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# Distribution of bowhead whales in the SE Beaufort Sea during late summer, 2007-2009

# Répartition des baleines boréales dans le sud-est de la mer de Beaufort en fin d'été, de 2007 à 2009

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## ABSTRACT

Strip-transect systematic aerial surveys were conducted over the Canadian Beaufort Sea in late August of 2007, 2008 and 2009 to examine the distribution of bowhead whales (*Balaena mysticetus*). A total of 24-26 N-S transect lines were flown in each survey, all under favourable survey conditions, along lines of longitude spaced at 15'. A total of 334 bowhead whales (244 sightings) including 10 calves, were observed on-transect by primary observers, mostly as individuals (76.6%) and groups of two (14.3%). The study area was divided into 20 km x 20 km grid cells, with the grid cell dimensions equal to the transect spacing. Transect segments within each grid cell were the basic sampling unit for subsequent calculations. The mean regional density of surfaced, visible bowhead whales was 1.81 bowheads/100 km$^2$ in 2007, 2.61/100km$^2$ in 2008 and 0.66/100 km$^2$ in 2009. Extrapolation of visible, surfaced whale counts on transect segments to unsurveyed areas in each grid cell were summed to yield an estimated 1,320 (95% CI 1036 to 1603) bowheads visible at the surface during the 2007 survey. When corrected for submerged whales, an estimated 4,884 to 5,280 bowheads or approximately 50% of the current estimate of stock size was estimated to have been in the study area at the time of the 2007 survey.

The distribution of bowheads was clumped in all years, with variance/mean ratios of 4.13, 5.38, and 2.63 in 2007, 2008 and 2009, respectively ($p<0.0001$). The proportion of the surveyed grid cells in which bowhead densities were $\geq$5 bowheads/100 km$^2$ (our working definition of an aggregation within a grid cell) were 11.1% (2007), 13% (2008), and 4.9% (2009). Bowheads aggregated in nine geographic locations within the study area in the 2007-2009 survey series. Not all of the nine areas were used in all years, and no more than six areas were used in any given year. The shallow, shelf waters offshore of the Tuktoyaktuk Peninsula were the most attractive to bowheads in all years of the 2007-2009 survey series, with 47.3% of all whales sighted (66.5% of sightings). The other eight areas where bowheads aggregated had from 1.5% to 6.3% of the total on-transect bowhead whales, and in total (28.1%). The importance of these other areas combined did not equal that of the Tuktoyaktuk Peninsula aggregation area, at least in terms of number of bowheads sighted.

In summary, bowhead whales aggregate in the SE Beaufort Sea each summer for feeding, and appear to do so starting in early August and through to late September or early October. They utilize several different areas for feeding, moving amongst these locations to some extent over the course of the summer. Up to 50% of the population may use the Canadian Beaufort Sea at any one time, and of those in Canadian waters, the majority tends to feed on continental shelf waters offshore of the Tuktoyaktuk Peninsula in waters 20-50 m deep. The propensity of bowheads to aggregate, and a real-time knowledge of the aggregation areas they use in a given season, provides a framework for the establishment of mitigative measures relating to seismic surveys in the Beaufort Sea.

# RÉSUMÉ

On a procédé à des relevés aériens systématiques par transects en bande de la mer canadienne de Beaufort à la fin du mois d'août 2007, 2008 et 2009 afin d'étudier la répartition des baleines boréales (*Balaena mysticetus*). Au total, 24 et 26 transects nord-sud ont été survolés lors de chaque relevé, toujours dans des conditions de relevés favorables, le long de lignes de longitude espacées de 15 minutes. Au total, 334 baleines boréales (244 observations), y compris 10 baleineaux, ont été observées dans les transects par les principaux observateurs, la plupart évoluant seules (76,6 %) ou en groupes de deux (14,3 %). La zone d'étude a été divisée en sections de 20 kilomètres par 20 kilomètres, les sections étant de dimensions égales à l'espacement des transects. Les segments de transect au sein de chaque section ont formé les unités d'échantillonnage de base pour les calculs qui ont suivi. La densité moyenne régionale de baleines boréales visibles en surface était de 1,81 baleine/100 $km^2$ en 2007, de 2,61/100 $km^2$ en 2008 et de 0,66/100 $km^2$ en 2009. Les calculs de l'extrapolation des baleines visibles en surface dans les segments des transects appliqués aux zones non survolées dans chaque section de la grille ont été additionnés pour produire une estimation de 1 320 baleines boréales visibles en surface (intervalle de confiance de 95 % = de 1 036 à 1 603) lors du relevé de 2007. Après avoir apporté une correction pour tenir compte des baleines en plongée, on estimait que de 4 884 à 5 280 baleines boréales, soit environ 50 % de l'estimation actuelle du stock, se trouvaient dans la zone d'étude au moment du relevé de 2007.

On a regroupé la répartition des baleines boréales pour toutes ces années et on a obtenu des rapports de variance et des moyennes de 4,13, 5,38 et 2,63 en 2007, 2008 et 2009, respectivement ($p < 0,0001$). La proportion des sections de la grille survolée pour lesquelles la densité des baleines boréales était égale ou supérieure à cinq par 100 $km^2$ ($\geq$ 5/100 $km^2$), ce qui correspond à notre définition d'un rassemblement au sein d'une section de la grille, était de 11,1 % (2007), 13 % (2008) et de 4,9 % (2009). Les baleines boréales étaient rassemblées dans neuf régions géographiques de la zone d'étude lors des relevés réalisés de 2007 à 2009. Aucune de ces neuf régions n'est utilisée à l'année, et pas plus de six régions ont été utilisées lors d'une année donnée. Les eaux peu profondes du plateau au large de la péninsule de Tuktoyaktuk étaient les plus fréquentées par les baleines boréales pour les trois années des relevés, de 2007 à 2009, avec 47,3 % de toutes les baleines observées (66,5 % des observations). Dans les huit autres aires de rassemblement des baleines boréales, on a observé de 1,5 % à 6,3 % du total des baleines dans les transects, pour un total de 28,1 %. L'importance de toutes les autres régions réunies n'équivalait pas celle de la péninsule de Tuktoyaktuk, du moins quant au nombre de baleines boréales observées.

En résumé, les baleines boréales se regroupent dans le sud-est de la mer de Beaufort chaque été pour se nourrir, et elles semblent le faire dès le début d'août pour y demeurer jusqu'à la fin septembre ou le début d'octobre. Elles utilisent plusieurs aires pour se nourrir, se déplaçant parfois d'une zone à une autre au cours de l'été. Jusqu'à 50 % de la population fréquente à l'occasion la mer canadienne de Beaufort et, parmi celles présentes dans les eaux canadiennes, la majorité a tendance à se nourrir dans les eaux peu profondes, entre 20 et 50 mètres de profondeur, du plateau continental au large de la péninsule de Tuktoyaktuk. La propension des baleines boréales à se regrouper, de même que la connaissance en temps réel des aires de rassemblement qu'elles utilisent en une saison donnée, fournissent un cadre de travail pour l'établissement de mesures d'atténuation visant les activités de levés sismiques effectuées dans la mer de Beaufort.

# INTRODUCTION

There are two recognized populations of bowhead whales (*Balaena mysticetus*) in Canada (COSEWIC 2009). Bowhead whales of the Bering Sea population (also known as the Bering-Chukchi-Beaufort population B-C-B )(Burns *et al.* 1993) winter in the Bering Sea, and return to summer range in the Canadian Beaufort Sea and Amundsen Gulf annually. The spring migration occurs in April and May (Clark and Johnson 1984, George *et al.* 1989), with bowheads arriving far offshore in the Canadian Beaufort Sea (Moore and Reeves 1993) in late May and early June (ADFG 2009, Marko and Fraker 1981). The most recent estimate of stock size, based on the 2001 census at Point Barrow, is 10,470 (SE 1,351) with a 95% CI of 8,100-13,500 (George *et al.* 2004). A census is underway to update the population estimate in 2009-2010 (R. Suydam, North Slope Borough, pers. Comm.), and it has been suggested that this population be delisted (Gerber *et al.* 2007). The estimated annual rate of increase of the population from 1978-2001 was 3.4% (95% CI 1.7% - 5%) (George *et al.* 2004). Sighting rate of calves during the 2001 census at Point Barrow was 3.7% (George *et al.* 2004).

