

Offshore Distances of Bowhead Whales (*Balaena mysticetus*) Observed during Fall in the Beaufort Sea, 1982–2000: An Alternative Interpretation

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ABSTRACT. Nineteen years (1982–2000) of sighting data from fall aerial surveys of bowhead whales (*Balaena mysticetus*) in the Alaskan Beaufort Sea were analyzed to determine how patterns in the distribution of migrating bowhead whales relate to annual sea-ice conditions. Transect sighting rate (transect sightings/km) indicated (ANOVA; $F_{2,980} = 143.84, p < 0.0001$) that bowhead whales occurred farther offshore in years of heavy ice conditions (73.4 km, 95% CL: 67.2–79.6 km) than in years of moderate (49.3 km, 95% CL: 44.8–53.84 km), or light (31.2 km, 95% CL: 30.0–32.4 km) ice conditions. The most plausible explanation for the observed pattern in bowhead whale distribution is that in years of heavy ice conditions (annual pack ice; 1983, 1988, 1991), the developing landfast ice limits availability of shallow nearshore habitat, thus necessitating use of leads and ice openings in deeper water. We acknowledge that factors such as bathymetry, ocean currents, transport, and food availability may also interact to influence autumn distribution of bowhead whales. In heavy ice years, however, these factors likely exert less influence on bowhead whale distribution than in years with light to moderate ice conditions.

Key words: Alaska, Arctic, *Balaena mysticetus*, Beaufort Sea, bowhead whales, distribution, ice cover, migration

RÉSUMÉ. Les données automnales prélevées à partir de relevés aériens pendant 19 années chez les baleines boréales (1982–2000) (*Balaena mysticetus*) de la mer de Beaufort alaskienne ont été analysées dans le but de déterminer comment les tendances caractérisant la répartition des baleines boréales en migration se rapportent à l'état annuel des glaces et de la mer. Le taux de repérage transect (repérage transect/km) a indiqué (ANOVA; $F_{2,980} = 143.84, p < 0,0001$) que les baleines boréales se trouvaient plus loin au large pendant les années où il y avait beaucoup de glace (73,4 km, 95 % CL: 67,2–79,6 km) que pendant les années où la glace était modérée (49,3 km, 95 % CL: 44,8–53,84 km) ou légère (31,2 km, 95 % CL: 30,0–32,4 km). L'explication la plus plausible à la source de la tendance qui a été observée en matière de répartition des baleines boréales, c'est que pendant les années où il y a beaucoup de glace (banquise; 1983, 1988, 1991), la glace de rive en formation limite la disponibilité d'habitats de faible profondeur à proximité du littoral, ce qui nécessite l'utilisation de chenaux et d'ouvertures dans la glace en eau plus profonde. On reconnaît que des facteurs comme la bathymétrie, les courants océaniques, le transport et la disponibilité de la nourriture peuvent également entrer en interaction au point d'exercer une influence sur la répartition automnale des baleines boréales. Cependant, pendant les années où il y a beaucoup de glace, ces facteurs sont susceptibles d'exercer moins d'influence sur la répartition des baleines boréales que pendant les années où la couverture de glace varie de légère à moyenne.

Mots clés : Alaska, Arctique, *Balaena mysticetus*, mer de Beaufort, baleines boréales, répartition, couverture de glace, migration

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INTRODUCTION

The annual cycle of sea ice in the Beaufort Sea and its effect on general habitat availability for bowhead whales are well documented (Moore and Reeves, 1993). Bowhead whales (*Balaena mysticetus*) are generally thought to be closely associated with sea ice, at least for part of the year (Burns et al., 1981). In the fall, a portion of the Western Arctic stock of bowhead whales migrates westward from the Canadian Beaufort Sea and Amundsen Gulf, past Point Barrow, Alaska, through the Chukchi Sea, and into the

Bering Sea. Their migration begins in August and continues into November, depending on ice conditions (Ljungblad et al., 1986b; Moore and Reeves, 1993). Traditionally, there has been a tendency to extrapolate migration behavior observed during fall in the Alaskan Beaufort Sea to represent behavior for the entire Western Arctic (or Bering-Chukchi-Beaufort) stock of bowhead whales (Shelden and Rugh, 1995; Angliss and Lodge, 2002). It is becoming increasingly clear, however, that numbers of bowheads observed during autumn aerial surveys off the north coast of Alaska vary substantially from year to year and that the

