Updated Distribution and Relative Abundance of Cetaceans in the Eastern Chukchi Sea in 2006–8

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ABSTRACT

Information on the numbers and distributions of cetacean species in the Chukchi Sea is sparse and out-of-date. Aerial and vessel-based data on marine mammals were collected during the summer and fall of 2006 through 2008 in the eastern Chukchi Sea. Most vessel-based data were collected from industry vessels engaged in seismic and related support activities. Aerial survey data were collected from a fixed-wing aircraft in the nearshore region from Pt. Hope to Barrow using a randomized line-transect methodology. Distribution and relative abundance of species observed were similar to previous studies, allowing for annual variation and population increases of some species. Harbour porpoise (*Phocoena phocoena*), however, were more abundant and occupied offshore habitats not previously documented in the Chukchi Sea. Extralimital sightings of fin whale (*Balaenoptera physalus*) and humpback whale (*Megaptera novaeangliae*) were also recorded.

INTRODUCTION

Information on the numbers and distributions of cetacean species in the Chukchi Sea is sparse and out-of-date. Most of the available information is from 1982-84 surveys reported by Ljungblad *et al*. (1986), Moore *et al*. (1986a,b) and Clarke *et al.* (1989), and from 1989-91 surveys reported by Brueggeman *et al*., (1990, 1991, 1992). Since that time cetacean abundance in the Chukchi Sea appears to have increased (*i.e.*, George *et al*., 2004; Rugh *et al*., 2005). Distributions of these cetacean populations may also have changed as a result of population increases and/or changes in sea ice distribution, which may have been caused by global warming (Ferguson *et al*., 2001; Johannessen *et al*., 1999; Treacy *et al*., 2006; Tynan and DeMaster, 1997; Stirling and Parkinson, 2006). This paper presents data on the distribution and numbers of cetacean species in the eastern Chukchi Sea based on aerial and vessel-based surveys conducted during industry operations in the summer and autumn of 2006–8. The data were collected from a variety of platforms (vessel and fixed-wing aircraft) and survey methods including randomized line-transect surveys (aerial data) and opportunistic observations (most vessel data) during industry activities.

METHODS

Data were collected from two types of fixed-wing aircraft and numerous different vessels. Aerial surveys were conducted in nearshore areas from 0–37km from shore, and vessel-based data were limited to offshore areas, defined as >37km from shore (Fig. 1). For analysis purposes the data were divided into calendar months or summer (July and August) and fall (September–November) seasons. These seasons roughly correspond to the summering period for cetaceans in the area and separate the typical bowhead whale and beluga spring and fall migration periods. The presence of sea ice may alter the amount of available habitat for whales summering in the northern Chukchi Sea and sea ice varied across the three years. Ice remained in large portions of the northern Chukchi Sea through September of 2006, however in 2007 ice had retreated from the northern Chukchi Sea by early to mid-August. Ice conditions in 2008 were similar to 2006 in total area covered, but the concentration of ice in those areas was lower than in 2006.

Aerial Surveys

Aerial surveys were flown from Pt Barrow to Pt Hope, Alaska, between the coast or barrier islands to ~37km offshore (Fig. 1). Within this nearshore study area, two types of systematic transects were flown. "Sawtooth" surveys provided broad-scale survey coverage of nearshore waters. They consisted of 22 transect lines (total length ~1,015km) flown in a sawtooth pattern between the coastline and 37km offshore. The start point of the first transect line was randomly selected for each survey from within 15km of Pt Barrow. All subsequent transect line start/end points were correspondingly shifted along the coast and the 37km offshore limit to create a new survey route. Weather permitting, surveys were conducted twice per week from 9 July through 12 November 2006, but no surveys were flown from 26 July through 22 August due to aircraft unavailability. In 2007, surveys were flown from 10 July through 4 November and in 2008 from 15 July through 13 October.

Surveys were conducted at 305m or 457m above sea level in a Twin Otter or high-wing Aero Commander aircraft with bubble windows for the primary observers. Three observers were present during all surveys; one observer on each side of the aircraft recorded marine mammal observations and sighting conditions and the third observer operated a laptop computer. The aircraft position and altitude were automatically recorded onto the laptop from a GPS receiver. Environmental and sightability conditions including ice cover, cloud/fog cover ("sightability"), Beaufort wind force, and glare were recorded by each observer every two minutes while on transect. For each marine mammal sighting, the number, species, inclinometer angle when the sighting was perpendicular to the aircraft track, and any movement and behavioural information were recorded. Each observer dictated those and additional details of sightings into a digital voice recorder. After the survey, data entered into the computer during the flight were cross-checked against those recorded on the digital voice recorders and additional details of sightings were added to the database.

Vessel-based Surveys

Marine Mammal Observers (MMOs) aboard 18 different vessels (including seismic source vessels and support vessels) collected effort and sightings data used in this study. In all three years, vessels were present over a broad period of time and a broad geographic area, providing more information about marine mammals of the Chukchi Sea than could have been obtained from any one vessel (Fig 2). However, because the vessels were engaged in industry operations, effort was patchy across the Chukchi Sea and sampling was not conducted in a randomized transect manner. Vessels were pooled into two categories ("tall" [bridge height ≥11m] and "short" [bridge height <11m]) based on a statistical difference in mean sighting distance between the two groups. This allowed calculation of different $f(0)$ correction factors for use in density estimates for the two groups of vessels.

