visually counted by observers. Leads were closed when one whale passed in 2009 (Fig 10a), when three passed in 2010 (Fig. 10b), and when two passed in 2011. The distance offshore that the whales migrated from the survey station cannot be measured precisely, as transmissions are opportunistic and locations are generally not collected perpendicular to the perch. However, it was clear that all tagged whales migrated within 20 km of the observation perch (Citta et al. *In prep.*), which is approximately the maximum distance that hydrophones can detect calling whales. Hence, whales that passed the survey station while leads were closed could not have been detected by visual observation, but were likely available for detection by acoustic recorders.

Bowhead whales traveled 6–18 km north of Point Barrow before turning east to cross the Beaufort Sea. The route used by a whale in 2006 was farther north than that used by seven whales in 2009 (Fig. 11). In 2009, all whales used a similar route, despite not traveling together. In 2010, however, two of eight whales used a similar route to the 2006 whale while the other six used a route similar to the 2009 whales. All tagged whales migrated to Amundsen Gulf, Canada. In 2006, the one tagged whale arrived in Amundsen Gulf on 26 May, in 2009, six arrived between 3 and 20 May, and in 2010 eight arrived between 5 May and 13 June.

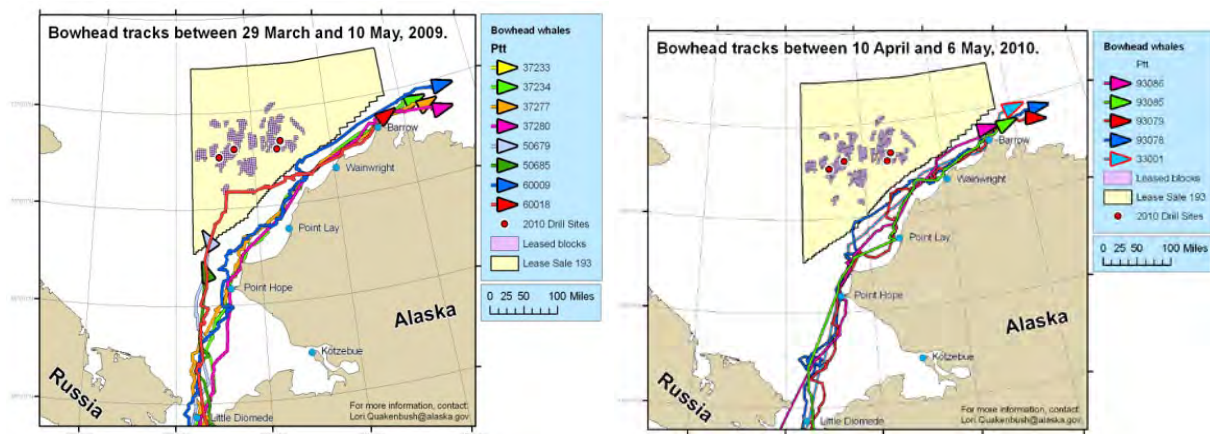


Figure 9. Tracks of tagged bowhead whales on spring migration through the Chukchi Sea in late March through early May, 2009 and 2010.