During July, bowheads are widely distributed throughout the offshore Canadian Beaufort Sea, singly or in small (2-3 surfaced animals) groups (Davis *et al.* 1982, Harwood and Borstad 1985). By mid-August, oceanographic conditions favour the concentration of the bowhead's planktonic prey items (Thomson *et al.* 1986), and the whales aggregate to feed in specific, recurrent areas on the summer range (Harwood and Smith 2002, Richardson *et al.* 1987). The return fall migration to the Bering Sea begins in late August, and continues through to late September. At the same time that bowheads are aggregated in the Canadian Beaufort Sea for summer feeding, recent satellite-tagging and aerial surveys have revealed that bowheads also aggregate to feed in summer (and in fall) at certain productive locations in the Alaskan Beaufort Sea and the Chukchi Sea (e.g., Barrow Canyon, Herald Canyon) (Goetz *et al.* 2008).

Bowhead feeding aggregations occur where oceanographic conditions favour the concentration of crustaceous zooplankton, their main prey item (Thomson *et al.* 1986). Bowhead whales must seek out areas where prey is adequately concentrated in order to meet their energy requirements (Lowry *et al.* 1994). Oceanographic features that lead to upwelling of nutrient rich waters are particularly important in determining zooplankton distribution (Harwood and Borstad 1985, LGL 1988). In the southeastern Beaufort Sea, 1985 and 1986 sampling of plankton in close proximity to feeding bowhead whales revealed predominantly (76-92%) copepods (*Limnocalanus macrurus, Calanus hyperboreus, Calanus glacialis*), as well as gammariid and hyperiid amphipods, euphausiids, mysids and isopods as the major prey items (LGL 1988). There is evidence of sex/age segregation within the various feeding aggregation areas in both Alaska and Canada (Koski and Miller 2009, Cubbage and Calambokidis 1987).

Some of the locations that feeding bowhead whales use in the Canadian Beaufort Sea include areas that have been subject to hydrocarbon exploration activity in the 1980s, and more recently, seismic surveying in 2001- 2002, 2006-2009. It is also of note that the bowhead whale fall migration route intersects areas of interest to the hydrocarbon industry in the Alaskan Beaufort Sea and in the central Chukchi Sea (US Minerals Management Service, www.MMS.gov).

The main objective of this study was to update our knowledge of bowhead distribution and habitat use in the SE Beaufort Sea, since regional surveys have not been done since the 1980's. Additional objectives were to provide bowhead whale location data to three concurrent projects in the southeast Beaufort Sea (oceanographic sampling, tagging of bowheads with satellite-linked transmitters, and Marine Mammal Monitoring during one or more seismic surveys).

## MATERIALS AND METHODS

### DATA COLLECTION

As much as possible, the surveys were conducted in a manner consistent with past surveys in the Canadian Beaufort Sea (1981-1986). The study area extended from the Alaska-Yukon border (141$^{o}$ W longitude) eastward to Cape Bathurst (128$^{o}$ W longitude), and from the 2 m isobath seaward to the edge of, or up to 60 km beyond, the shelf break. Offshore of the Yukon coast, the northern endpoints were 70 30 N, extending over waters 1000 m deep. Survey coverage was approximately 10%, and the approximate surface area of the study area was 80,000 km$^2$ with an east-west distance of 500 km.

A wide and shallow (up to 200 m depth) continental shelf extends up to 130 km from shore in the eastern sections of the study area. Beyond the continental shelf is the abyssal plain of the Canada Basin in the Arctic Ocean. During the summer months, the extent of open water is highly variable. The location and type of sea ice found in the Beaufort Sea in summer depends on a number of factors, most notably wind direction and its influence on ice clearing and encroachment (Thompson *et al.* 1986).

A total of 24 (26 in 2009) north-south transect lines were flown in each survey, along lines of longitude at intervals of 15' (Figure 1); transect lines ranged from 41 to 190 km in length. Surveys were flown on 22-23 August, 2007; 2, 4, 9 and 20 August 2008; and 15-20 August 2009. Two de Havilland Twin Otter aircraft, each with two primary observers and at least one secondary observer, were used to conduct the surveys. Each aircraft was equipped with a GPS (Global Positioning System) for navigation and a radar altimeter for maintenance of the survey altitude of 305 m ASL. Surveys were not attempted, or were aborted, if ceilings were below 305 m. Target ground speed for the survey was 200 km·h$^{-1}$. Both primary search positions in both aircraft were equipped with bubble windows in the rear (2007, 2008) and second front seat (2009) positions. As rough seas and glare from the sun significantly reduce the detectability of marine mammals in aerial surveys (Davis *et al*. 1982, Holt and Cologne 1987, Harwood and Stirling 1992), surveying was attempted only when sea states were Beaufort 0 (calm, sea like a mirror), 1 (light air, ripples but without crests), 2 (light breeze, small wavelets with crests that do not break), or 3 (gentle breeze, large wavelets with crests that are beginning to break).

A strip transect method was used (Caughley 1977), with a strip width of 2.0 km (1.0 km per side). Bowheads were detected with equal frequency across transect strips of this size in previous surveys in this region, using the same methodology (Davis *et al.* 1982, McLaren and Davis 1985, Harwood and Borstad 1985, Duval 1986, Ford *et al.* 1988). Prior to the start of each day's transects, the 2-km strip (1 –km per side) was defined by marks on the bubble windows by the primary observers, offset from the flight path by 50 m to account for reduced downward visibility over the flight path (Norton and Harwood 1986). With the observers head positions 'fixed', the strip was marked on the bubble windows representing a swath 50-1050 m next to the flight path (inclinometer readings of 81$^{o}$-16$^{o}$ from the horizon, inclusive). At the time of a sighting, observers resumed their fixed reference head position to determine if the sighting was on- or off- transect. Individual hand-held Garmin GPS Map 76 units, each with an external antenna, were used by the primary and secondary observers to record geographic positions.

Primary observers collected data only on cetacean sightings (number in group, species, GPS waypoint, presence of calves), and were instructed not to take their eyes off the transect strip during all on-transect effort. Only the observations of bowheads that were made by the two primary observers on-transect were used for the calculation of bowhead densities and estimates of relative abundance. To ensure a consistent and uninterrupted search, we did not depart from the transect lines to circle groups of whales that were sighted. Secondary observers served as 'back-ups' to the primary observers (in case of illness, for example), photographers, and recorders of primary observer's sighting data, off-transect sightings, seal sightings, geographic locations and times, weather, ice, survey conditions and glare. An on-board intercom system was used for communication among all observers and pilots on each aircraft.

The usual flight time was 6-8 h per day. To minimize fatigue, observers rested during ferrying flights, refuelling stops, and during 9-10 min transit flights between transects. At the beginning and end of each transect, observers recorded the time using synchronized digital watches (min, s), transect number, direction of flight (compass points), seat position, glare levels (nil, moderate, strong, forward or back) and sea state (Beaufort Scale of Wind Force). The secondary observer(s) recorded concentration of ice according to five categories (0/10, 1/10-3/10, 4/10-6/10, 7/10-9/10, >9/10), and all other survey conditions including glare, ceilings, sea state.

## DATA ANALYSIS

GPS waypoints and tracks were downloaded from the GPS units after each survey, and bowhead sightings tabulated in Excel and plotted using Environmental Systems Research Institute (ESRI) (2004). The proportion of calves, sighting rates, and group sizes were tallied in Excel and SAS V.8 (1990).