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number of whales encountered in any one year actually represents a small fraction (< 10%; Minerals Management Service, unpubl. data) of the Western Arctic stock (George et al., 2004). During the migration through the central Alaskan Beaufort Sea, many of the migrating whales tend to select inner and outer shelf waters with little to no ice (Moore et al., 2000), presumably to take advantage of available zooplankton (i.e., copepods and euphausiids; Lowry, 1993). In some years, bowheads may congregate and feed in nearshore waters (Lowry and Frost, 1984; Lowry, 1993) early in the ice-free period (August–September), though such aggregations have been documented near Point Barrow well into October (Landino et al., 1994). It is during this transition from relatively open-water to ice-dominated conditions that whale behavior tends to shift from “social” (e.g., feeding, milling, resting) to predominantly “migratory” (e.g., swimming and diving) movements, with whales swimming medium to fast (Ljungblad et al., 1986c).

The U.S. Department of the Interior has sponsored spring and fall aerial surveys of bowhead whales in the Beaufort Sea for monitoring purposes since 1979 (Treacy, 2002), and the present research is considered a follow-up to previous work (Moore and Clarke, 1992; Moore and Reeves, 1993; Moore and DeMaster, 1997; Moore, 2000; Moore et al., 2000). One goal of the current monitoring project is to describe distribution and movement patterns of bowhead whales in the fall, when they migrate westward across the Alaskan Beaufort Sea. Here, we include analysis of offshore distance of bowhead whales encountered during fall surveys and describe the pattern of bowhead distribution as a function of annual sea-ice conditions. The extensive aerial survey database that we analyzed overlaps somewhat that analyzed by Moore (2000), Moore et al. (2000), and others (1982–91), but our analysis includes more recent information (1992–2000) and an alternative interpretation of the data.

METHODS

Study Area and Survey Protocol

The fall bowhead aerial survey project is based on a set of random field transects within established geographic blocks (Survey Blocks 1–12, Fig. 1) in Chukchi and Beaufort Sea offshore areas along the north Alaskan coast (140–157° W longitude and south of 72° N latitude). Surveys have operated from Deadhorse (Prudhoe Bay), Alaska. The primary survey platform, a de Havilland Twin Otter, was equipped with an additional fuel tank within the passenger compartment to maximize long-range capability. The aircraft was also fitted with two medium-sized bubble windows behind the cabin bulkhead and one on the aft starboard side that afforded complete trackline viewing. Observers and pilots were linked to common communication systems so that sightings of marine mammals

could be relayed between observers, increasing the probability of detection while decreasing the potential for re-sampling. A portable laptop computer was used aboard the aircraft to store and analyze flight data (using Visual Basic) and observational data (using Microsoft Access). The aircraft was equipped with either a Global Navigation System (GNS 500) or a Garmin III Global Positioning System (GPS) with an external aircraft antenna that provided continuous position updating. A custom moving map in Visual Basic permitted observers to view the aircraft’s trackline in real time. A multi-columnar data table permitted several entries of sighting and position-update data to be logged and edited simultaneously. Data on sightings included date, time, latitude and longitude, altitude, aircraft position, sea state (Beaufort Scale; Chapman, 1977), ice cover (percent of sea surface), species, total number, behavior, size (adult, subadult, cow-calf pair), swim direction and speed (if applicable), and inclinometer angle. Surveys were generally flown at a target altitude of 462 m (1500 feet) and a flight speed of roughly 220–250 km/h (120–140 knots). Surveys were aborted when cloud ceilings were consistently less than 305 m (1000 feet) or when sea state was consistently over Beaufort 4 (Moore et al., 2000:434). Daily flight patterns were based on sets of unique computer-generated transect grids for each survey block given constraints of local weather patterns.

Data Sorting and Analysis

Sea-ice conditions were grouped into three categories (heavy, moderate, and light) on the basis of data obtained from the United States Navy/NOAA Joint Ice Center (Navy/NOAA, 2002). Data obtained from the Joint Ice Center are relevant to our study because they provide a reasonable delineation of ice conditions for the Beaufort Sea study area and because there was a strong relationship (see Moore, 2000) between Navy/NOAA records and the year-rank based on ice conditions observed during surveys. For each year analyzed, we refined Joint Ice Center (JIC) rankings of sea-ice severity using their point system, which takes into account (a) distance (nautical miles; hereafter nmi) from Point Barrow northward to the ice edge on 15 September, (b) distance from Point Barrow northward to the five-tenths ice-concentration boundary on 15 September, (c) number of days the entire sea route to Prudhoe Bay was ice-free, (d) number of days the entire sea route to Prudhoe Bay was less than five-tenths ice concentration, and (e) number of days from the initial date the entire sea route to Prudhoe Bay was less than five-tenths ice concentration through 1 October. September 15 was chosen because it fell within the month with the greatest number of bowhead whale sightings and more appropriately describes ice conditions encountered by whales across the survey period (early August to late October, but generally the survey starts on or about 1 September). Sea-ice rankings were a sum of the scores for

