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# Marine mammal distribution and abundance in an offshore sub-region of the northeastern Chukchi Sea during the open-water season

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ABSTRACT

This paper describes the distribution and abundance of marine mammals during the open-water season within and near three offshore oil and gas prospects in the northeastern Chukchi Sea, known as the Klondike, Burger, and Statoil study areas. We collected vessel-based marine mammal data during July–October 2008–2010 along line transects oriented in a north–south direction. Over this period, we surveyed ~18,600 km of on-transect effort in the three study areas. Sightings of cetaceans were rare. The bowhead whale was the primary cetacean species sighted and was mostly observed in October (33 of 35 animals). Pinnipeds were the most abundant marine mammals in the study area, with 980 seals and 367 walruses recorded on transect. Most seals were observed as solitary animals, while walruses were often observed in aggregations. We calculated seal and walrus densities using species-specific detection functions corrected for probability of detection. There was high interannual variability in the abundance of seals and walruses that for some species may be related to interannual differences in ice conditions. Notwithstanding this variation, the distribution data suggest that benthic-feeding bearded seals and walruses generally were more common in the Burger and Statoil study areas, which can be characterized as more benthic-dominated ecosystems. The distribution of ringed/spotted seals did not show any statistically significant differences among the study areas, although a slight preference for the Klondike and Statoil study areas was suggested. Both of these study areas are affected by Bering Sea Water from the Central Channel and have a stronger pelagic component than the Burger study area. Continued sampling of these areas will help establish whether the observed trends in marine mammal distribution and abundance are persistent.

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Physical and ecological characteristics of the Chukchi Sea are influenced seasonally by warm, nutrient-rich Bering Sea Water that enters through the Bering Strait during spring (Weingartner et al., 2005; Woodgate and Aagaard, 2005). This influx of biomass and nutrients results in high biological productivity (Grebmeier and McRoy, 1989; Springer and McRoy, 1993) that supports various marine mammal populations.

chers, substantial information is available about marine mammals in the Chukchi Sea, including information from historical whaling records (Bockstoce, 1986; Bockstoce et al., 2005), traditional knowledge (e.g., Quakenbush and Huntington, 2009), and research (e.g., Burns and Eley, 1978; Moore and DeMaster, 1998; Lowry et al., 2000; Quakenbush et al., 2010). Cetacean species that have been observed most commonly in the northeastern Chukchi Sea include bowhead whales (*Balaena mysticetus*), beluga whales (*Delphinapteras leucas*), and gray whales (*Eschrichtius robustus*; e.g., Moore and DeMaster, 1998; Clarke and Ferguson, 2010; Moore et al., 2010). Pinniped species that most commonly occur in the Chukchi Sea include the ringed seal (*Pusa hispida*), spotted seal (*Phoca larga*), bearded seal (*Erignathus barbatus*), and walrus (*Odobenus rosmarus*; Burns, 1970; Lemons and Christman, 2012). The ribbon seal (*Histriophoca fasciata*) also occurs in the Chukchi Sea, but most commonly inhabits the Sea of Okhotsk and Bering Sea (Boveng et al. 2008).

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The Chukchi Sea is covered by sea ice in late winter and spring and is mostly ice-free in late summer and fall, a process that drives seasonal movements of marine mammals that use the Chukchi Sea mainly for foraging and migration during the open-water period. The ice edges form important habitat for seals and walruses. Of the marine mammal species discussed in this paper, only ringed and bearded seals are considered to be year-round residents in the Chukchi Sea (Burns, 1970; Burns and Eley, 1978; Burns et al., 1981; Kelly, 1988a, 1988b). Ringed seals have adapted to life in the landfast sea ice by maintaining breathing holes and constructing lairs in snowdrifts or ice rubble in landfast or heavy pack ice (Smith et al., 1991). Bearded seals seldom maintain breathing holes and, thus, largely occur in the drifting offshore pack ice (Burns, 1970; Burns and Eley, 1978). Spotted seals, ribbon seals, most bearded seals, ringed seals (especially subadults), and walruses migrate south towards the Bering Sea during the fall (Burns, 1970; Fay et al., 1997; Lowry et al., 1998; Boveng et al., 2008; Crawford et al., 2012) as do bowhead, beluga, and gray whales (Moore and DeMaster, 1998).

Animals tagged with satellite/radio transmitters and dive recorders have provided detailed information on seasonal movements in relation to the formation and retreat of sea ice, habitat use, and foraging behavior of individual seals and walruses (Lowry et al., 1998; Jay et al., 2010, 2012; Cameron et al., 2010; Boveng et al., 2012; Crawford et al., 2012; Herreman et al., 2012). Information on behavior and movements of individual animals is useful in evaluating distribution and abundance data obtained through spring aerial surveys (e.g., Burns and Eley, 1978; Gilbert 1989a, 1989b; Fay et al., 1997; Bengtson et al., 2005). Acoustic records of vocalizing whales, seals, and walruses throughout the northeastern Chukchi Sea and satellite tagging data also have increased understanding of the temporal and spatial distribution of marine mammals (e.g., Suydam et al. 2001; Moore et al., 2006; Berchok et al., 2010; Quakenbush et al. 2010; Delarue et al., 2011).

Most marine mammal studies cover large areas documenting large-scale movements of marine mammals. In contrast, this paper presents results from vessel-based observations on the abundance and distribution of marine mammals during the open-water season in three offshore oil and gas prospects (the Klondike, Burger, and Statoil study areas) in the northeastern Chukchi Sea. This study is part of a multi-year, interdisciplinary program aimed at establishing a baseline dataset for predicting and mitigating potential impacts of oil and gas exploration and development.

Despite the proximity of the three study areas to one another, the geomorphology of the Chukchi shelf, the flow of currents during the open-water season, and the wind patterns influence the physical and biological oceanography of each study area differently. The high interannual variability in the timing of ice retreat in the northeastern Chukchi Sea is associated mostly with the seasonal evolution of the east–west component of the winds. Westerly winds tend to force ice offshore, resulting in open water along the coast, whereas easterly winds tend to trap ice along the coast (Weingartner et al., 2013). Because of the proximity to the Central Channel, water masses in the Klondike study area and in the western part of the Statoil study area are generally warmer and less saline than in the Burger study area (Weingartner et al., 2013), whereas the central and eastern part of the Statoil study area is similar to the Burger study area.

The influence of Bering Sea Water and water from melting sea ice affects plankton, benthos, and fish communities in each of the three study areas differently (Day et al., 2013). The Klondike study area contains more attributes of a pelagic system with higher biomass of oceanic zooplankton, more fishes, and more planktivorous seabirds than does Burger (Gall et al., 2013; Norcross et al., 2013; Questel et al., 2013). The Burger study area is a more benthic-dominated system, with higher density and biomass of benthos (Blanchard et al., 2013) than the Klondike study area. The Statoil study area can be characterized as intermediate with both pelagic and benthic components (Day et al., 2013). The small size of the study areas allows observations in a dense transect grid to detect small-scale patterns of marine mammal distribution and abundance on repeated surveys each field season.