The study area was divided into 20 km x 20 km grid cells (Harwood 1989, Robertson and Robertson 1987,Harris *et al.* 2008), with the grid cell dimensions essentially equal to the transect spacing (19.9 km at 70$^{o}$N latitude) (Fig 1). The variance to mean (V/M) ratio of whale counts per grid cell was calculated for each survey since the ratio of these two parameters equals one for a Poisson (random) distribution. The index of dispersion ($I_d$=V(n-1)/M) was calculated (Southwood 1978) to determine and compare significance of departures of the V/M from unity, i.e., clumping.

A working definition of a bowhead whale feeding aggregation area (Harris *et al.* 2008) of $\geq$5 bowheads/100 km$^2$ surveyed was applied to depict the location of areas that were most attractive to bowheads at the time of the surveying. This definition was developed jointly by Fisheries and Oceans Canada (DFO), stakeholders and industry in July 2007 (Harris *et al.* 2008), and is revisited annually. Aggregation and non-aggregation grid cells were coded accordingly and plotted using ESRI (2004), for individual years and for all years combined.

Habitat variables were obtained as follows: ice (from secondary observer records); bathymetry (International Bathymetric Chart of the Arctic Ocean, v. 2.23, March 8, 2008; http://www.ngdc.noaa.gov/mgg/bathymetry/arctic), sea surface temperature (Alaska Ocean Observing System, AVHRR daily composites; http://ak.aoos.org/data/satellite/avhrr/tif/sst), and slope (derived from IBCA data using ESRI's Spatial Analyst Extension with 750 m interpolated cell size).

Mean bowhead density and standard error for each survey were calculated as total on-transect sightings/total area surveyed using PROC UNIVARIATE (SAS 1990). The estimated number of bowheads visible at the surface and the associated sampling standard error of that estimate were calculated using the difference method for systematic surveys (Yates 1960, Kingsley and Hammill 1991) where the estimated number of whales seen was calculated using the formula:

$$Y = \left(\frac{W}{w}\right)\sum y_i$$

where Y is the estimated number of bowheads at the surface, W is the distance between transect segments, w is the width of the transect segment and $y_i$ is the number of surfaced bowheads seen in the $_i$th transect segment. The approximate sampling standard error for the estimate of Y is given by the formula:

$$SE(Y) = \left(\frac{W}{w}\right)\sqrt{\frac{n}{2}\sum\frac{d_i^{\,2}}{(n-1)}}$$

where SE is the standard error of the estimate Y, and $d_i$ is the difference between adjacent transect segments. The n-1 is from Yates' (1960) n' which is the number of comparisons minus 1.

## RESULTS

### SURVEY EFFORT AND SIGHTINGS

Details of the survey effort and on-transect sightings from the systematic strip-transect aerial surveys of the SE Beaufort Sea in Canada in 2007-2009 are summarized on Table 1. A total of 24-26 transect lines were flown in each year, resulting in coverage of 246 grid cells, 199 in 2007, 146 in 2008, and 223 in 2009 (Figure 1). In 2007, the study area was surveyed within 48 hr under the requisite survey conditions. In 2009, ice encroached on the northern ends of all transect lines, although we were able to complete all flying under calm seas and clear skies. In 2008, fog and/or low cloud precluded reaching the northern endpoints of transects 1-16 on all survey flights. As well there were extensive interruptions in survey progression due to weather (18 days separated our first and last flight). Otherwise, all transects were completed to the target endpoints in all years, at the desired survey altitude of 305 m ASL and with the requisite survey conditions

A total of 334 bowhead whales (244 sightings) were sighted on-transect by the primary observers. Most bowheads were observed singly (n=187, 76.6%) or as pairs (n=35, 14.3%). Groups of 3 (5.7%), 4 (2.5%), 5 (0.4%) and 6 (0.4%) were less common. The occurrence of single-animal sightings was similar in all survey years: 2007 (75.5%), 2008 (76.0%), 2009 (79.6%).

Cows with calves were observed in all surveys, comprising 3.0% of the whales seen in 2007, 1.5% in 2008, and 6.1% in 2009 (Table 1). Most calves were observed offshore of the Tuktoyaktuk Peninsula (7/10), although in the 2009 survey, a calf was seen in waters offshore of each of the Yukon coast, the Mackenzie Delta and Cape Bathurst.

The density of surfaced, visible bowhead whales was variable among years: the lowest density observed was in 2009, with 0.66 bowheads/100 $km^2$; the highest density we observed was 2008 (2.62 bowheads/100 $km^2$; Table 2).

Extrapolation of visible, surfaced whale counts to unsurveyed areas is instructive to examine the relative proportion of the bowhead population that might be using the SE Beaufort Sea at the time of the surveying (Table 2). The survey with the most synoptic coverage was Aug 22-23 2007, and for that survey we estimate that 1,320 (95% CI 1036 to 1603) bowheads were visible at the surface at the time of the survey. The calculated CV of that estimate was 10.7%. As most (90.9%) groups consisted of one or two whales, an adjustment for group size was not warranted.

## DISTRIBUTION

The locations in which on-transect, visible surfaced bowhead whales were sighted (Figure 2a, b, c) show how the distribution was clumped in all three years. The departures of the V/M ratios from unity were all significant ($p<0.0001$; table 2), and indices of dispersion also reflect clumping by this species on the summer range (Table 2). The location of grid cells which met our working criteria (transect segments with $\geq$5 bowheads/100 $km^2$, equivalent to sighting 3 or more bowheads within 2 min while surveying at 200 km/h) as aggregation areas are shown on Figs 2a, b, c as solid coloured grid cells).

The proportion of grid cells with survey coverage in which bowheads were observed was 23.1% (2007), 31.5% (2008) and 15.2% (2009). The proportion of the grid cells with survey coverage in which bowheads were aggregated was 11.1% (2007), 13% (2008), and 4.9% (2009) (Figure 3). These were higher than proportions observed during the aerial survey series in 1981-1986, during which time bowheads aggregated in 0.5 - 6.0% of the grid cells with survey coverage (Table 3). The number of surfaced, visible bowheads observed in the aggregation cells was 102/132 (2007), 111/136 (2008) and 39 /66 (2009).

In each year of the 2007-2009 surveys, bowheads were observed to aggregate in six of nine different geographic aggregation areas (Table 4), although not all areas were used in all years. These are the same aggregation areas that were seen to be used by bowheads in the 1980's surveys. Waters 20-50 m deep located offshore of the Tuktoyaktuk Peninsula (Inner Shelf) were the most attractive to bowheads, in all years of the survey series, with 47.3 % of all whales sighted and 66.5% of the total sightings (Figure 3). The other areas, Komakuk, Mackenzie Canyon, Interface, Outer Shelf, Bathurst, Yukon Coast, Kugmallit Canyon and the Shelf Break had from 1.5% to 6.3% of the total on-transect bowhead whales (Figure 3), and even collectively did not match the relative importance of the Tuktoyaktuk Peninsula aggregation area to bowheads, at least in terms of numbers sighted. The remaining on-transect bowhead whales sighted (24.7%) were observed in grid cells that did not meet our working definition of a bowhead aggregation, however, all but eight of the grid cells with bowheads were adjacent to aggregation area grid cells.

The Tuktoyaktuk Peninsula Inner Shelf (20-50 m), the Interface and Kugmallit Canyon had aggregations in all three years of the survey series; Mackenzie Canyon, the outer shelf of the Tuktoyaktuk Peninsula (50-100 m), and Bathurst had aggregations in two years of the survey series; and Komakuk, Yukon and the Shelf Break had aggregations in one year of the series.

## DISCUSSION

When techniques are standardized and biases minimized, visual census remains an appropriate and cost-effective method for Arctic marine mammal survey work. Systematic aerial surveys are appropriate for a study such as this with the objectives of mapping distribution, examining habitat use and estimating relative abundance (Caughley 1977). The costs of positioning aircraft and fuel in such a large region necessitate the use of a systematic (vs randomized) design (Robertson and Robertson 1987).