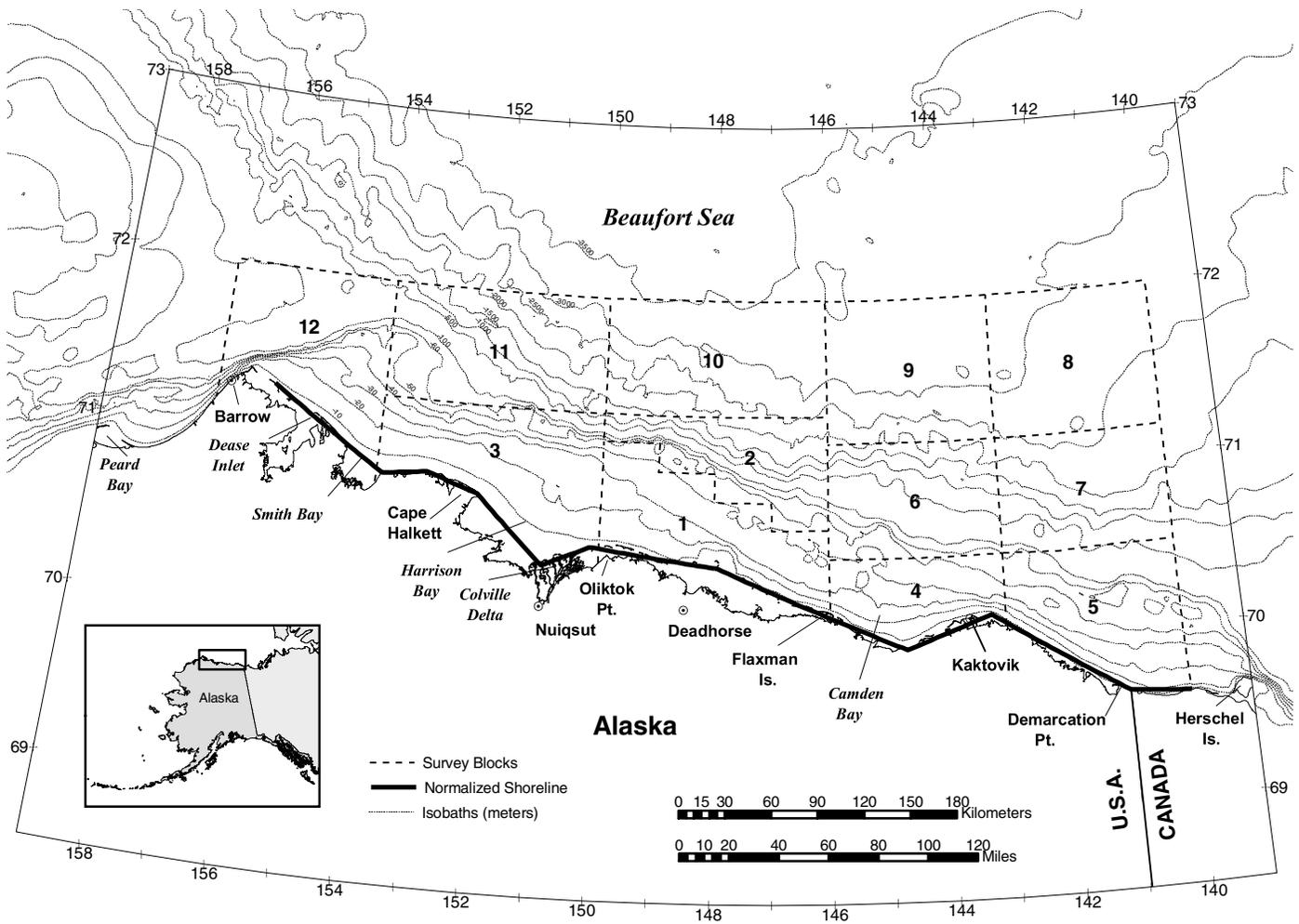


FIG. 1. Graphical representation of the aerial survey study area depicting survey blocks, normalized shoreline, isobaths, and important regional landmarks in the Beaufort Sea, Alaska.

all five categories (described above) recommended by JIC personnel. Using this system, we categorized ice conditions as heavy (> 250 points), moderate (125–249 points), or light (0–124 points). Even though we recognize that intra- and inter-annual variation exists relative to freeze-up, we believe that JIC rankings provide an appropriate basis for classification of sea-ice conditions used in the present study.