## 2. Methods

### 2.1. Sampling design

Observers recorded all marine mammals sighted along transect lines within three study areas that were each approximately 3000 km$^2$ in size. The sampling grid in the Klondike and Burger study areas consisted of 16 primary and 15 secondary transect lines, each 56 km in length, oriented in a north–south direction, and evenly spaced across the study area (Fig. 1). The Statoil study area was not square, resulting in 19 primary and 19 secondary transect lines of variable length, ranging from 42 to 56 km. The spacing between the primary and secondary transect lines was 1.8 km in each study area. The total line length of the primary transect lines was 889 km in the Klondike and Burger study areas and 861 km in the Statoil study area. Generally, only primary transect lines were surveyed. When these transect lines were not accessible (e.g., due to the presence of sea ice) we surveyed the closest secondary transect line instead.

In 2008 and 2009, we surveyed the Klondike and Burger study areas three times each year. In 2010, we surveyed the Klondike and Statoil study areas two times each and the Burger study area three times. The start and end dates of each survey period varied slightly each year (Fig. 2). The Klondike study area was always sampled first during each survey period, the Burger study area was surveyed second, and the Statoil study area last.

### 2.2. Data collection

One dedicated observer searched for marine mammals during daylight hours from the bridge or flying bridge of the vessels, with eye height ~5–6.5 m above sea level. This observer systematically scanned an area of 180° centered on the vessel's trackline with the naked eye and Fujinon 7 × 50 reticle binoculars while the vessel moved along the tracklines with a speed ranging from 5 to 9 kt (~9.3–17 km h$^{-1}$). Another marine mammal observer, located on the bridge, assisted in the monitoring effort and passed on sighting information to the dedicated observer. The dedicated observer entered all information on datasheets in 2008 and directly into a computer with TigerObserver™ software (TigerSoft, Las Vegas, NV) in 2009 and 2010. Navigation-based software (TigerNav™) linked the date, time, vessel position, water depth (to nearest 0.1 m), sea-surface temperature (to nearest 0.1 °C), and sea-surface salinity (to nearest 0.1 PSU [Practical Salinity Unit]) to every observation. Upon sighting a marine mammal (or group of animals) the observer recorded the following information:

- Environmental data: sea state (Beaufort scale), ice cover (10% increments), visibility (km), and sun glare (in % of observation area). Environmental data were recorded at the start and end of each transect line, when there was a change in observer, and when there was an obvious change in one or more of the environmental variables;
- Sighting data: species, group size, number of juveniles, behavior, bearing and distance of the animal(s) relative to the vessel, heading of the animal(s), rate of movement (pace), sighting cue (what aspect of the animal drew the attention of the observer, i.e., head, fluke, blow, etc.), identification confidence, and person

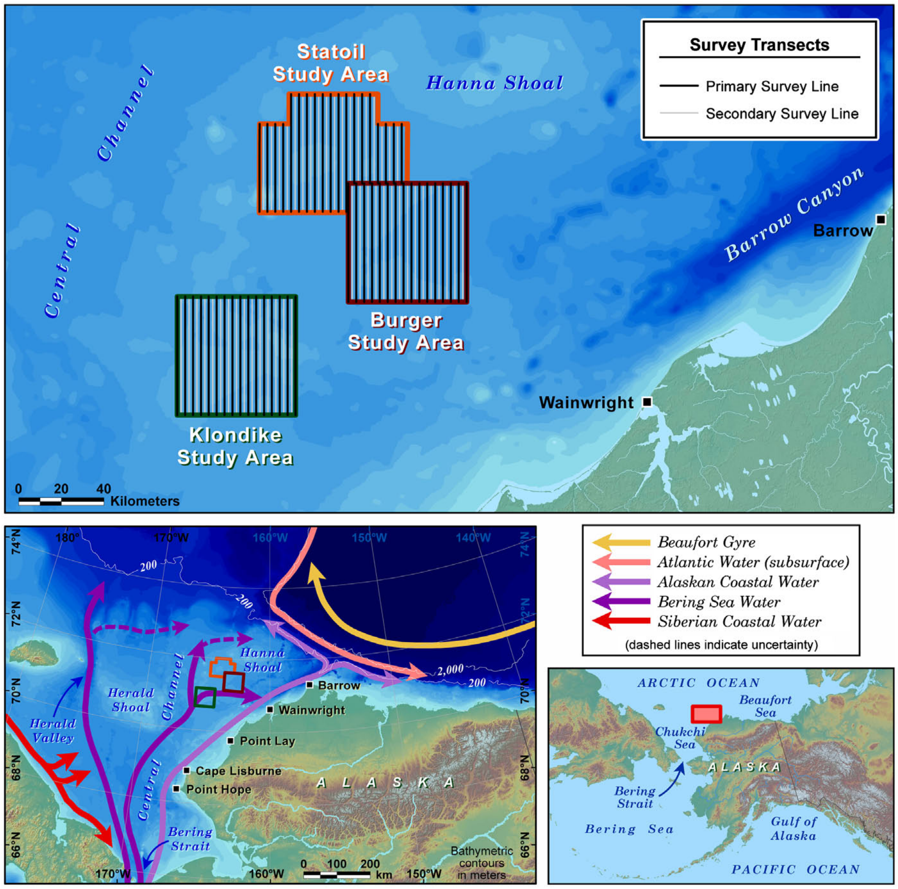


**Fig. 1.** Location of the three study areas in the northeastern Chukchi Sea, with the layout of survey transect lines (upper graph) and the main geographic features and prevailing currents (lower left graph).

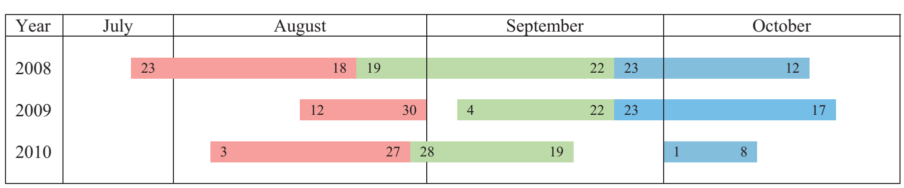


**Fig. 2.** Survey start and end dates by year, 2008–2010. The colors indicate the three separate surveys each year, when each study area was sampled once. In 2010, the Klondike and Statoil study area were not sampled in October. The Statoil study area was only sampled in 2010.

who sighted the animal. Ringed and spotted seals were often difficult to differentiate, especially when they appeared at the surface for a short time or were detected at a large distance. The category "ringed/spotted seal" therefore was introduced to record seal sightings that could not be identified as either. Distances to marine mammals were determined visually using reticle binoculars and/or by visual estimates.