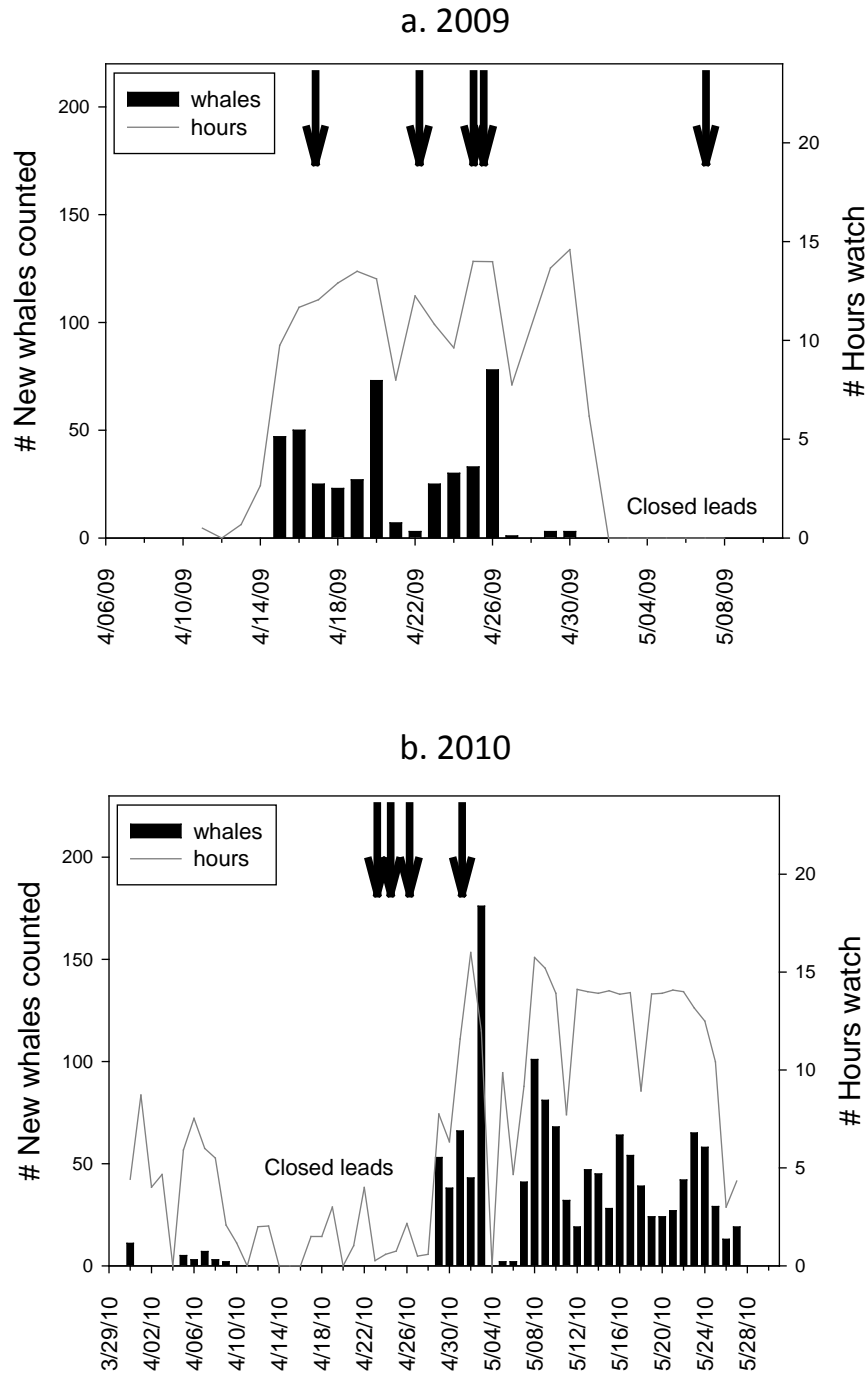


Figure 10. Date of passage for whales with tags and the number of whales counted during the spring survey of BCB bowhead whales at Barrow in a) 2009 and b) 2010. Arrows indicate when tagged whales passed the survey location. Bars indicate the number of whales counted and the line indicates the number of hours observers were on watch.

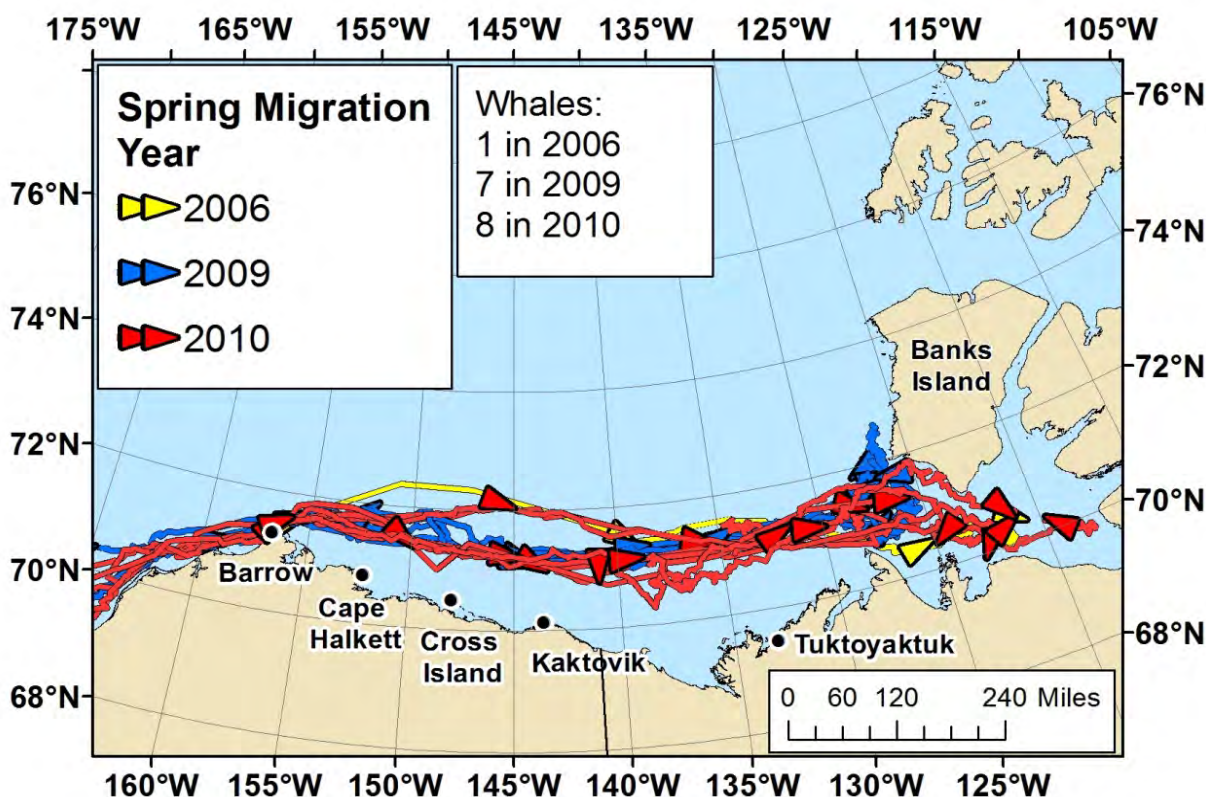


Figure 11. Tracks of tagged bowhead whales on spring migration through the Beaufort Sea in May 2006, 2009, and 2010.

One tagged whale (B09-09) migrated a month later than other whales, passing Cape Pe'ek on 26 May (Fig. 12). This was the only tagged whale that did not migrate to the Beaufort Sea. Although this whale was tagged near Point Barrow on 29 August 2009; it did not return to Point Barrow the following spring, but summered along the northern coast of Chukotka and was ~160 km northwest of the Diomed Islands on 21 August 2010 when the tag stopped transmitting. We do not know where B09-09 summered prior to being tagged near Point Barrow in 2009. In 2010, we think it unlikely that this whale returned to Point Barrow prior to the fall migration after the tag stopped transmitting. Thus, we suggest some whales may not return to the same summering area each spring.

In 2001, Melnikov and Zeh (2007) counted 470 (95% CL 332 to 665) bowhead whales passing Cape Pe'ek, near Uelen, Russia (Fig. 12), between 23 May and 14 June. The spring migration past Point Barrow was believed to be over by 7 June 2001 (George *et al.*, 2004). Based upon travel velocities observed by Melnikov and Zeh (2007), few of the whales observed at Pe'ek in June could have migrated past Point Barrow before 7 June. As such, Melnikov and Zeh (2007) suggested that the whales they observed were migrating to the Chukchi Sea, not the Canadian Beaufort. Based upon the movements of B09-09, it is clear that some whales do not migrate past Point Barrow every year in spring and that spring migration counts near Barrow (e.g., Zeh *et al.* 1993, George *et al.* 2004) do not count the entire BCB stock.