Visual monitoring methods were similar to those used during many previous seismic cruises conducted under Incidental Harassment Authorizations (IHAs) issued by U.S. National Marine Fisheries Service (NMFS) to U.S. companies since 2003, and with some variation, under IHAs issued for seismic programs in the Alaskan Arctic since 1996. Standard visual observation methods are described in detail elsewhere (Reiser *et al*., 2009). At least one MMO maintained a visual watch for marine mammals during all daylight hours onboard each seismic source and all support vessels associated with seismic operations. Observers focused their search effort forward and to either side of the vessel, searching aft of the vessel occasionally while it was underway. Watches were conducted with the unaided eye, Fujinon 7×50 reticule binoculars, higher powered (18× or 20×) image stabilized binoculars or Big Eye binoculars (25×150).

Data collected routinely during watch included the number of observers on duty, vessel activity, visibility conditions, and Beaufort wind force. Data collected during sightings included species, number, direction and distance at initial sighting and subsequent resightings, movement, and behaviour. All data were recorded onto paper datasheets or directly into an electronic database.

Data Selection

Aerial survey data were used for analysis when Beaufort wind force was ≤4, sightability was categorized as moderately impaired or better, and glare was categorized as moderate or better.

Vessel-based effort and sightings were used for analysis when they were made during daylight periods without active seismic or in areas where seismic sounds were <120 dB re 1 μPa (rms), excluding

- periods 0–2h after the airguns were turned off (post-seismic), which allowed for normalization of cetacean distribution after periods of seismic activity;
- periods when another vessel was present within 5km to the forward 180°, as the presence of another vessel may have altered the distribution of cetaceans;
- periods when ship speed was <3.7km/h (2kt);
- periods with seriously impaired sightability. These included periods with one or more of the following: visibility <3.5km, Beaufort wind force (Bf) >5 (Bf >2 for cryptic species such as porpoises, minke whales, and beluga whales), or >60º severe glare between 90º left and 90º right of the bow.

Data from support vessels were considered "non-seismic" and therefore useable in analyses if collected >2h after all airguns had been turned off or when the vessel was operating in an area where sounds from an active seismic survey were <120 dB re 1 μPa.

Density Estimation
Line transect methodology (Buckland *et al*., 2001) was used to convert survey effort and marine mammal sightings to estimates of density for each species. Probability detection functions *f*(0) were calculated for each species within each vessel group (or aircraft) from the survey data using the program DISTANCE (Thomas *et al*., 2006, version 5.0, release 2). Density estimates included corrections for availability bias [$g_a(0)$] using historic surfacing and dive data for each species (Table 1). Confidence intervals around the monthly estimate of whales present within the aerial survey study area were calculated from the individual survey estimates within the given month using a bootstrap method.

RESULTS

Aerial Surveys
In total 41,961km of sawtooth transects were flown in useable observation conditions during 25, 28, and 24 surveys in 2006, 2007, and 2008, respectively. The sightability and availability correction factors used in density estimates are given in Table 1.

Beluga whales (*Delphinapterus leucas*) were present in the greatest numbers in July of all three years (Table 2). Monthly estimates of the number of beluga present within the study area ranged from 0 in August–October, 2008 to 1,645 (CV=0.60) in July, 2007. The number of beluga present in the fall months was somewhat higher in 2006 than 2007 or 2008, but the difference was not large. Most belugas were sighted in the northern half of the study area (Fig 3).

Very few bowhead whales (*Balaena mysticetus*) were observed from July through September in any year (Table 3). Numbers increased greatly during the last month of surveys in all three years with estimates of the number of whales present within the study area ranging from zero in most of the summer months of all years to 634 (CV=0.23) in late October and early November, 2007. The geographic distribution of bowhead sightings was similar to that of belugas, with most sightings occurring north of Pt. Lay (Fig 4).

Larger numbers of gray whales (*Eschrichtius robustus*) were sighted in summer compared to fall of all years (Table 4). Additionally, density estimates during July and August were 2 to 5 times greater in 2007 and 2008 than in 2006. Feeding behaviour was recorded for 79% of the sightings across the three years. The estimated number of gray whales present during the fall months fell by more than half compared to the summer months except in September of 2008. Similar to the other species, gray whales were also sighted in larger numbers in the northern portion of the study area (Fig. 5).

Vessel-based Surveys
Total effort that met the analysis criteria described in Methods was similar in 2006 (11,862km) and 2007 (11,955km), but was much greater in 2008 (25,895km). Over the three years more than half of the effort was conducted during Beaufort wind force 2 and 3 (Table 5). Less effort occurred in the fall of each year and the effort available from fall of 2007 was notably skewed towards wind force 4 and 5 (Table 5). There were fewer data available for cryptic species, such as the harbor porpoise and Minke whale (*Balaenoptera acutorostrata*) since data collected in conditions above Beaufort wind force of 2 were excluded from analyses. Total effort for cryptic species was 5,036km in 2006, 5,162km in 2007, and 10,989km in 2008 (Table 5). In the fall of 2007, in particular, there was little useable effort for cryptic species (707km; Table 5).