## 2.3. Data analysis

### 2.3.1. Species densities

We analyzed distribution and abundance patterns for marine mammals by estimating corrected densities (number of animals $km^{-2}$) for each study area and year using distance-sampling methodology (Buckland et al., 2001, 2004), which builds on the fundamental concept that the probability of detecting an animal decreases with increasing distance from the transect line. One of the assumptions of distance sampling is that all animals available at perpendicular-distance zero from the observer (i.e., on the transect's centerline) are detected [$g(0)=1$]. However, marine mammal sighting data from vessel-based line-transect surveys commonly violate this assumption [i.e., $g(0)<1$] due to two types of detection bias (Marsh and Sinclair, 1989): availability and perception bias. Availability bias is the number of animals missed on the transect line because they were not available for detection (e.g., animals that are underwater). Perception bias is the number of animals available for detection on the transect line, but missed by the observer. Because information on dive time for seal and walrus species during the open water period does not exist, availability bias was not taken into account in this study. Likewise, no information was collected to determine perception bias and the assumption of $g(0)=1$ therefore resulted in underestimates of our corrected density data.

We used software program Distance 6.1 Release 1 (Thomas et al., 2010) for modeling a detection function with which the proportion of animals missed at different perpendicular distances from the transect line can be estimated. The number of cetacean sightings was too low to model a detection function with confidence. To derive at the optimal model for estimating the detection function for seals and walruses we conducted exploratory analyses that included a subset of the 2008–2010 data, based on the following criteria:

- Only on-transect data were used because observations made along these lines meet the assumptions of line transect theory.
- Only sightings with similar sighting cues, and, thus, equal detection probability, were used. Use of this criterion resulted in:
  - Exclusion of sightings on ice (only applicable to 2008), because the detection probability of marine mammals on ice or in water varies greatly. The total number of sightings on-transect and on ice was too low for calculating a separate detection function for on-ice sightings (seal $n=5$; walrus $n=7$).
  - Grouping of species of similar size and behavior for datasets with small sample sizes. We grouped all ringed and spotted seal sighting data (which included sightings categorized as ringed/spotted seals) and calculated a separate detection function for bearded seal, unidentified seal, and walrus sighting data.

For each group of species, we used Conventional Distance Sampling (CDS) and Multiple Covariate Distance Sampling (MCDS) analyses tools to find the model that fitted the distribution of perpendicular distances best. We tested various strategies for truncation and binning of perpendicular distances and included covariates in the model that, besides distance, have also the potential to affect probability of detection (i.e., sea state, glare amount, observer, and vessel). We assessed the fit of two different model types (hazard-rate and half-normal) with diagnostic plots, the Kolmogorov goodness-of-fit test, and the Akaike's Information Criterion or AIC (following Buckland et al., 2004). The input parameters of the best-fitted model were entered into the distance-sampling model portion of the Mark Recapture Distance Sampling (MRDS) engine that allowed us to apply the estimated detection function to a subset of the data and to estimate corrected densities and 95% confidence intervals for each species, study area, and year (Buckland et al., 2001).

Because identifying individual spotted and ringed seals was challenging (i.e., only 30% positive identification for each species), we pooled all ringed and spotted seal sightings together with the combined ringed/spotted seal category for the density analyses. The large percentage of seal sightings classified as unidentified seals also had to be taken into account to avoid an underestimation of densities for ringed/spotted and bearded seals. We used the ratio of identified ringed/spotted and bearded seal densities of each study area and year as an estimation of their proportions within the “unidentified species” densities. We then added the proportional density of ringed/spotted and bearded seals as determined from the density of unidentified seals to the densities of the identified animals. Applying the ratio of identified seal species to the unidentified individuals assumes that the challenge of identifying the observed animals is similar between ringed/spotted and bearded seals, thus we recognize this might overestimate the more-identifiable bearded seal densities. Overall, this assumption seems reasonable considering the conditions of occurrences where sightings are classified as unidentified (i.e., animals at large distances from the vessel, at the surface for a very short time, and/or a small part of the body visible). The adjustment increased densities for each species but did not change observed patterns in abundance.

With statistical software R 2.13.1 (http://www.r-project.org/) we examined differences in seal and walrus densities between the Klondike and Burger study areas and among years using ANOVA analyses on double square-root transformations of the data. We tested for significance with the Tukey test for multiple comparisons of means (reported as 95% confidence interval [CI]). We ran a separate test to determine differences among the three study areas for 2010, since Statoil was sampled only in that year. In all statistical tests, the level of significance ($\alpha$) was 0.05.

*2.3.2. Spatial distribution*

We developed kernel density maps of on-transect sightings for each species and year to illustrate temporal and spatial patterns of distribution. Kernel density maps were created in ArcGIS10.0's Spatial Analyst extension by using on-transect data (excluding on-ice observations) from all surveys combined within a year. Kernel densities were calculated from average sighting density weighted by the number of individuals and were grouped based on a Natural Breaks (Jenks) distribution. We did not correct the kernel densities for availability and perception bias or for effort.

## 3. Results

Seasonal retreat of sea ice varied among the three survey years (Weingartner et al., 2011). In 2008, ice was present in the study areas until early (Klondike study area) to mid-September (Burger study area). In contrast, the northeastern Chukchi shelf was largely ice-free by mid-August 2009, with only small, diffuse patches remaining over Herald and Hanna shoals. In 2010, the northeastern shelf was completely ice-free by mid-August. The on-transect effort during the 2008–2010 marine mammal surveys added up to a total of 18,605 km across the three study areas (Fig. 3). The smaller on-transect sampling effort in 2008 in the Burger study area was due to the presence of sea ice in the northwestern part of the study area until mid-September.

Sightings of whales were rare except for bowhead whales. The 24 on-transect sightings of 35 bowhead whales accounted for 56% of all cetacean sightings (Table 1). Except for one sighting of two animals in the Statoil study area in mid-September, all bowhead whales were sighted in the Burger study area in October, with the largest number in 2010 (19 sightings of 28 animals). We had five gray whale sightings totaling seven individuals, with three animals in the Klondike study area and four in the Burger study area. Killer whales (*Orcinus orca*), and harbor porpoises (*Phocoena phocoena*) occurred in similar numbers (9 and 7 animals, respectively); all in 2008 in the Klondike study area. We observed one minke whale (*Balaenoptera acutorostrata*) in 2009, also in the Klondike study area.