We classified 1983, 1988, and 1991 as having heavy ice conditions. Distance from Point Barrow to the five-tenths ice concentration on 15 September ranged from 16 to 40 km (10 to 25 nmi). We considered 1984, 1985, and 1992 as having moderate ice conditions: the same distance range was 40 to 121 km (25 to 75 nmi). The years 1982, 1986, 1987, 1989, 1990, and 1993–2000 were categorized as having light ice conditions, and the distance ranged from 80 to 386 km (50 to 240 nmi). We assumed that heavy, moderate, and light classifications relative to pack ice were also indicative of landfast ice conditions for that year.

To examine preliminary patterns in fall bowhead distribution, we generated maps based on Universal Transverse

Mercator coordinates for each sighting, using a geographical information system (GIS) (ArcView, Vers. 3.2; ESRI, 1999). Though informative, maps of raw sighting data may not be representative of actual observations because of spatial differences in sampling effort, in part attributed to local weather patterns. We therefore accounted for sighting effort in our analysis by applying a grid matrix superimposed across the study area using the GIS. The matrix consisted of approximately equilateral grid cells sized 5' latitude by 15' longitude. Sighting rates for each grid cell were calculated as the number of sightings made on transect per kilometer flown in September and October. We "standardized" the shoreline by connecting with straight lines 11 points across the Beaufort Sea coast from 156° to 140° W (Treacy, 2002). Inclusion of a standardized shoreline provided a frame of reference to evaluate annual deviations from a "migration axis." In addition, the standardized shoreline accounted for discontinuities in shoreline configuration from east to west relative to distance offshore for bowhead whale observations. The study area was bounded in the east by the shoreline at roughly 69.5° N,

