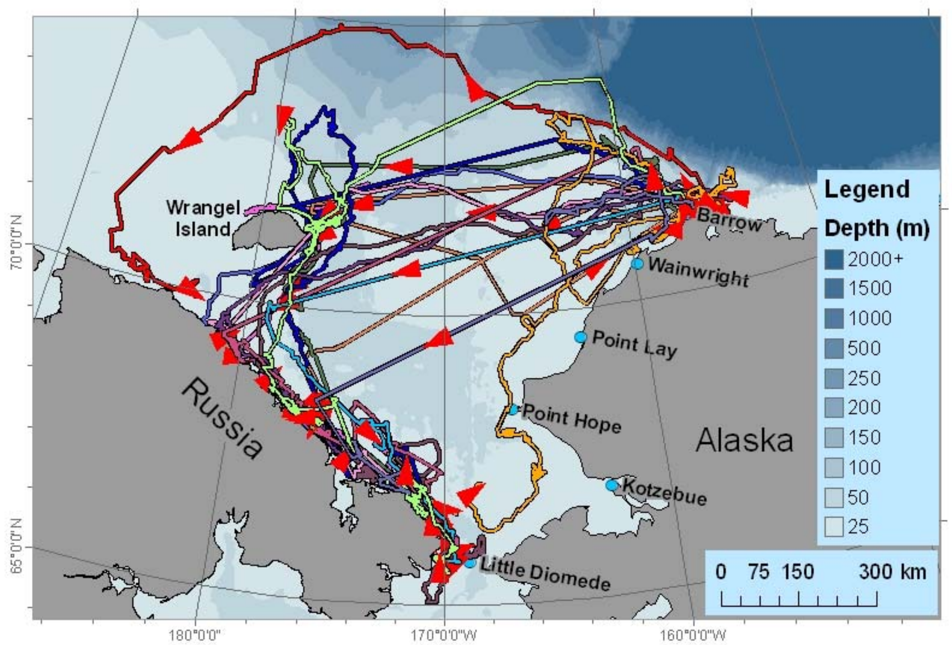
Summary maps of fall movements of bowhead whales in the Chukchi Sea

To describe whale movements across the Chukchi Sea, we use a combination of maps that show either track lines (i.e., maps that "connect the dots") or kernel densities:

Track lines:

Track lines are most useful for identifying where whales crossed the Chukchi Sea. The first map (Figure 1) shows a summary of the track lines for all whales that crossed the Chukchi Sea (*n* = 20 whales). However, track lines do have some limitations. Note that we received few locations for some whales as they crossed the Chukchi. These track lines can be identified in the map based upon how many "zig-zags" there are in the track line. For whales with few locations, the tracks appear to be very straight, because we are connecting locations that are separated by large distances. We do not know exactly where these whales crossed the Chukchi.