Overall, the numbers of cetacean sightings from vessels were similar in 2006 and 2007 (Table 6). Effort and sightings were greater in 2008 than in the previous two years. Seasonal patterns differed among years, with similar numbers of cetacean sightings in the summer and fall of 2006, but many more sightings in the summer than the fall in 2007 and 2008 (Table 6). Harbor porpoise and Minke whale were consistently observed in larger numbers during summer than fall across all three years. Gray whale observations showed a similar trend except that more gray whales were observed in the fall than summer of 2006. The largest numbers of bowheads were observed in the fall of 2006, with small numbers observed during all other years and seasons.

Using the correction factors presented in Table 7, densities of cetacean species observed from vessels were calculated (Table 8). The 2006 density estimates show an increase in bowhead whale and gray whale numbers in the fall (Table 8). Bowhead whale density estimates were low in both the summer and fall of 2007, but showed an increase in the fall in 2008. Gray whale density was higher in the summer than the fall, in both 2007 and 2008. Harbor porpoise densities were similar between summer and fall in 2007 and 2006 (Table 8), but as previously noted, there was limited useable effort for cryptic species in the fall of 2007, so the fall estimate should be viewed with caution.

DISCUSSION

Aerial and vessel-based surveys in 2006–8 documented cetacean distribution and abundance in the northeastern Chukchi Sea and provided the first quantitative data since surveys conducted there in the 1980s and early 1990s. In a few cases, species uncommon to the Chukchi Sea were documented, including two fin whale sightings (*Balaenoptera physalus)*, four humpback whale sightings (*Megaptera novaeangliae)*, and generally higher numbers of harbour porpoise (*Phocoena phocoena),* that were not limited to coastal areas. However, the species present and their relative abundances were generally similar to what has previously been reported for the area (MMS, 2007).

Beluga Whales

Belugas were not sighted by vessel-based observers at any time in 2006 or 2007 and only once in 2008. During June and July, belugas congregate in lagoons and nearshore waters along the Chukchi Sea coast, especially Omalik and Kasegaluk Lagoons near Point Lay (Huntington *et al.,* 1999; Suydam *et al.,* 2001). Consistent with this, beluga sighting rates during aerial surveys were highest in July and most sightings occurred within 5km of shore. The largest congregation of beluga whales was observed on 9 July during the first survey in 2006, when 295 belugas were counted in a single sighting during a coastline survey. There was high variability in the numbers of beluga whales observed along aerial transects from August through November with most whales recorded farther offshore. This was consistent with the observations of Clarke *et al.* (1993) and Moore (2000) who reported that beluga whales were distributed over a wide range and utilized offshore habitats during fall migration through the Chukchi Sea.

Satellite tracking of eastern Chukchi Sea beluga whales from 1998 to 2002 indicated that by August some beluga whales moved north of Barrow into the northern Chukchi and Beaufort seas (Suydam *et al.,* 2001, 2005). Some of the tagged whales moved into the Canadian Beaufort Sea suggesting overlap between the Eastern Chukchi Sea and the Beaufort Sea stocks. The detection rate during aerial surveys increased slightly in October and November of 2006 when beluga whales would be expected to return to the Chukchi Sea (Suydam *et al.,* 2001, 2005) but a similar increase was not recorded in fall 2007 or 2008. More of the 2006 late-season sightings occurred in a band 30-39km band from shore rather than along the shoreline.

Bowhead Whales

The Bering-Chukchi-Beaufort (BCB) stock of bowhead whales migrates north from wintering areas in the Bering Sea through the Chukchi Sea in early-spring (April–May) and arrives in the summering areas in the eastern Beaufort Sea and Amundsen Gulf in June–July (Moore and Reeves, 1993). Most of the bowhead whales that winter in the Bering Sea are thought to migrate to the Beaufort Sea during this period. However, Moore (1992) reported 26 sightings of bowhead whales during aerial surveys in July and August in the northeastern Chukchi Sea from 1975 to 1991 and suggested that some bowhead whales may summer in the Chukchi Sea. In 2006–8, nine total bowhead whale sightings were recorded in the Chukchi Sea in July including all aerial survey types and sightability conditions and only three were recorded in August.

Aerial and vessel survey data from 2006 indicated an increase in bowhead whale abundance during the fall, as would be expected based on the known migration pattern. However, aerial survey data indicated that peak bowhead whale abundance in the nearshore area did not occur until November, with most sightings in the Pt. Franklin area. This late pulse of whales along the Chukchi Sea coast was somewhat unexpected, since past ship-based surveys in September and October of 1992 and 1993 did not record any bowhead sightings along the western coast of Alaska between Point Hope and Barrow (Moore *et al.,* 1995). However, little prior information was available on bowhead movements in the Chukchi Sea during November. Densities from vessel observations indicated that bowhead whales were also more common in the fall (except in 2007) although no bowheads were recorded in November. Recent satellite tagging data confirm earlier evidence that many bowhead whales continue their westward migration across the northern Chukchi Sea to the coast of Chukotka in the western Chukchi Sea before migrating south toward the Bering Sea (Mate *et al.,* 2000; Quakenbush *et al.*, 2009). The path of most satellite-tagged bowhead whales through the Chukchi Sea in fall was just north of most vessel survey effort. The offset of peak bowhead observations from vessels (in October) and aircraft (in November) may reflect a change in migration routes used by whales later in the year.