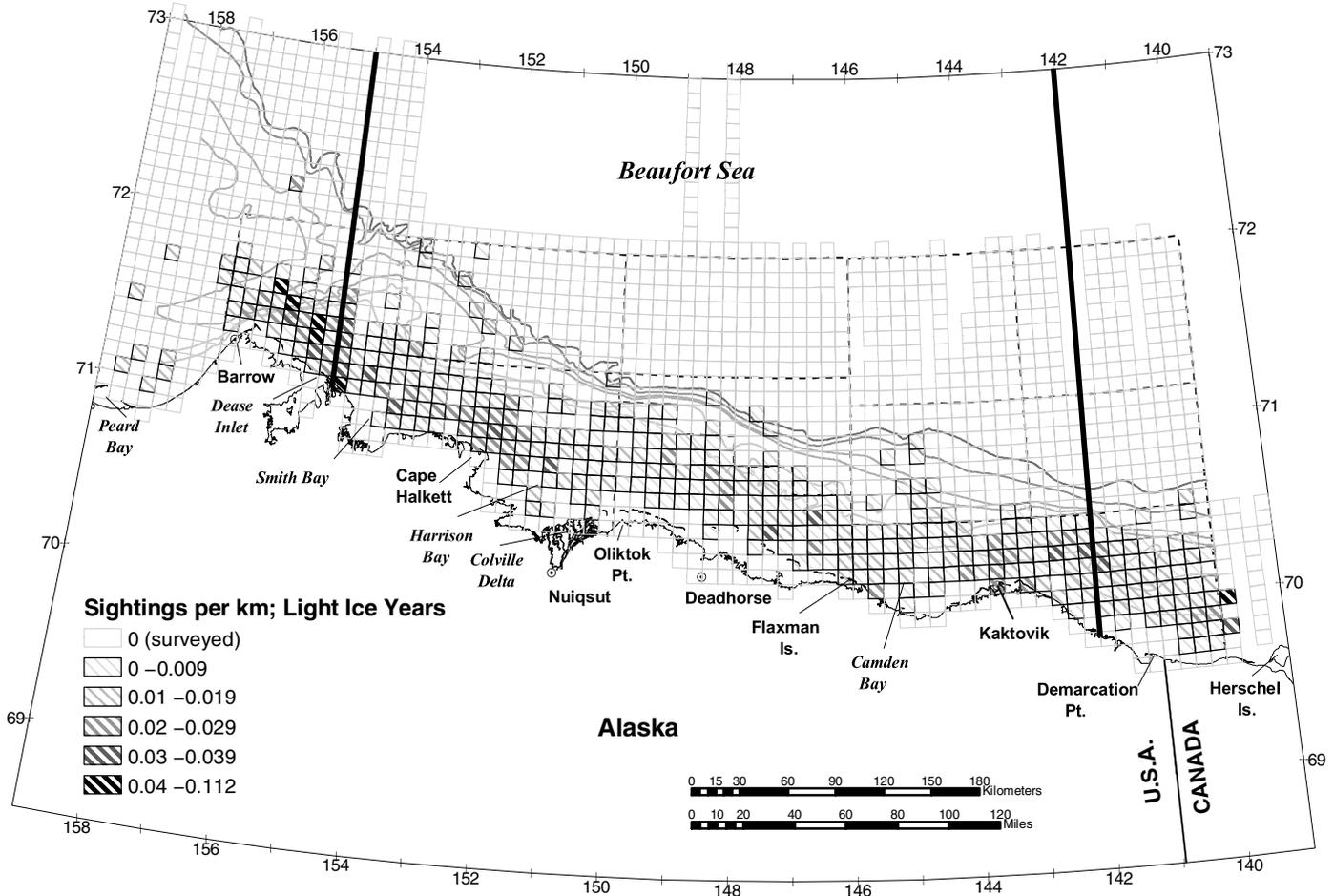


FIG. 2. Sighting rates in light-ice years (1982, 1986–87, 1989–90, 1993–2000) for bowhead whales (*Balaena mysticetus*) in the Alaskan Beaufort Sea. Rates from annual fall survey of the Bowhead Whale Aerial Survey Project (1982–2000) are adjusted for effort on transects during the relevant ice conditions. Aerial survey effort was likely greater within the area bounded by the dark vertical bars (142° W and 155° W) because of local weather patterns and level of offshore oil and gas activities.

140° W and in the west by the shoreline near Barrow at roughly 71° N, 156° W (Fig. 1).

We used a one-way Analysis of Variance (ANOVA) to evaluate distances from the standardized shoreline to locations of bowhead whale sightings. In this paper, a sighting represents one whale or more whales in apparent association (on-transect whales only) and does not include dead whales or repeat observations. In the analysis, distance offshore from a standardized shoreline represents a continuous response variable with categorical sea-ice condition as a main effect. We limit our inferences to the target population; that is, the results described below include only those bowhead whales observed on transect within the study area during the period of observation. We did not consider whales potentially “missed” (i.e., under water, under ice, or on surface, but not seen) in the analysis, nor did we consider whales not observed because they were present outside the survey period or beyond the geographical coverage of the study area. We used Tukey HSD as a post hoc multiple comparison procedure because this test sets experiment-wise error rate to that of all pair-wise comparisons (Wilkinson and Coward, 1999). All tests

were performed using STATISTICA (StatSoft, 1995), and alpha level was set at $p = 0.05$.

RESULTS

Distance offshore to bowhead whales was related to ice conditions ($F = 143.84$, $df = 2$, 980 ; $p < 0.0001$). Post-hoc comparisons indicated differences (Tukey HSD; $p < 0.0001$) among the three ice-cover categories. Bowhead whales occurred farther offshore in years of heavy ice conditions (73.4 km, 95% CL: 67.2–79.6 km) than in years of moderate (49.3 km, 95% CL: 44.8–53.84 km) or light (31.2 km, 95% CL: 30.0–32.4 km) ice conditions (Figs. 2–4). For sightings ($n = 864$) during years of light ice conditions (1982, 1986, 1987, 1989, 1990, and 1993–2000), highest sighting rates of bowhead whales generally occurred in shallower, near-shore waters reflecting coastal contours (Fig. 2). For sightings ($n = 74$) in years of moderate ice conditions (1984, 1985, and 1992), whales were generally observed in mid-range waters inshore from the shelf break (Fig. 3). For sightings ($n = 45$) in years of heavy ice