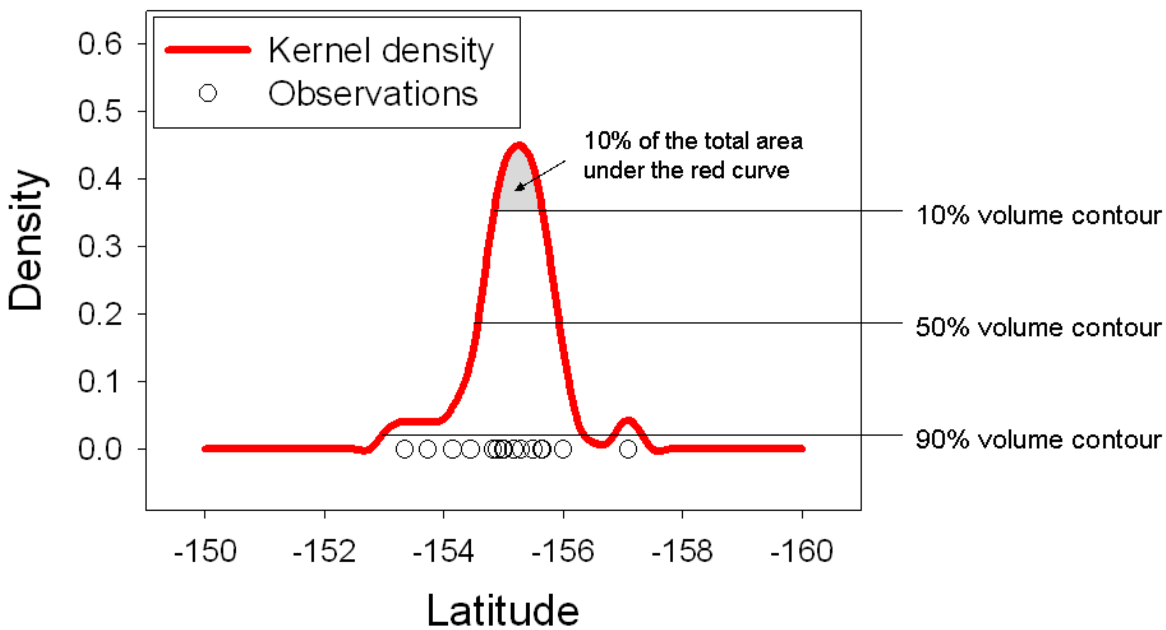
Figure 1. Track lines of bowhead whales in the Chukchi Sea in the fall.



Kernel densities:

To describe the general distribution of whales within the Chukchi Sea by month, we summarized the locations of tagged whales (*n* = 18 whales) with a "kernel density" (e.g., Silverman 1986; Worton 1989; Wand and Jones 1995). Kernel densities are simply maps that show "hot spots" of whale locations. Kernel density estimation takes a series of locations and then fits a probability density (usually a normal distribution) to each location. These distributions are summed to generate an overall probability density. It is easiest to think of these densities as "concentrations". As an example, assume we have a set of bowhead locations that are centered on -155 degrees longitude; these locations are represented by the hollow circles in Figure 2 and the resulting kernel density is the red line. Areas of high use have high density or concentration. We can describe areas of concentration by examining the volume under the density curve (i.e., the red line). For example, in Figure 2, the region with the highest density or the most concentration is within the 10% volume (Figure 2). In words, 10% of the curve's area occurs above this line. In two dimensions (latitude and longitude), we can show the different percentage volumes as contours, much like a topographical map. We color coded our density maps with red areas showing the highest densities (10% volume contour) and blue areas showing the lowest densities (90% volume contour).

Figure 2. Schematic showing a one-dimensional kernel density.



A kernel density is easier to interpret than visually examining separate track lines or scatter plots of whale locations. As such, a kernel density only indicates areas where whales spend the majority of their time and inferences regarding the importance of different areas must be made with caution. For example, low density areas might be very important for migration. **As such, the kernel density maps are useful for identifying potential feeding areas but are inappropriate for identifying migration corridors.** The track lines are more appropriate for identifying migration corridors.

A complete description of our methods will be contained in an upcoming manuscript; however, a brief description is warranted. We first filtered the raw Argos locations based upon velocity and the angles between series of locations (see Freitas et al.