Ringed seals, spotted seals, bearded seals, and walruses were the most frequently observed species in the northeastern Chukchi Sea during the open-water period, with 980 seals and 367 walruses recorded in 853 and 109 on-transect sightings, respectively. The number of seal and walrus sightings on sea ice was low (Table 1) because sea ice was seen only in 2008 and because the vessel

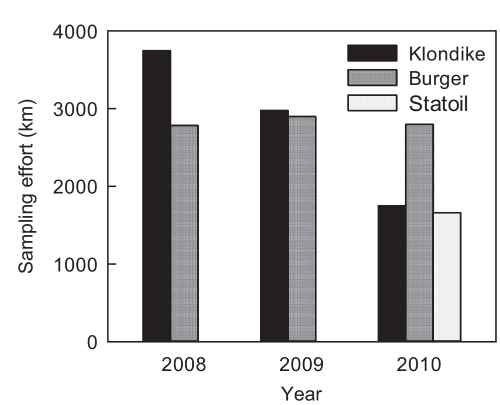


**Fig. 3.** Sampling effort (km) of on-transect marine mammal surveys in the northeastern Chukchi Sea, by study area, 2008–2010.

**Table 1**
Number of sightings and individuals of cetaceans and pinnipeds observed on-transect in the three study areas of the northeastern Chukchi Sea, 2008–2010. –= not observed.

| | In water | | On ice | | Total | |
|---|---|---|---|---|---|---|
| | Sightings | Individuals | Sightings | Individuals | Sightings | Individuals |
| Cetaceans | | | | | | |
| Bowhead whale | 24 | 35 | – | – | *24* | *35* |
| Gray whale | 5 | 7 | – | – | *5* | *7* |
| Harbor porpoise | 3 | 7 | – | – | *3* | *7* |
| Killer whale | 2 | 9 | – | – | *2* | *9* |
| Minke whale | 1 | 1 | – | – | *1* | *1* |
| Unidentified cetacean | 3 | 3 | – | – | *3* | *3* |
| Pinnipeds | | | | | | |
| Bearded seal | 193 | 198 | 1 | 1 | *194* | *199* |
| Ribbon seal | 6 | 6 | 0 | 0 | *6* | *6* |
| Ringed seal | 83 | 91 | 1 | 1 | *84* | *92* |
| Spotted seal | 50 | 52 | 0 | 0 | *50* | *52* |
| Ringed/spotted seal | 210 | 226 | 2 | 2 | *212* | *228* |
| Unidentified seal | 306 | 402 | 1 | 1 | *307* | *403* |
| Walrus | 102 | 193 | 7 | 174 | *109* | *367* |

avoided areas with heavy ice cover. All seven on-ice seal sightings consisted of solitary animals. Walruses, however, were seen in larger aggregations on the sea ice. On 13 September 2008, seven groups totaling 174 animals were recorded hauled out on nearby ice in the Burger study area while the vessel was traveling along the transect lines. In addition, two off-transect on-ice walrus sightings consisting of one aggregation of ~700 animals in the Burger study area on 13 September 2008 and one animal in the Klondike study area on 20 August 2008 were observed.

### 3.1. Effects of environmental conditions on detection

Environmental parameters can influence the effectiveness with which observers are able to detect animals. The overall trend in sea-state occurrence was very similar among years, with Beaufort Scale 3 being the most common sea state (Fig. 4) during surveys. This sea state corresponds to a wind speed of 13–18.5 km h$^{-1}$ and wave height of 0.6–0.9 m. Visibility conditions were most favorable in 2009, with 72% of all effort occurring when visibility was 8 km or more and only 0.6% when visibility was < 500 m (Fig. 4).

The number of sightings per km varied with sea-state and visibility categories (Fig. 5). The number of seal sightings decreased with increasing sea state, however walrus sightings failed to show such a relationship. Visibility conditions did not show a clear pattern with the number of seal or walrus sightings (Fig. 5), likely because ~90% of all sightings were observed at distances of ≤500 m (Fig. 6). Whales were primarily sighted at distances > 1 km (~66% of the total sightings; Fig. 6), when visibility was 8–10 km (90% of the total sightings).

### 3.2. Densities

The performance of the various models and covariates tested for ringed/spotted seal, bearded seal, and walrus data were very close, which we attribute mainly to the nature of the data, i.e., clustered occurrence of sightings. However, based on a combination of diagnostic plots, the Kolmogorov goodness-of-fit test, and AIC (Akaike's Information Criterion we selected as the best-fitted models for the 2008–2010 dataset the half normal model with sea state and vessel as covariates for ringed/spotted seal data, the hazard rate model with sea state as covariate for bearded and unidentified seal data, and the hazard rate model without covariates for walrus data (Table 2). Other covariates tested, such as cluster size, visibility, and observer, did not make it into the best model. The best model results were obtained

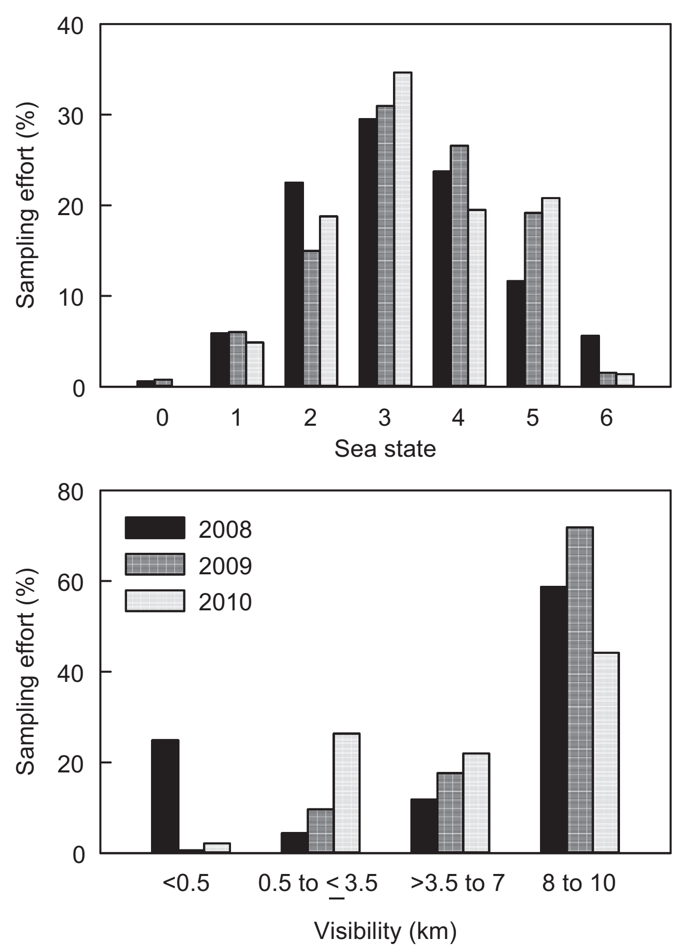


**Fig. 4.** Sea state and visibility conditions (% of total sampling effort) during on-transect surveys in the northeastern Chukchi Sea, 2008–2010. Sea state is in Beaufort windforce scale and visibility is in kilometers.

with a truncation distance of 500 m, distance bins of 100-m intervals, and sea-state data grouped into two categories (low = 0–2; high = 3–5). Average on-transect densities of seals and walruses in number of individuals km$^{-2}$ for each study area and year ranged from 0.011 to 0.091 individuals km$^{-2}$ for ringed/spotted seals, 0.003 to 0.0550 individuals km$^{-2}$ for bearded seals, and 0.005 to 0.044 individuals