Acoustic recorders placed along the Chukchi Sea coast from 12 September–12 October detected many bowhead whale vocalizations in 2006 (Clark, 2007). Analysis of bowhead vocalizations from acoustic recorders deployed across a larger portion of the Chukchi Sea in 2007 were confounded by a very large number of overlapping and similar walrus calls so the final results are not considered reliable (Martin *et al.*, 2009). Recorders deployed in similar locations in 2008 failed to function properly so acoustic data are very limited. In 2006, bowhead whales were recorded in the fall by the hydrophone arrays at Barrow, Wainwright, and Pt Lay, but not at Cape Lisburne where the three recorders farthest offshore were not recovered. Hydrophones near Barrow detected bowhead whales on each recorder. Detections decreased from Pt Barrow to Pt Lay, and a shift in detections relative to the coast occurred from Wainwright (located between Pt Barrow and Pt Lay), where there was a uniform distribution in detections, to Pt. Lay, where there were mostly inshore detections. The reduction in call detections at the acoustical arrays from Barrow to Pt. Lay also suggests a possible offshore dispersal of bowheads as they migrated southwest (or west) through the Chukchi Sea at this time of year.

Gray Whales

Gray whale use of nearshore habitats was consistent with previous observations (Moore and DeMaster, 1998; Moore *et al.,* 2000) which reported that gray whales in the Chukchi Sea selected coastal and shoal waters. Moore *et al.* (2000) reported gray whales summering in the Chukchi Sea clustered along the shore primarily between Cape Lisburne and Point Barrow. In autumn Moore *et al.* (2000) reported gray whales clustered near shore at Point Hope and between Icy Cape and Point Barrow, as well as in offshore waters northwest of Point Barrow at Hanna Shoal. Moore *et al.* (1986a) observed inter-annual variability in gray whale abundance with peak abundance occurring in July (1982), August (1983), and September (1984).Our data show a shift from July when most whales were sighted further from shore and were travelling, to all subsequent months when most sightings were of feeding whales along the coastline. This suggests that in July gray whales may have been moving into the Chukchi Sea and that from August to September they were actively feeding in the study area.

Gray whale was the most common cetacean species sighted from vessels in July and August of the three years (Tables 6 and 8). Seismic survey activities and vessel operations generally occurred farther offshore and the reduced number of gray whale sightings from vessels during the later months may have resulted from vessel locations as well as out-migration to the south.

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Table 1

Correction values used in estimating densities from aerial survey data. Sightability correction factors were derived from the survey data separately for each year and altitude so ranges are shown. Availability correction factors were calculated from the sources indicated.

	$f(0)$				
	Aero Commander	Twin Otter			
Altitude	305m	305m	457m	$g_a(0)$	$g_a(0)$ Source
Beluga	2.99	2.05 - 2.39	2.32 - 2.52	0.58	from Martin and Smith (1992)
Bowhead Whale	-	1.96 - 2.07	2.22 - 2.24	0.144	from Thomas *et al.* (2002)
Gray Whale	2.35	1.87 - 2.22	1.81 - 2.19	0.32, 0.292	(migrating, feeding) from Forney and Barlow (1998), Wursig et al. (1986)

Table 2

Estimated numbers of belguas in the sawtooth survey area of the eastern Chukchi Sea by month in 2006–8, including allowance for $f(0)$, and $g_a(0)$ correction factors.

Year/Month	No. of Surveys	Effort (km)	Sight.	Ind.	Density (No./1000km^2)	Est. No. Whales	CV	95% C.I.	
2006									
July	6	3185	3	10	9.6	183	0.63	0	436
August	3	1103	1	1	1.5	29	0.82	0	87
September	6	2898	5	5	3.9	75	0.65	0	177
Oct-Nov	10	5292	6	10	4.6	88	0.65	0	213
2007									
July	5	2515	21	329	127.3	1645	0.60	0	3792
August	8	5248	19	122	18.9	185	0.52	46	391
September	7	3569	2	4	2.4	45	0.68	0	113
Oct-Nov	9	2371	3	3	2.4	47	0.86	0	127
2008									
July	6	3018	5	10	3.7	69	0.89	0	201
August	7	4668	0	0	0.0	0	-	-	-
September	7	3455	0	0	0.0	0	-	-	-
October	5	2999	0	0	0.0	0	-	-	-

Table 3

Estimated numbers of bowhead whales in the sawtooth survey area of the eastern Chukchi Sea by month in 2006–8, including allowance for $f(0)$, and $g_a(0)$

Year/Month	No. of Surveys	Effort (km)	Sight.	Ind.	Density (No./1000km^2)	Est. No. Whales	CV	95% C.I.	
2006									
July	6	3185	1	1	1.3	24	0.95	0	79
August	3	1103	0	0	0.0	0	-	-	-
September	6	2898	2	2	2.8	53	0.91	0	162
Oct-Nov	10	5292	12	18	30.7	594	0.76	0	1648
2007									
July	5	2515	0	0	0.0	0	-	-	-
August	8	5248	0	0	0.0	0	-	-	-
September	7	3569	0	0	0.0	0	-	-	-
Oct-Nov	9	2371	11	11	33.2	634	0.23	329	900
2008									
July	6	3018	0	0	0	0	-	-	-
August	7	4668	0	0	0	0	-	-	-
September	7	3455	2	2	1.4	27	0.95	0	88
October	5	2999	3	4	6.1	115	0.87	0	340

Table 4

Estimated numbers of gray whales in the sawtooth survey area of the eastern Chukchi Sea by month in 2006–8, including allowance for $f(0)$, and $g_a(0)$ correction factors.