2007, 2008). We then filtered locations that fell on land. Transmitters lasted different periods of time and did not transmit with equal frequencies. Hence, transmitters provided differing amounts of information regarding fall movements. To help standardize the contributions of separate whales through time, we split the day into four six-hour long periods. Within each time period we selected the location with the highest quality code. When multiple locations had the same location quality code, we selected the location that was transmitted the earliest within the time period, thereby spacing the locations over time. While this helped space locations throughout the day and equalized the contribution of information from tags that differed in daily transmission frequency, it did not account for tags that lasted a different number of days. To account for differences in tag life we weighted the contribution of individual whales by the number of locations used to compute the kernel density for each whale. We first computed a kernel density for each whale within each month. For each whale's density, we then removed cell probabilities on land that were greater than zero. We did this by multiplying each whale's cell density by a separate density that was coded 1 for water and 0 for land. We then rescaled the density so it integrated to 1. The kernel density within each grid cell was then multiplied (i.e., weighted) by the proportion the data from that month that was contributed by that whale. The cell densities for each whale were then summed to generate an single density for all whales. The kernel densities were computed using package "ks" (Duong 2007a, 2007b) in R version 2.5.1 (R Development Core Team 2007). We used Smoothed Cross-Validation (SCV) to estimate the bandwidth, as described by Duong and Hazelton (2005). Kernel densities for each month are in Figures 3-6.

Although this is the best information available on the fall distribution of whales in the Chukchi Sea, these densities should be considered preliminary. Whales that we didn't tag may have behaved differently. For example, we know that subsistence whalers observed whales near St. Lawrence Island approximately one month before any of the tagged whales were observed that far south. Hence, we know that whales are spending time outside of the current range of our kernel densities.

For more information, contact Lori Quakenbush at the Alaska Department of Fish and Game; 907-459-7214; lori.quakenbush@alaska.gov.

Figure 3. Kernel density of bowhead whale locations in September.

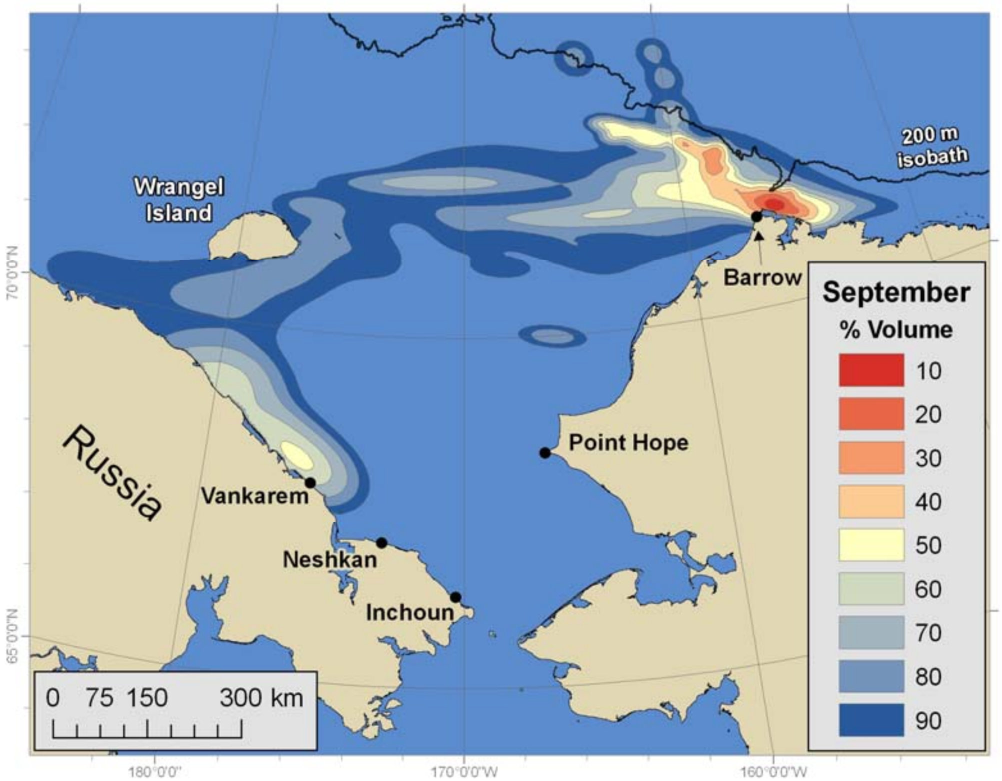


Figure 4. Kernel density of bowhead whale locations in October.