It is difficult to obtain representative distribution data through aerial census, particularly when the species being studied is clumped and the study area is large. Counts have to be extrapolated to large, unsurveyed areas. Sampling intensity is generally low, and dependent on the size of the study area and availability and range of the survey aircraft. Changing weather and ice conditions, and the potential for differential movements and surfacing behaviour of certain age classes complicate this further. Not all animals in a given group are necessarily at the surface during a survey pass, and it is possible that animals in large groups are more readily detected than individuals. However, interpreted in the broad sense intended, the results of this study provide reasonable estimates of trends in bowhead whale distribution in the SE Beaufort Sea since the most fundamental biases associated with open water surveys (Holt and Cologne 1987) were minimized. This was achieved by collecting data only under optimum survey conditions, and through ensuring consistency with respect to observers, using multiple survey platforms to take advantage of periods of favourable survey conditions, and using standardized survey protocols (Norton and Harwood 1986).

The strip transect method was used to maximize the time available to primary observers for searching, and for consistency with past surveys (Davis *et al.* 1982, Harwood and Ford 1983, McLaren and Davis 1985, Harwood and Borstad 1985, Duval 1986, Ford *et al*. 1988). A strip transect is appropriate for species that occur at high densities and form large, loose aggregations (Ogutu *et al.* 2006). The accurate estimation of perpendicular sighting distances for each sighting, a requirement of the line-transect method, is time-intensive and could compromise the amount of time observers have for searching and detecting surfaced whales (Krzysik 1998).

Of our three surveys, the 2007 survey was flown without interruption in spatial or temporal coverage. On Aug 22-23 2007, we estimated 1,320 surfaced, visible bowheads in the study area, a regional density of 1.806 bowheads/100 $km^2$ surveyed, and had an on-transect count of 132 bowheads. These values were all higher (by as much as 7-fold) than comparable values for surveys in August 1981-1986 (Harwood and Ford 1983, MacLaren and Davis 1985, Richardson *et al.* 1987, Moore and Clarke 1991). Since the study area, design, and survey methods were essentially identical, the increase in sightings and therefore relative abundance of bowheads in the 2007 and 2008 surveys may reflect an increase in the size of the stock since the 1980's surveys, or an increase in the use of the SE Beaufort Sea by bowheads, or both. The lower density found in 2009, despite more extensive survey coverage, supports the latter and may have been linked in 2009 to the presence of ice over a portion of the study area. The census at Point Barrow planned for spring 2010 is expected to provide new data to examine whether or not the stock has increased in size since 2001.

It is instructive to apply a correction factor for (undetected) whales below the surface that would have been missed by observers, and such factors are expected to be available in the future from bowheads tagged in the SE Beaufort Sea in 2006-2009 (ADFG 2009). In the interim, Davis *et al.* (1982) estimated bowheads in the Beaufort Sea spend 27.2% of their time at the surface.

Using dive data collected from tagged bowheads in the Eastern Arctic, Dueck *et al.* (2006) estimated the proportion of time that bowheads spend at the surface as 25.3% (95% CI 0.17-0.33). Correcting our Canadian Beaufort Sea 2007 estimate by a factor of 3.7 (100/27.2) or 4.0 (100/25.3) produces an estimate of 4,884-5,280, equivalent to approximately half of the present estimated of the size of the stock (George *et al.* 2004). Given (1) our growing knowledge that bowheads utilize habitats in the Canadian Beaufort region during summer that were beyond the area we were able to survey (Amundsen Gulf, Cape Parry, west and north coasts of Banks Island), (2) evidence from recently tagged whales that some leave the SE Beaufort in early August (e.g., prior to the timing of our survey), and (3) that bowheads also occur offshore of Point Barrow during August, the broad estimate of 4,884 - 5,280 bowheads using the study area in late August 2007 could have represented as much as one-half of the stock.

There is evidence that bowheads aggregate earlier in the season than was the case in the 1980's, possibly by two weeks or more. The proportion of calves we observed in the survey (3.0%) is similar to the proportion of calves seen in the last census at Point Barrow in 2001 (3.7%) (George *et al.* 2004), and group sizes, V/M ratios, and indices of dispersion from the present survey series were all comparable to that reported for the 1980's survey series (Harwood 1989). The proportion of sightings in aggregations, and the general areas where bowheads aggregated in 2007-2009, was also consistent with findings from the 1980's (Figure 3; Harwood and Smith 2002). We have identified nine broad geographic areas where bowheads tend to aggregate in the SE Beaufort Sea (Figure 4). A summary of areas used by bowheads in August of 2007, 2008 and 2009 (Figure 5) reveals similarities and differences among years. One of these areas, the shallower waters of the continental shelf offshore of the Tuktoyaktuk Peninsula was the most attractive to bowheads, with more of the on-transect sightings than all other aggregation areas combined, and was used in all three years of the survey series. Even whales seen outside of the aggregation areas defined in this study were mostly in areas adjacent to the aggregations.

Results from each year's aerial survey were integrated into DFO's recommended mitigations for seismic activities in the Beaufort Sea. The seismic operator's strategy for mitigation was to ensure that all seismic surveys within defined bowhead whale aggregation areas were completed only in high visibility (no fog, daylight, low sea states) (Joynt and Harwood 2009). This was to ensure that Marine Mammal Observers were able to detect and identify marine mammals in the Safety Zone (SZ), and thus invoke any necessary shutdowns of the seismic equipment to protect whales if they came too close to the ship. If darkness or fog impeded the view of the entire SZ while the ship was in a defined aggregation area, then a shut down of the seismic survey was invoked also until full visibility was regained (Joynt and Harwood 2009, Harwood *et al*. 2009). The propensity for bowheads to aggregate, and a real-time knowledge of the aggregation areas they are using in a given year, provides DFO with the opportunity to: (1) establish mitigation procedures that protect bowheads from disturbance and/or injury due to the conduct of seismic surveys *within* localized bowhead feeding areas, and to (2) establish mitigation procedures that may be less restrictive *outside* the feeding areas.

It is known that bowheads do not aggregate in the same areas each year, and that bowheads also move amongst aggregation areas within a given year to some extent (ADFG 2009). We also have evidence from tagging studies that bowheads will travel to locations where aggregations existed in a previous year(s), and may or may not stay there for a period of time, presumably on the basis of food availability at the time (ADFG 2009). Differences between years are thought to be linked to changes in oceanographic conditions which concentrate the zooplankton prey sought by bowheads. In 2008, the locations of bowhead whale feeding aggregations off the Tuktoyaktuk Peninsula that were identified during the aerial survey were communicated within 24 hours to the MV Nahidik (oceanographic sampling vessel) to facilitate a separate study which involved sampling of zooplankton amongst feeding whales (Walkusz, W. DFO, unpubl. data).

In summary, bowhead whales aggregate in the SE Beaufort Sea each summer for feeding, and appear to do so starting in early August and through to late September or early October. They utilize several different areas for feeding, moving amongst these locations to some extent over the course of the summer. Up to 50% of the population may use the Canadian Beaufort Sea at any one time, and of those in Canadian waters, the majority tends to feed over continental shelf waters offshore of the Tuktoyaktuk Peninsula in waters 20-50 m deep.