Year/Month	No. of Surveys	Effort (km)	Sight.	Ind.	Density (No./1000km^2)	Est. No. Whales	CV	95% C.I.	
2006									
July	6	3185	8	13	6.8	130	0.33	48	222
August	3	1103	1	3	4.9	95	0.86	0	313
September	6	2898	3	4	2.0	38	0.55	0	78
Oct-Nov	10	5292	1	1	0.2	4	0.4	0	14
2007									
July	5	2515	22	25	15.8	301	0.30	103	460
August	8	5248	71	85	23.1	138	0.28	219	683
September	7	3569	10	12	7.2	137	0.5	30	294
Oct-Nov	9	2371	0	0	0.0	0	-	-	-
2008									
July	6	3018	37	50	38.5	729	0.39	266	1364
August	7	4668	27	34	12.0	230	0.28	115	362
September	7	3455	14	15	9.2	174	0.36	48	297
October	5	2999	3	3	1.5	28	0.56	0	60

Table 5

Visual observation effort (km) meeting useability criteria by year, season, and Beaufort wind force during vessel operations in the eastern Chukchi Sea, 10 July–24 October 2006, 10 July–7 November 2007, and 16 July–17 October 2008.

	Beaufort Wind Force						
Season/Year	0	1	2	3	4	5	**Total**
Summer 2006	151	1,043	1,548	1,511	1,353	411	**6,017**
Fall 2006	340	566	1,389	1,296	1,272	982	**5,845**
Total 2006	491	1,609	2,937	2,807	2,625	1,393	**11,862**
Summer 2007	174	1,302	2,980	2,509	970	677	**8,612**
Fall 2007	0	134	573	820	983	833	**3,343**
Total 2007	174	1,436	3,553	3,329	1,953	1,510	**11,955**
Summer 2008	579	3,831	5,349	5,414	4,322	1,844	**21,339**
Fall 2008	0	423	807	1,758	1,214	354	**4,556**
Total 2008	579	4,254	6,156	7,172	5,536	2,198	**25,895**

Table 6

Numbers of cetacean sightings (total number of individuals) in the eastern Chukchi Sea sighted from vessels during periods meeting data analysis criteria, by year and season.

	2006		**2007**		**2008**	
	Summer	Fall	Summer	Fall	Summer	Fall
Unidentified Whale	8 (9)	5 (7)	3 (3)	2 (4)	9 (12)	1 (2)
Odontocetes						
Beluga	0	0	0	0	1 (2)	0
Harbor Porpoise	10 (13)	3 (7)	9 (13)	1 (3)	13 (24)	1 (1)
Killer Whale	0	1 (2)	1 (1)	0	0	0
Unidentified Odontocete	3 (4)	0	1 (1)	0	0	0
Mysticetes						
Bowhead Whale	3 (3)	22 (41)	5 (6)	1 (1)	5 (13)	5 (29)
Fin Whale	0	0	0	0	2 (4)	0
Gray Whale	9 (13)	16 (33)	28 (57)	4 (9)	70 (149)	9 (16)
Humpback Whale	0	0	2 (3)	1 (2)	1 (1)	0
Minke Whale	3 (3)	0	3 (3)	0	8 (10)	0
Unidentified Mysticete	2 (2)	1 (1)	5 (6)	1 (4)	63 (96)	12 (16)
Total	38 (47)	48 (91)	57 (93)	10 (23)	172 (311)	28 (64)

Table 7

Correction factors used to estimate densities of cetaceans from vessel-based data. Short (bridge height <11m) and tall (bridge height ≥11m) vessel *f*(0) values for each species, year, and season were derived from data collected during vessel operations in the eastern Chukchi Sea so ranges are shown. Too few data were available for cryptic species so an *f(0)* value of 0.369 from Barlow and Gerrodette (1996) was used. Availability values, $g_d(0)$ were taken Forney and Barlow (1998); $g_a(0)$ was 1.00 for all species.

	f(0)		
	Short Vessels	Tall Vessels	$g_d(0)$
Beluga Whale	0.369	0.369	0.840
Bowhead Whale	0.915 - 0.772	0.549 - 0.332	0.902
Fin Whale	0.915 - 0.772	0.549 - 0.332	0.902
Gray Whale	0.915 - 0.772	0.549 - 0.332	0.902
Harbour Porpoise	0.369	0.369	0.768
Humpback Whale	0.915 - 0.772	0.549 - 0.332	0.902
Killer Whale	0.915 - 0.772	0.549 - 0.332	0.561
Minke Whale	0.369	0.369	0.840
Undentified Mysticete	0.915 - 0.772	0.549 - 0.332	0.902
Unidentified Odontocete	0.915 - 0.772	0.549 - 0.332	0.561
Unidentified Whale	0.915 - 0.772	0.549 - 0.332	0.902

Table 8

Density estimates (individuals per 1000 km^2) for cetacean species observed in the eastern Chukchi Sea during vessel operations from July–November, 2006–8. Densities include *f*(0) and *g*(0) corrections shown in Table 7.