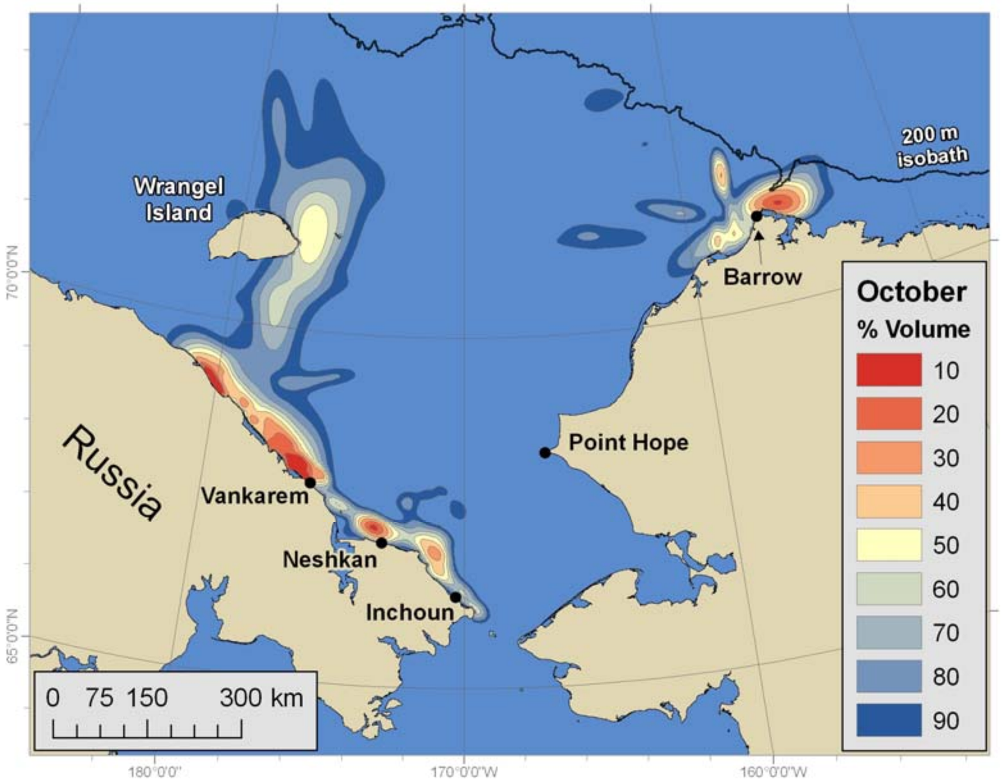


Figure 5. Kernel density of bowhead whale locations in November.