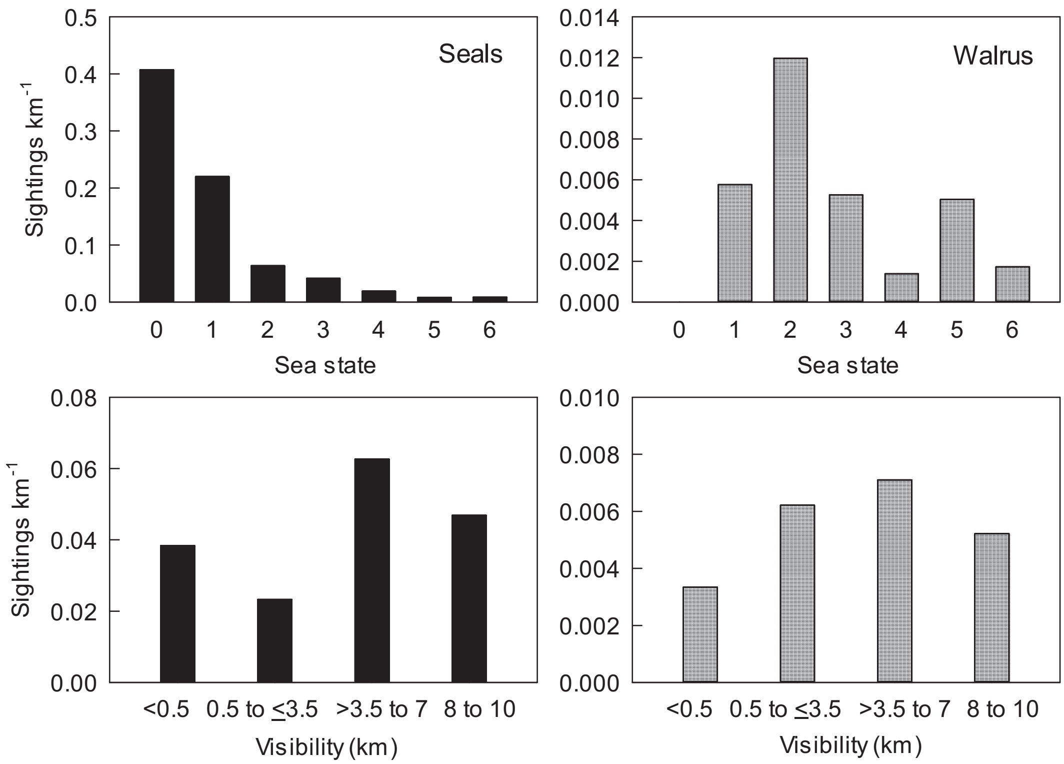


**Fig. 5.** Seal and walrus sightings per km for each sea-state and visibility category in the northeastern Chukchi Sea, 2008–2010. Sea state is in Beaufort windforce scale and visibility is in kilometers.

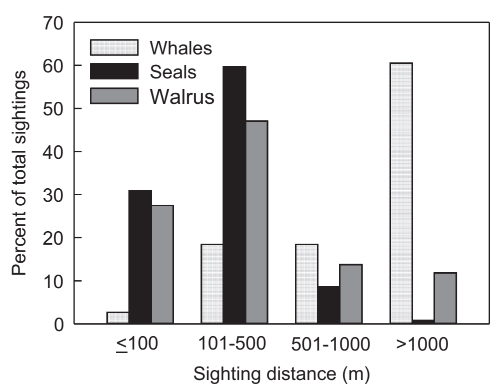


**Fig. 6.** Proportion of whale, seal, and walrus sightings (in % of total sightings of each species group) observed within four distance categories as recorded from the vessel in the northeastern Chukchi Sea, 2008–2010.

$km^{-2}$ for walruses (Fig. 7). Large confidence intervals for pinnipeds in each study area and year were caused by occurrences of sightings in clusters, large numbers of zero samples, and/or small number of sightings. Adjusted seal densities, i.e., the densities that account for the unidentified seal sightings, were 9–90% higher (Table 3).

Comparison of ringed/spotted seal densities among years for the Klondike and Burger study areas shows that densities were highest in 2008 ($P<0.001$; Fig. 7). There was no difference in densities of ringed/spotted seals among study areas within each year ($P>0.05$). The Statoil study area was surveyed only in 2010, with ringed/spotted seal densities similar to those in the other two study areas ($P>0.05$).

Bearded seal densities in the Klondike and Burger study areas were higher in 2008 than in 2009 ($P<0.001$), but were not significantly higher than in 2010 (Fig. 7). Although bearded seal densities in the Burger study area appeared to be higher than in the Klondike study area, this difference was only significant for 2008 ($P<0.001$). Bearded seal densities in the Statoil study area in 2010 were significantly higher than in the Klondike study area ($P=0.003$), but not higher than in the Burger study area ($P=0.19$).

Walrus densities (excluding on-ice sightings) in the Burger and Klondike study areas were similar among years ($P>0.05$; Fig. 7). Although each year higher mean walrus densities were recorded in the Burger study area than in the Klondike study area, this difference was only significant in 2009 ($P=0.004$). Walrus densities in the three study areas in 2010, appeared to be highest in the Burger and Statoil study areas, but were not statistically different from the densities in the Klondike study area ($P>0.05$).

### 3.3. Distribution

The kernel-density maps of ringed/spotted seals, bearded seals, and walruses reveal the interannual spatial trends in abundance (Fig. 8). This spatial representation shows how clustered occurrences of animals leads to high confidence intervals in density estimates, e.g., the 2008 ringed/spotted seal density in the Klondike study area and the 2010 bearded seal density in the Statoil study area (Fig. 7). The re-occurrence of the concentration of ringed/spotted seals in the south-central Klondike study area in 2008 and 2009 is interesting, though it was not apparent in 2010. The kernel densities show that bearded seals and walruses were more commonly sighted in the Burger and Statoil study areas than in the Klondike study area, with the most bearded seals in Statoil and the most walruses in Burger.