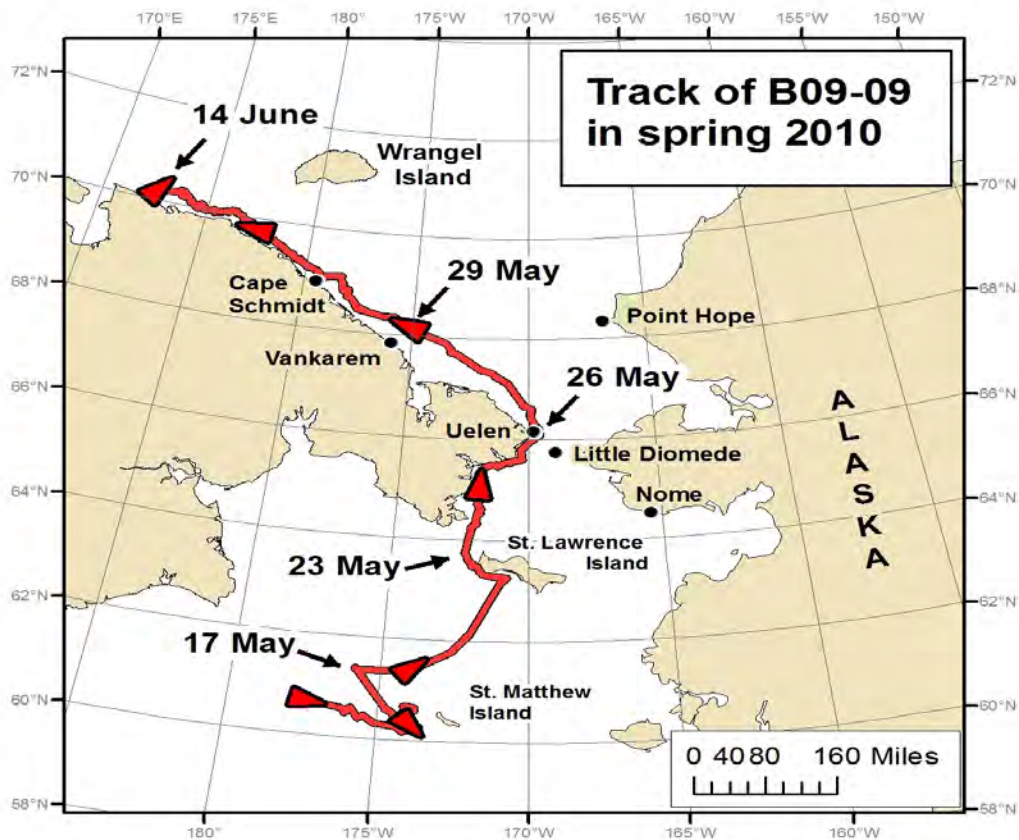


Figure 12. Track of the only tagged whale that did not migrate through the Beaufort Sea to Amundsen Gulf during this study.

Summer. Tagged bowhead whales used the Canadian Beaufort Sea and Amundsen Gulf as far east as Ulukhaktok, NWT (formerly Holman, 117.75° W. Longitude) during spring and summer (May–mid-September; Fig. 13). Although not all tagged whales stayed in this area all summer. One whale remained within Amundsen Gulf from 26 May until 3 August and then again from 14 August to 17 September (Figs. 13 and 14). Between 3 and 14 August, this whale left Amundsen Gulf and traveled to the north end of Banks Island before returning (Quakenbush et al. 2010b, Heide-Jørgensen et al. 2011). 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, Quakenbush et al. 2010b).

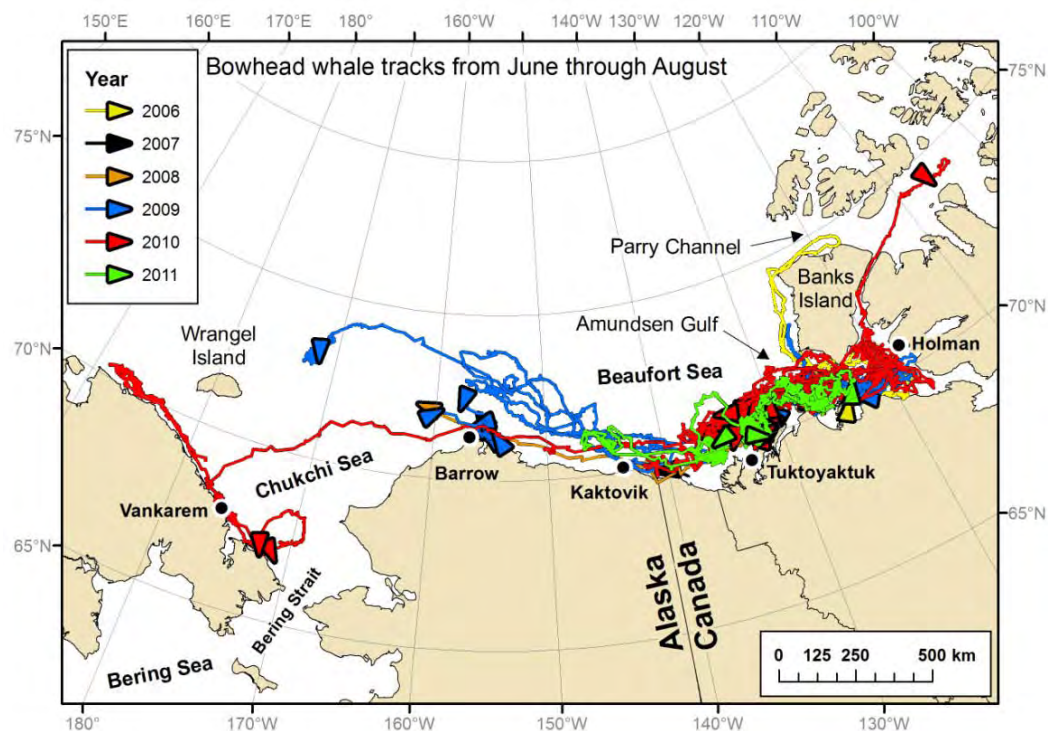


Figure 13. Summer (June–August) movements of tagged whales in 2006, 2008, 2009, not 2010.