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Table 1. Aerial survey effort, sightings and habitat variables during August 2007-2009 systematic aerial surveys

| | 2007 | 2008 | 2009 | 2007-2009 pooled |
|---|---|---|---|---|
| survey dates (August) | 22-23 | 2-20 | 15-20 | |
| $km^2$ surveyed | 7194 | 5088 | 8598 | 20880 |
| no. bowheads on-transect | 132 | 136 | 66 | 334 |
| no. bowheads sightings on-transect | 94 | 96 | 54 | 244 |
| no. bowhead calves on-transect (%) | 4 | 2 | 4 | 10 (3%) |
| mean group size | 1.4 | 1.4 | 1.2 | 1.4 |
| range group size | 1-6 | 1-5 | 1-3 | |
| no. bowheads/100 $km^2$ (density) | 1.81 | 2.62 | 0.66 | |
| SE (density) | 0.34 | 0.5 | 0.13 | |
| no. of cells with survey coverage | 199 | 146 | 223 | |
| no. of cells with bowheads | 46 | 46 | 34 | |
| no. of cells with aggregation | 22 | 19 | 11 | |
| % of grid cells with aggregation | 11.1 | 13 | 4.9 | |
| mean water depth (m) surveyed | 47.8 | 40.2 | 70.5 | 49.8 |
| range of water depths (m) | 6-769 | 8-158 | 2-891 | |
| mean slope ($^o$ change over 1 km) | 0.11 | 0.08 | 0.21 | 0.12 |
| range of slope ($^o$ change over 1 km) | 0-2.21 | 0-0.82 | 0-2.43 | |
| mean SST ($^oC$) | 4.4 | na | 3.2 | 4.3 |
| range of SST ($^oC$) | 2.3-6.5 | na | -0.2-7.5 | |
| sightings in ice (%) | 0 | 0 | 11% | |

* aggregation, defined here as $\geq$5 bowheads sighted/100 $km^2$ surveyed

Table 2. Estimated density of bowhead whales (no./$km^2$) and standard error (SE), and estimated number, standard error (SE) and 95% confidence interval of surfaced, visible bowhead whales by primary observers in strip-transect aerial surveys of the SE Beaufort Sea, August 2007-2009

| Year | Survey dates | no. grid cells surveyed | survey area $km^2$ | density no. bowheads/100 $km^2$ | | Est. No. of surfaced bowheads | | |
|---|---|---|---|---|---|---|---|---|
| | | | | mean | SE | No. | SE | 95% CI |
| 2007 | 22-23 Aug | 199 | 7111.56 | 1.806 | 0.338 | 1320 | 141.8 | 1036-1603 |
| 2008 | 2-20 Aug | 146 | 5054.45 | 2.616 | 0.503 | 1360 | 165.7 | 1028-1691 |
| 2009 | 15-20 Aug | 223 | 8415.11 | 0.660 | 0.132 | 660 | 133.9 | 392-928 |

Table 3. Number of grid cells with bowhead aggregations (>5 bowheads/100 km$^2$), 1981-1986 and 2007-2009

| Year | Month | No. grid cells surveyed | non-aggreg. cells | no. cells with aggreg. | % with aggregations | Reference |
|---|---|---|---|---|---|---|
| 1981 | August | 285 | 278 | 7 | 2.46 | Davis *et al.* 1983 |
| 1981 | September | 235 | 231 | 4 | 1.70 | Davis *et al.* 1983 |
| 1982 | August | 181 | 174 | 7 | 3.87 | Harwood and Ford 1983 |
| 1982 | September | 181 | 174 | 7 | 3.87 | Harwood and Ford 1983 |
| 1983 | August | 193 | 192 | 1 | 0.52 | McLaren and Davis 1985 |
| 1983 | September | 200 | 194 | 6 | 3.00 | McLaren and Davis 1985 |
| 1984 | August | 288 | 281 | 7 | 2.43 | Harwood and Borstad 1985 |
| 1984 | September | 278 | 270 | 8 | 2.88 | Harwood and Borstad 1985 |
| 1985 | August | 163 | 161 | 2 | 1.23 | Duval 1986 |
| 1985 | September | 92 | 88 | 4 | 4.35 | Duval 1986 |
| 1986 | August | 150 | 141 | 9 | 6.00 | Ford *et al.* 1988 |
| 1986 | September | 198 | 187 | 11 | 5.56 | Ford *et al.* 1988 |
| 2007 | August | 199 | 177 | 22 | 11.06 | this study |
| 2008 | August | 146 | 127 | 19 | 13.01 | this study |
| 2009 | August | 223 | 212 | 11 | 4.93 | this study |

Table 4. Number (%) of on-transect bowhead whales, by aggregation area, 2007-2009

| Area | Year of Survey | | | Total Whales | |
|---|---|---|---|---|---|
| | 2007 | 2008 | 2009 | n | % |
| 1. Inner Shelf | 64 | 83 | 11 | 158 | 47.3 |
| 2. Komakuk | 21 | 0 | 0 | 21 | 6.3 |
| 3. Mackenzie Canyon | 0 | 10 | 4 | 14 | 4.2 |
| 4. Interface | 3 | 5 | 5 | 13 | 3.9 |
| 5. Outer Shelf | 7 | 0 | 6 | 13 | 3.9 |
| 6. Bathurst | 0 | 3 | 9 | 12 | 3.6 |
| 7. Yukon Coast | 0 | 8 | 0 | 8 | 2.4 |
| 8. Kugmallit Canyon | 2 | 2 | 4 | 8 | 2.4 |
| 9. Shelf Break | 5 | 0 | 0 | 5 | 1.5 |
| outside or adjacent to aggregation area[1] | 30 | 25 | 27 | 82 | 24.6 |
| total | 132 | 136 | 66 | 334 | 100.0 |

[1] as defined Table 1

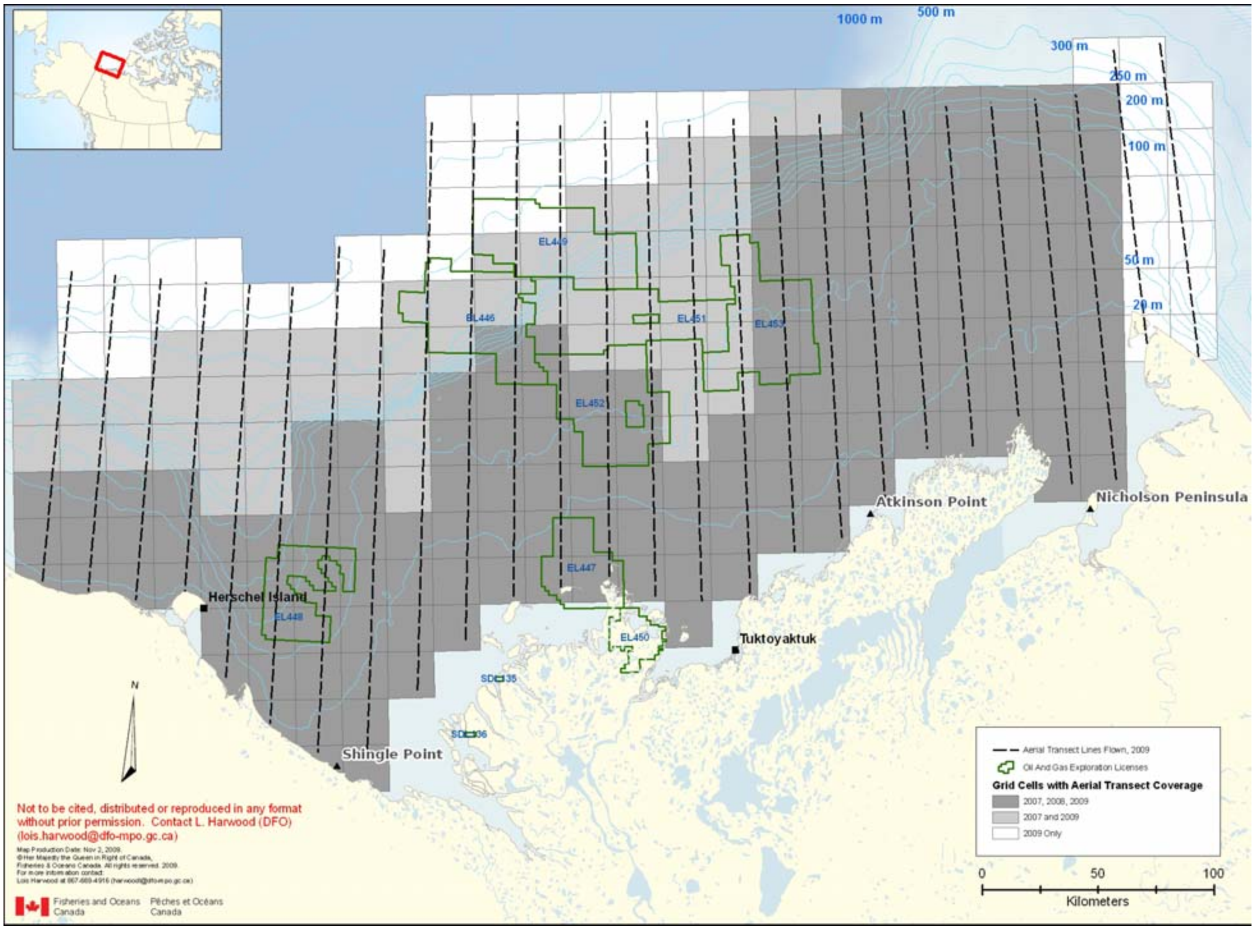


*Figure 1. Grid cell scheme, location of aerial survey transects, and coverage during August 2007-2009.*