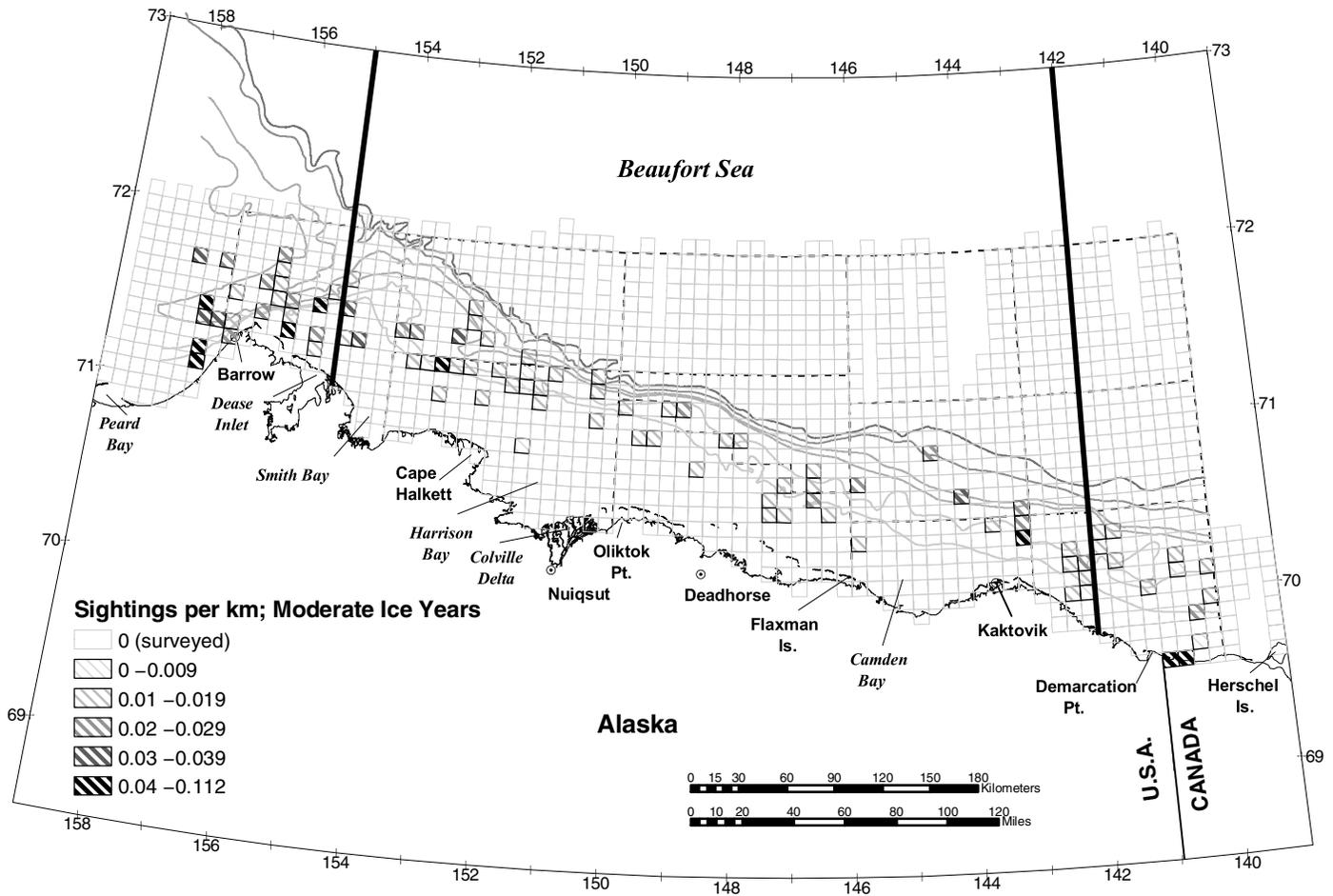


FIG. 3. Sighting rates in moderate-ice years (1984–85, 1992) for bowhead whales (*Balaena mysticetus*) in the Alaskan Beaufort Sea (survey information as in Fig. 2).

conditions (1983, 1988, and 1991), the whales observed occupied deeper, offshore waters near the shelf break (Fig. 4). These results primarily describe whales within the central Beaufort Sea portion of the study area (142–155° W longitude; see vertical bars in Figs. 2–4), as this pattern was not nearly as evident east of Kaktovik and west of Dease Inlet.

DISCUSSION

In general, fall aerial surveys in the central Alaskan Beaufort Sea showed that bowhead whale distribution was strongly influenced by sea-ice conditions (Figs. 2–4). During years of moderate to heavy sea-ice conditions, bowhead whales frequented deeper slope waters (200 to 2000 m) than in light-ice years, when whales concentrated in inner-shelf waters (< 50 m) (Fig. 2; see also Fig. 1 in Moore, 2000). Mate et al. (2000) found that 65% (259 of 400 useable fixes) of satellite-acquired locations for eight juvenile bowhead whales tagged near Shingle Point, Northwest Territories, Canada, occurred in depths of 0 to 50 m irrespective of ice conditions. Though we did not consider water depth (bathymetry) per se in this analysis, bowhead

whales in the Beaufort Sea do tend to occur more frequently in depths under 100 m (Mate et al., 2000; Moore, 2000) and may relate to water depth as a function of ice conditions or local feeding opportunities (Lowry, 1993) when pack ice or new landfast ice becomes an impediment to movements. Numerous other factors may contribute to fall distribution of bowhead whales in the Beaufort Sea, particularly in light-ice years. Such factors include (but are not limited to) bathymetry, transport or current (Moore, 2000), food availability (Lowry and Frost, 1984; Lowry, 1993; Landino et al., 1994), and their interactions. Considering the strength of association noted above, we believe these factors may be less important under moderate or heavy ice conditions because changes in the ocean environment presumably influence habitat-use decisions by bowhead whales. That is, as landfast ice advances and annual pack ice moves shoreward, coming into contact with the floating fast ice, a zone of ridging develops (see Barnes et al., 1978), thus restricting habitat available to migrating whales. This relatively brief transition in which ridging occurs likely results in a concomitant change in whale behavior; at this time, whales are observed almost exclusively in offshore leads and ice openings.