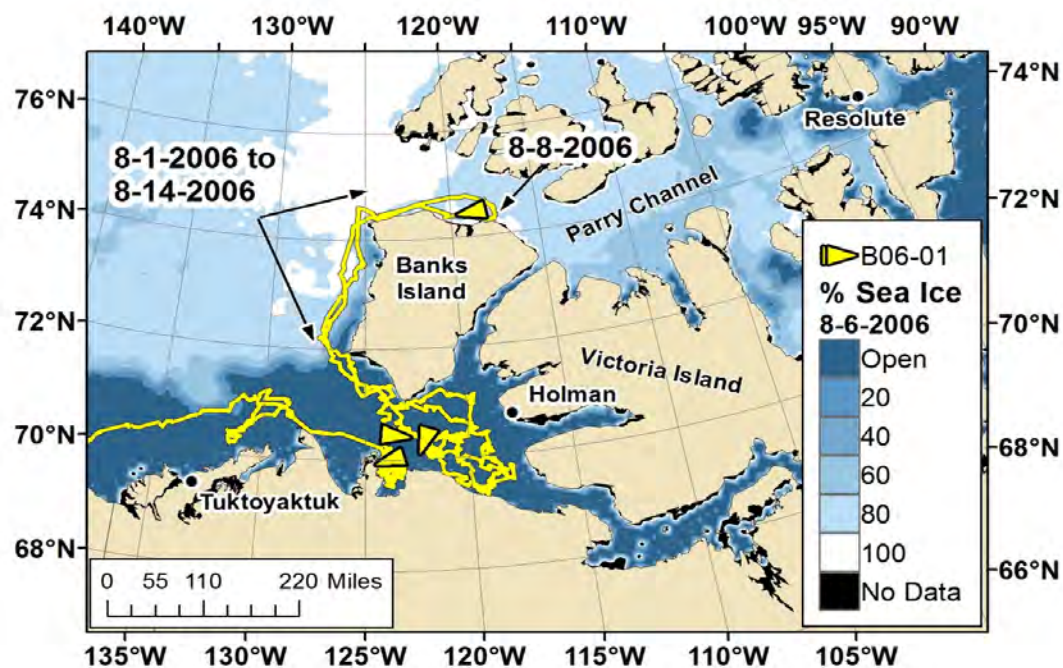


Figure 14. Summer movements of one tagged whale that traveled north of Banks Island in August 2006.

In August 2010, a whale tagged near Barrow in 2009 traveled north through the Prince of Wales Strait between Banks and Victoria islands and then east to spend about two weeks in Viscount Melville Sound, a main route of the Northwest Passage. Interestingly, a whale tagged in West Greenland also went north but then west to the same area arriving a few days after the Alaskan whale had left (Fig. 15). Although, both whales returned to their respective ranges later in September (Heide-Jørgensen et al. 2011), these movements indicate that the two stocks can intermingle in summer.

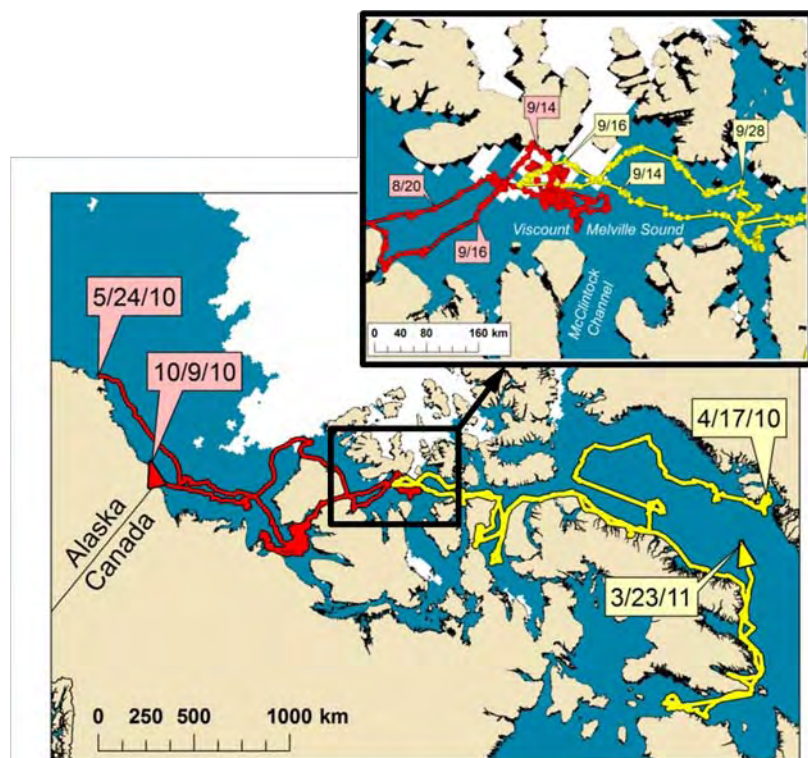


Figure 15. Tracks of two bowhead whales that entered the Northwest Passage in September 2010. One tagged whale from the Bering-Chukchi-Beaufort stock traveled north and east while a second tagged whale from the Baffin Bay-Davis Strait stock traveled north and west to Viscount Melville Sound.

Other unexpected movements occurred in summer 2009. One tagged whale (B08-07) left Amundsen Gulf on 1 June, crossed into the Alaskan Beaufort Sea on 7 June, and traveled west about 150 km offshore of Barrow, arriving there on 11 June. B08-07 remained offshore of Barrow until 14 July, when it returned to the Canadian Beaufort Sea until migrating back towards the Chukchi Sea on 29 July (Fig. 16). Another tagged whale B08-12 made a similar summer transit of the Beaufort Sea from Canada to Barrow and back to Canada in August 2009. This whale left Amundsen Gulf on 21 July, arrived offshore of Barrow on 8 August, and then crossed back into the Canadian Beaufort on 20 August (Fig. 16). In 2010, one whale traveled back toward Barrow, leaving Canada on 13 July, but continued past Barrow on 21 July and was on the Chukotka coast by 28 July (Fig. 16). This whale came within 100 miles of B09-09, the whale that stayed along the coast of Chukotka all summer (Fig. 12).