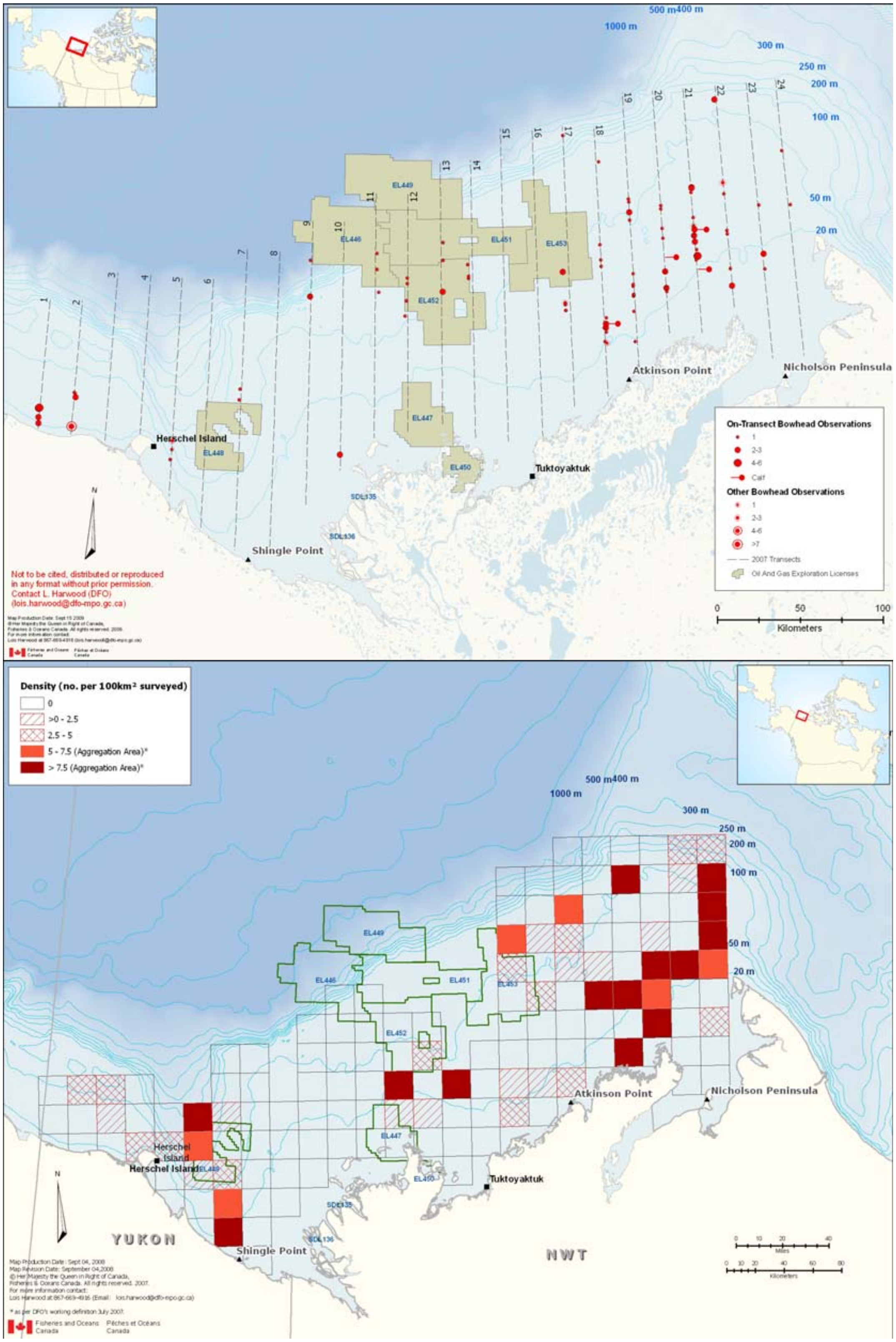


*Figure 2a. Bowhead whale observations, densities and feeding aggregations in the SE Beaufort Sea, August 2007*

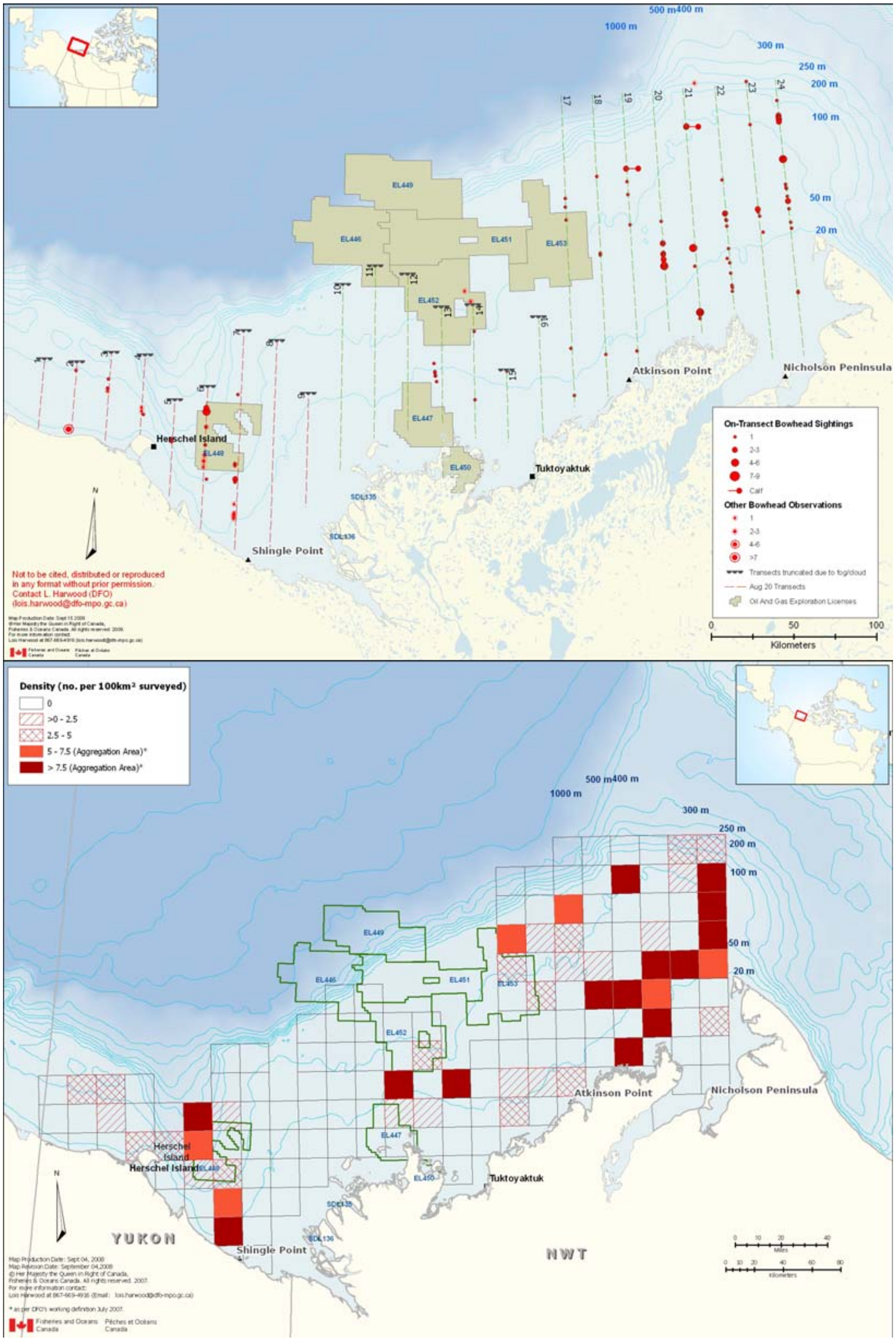


*Figure 2b. Bowhead whale observations, densities and feeding aggregations in the SE Beaufort Sea, August 2008*