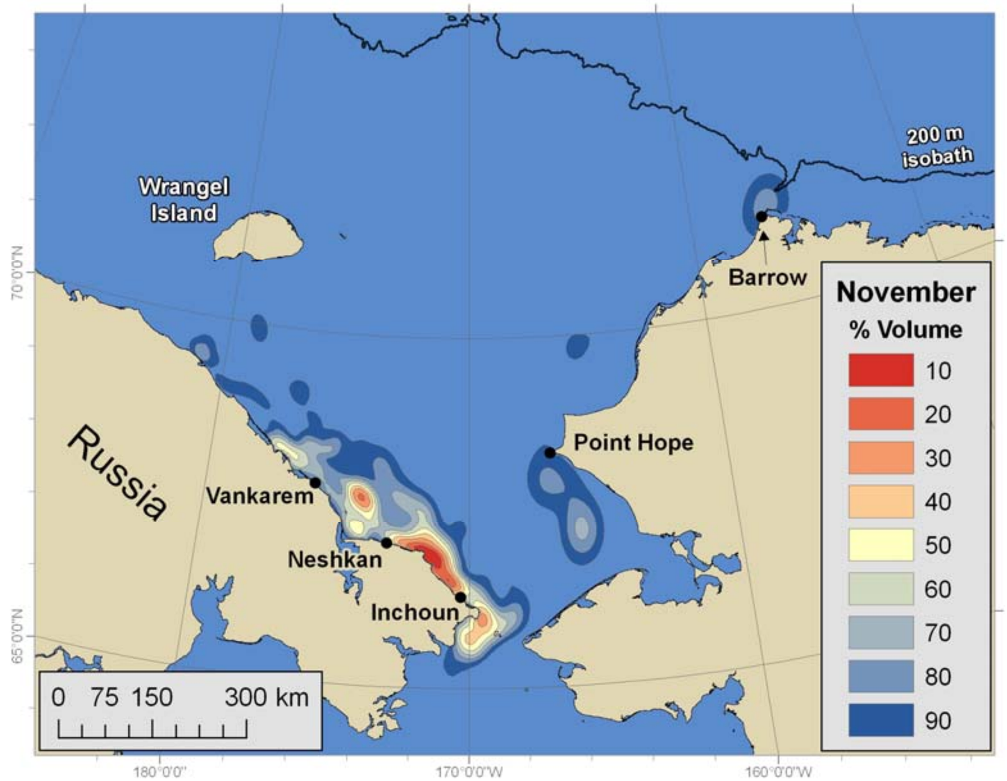
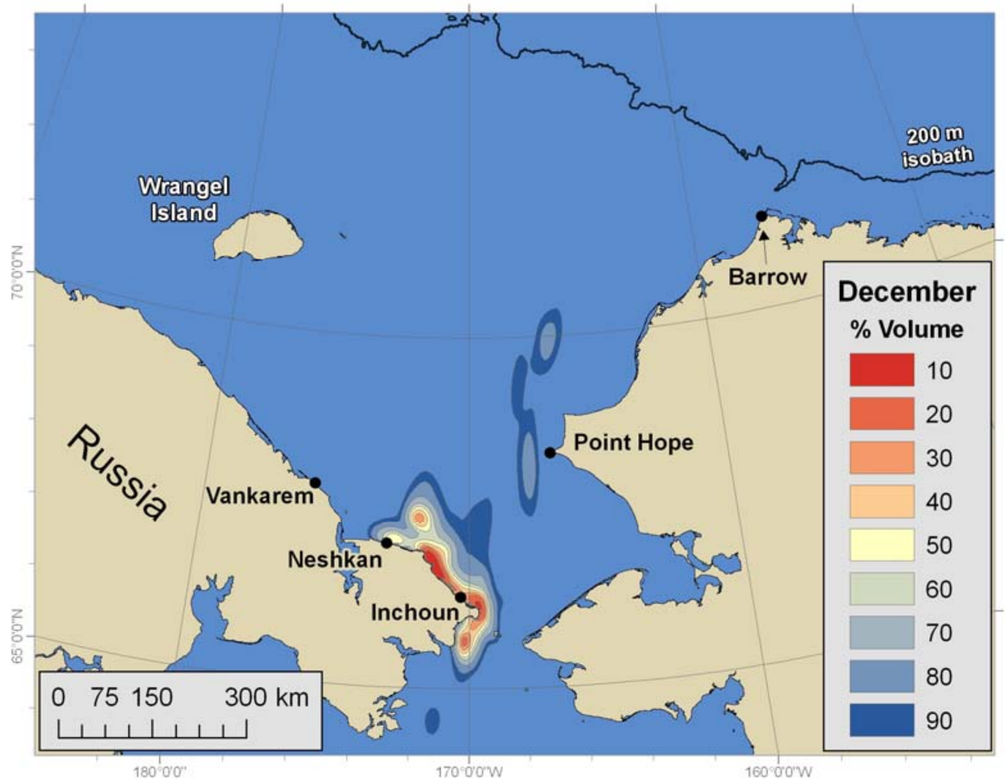


Figure 6. Kernel density of bowhead whale locations in December.



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