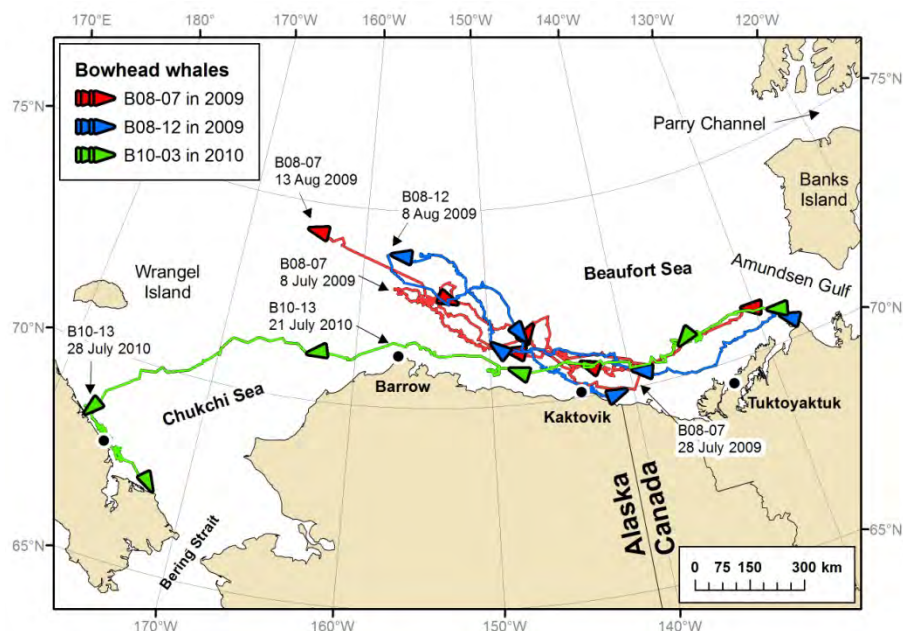


Figure 16. Tracks of two tagged bowhead whales that transited the Beaufort Sea in summer 2009 (red and blue) in addition to the spring and fall migrations, and one whale that migrated across the Chukchi Sea in summer 2010 (green).

Fall. Dates by which tagged whales left the Canadian Beaufort Sea in fall ranged from 14 July to 25 October. Most of the westward tracks across the Beaufort Sea were over the shelf and within 100 km of shore; however, one whale in 2006 and one in 2009 traveled farther offshore than the others (Fig. 17). Fall tracks were notably closer to shore than in spring (Fig. 18).

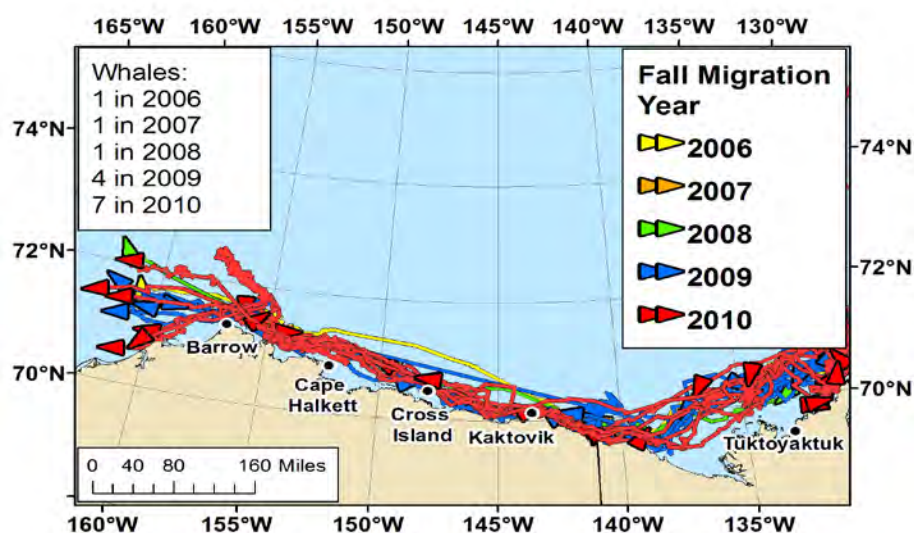


Figure 17. Tracks of tagged bowhead whales traveling westward across the Beaufort Sea during fall migration.

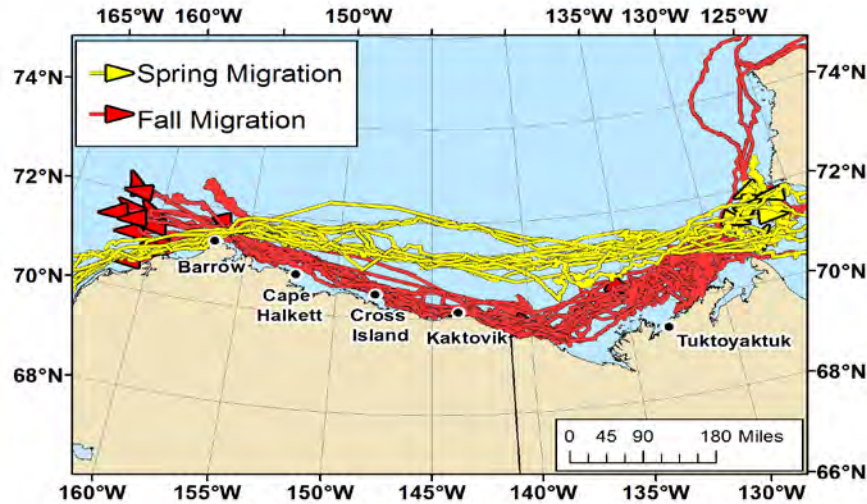


Figure 18. Tracks of tagged bowhead whales in spring (yellow) superimposed on tracks of tagged bowhead whales in fall (red) for all years showing that spring migration occurs farther from shore than in fall.

Whales passed Point Barrow during the fall migration between 21 July and 2 November. This range of dates does not include whales tagged near Barrow in the same season, as this tagging only occurs prior to or after the fall hunting season concludes. Hence, we only considered whales that were tagged in Canada or at Barrow in a prior season or year. The median date of passage was 10 October ($n=15$; all years pooled). Once past Barrow, most tagged bowhead whales traveled across the Chukchi Sea to Wrangel Island, and then south to the Chukotka coast (Fig. 19) where most remained until December when they entered the Bering Sea (Quakenbush et al. 2010a). A few whales circled back to Barrow before continuing on their migration (See Figure 3 of Quakenbush et al. 2010a).