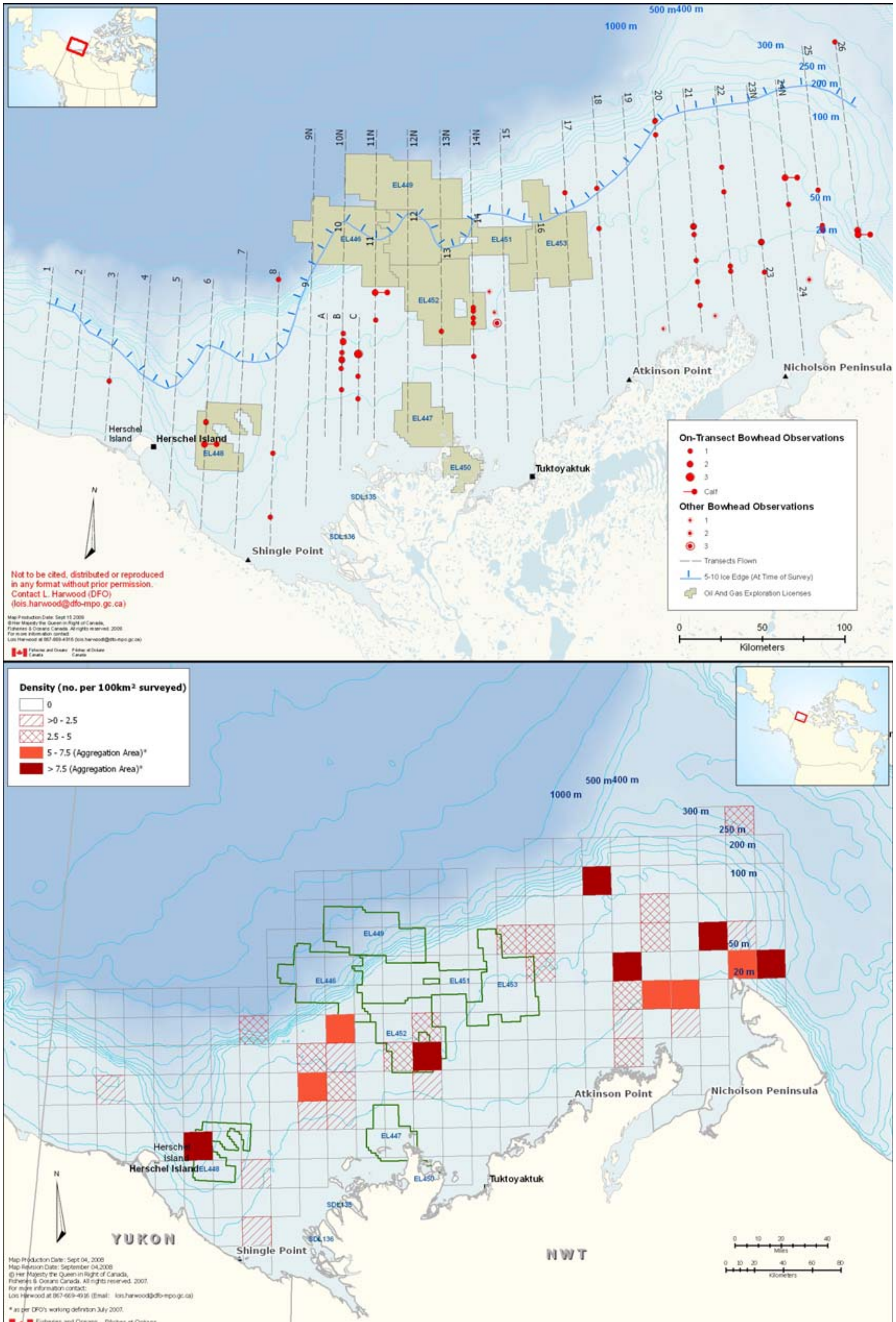


*Figure 2c. Bowhead whale observations, densities and feeding aggregations in the SE Beaufort Sea, August 2009*

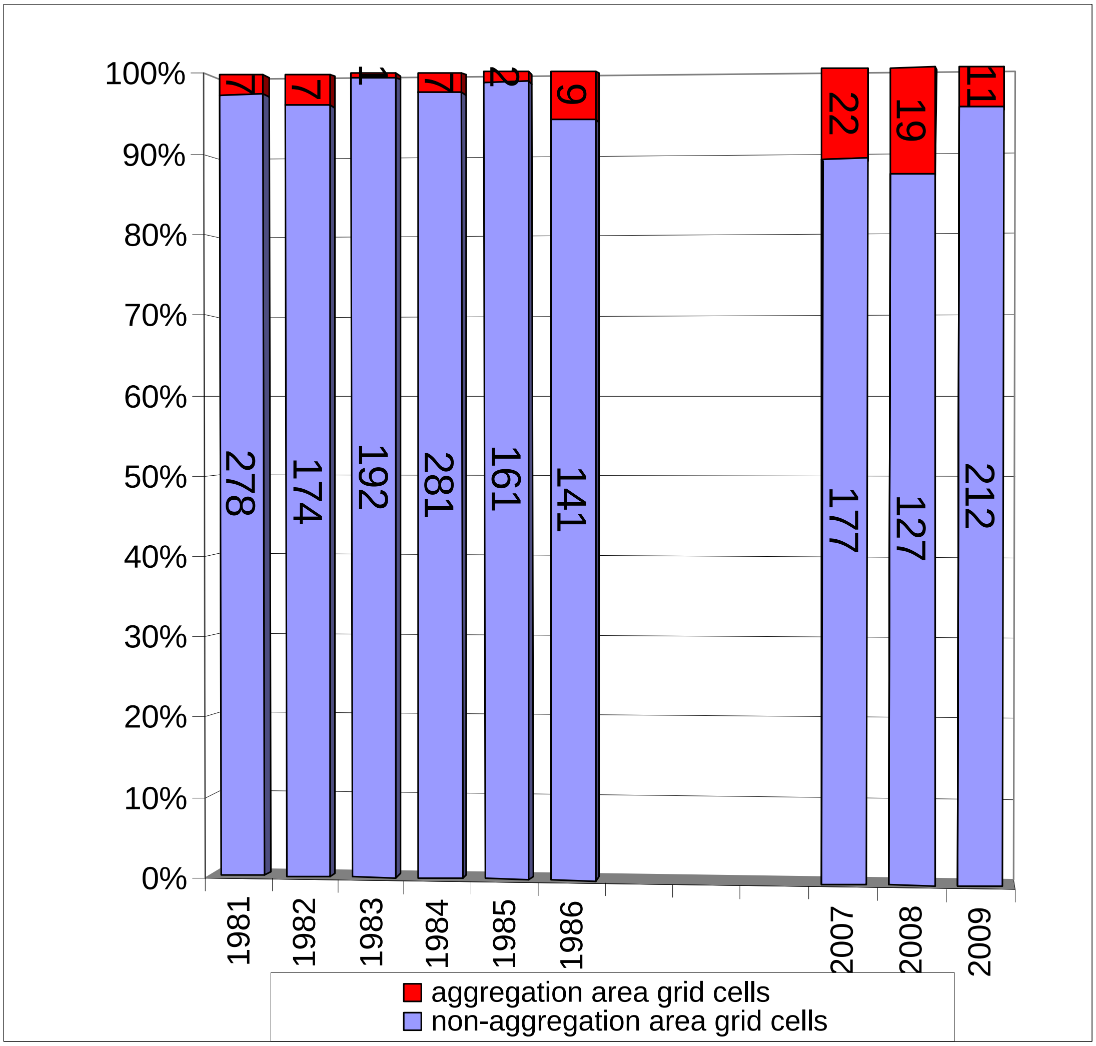


*Figure 3. Proportion of grid cells survey 1981-1986 and 2007-2009 which met the bowhead whale aggregation area definition of ≥5 bowheads/100 km² surveyed.*