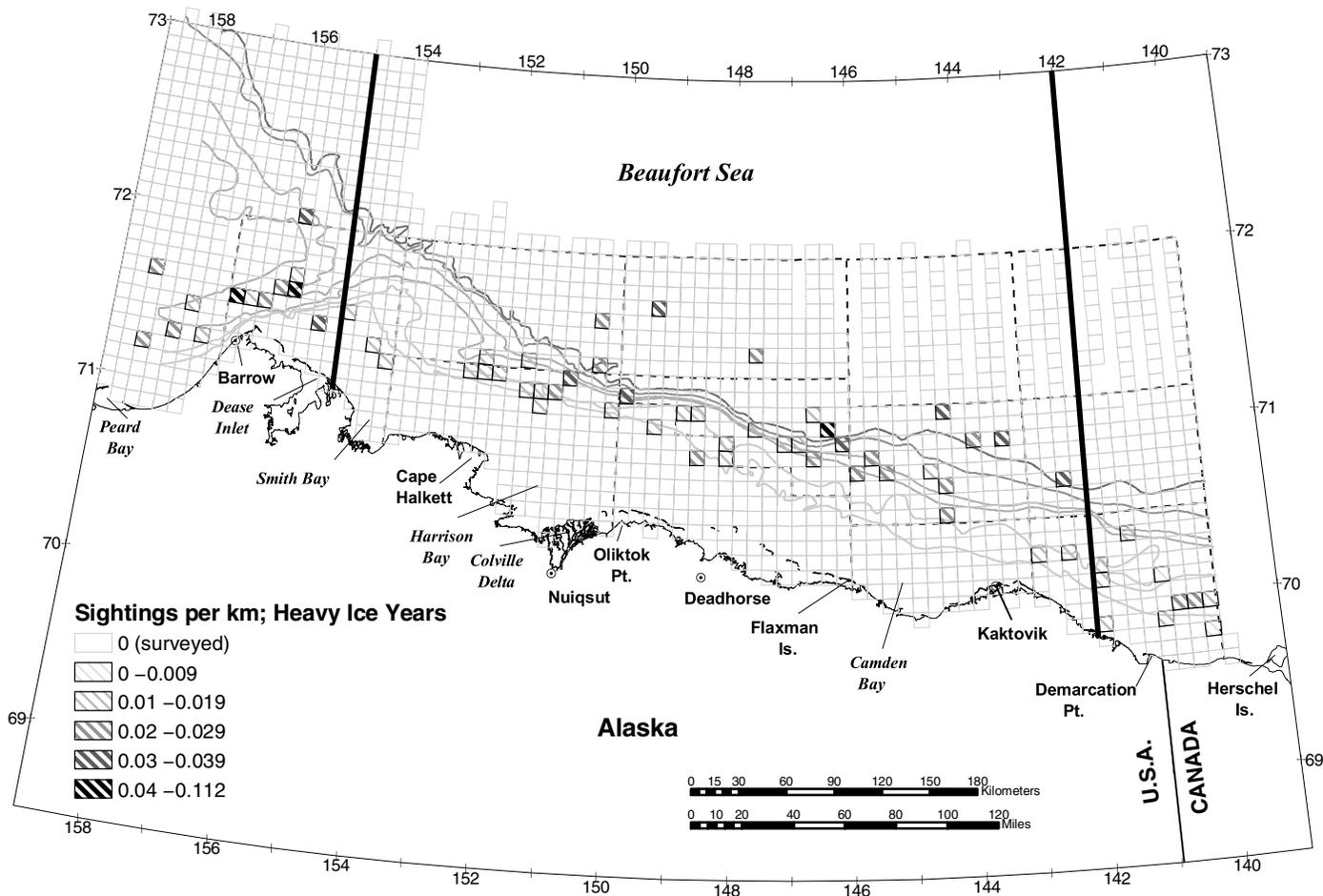


FIG. 4. Sighting rates in heavy-ice years (1983, 1988, 1991) for bowhead whales (*Balaena mysticetus*) in the Alaskan Beaufort Sea (survey information as in Fig. 2).