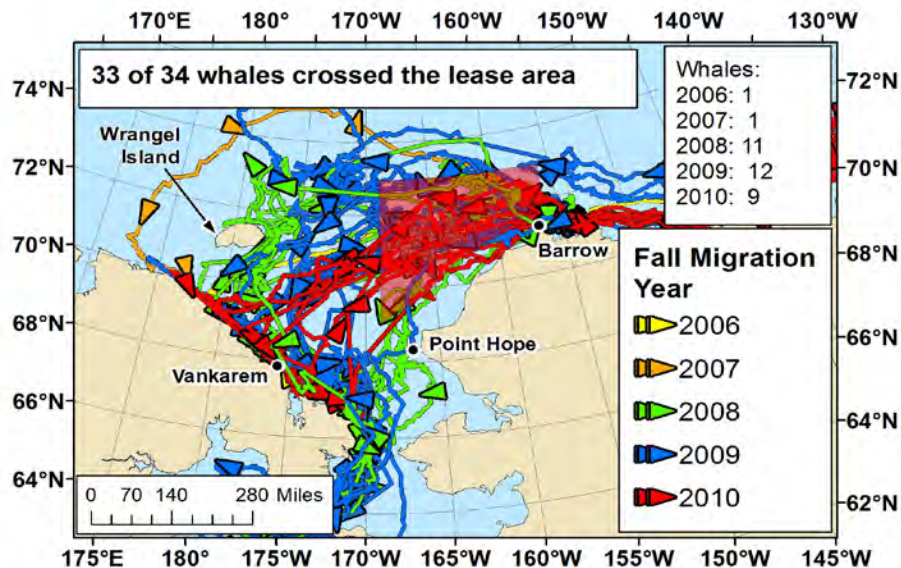


Figure 19. Tracks of 32 satellite-tagged bowhead whales in the Chukchi Sea from August through December, 2006–2010.

Areas where tagged bowhead whales spent the most time during the fall migration included Point Barrow, Wrangel Island, and along the northern coast of Chukotka, from Cape Schmidt to Uelen (Fig. 20). These areas should be considered important habitats for feeding given our data (Quakenbush et al. 2010a) and the observations of others (Moore et al. 1995, Zelensky et al. 1995).

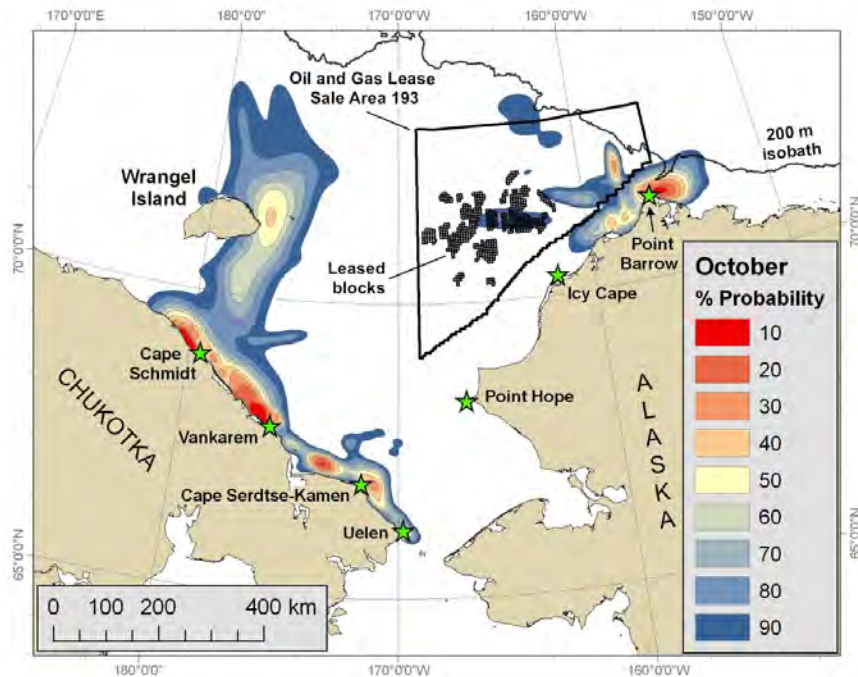


Figure 20. Kernel density contours showing the probability of use (%) by bowhead whales in October, 2006–2008. This is Figure 5 in Quakenbush et al. 2010a.

Although the routes taken across the Chukchi Sea were annually variable, the use of the Russian coast of Chukotka was consistent (Fig. 21). The area immediately adjacent to Wrangel Island was used in 2008 while an area north and east of there was used in 2009 and Wrangel Island was bypassed altogether in 2010 (Fig. 21). On the contrary, the area within 80 km of the Chukotka coast was used each year and 30 bowhead whales spent an average of 26.6 days between Cape Schmidt and Uelen between September and December. Together the consistent use and the long residence time indicate that this is an important area, probably for feeding.

Interactions with Industrial Activities. There was considerable inter-annual variability in the routes tagged bowhead whales used to cross the Chukchi Sea, however, the size and location of an oil and gas lease area in the U.S. Chukchi encompassed all but one of the satellite-tagged whale tracks leaving Barrow in the fall (Figs. 19 and 21). Industrial activities are more concentrated in the blocks that have been leased, which occur in a more restricted area of the total lease area.