## 4. Discussion

### 4.1. Whale observations

During the open-water period of late July–early October 2008–2010, we recorded few cetacean species in the northeastern

**Table 2**
Summary of seal and walrus data and model parameters that form the basis of the detection function used to calculate densities.

| | Bearded seal | Ringed/spotted seal | Unidentified seal | Walrus |
|---|---|---|---|---|
| Number of observations | 208 | 346 | 283 | 89 |
| Average cluster size | 1.02 | 1.08 | 1.36 | 2.02 |
| Model | Hazard rate | Half normal | Hazard rate | Hazard rate |
| Covariates | sea state | sea state+vessel | sea state | none |
| Average probability of detection | 0.52 | 0.42 | 0.44 | 0.37 |
| Coefficient of variation (%) | 4.88 | 4.35 | 6.02 | 23.92 |

Chukchi Sea. The majority of cetacean sightings were bowhead whales (56%), pre-dominantly observed in October in the Burger study area. This is consistent with distributional data for bowhead whales from offshore aerial surveys that show the greatest number of sightings in October, mostly near Barrow, but also offshore within or near our study areas (Clarke and Ferguson, 2010). Recent satellite-tagging data indicate that most bowhead whales migrating in September and October transit across the northern Chukchi Sea to the Chukotka coast, Russia before heading south into the Bering Sea (Quakenbush et al., 2010). Their migratory paths cross Burger and Statoil more often than they do the Klondike study area. A similar migration pattern is shown based on detections of bowhead vocalizations (Delarue et al., 2011; Hannay et al., 2013). The two pods of nine killer whales in the Klondike study area in 2008 was a surprising observation, although killer whales have been reported in the northeastern Chukchi Sea in low numbers in the past (Brueggeman et al., 1990; George et al., 1994) and a few killer whale vocalizations have also been detected during the open water period of 2010 (Delarue et al., 2011).

### 4.2. *Interannual variation of seal and walrus densities*

We have used Program Distance to calculate seal and walrus densities to account for factors that affect probability of detection. The best-fitted models for the detection function showed that sea state was the main factor influencing detection of seals, but not of walruses. Walruses are bigger than seals, often have large tusks, generally occur in groups, and remain at the surface longer, hence they are easier to detect than seals. The most common sighting cue for seals is their head, which generally is present at the sea surface for a limited amount of time, thus higher sea states hamper their detection, even when visibility is good. Although factors affecting probability of detection at the surface were taken into account, we lacked correction factors to fully compensate for animals unavailable (i.e., diving) to the observer, resulting in underestimates of our density data.

Seals (ringed, spotted, and bearded seals) and walruses were sighted frequently in the offshore northeastern Chukchi Sea during the open-water seasons of 2008–2010, although there was high variability among years. The association with sea ice retreat during the northward summer migration of seals and walruses (Fay, 1974; Boveng et al., 2009; Cameron et al., 2010; Kelly et al., 2010; Garlich-Miller et al., 2011; Crawford et al., 2012) likely accounted for some of the annual differences in densities observed during this study. For example, highest densities of ringed/spotted seals were recorded in 2008, when sea ice remained in the Klondike study area until early September and in the Burger study area until mid-September. Ringed/spotted seal densities were similar between 2009 and 2010, which were both low-ice years. It is likely that most seals categorized as ringed/spotted in 2008 were ringed seals, because they are known to be highly adapted to sea ice to which they have a strong association, whereas spotted seals often use shore-based haulouts and are therefore less dependent on sea ice (Lowry et al., 1998, 2000). The presence of sea ice did not appear to affect bearded seal densities

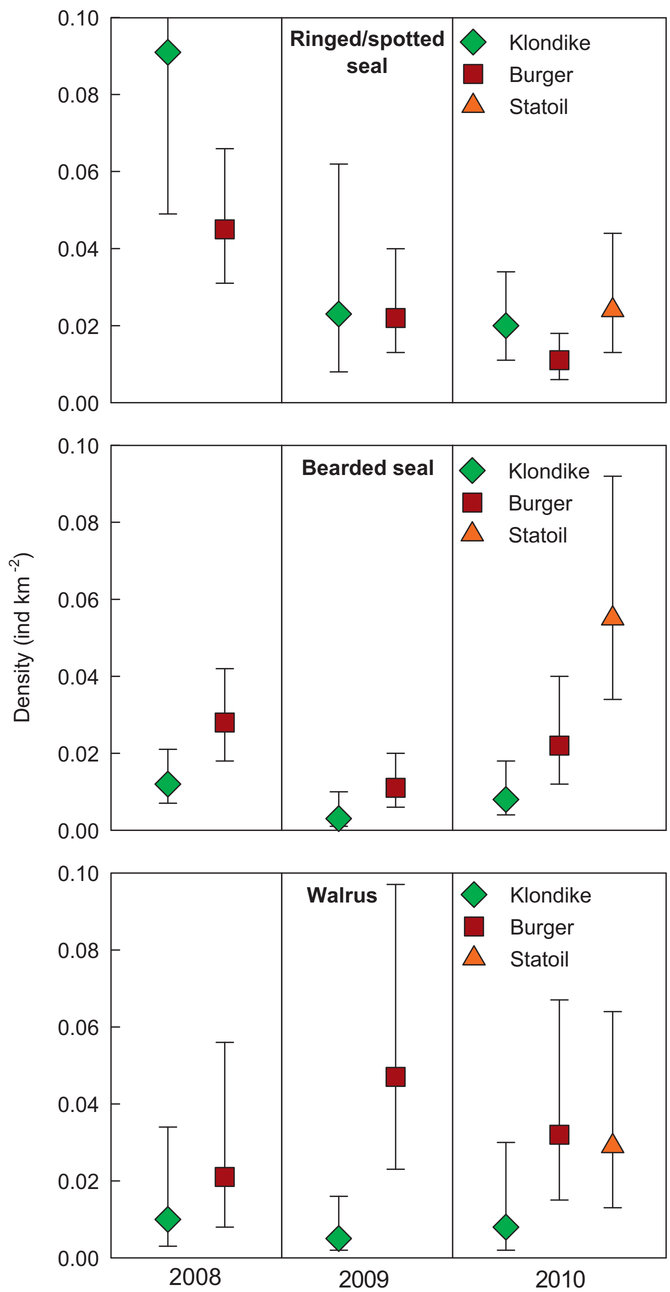


**Fig. 7.** Density (individuals km$^{-2}$) of ringed/spotted seals, bearded seals and walruses (±95% confidence limits) in the northeastern Chukchi Sea, by study area, 2008–2010.

as strongly as those of ringed/spotted seals because densities were similar in 2008 (heavy ice) and 2010 (no ice). The number of seals observed on the sea ice were not included in the density estimates,

**Table 3**
Ringed/spotted and bearded seal densities (individuals km$^{-2}$) adjusted for the proportion of unidentified seal densities.

| | 2008 | | 2009 | | 2010 | | |
|---|---|---|---|---|---|---|---|
| | Klondike | Burger | Klondike | Burger | Klondike | Burger | Statoil |
| Density (individuals km$^{-2}$) | | | | | | | |
| Ringed/spotted seals | 0.091 | 0.045 | 0.023 | 0.022 | 0.020 | 0.011 | 0.024 |
| Bearded seals | 0.012 | 0.028 | 0.003 | 0.011 | 0.008 | 0.022 | 0.055 |
| Unidentified seals | 0.009 | 0.010 | 0.009 | 0.012 | 0.025 | 0.009 | 0.012 |
| Ratio | | | | | | | |
| Ringed/spotted seals | 88% | 62% | 88% | 67% | 71% | 33% | 30% |
| Bearded seals | 12% | 38% | 12% | 33% | 29% | 67% | 70% |
| Adjusted density (individuals km$^{-2}$) | | | | | | | |
| Ringed/spotted seals | 0.099 | 0.051 | 0.031 | 0.030 | 0.038 | 0.014 | 0.028 |
| Bearded seals | 0.013 | 0.032 | 0.004 | 0.015 | 0.015 | 0.028 | 0.063 |
| Density increase | 9% | 13% | 35% | 36% | 90% | 27% | 17% |