	No. individuals / 1000 km^2					
	2006		**2007**		**2008**	
	Summer	Fall	Summer	Fall	Summer	Fall
Beluga Whale	0.00	0.00	0.00	0.00	0.10	0.00
Bowhead Whale	0.60	5.00	0.40	0.10	0.30	3.20
Fin Whale	0.00	0.00	0.00	0.00	0.10	0.00
Gray Whale	0.90	2.40	3.10	1.10	2.00	1.00
Harbor Porpoise	1.10	1.30	1.60	1.00	0.90	0.20
Humpback Whale	0.00	0.00	0.20	0.10	0.05	0.00
Killer Whale	0.00	1.40	0.10	0.00	0.00	0.00
Minke Whale	0.30	0.00	0.70	0.00	0.10	0.00
Unidentified Mysticete	0.41	0.20	0.40	0.60	2.10	1.70
Unidentified Odontocete	0.66	0.00	0.10	0.00	0.00	0.00
Unidentified Whale	0.31	0.70	0.20	0.00	0.20	0.20

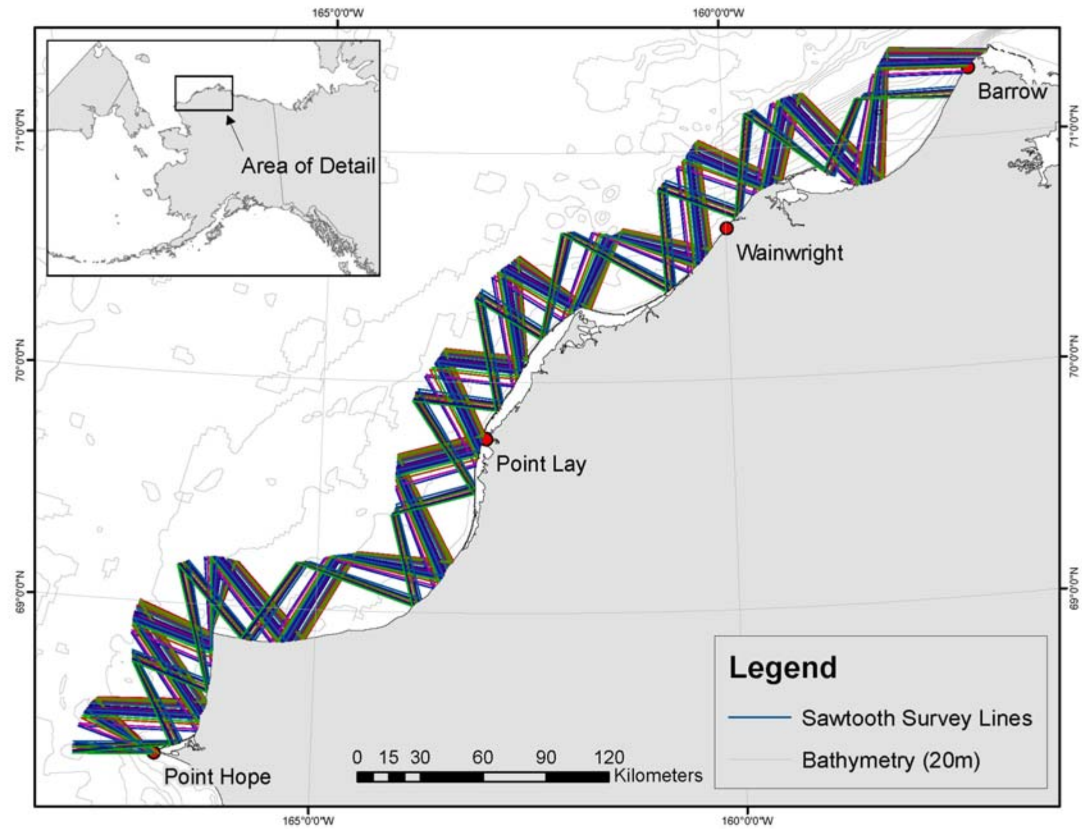

Figure 1. Aerial survey sawtooth transects flown July–November of 2006–2008 along the northeastern Chukchi Sea coast.