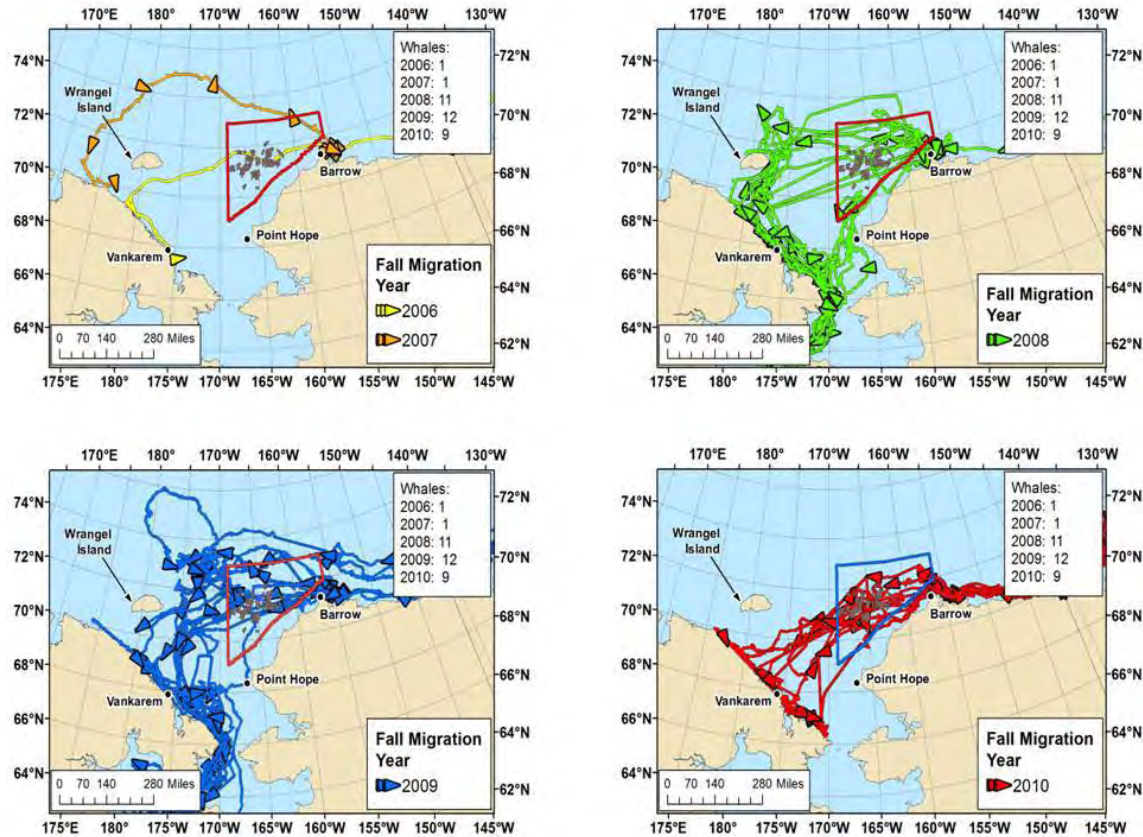


Figure 21. Tracks of satellite-tagged bowhead whales showing different paths across the Chukchi Sea by year but consistent use of the Russian coast in August through December, 2006 through 2010. The oil and gas lease sale area is outlined in red (or blue) and the leased blocks appear inside the outline in gray.

The areas of interest for oil and gas activities coincide in time and space with the major bowhead summer feeding area near the Tuktoyaktuk Peninsula in Canada (Fig. 22) and along the fall migration corridor in the Alaskan Beaufort Sea and in the Chukchi Sea. For example, one tagged whale went through four active industrial areas in 2006, two of which were conducting seismic operations when the whale passed by (Fig. 23).

Commercial shipping in the Arctic is expected to increase as sea ice decreases. Both shipping routes, the Northern Sea Route along the northern Russian coast, and the Northwest Passage through the Canadian Archipelago, will go through Bering Strait. The entire population of BCB bowhead whales (>12,000 individuals) passes through Bering Strait each spring and fall between wintering and summering areas. As such, Bering Strait is an area of concern for interactions with ship traffic (Reeves et al. 2012). Ships traveling on the west side of the Diomedes and along the Chukotka coast between October and December could encounter a high proportion of the population (Figs. 2 and 20). Ship strikes in the Atlantic are the greatest source of mortality for right whales (*Eubalaena glacialis*; Moore et al. 2004). It is thought that bowhead whales may be as vulnerable to ship strikes as Atlantic right whales, due to their swimming speed and feeding behavior (Reeves et al. 2012); however, bowheads are known to be more sensitive and difficult to approach during migration (Richardson 1999).

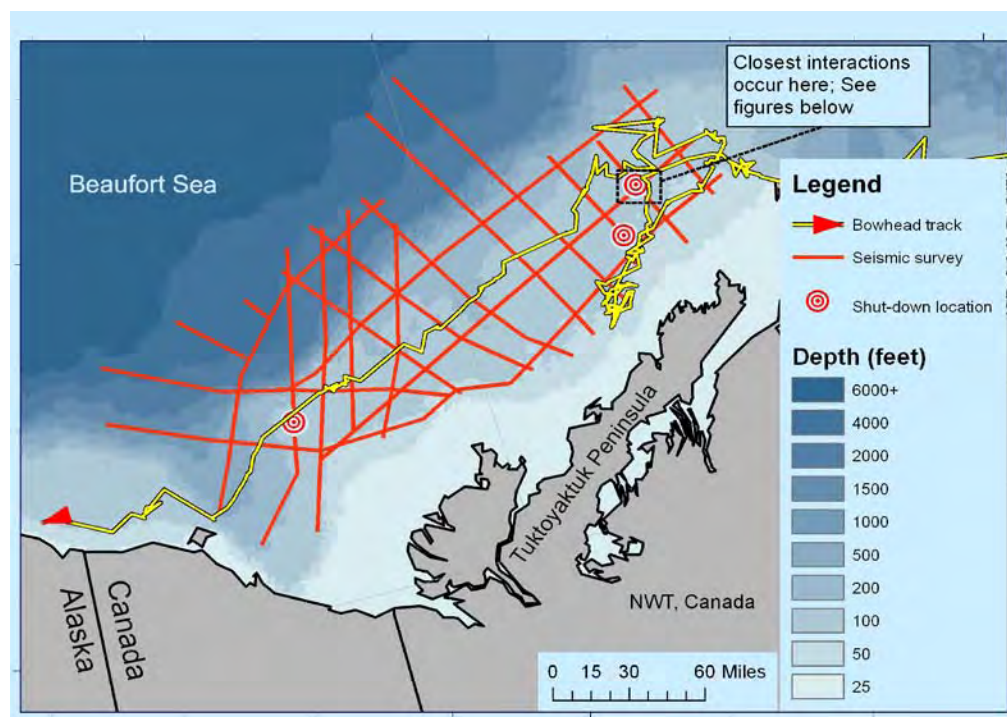


Figure 22. Tracks of a tagged bowhead whale (yellow line) within a marine seismic operation in the Canadian Beaufort Sea in 2006.