We acknowledge that ice conditions at Barrow or Prudhoe Bay may not be representative of ice conditions at Kaktovik; however, we feel that the “point system” used in this paper to describe annual ice conditions and the subsequent rankings are justified and provide a reasonable proxy for conditions across the Beaufort Sea, at least at a large spatial scale. Ice conditions may vary spatially on a given date and temporally within a given survey year, though generally spatial variation is lessened for extremely heavy ice years or when open water persists for almost the entire survey period (i.e., light ice conditions). For the most part, ice-cover categories defined in the paper agree with those of Moore (2000). Heavy-ice years defined in our study (1983, 1988, and 1991) were similar to those noted by Moore (2000). A difference was documented for moderate versus light ice conditions, and only for two years (1982 and 1987). Moore (2000:450) considered 1982 and 1987 as moderate-ice years, while we ranked them as light-ice years. These differences are likely due to three factors. First, Moore (2000: Table 1 footnotes) elected to use only two criteria to rank sea ice: number of ice-free days between Point Barrow and Prudhoe Bay and number of days with 50% ice cover conditions between Point Barrow and Prudhoe Bay. Second, Moore (2000) re-scored

the original Navy/NOAA ranks to include only the years of her study (1982–91). Finally, ranks are relative and may change with inclusion of more years. Moore (2000) had fewer years that ultimately determined the overall ranks, regardless of criteria used. Though useful in describing ranks of annual sea-ice conditions in the western and central Beaufort Sea at a large spatial scale, the rankings provided by Navy/NOAA may not be at an appropriate resolution to deal with small-scale ecological questions (Weins, 1989; Levin, 1992). Future researchers may wish to incorporate other metrics of ice cover and ice conditions obtained simultaneously with whale sightings in their analysis of bowhead whale distribution and behavior.

Our methods are unbiased relative to survey effort or sighting conditions (Cosens et al., 1997; Cosens and Innes, 2000) and results are representative of actual distributions of fall bowhead whales using nearshore (70° to 72° N) waters in the central Alaskan Beaufort Sea (but see Moore, 2000; Moore et al., 2000). Since we were not interested in deriving density or population estimates, any biases related to survey methodology are reduced (Eberhardt, 1978; Burnham et al., 1980). Our surveys encompassed the peak of fall movements (Sept-Oct; Moore and Reeves, 1993) with nearly complete coverage of the entire study area

each year. We recognize the potential for sex- and age-specific segregation to occur either spatially or temporally during fall migration of bowhead whales in the Beaufort Sea (Braham, 1995; George et al., 1995; Cosens and Innes, 2000; but see Moore and Reeves, 1993:351). However, the monitoring protocol precluded an analysis of differences in migration axes relative to sex-age cohorts. Similarly, since the survey protocol does not require circling to document all whale sightings, the number of calves observed is probably biased low (Moore and Reeves, 1993:351; Cosens and Blouw, 2003). Sightings of cow-calf pairs represent a small fraction of total bowhead whale sightings in any given year; however, number of calves sighted may be higher in years when large feeding aggregations are sighted simply because more time is spent circling larger groups (Minerals Management Service, unpubl. data; see also Ljungblad et al., 1986a, c).

Patterns of association of bowhead whales and ice are becoming increasingly clear. The most logical explanation for the observed pattern in bowhead whale distribution was that in years of heavy ice conditions, developing landfast ice limited availability of shallow nearshore habitat, thus necessitating use of leads and ice openings in deeper water for migratory movements. Our results in conjunction with previous work (Ljungblad et al., 1986c; Moore and Clarke, 1992; Moore and Reeves, 1993; Moore, 2000; Moore et al., 2000) clearly demonstrate a pattern of association between bowhead whales observed during the fall migration and sea-ice conditions. While factors other than sea ice may have localized effects on individual animals, the overall distance from shore of the surveyed population within the central Alaskan Beaufort Sea is most strongly affected by annual sea-ice conditions. In this study, we did not consider behavior per se (e.g., feeding, milling, and swimming) as a factor in describing bowhead whale distribution relative to sea-ice conditions. Future analyses of bowhead whale distribution should consider inclusion of behavior because whale distribution and movements are likely a function of the whale's proximate response to environmental cues. Furthermore, we recommend that future researchers on bowhead whale distribution expand their data collection techniques to incorporate potentially important covariates at the same spatiotemporal scale that could be included in a more robust multivariate framework (see McGarigal et al., 2000).

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