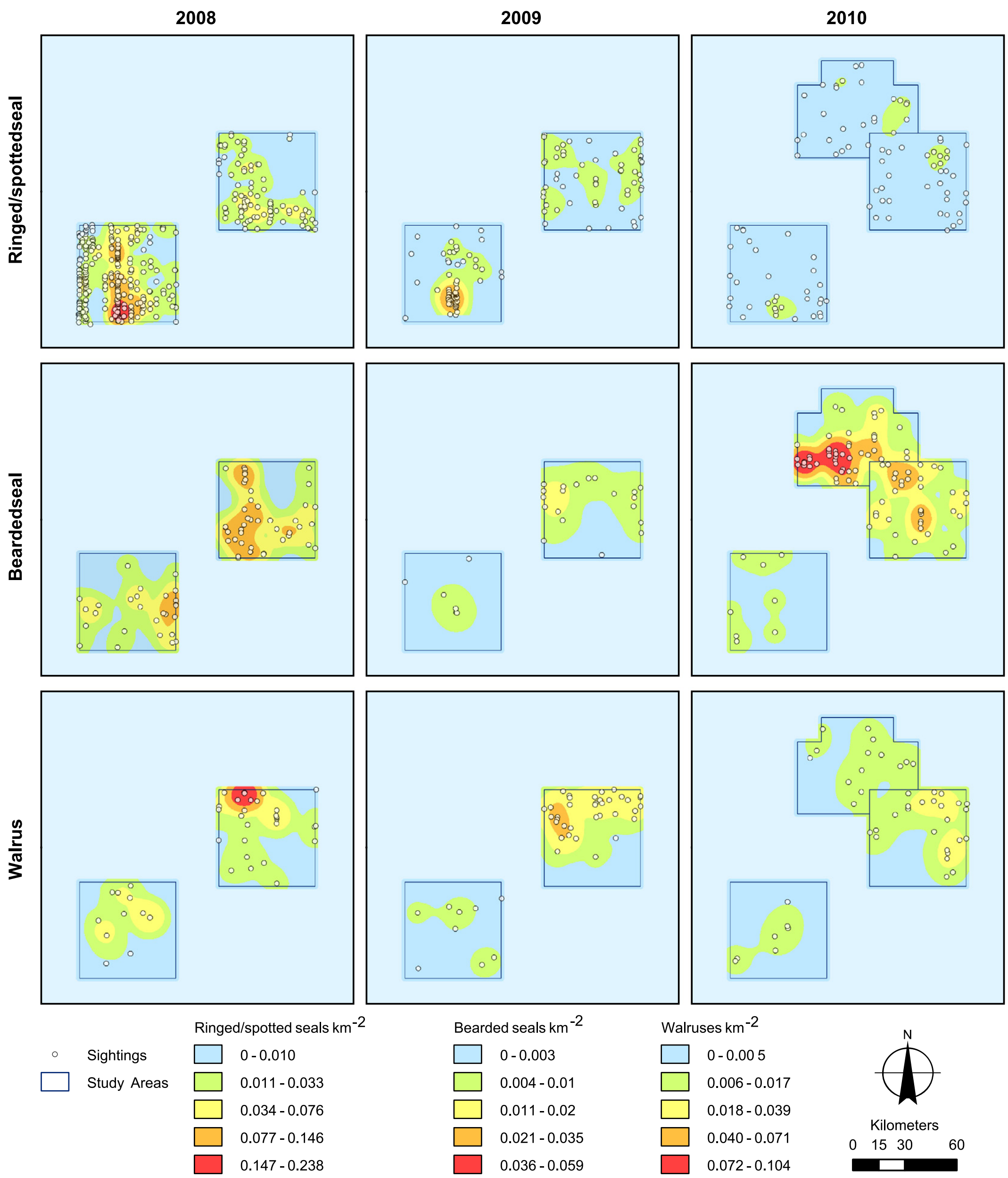


**Fig. 8.** Kernel densities showing the spatial distribution of ringed/spotted seals, bearded seals, and walruses in the northeastern Chukchi Sea, by year, 2008–2010. Kernel densities were created using average sighting density weighted by the number of individuals and grouped by statistical Natural Breaks (Jenks).

but this number was low (5 animals total) and would not have changed the observed annual variations.

Walrus densities also were very similar among years, implying that the presence of sea ice in 2008 did not influence the abundance of walrus in the area. However, large groups of walruses were observed on the sea ice in Burger (seven on-ice sightings of 174 animals) which were not included in the density calculations, but whose inclusion would have made Burger's mean densities even more consistent among years. We also observed an aggregation of ~700 animals on the sea ice in Burger while off-transect.

### 4.3. Spatial distribution of seals and walruses

The interdisciplinary nature of this study provides information on the physical oceanography and associated patterns in abundance and biomass of marine mammal prey species (Day et al., 2013). It also provides information on marine mammal presence determined by records of their vocalizations (Hannay et al., 2013) to relate to the small-scale patterns of distribution and abundance of marine mammals by visual observations. The acoustically-determined distributional patterns in 2009 and 2010 showed more bearded seals and walruses in the Burger and Statoil study areas than in the Klondike study area (Fig. 9), in agreement with our visual observations (Fig. 8). Differences in distribution between years also were consistent between the visual observations and call detections, with fewer bearded seal observations and lower call-counts in 2009 than in 2010 and fewer walrus observations and lower call-counts in 2010 than in 2009. Unfortunately, comparisons between visual and acoustic data were not possible for ringed/spotted seals because their vocalizations were detected only sporadically during the open-water season (Hannay et al., 2013)

We suggest that the observed distribution of seal species and walruses among the three study areas in the northeastern Chukchi Sea within each year during the open water season was mainly the result of food availability. Satellite-tagging data has revealed that ringed and spotted seals forage in different ways (Lowry et al., 1998, 2000; Kelly et al., 2010; Herreman et al., 2012). Ringed seals spend 90% or more of their time in the water during the open-water period and early part of freeze-up when they forage most intensively (Kelly et al., 2010). Their diet shows pronounced seasonal variation, with Arctic cod (*Boreogadus saida*) as the main food source in fall and winter, shifting to crustaceans (mostly shrimp, amphipods, and mysids) during spring and summer (Burns and Eley, 1978; Lowry et al., 1980a) depending on prey availability. Spotted seals make foraging trips. They stayed an average of two days at coastal haulouts between foraging trips that lasted, on average, nine days (Lowry et al., 1998, 2000). Like ringed seals, they also have a flexible diet and can feed on whatever prey items are available and abundant (Kato, 1982; Bukhtiyarov et al., 1984), although they mainly target schooling fish (specifically Arctic cod) and shrimp.