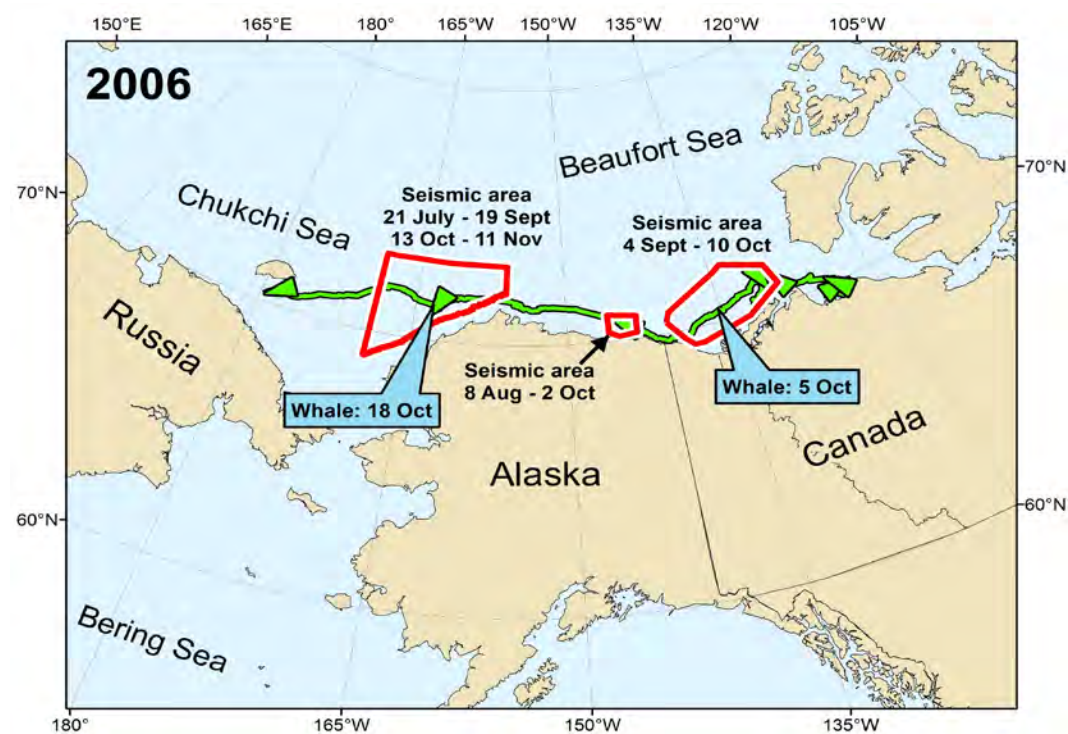


Figure 23. Track of a tagged bowhead whale and active industrial areas in 2006.

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

- 1) wintering areas, movements and behavior in the Bering Sea;
- 2) whales that did not pass Barrow on the spring migration, summered in the Chukchi Sea, and were not counted during the spring ice-based surveys;
- 3) extensive summer movements include travel far to the north and northeast overlapping with bowheads from the Baffin Bay-Davis Strait stock, summer travel between Canada and Barrow, and summer travel between Canada and Russia, in addition to the spring and fall migrations;
- 4) fall movements coincided in space and time with industrial activities (i.e., oil and gas, potentially shipping)
- 5) areas with long residence time indicate probable feeding areas; these areas include: Amundsen Gulf, Barrow, Wrangel Island (some years), the Chukotka coast, and possibly the Bering Sea; and
- 6) annual variability in migration routes and timing.

This telemetry study was not designed to address stock segregation, and our tagging locations were not optimal for such an analysis. Nevertheless, none of the movements from tagged whales suggest a multi-stock condition exists within BCB bowhead whales. The one whale that did not pass Barrow in the spring and instead summered in the Chukchi Sea was tagged near Barrow in August the previous year. This behavior suggests that individuals may change their summer areas from year to year, possibly due to their reproductive condition. For the two BCB whales that traveled into the range of the Baffin Bay-Davis Strait stock, both did so during the non-breeding season and both returned to their stock's range in fall prior to the normal fall migration.

Using the information from this study, an updated map of the seasonal occurrence and migration corridors of BCB bowhead whales is shown in Figure 24.

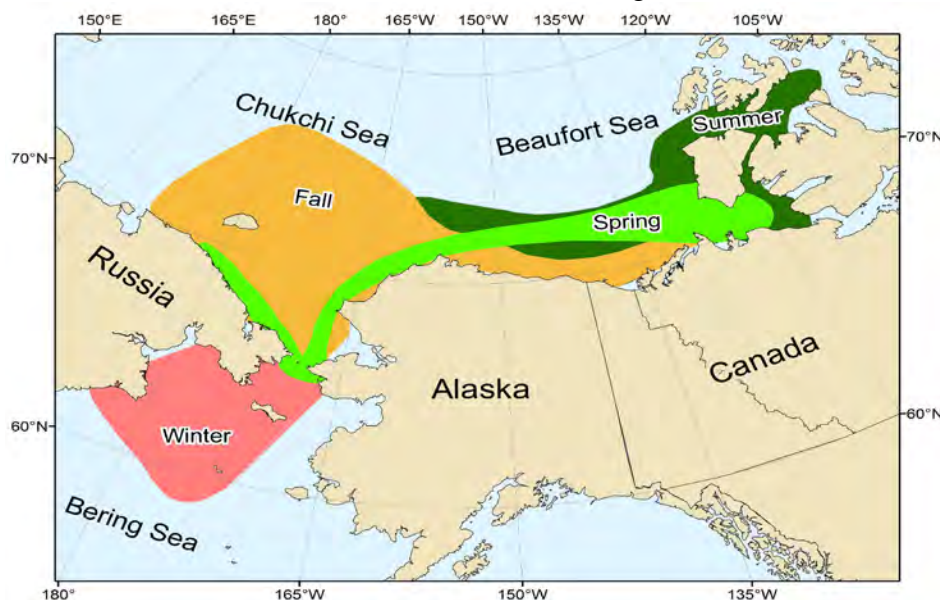


Figure 24. Generalized range of the BCB bowhead whale, as inferred from this study.

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