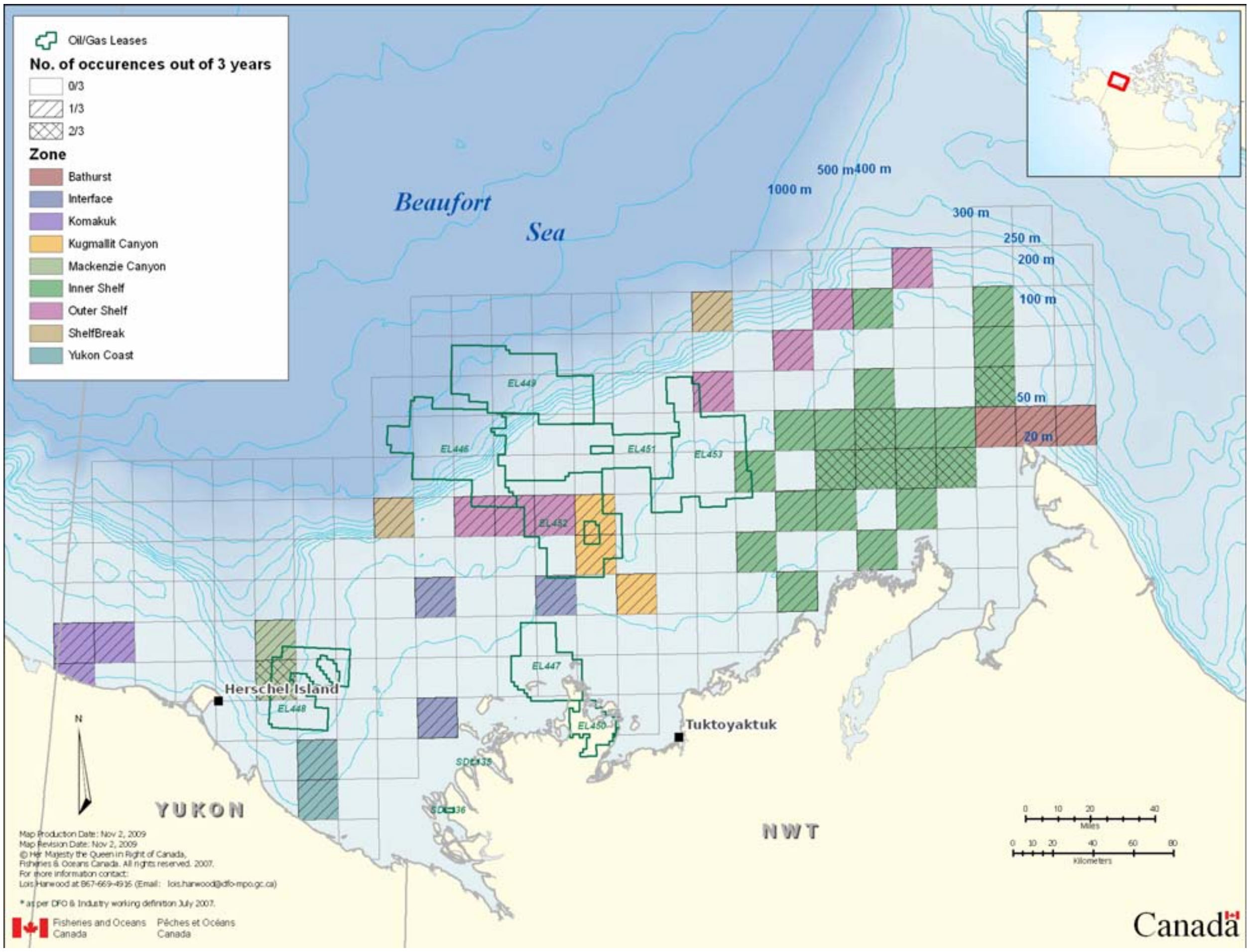


*Figure 4. Geographic areas where bowhead whales aggregated in the SE Beaufort Sea, August 2007-2009.*

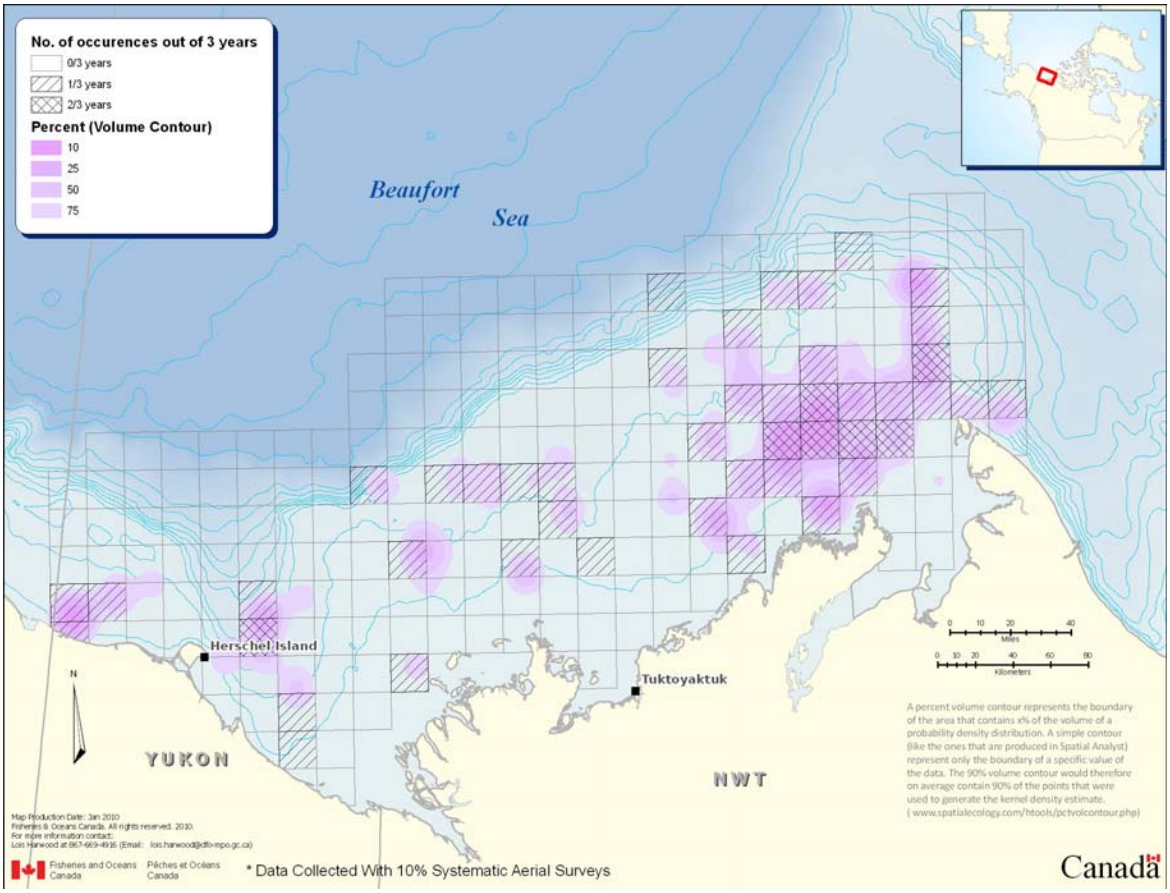


*Figure 5. Percent volume contours for bowhead whales sighted in the SE Beaufort Sea during systematic aerial surveys, August 2007-2009.*