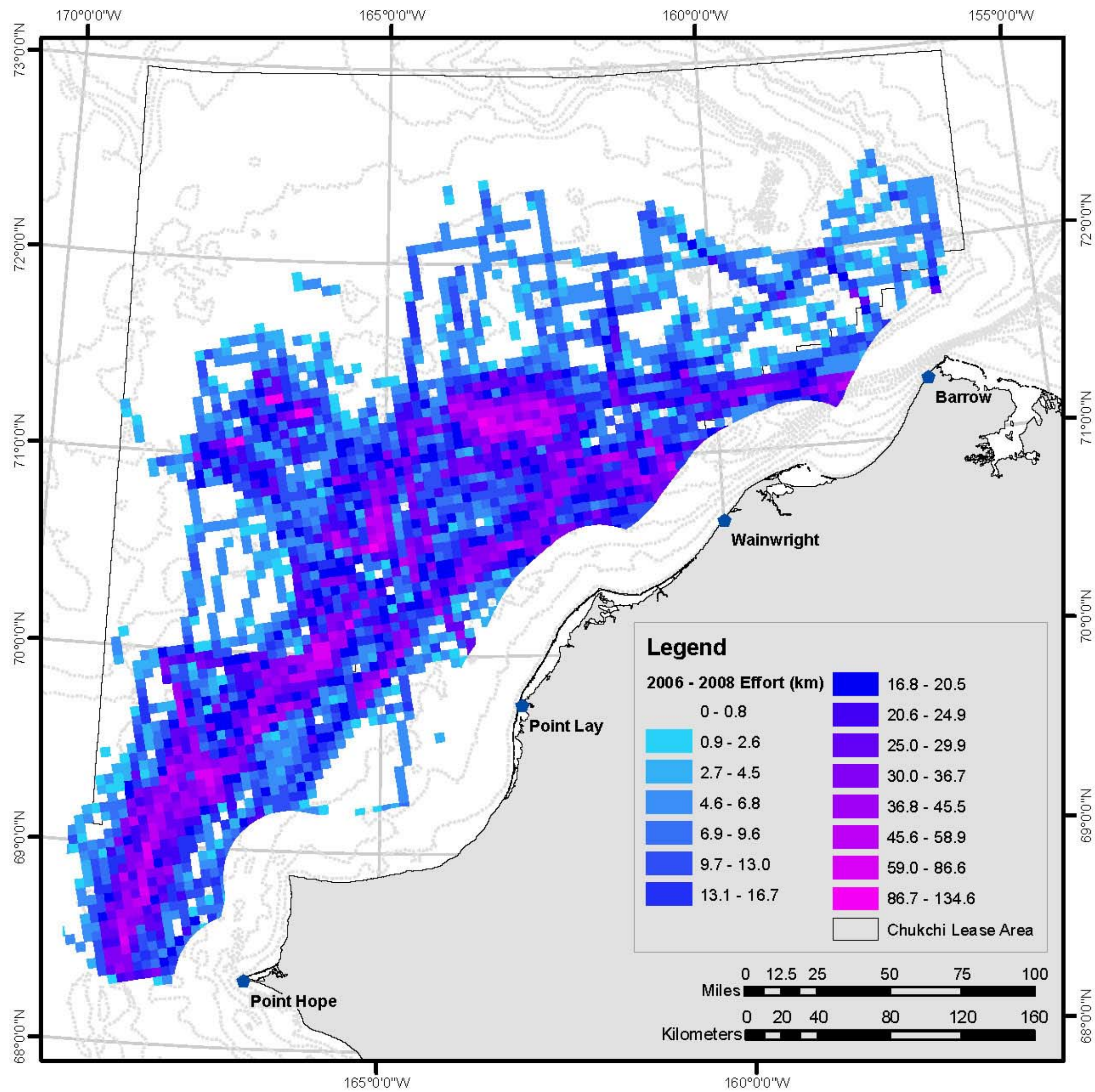

Figure 2. The amount of vessel-based observation effort (km) within 25 km^2 grid cells that occurred >37km from shore in the Chukchi Sea from 2006–8.

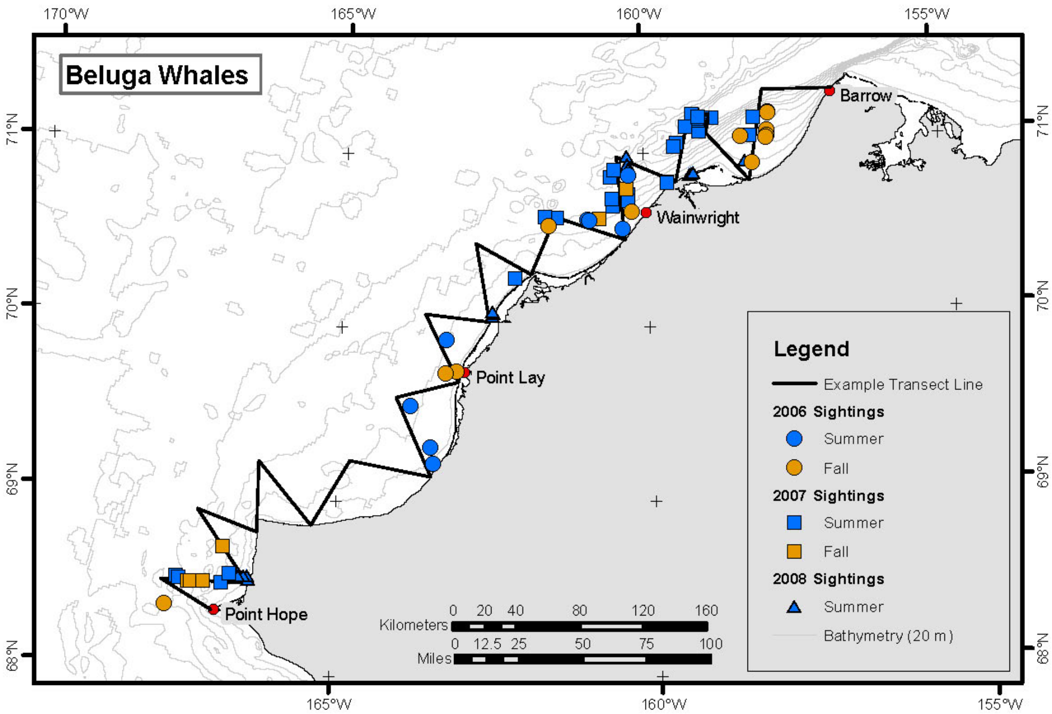

Figure 3. Locations of beluga whale sightings during aerial surveys in the eastern Chukchi Sea during July–November 2006–8.