Ringed and spotted seal abundance was similar between our three study areas. However, based on the kernel density maps and number of off-transect sightings per km effort (unpublished), there appeared to be a slight preference for the Klondike and Statoil study areas. The Klondike and Statoil study areas are affected by Bering Sea Water from the Central Channel and have a stronger pelagic component than the Burger study area. The biomass of zooplankton species, such as copepods and euphausiids, was generally higher in the Klondike than in the Burger study area, although less apparent in 2010 (Questel et al., 2013). The Klondike study area also had a higher total fish density, although the density of Arctic cod was abundant throughout the three study areas (Norcross et al., 2013). The lack of a clear distributional pattern related to food availability for ringed and spotted seals in this study probably reflect their flexible diet habits and the mobility of their primary prey species.

Densities of bearded seals were higher in the Burger and Statoil study areas than in the Klondike study area during the years with highest densities (2008 and 2010), and benthic studies suggest that the density and biomass of their potential food sources was also higher in these study areas (Blanchard et al., 2013). Walruses also occurred in higher numbers in the Burger and Statoil study areas

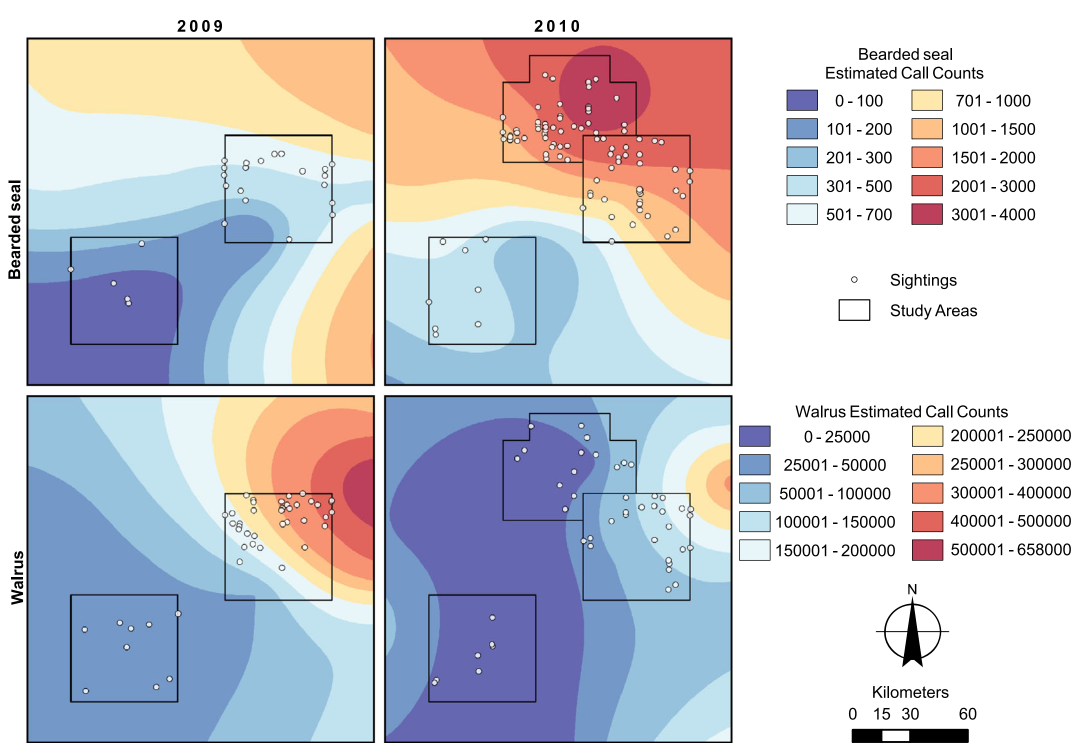


**Fig. 9.** Bearded seal and walrus call-count surface plots with visual sightings covering the three study areas during the period late July to mid-October 2009 and 2010 (modified from Hannay et al. (2013)). Details on the recorder locations and call-detection methodology can be found in Hannay et al. (2013).

than in the Klondike study area. This difference was only statistically significant in 2009, which was mainly due to the clustered occurrence and low sample size for area × year resulting in large confidence intervals. Also, walrus aggregations observed on ice in Burger in 2008 were not included in the density estimates. Comparison of distribution patterns of bearded seals and walrus as recorded by visual observations in 2009 and 2010 with vocalizations during the open water period as detected on acoustic recorders (Hannay et al., 2013) confirmed the general distribution pattern with lowest abundance in the Klondike study area. Bearded seals are predominantly epibenthic feeders that forage on or near the bottom at depths $<100$ m (Burns, 1981). They use their whiskers to search for prey on and in soft-bottom substrates (Marshall et al., 2008). Their diet is variable and depends on age, location, season, and prey availability (Lowry et al., 1980b; Kelly, 1988b); their primary food consists of shrimp, crabs, gastropods, and clams, but also includes schooling and demersal fish (Lowry et al., 1980b; Burns, 1981; Antonelis et al., 1994). Near Wainwright, clams were the most important component of their diet during late spring and summer more than 30 years ago (Lowry et al., 1980b).

Satellite tagging data showed that walruses made foraging trips from land or ice haulouts that ranged from a few hours up to several days (Ray et al., 2006). Although some of the walruses encountered in the offshore northeastern Chukchi Sea were traveling to an onshore or offshore haulout or to a foraging area, most were probably actively foraging (Jay et al., 2012). Like bearded seals, walruses also eat primarily benthic invertebrates (Fay, 1982; Dehn et al., 2007; Sheffield and Grebmeier, 2009), although fishes and other vertebrates occasionally are recorded in their diet (Fay, 1982; Sheffield and Grebmeier, 2009). They are able to dive to depths $>100$ m, but usually forage in shallower waters where their benthic prey is most abundant (Fay and Burns, 1988). Considering the food preferences of bearded seals and walruses, and the higher densities of potential food organisms in the Burger and Statoil study areas (Blanchard et al., 2013), the distributional pattern of bearded seals and walruses as observed in this study were consistent with a relationship to food availability.

## 5. Conclusion

Overall, the data collected from 2008 to 2010 have provided valuable information about marine mammal distribution and abundance on a local scale in the northeastern Chukchi Sea. Because many factors play a role in marine mammal movements, it is not surprising that the interannual variability in density and distribution was high. The results suggest that physical and biological oceanographic conditions within the three study areas affected the distribution and abundance of bearded seals, walruses, and ringed/spotted seals differently. Further observations will help establish if these patterns are persistent.

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