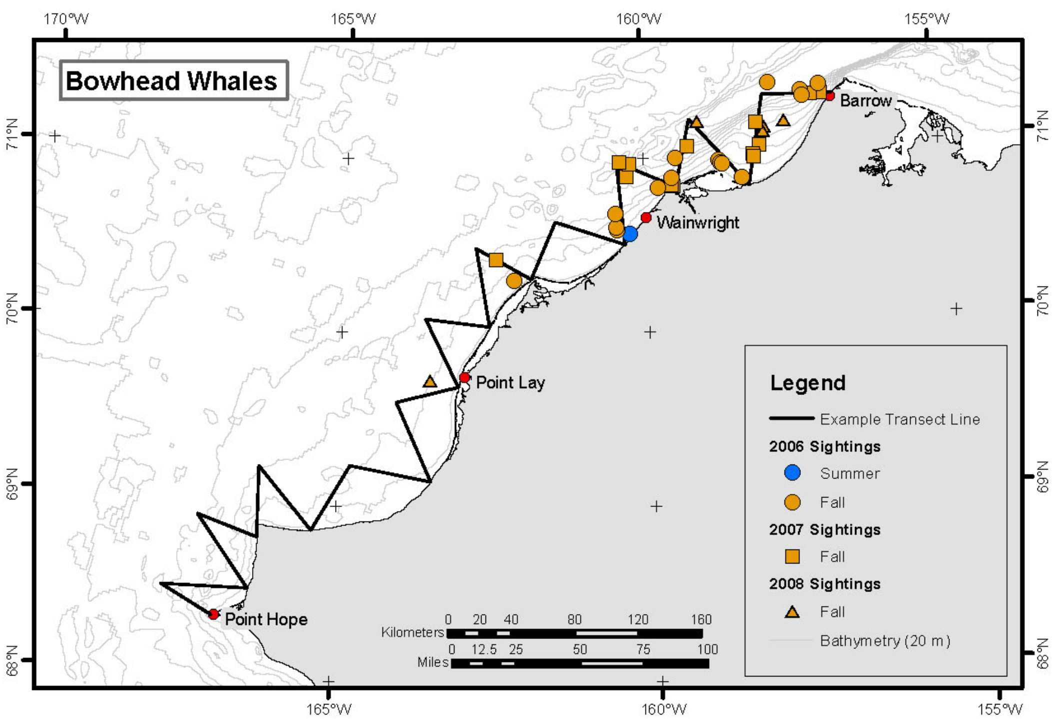

Figure 4. Locations of bowhead whale sightings during aerial surveys in the eastern Chukchi Sea during July–November 2006–8.

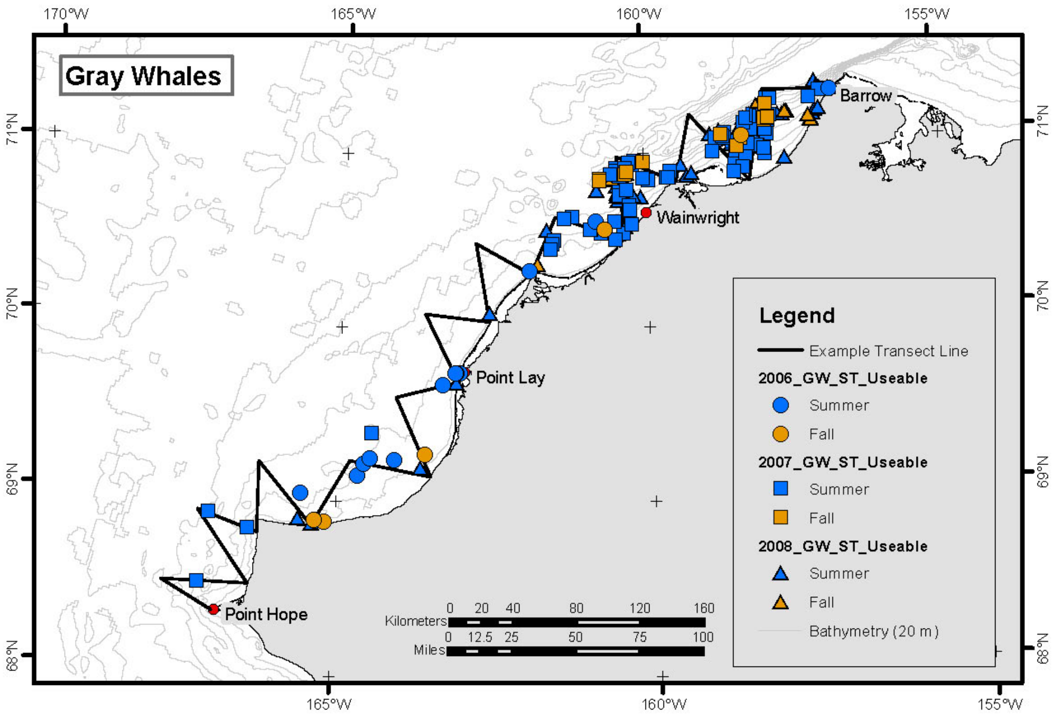

Figure 5. Locations of gray whale sightings during aerial surveys in the eastern Chukchi Sea during July–November 2006–8.