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Observations of mortality associated with extended open-water swimming by polar bears in the Alaskan Beaufort Sea

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Abstract During aerial surveys in September 1987–2003, a total of 315 live polar bears were observed with 12 (3.8%) animals in open water, defined for purposes of this analysis as marine waters >2 km north of the Alaska Beaufort Sea coastline or associated barrier islands. No polar bear carcasses were observed. During aerial surveys in early September, 2004, 55 polar bears (*Ursus maritimus*) were seen, 51 were alive and of those 10 (19.9%) were in open water. In addition, four polar bear carcasses were seen floating in open water and had, presumably, drowned. Average distance from land and pack ice edge for live polar bears swimming in open water in 2004 ($n = 10$) were 8.3 ± 3.0 and 177.4 ± 5.1 km, respectively. We speculate that mortalities due to offshore swimming during late-ice (or mild ice) years may be an important and unaccounted source of natural mortality given energetic demands placed on individual bears engaged in long-distance swimming. We further suggest that drowning-related deaths of polar bears may increase in the future if the observed trend of regression of pack ice and/or longer open water periods continues.

Introduction

Polar bears (*Ursus maritimus*) depend on the vast expanses of Arctic sea ice for hunting their primary prey species, ringed (*Phoca hispida*) and bearded (*Erignathus barbatus*) seals (Stirling and Derocher 1993, Stirling et al. 1993) and locating potential mates. In some locations, they rely heavily on fat stores to meet energetic demands incurred during the open water fasting period (Ramsay and Stirling 1988; but see Derocher et al. 1993).

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There is evidence that total extent of Arctic sea ice has declined at an annual rate of 3–5% over the past several decades, although these declines are not consistent across the Arctic (Comiso 2003, 2005; Stroeve et al. 2004). Warming trends in the Arctic (Comiso 2003) also appear to be affecting thickness of multiyear ice in the polar basin (Rothrock et al. 1999) and perennial sea ice coverage (declines 9% per decade) (Comiso 2002a, b). Concerns have been raised over apparent declines in the minimum extent of summer ice pack and temporal increases in the open water period, and the potential for impacts on polar bears and their populations (Stirling and Derocher 1993; Stirling 2002; Derocher et al. 2004).

Evidence of potential negative effects from reductions in Arctic sea ice comes from long-term monitoring of polar bears in Canada. Mean monthly (April–June) surface air temperatures in western Hudson Bay increased at a rate of 0.2–0.3°C per decade during 1950–1990 (Skinner et al. 1998) and annual ice breaks up 2.5 weeks earlier than 30 years ago (Stirling et al. 1999; Derocher et al. 2004; Gough et al. 2004). Female polar bears in this region are now coming ashore roughly 2 weeks earlier and in poorer condition (Derocher and Stirling 1992; Stirling and Lunn 1997; Stirling et al. 1999). Long-term declines in birth rates and reduced cub weights in conjunction with delayed fall dispersal onto the ice by females and associated young are indicative of negative population effects, at least at a regional scale (Stirling and Derocher 1993; Stirling et al. 1999; Derocher et al. 2004). Though these sublethal effects are now recognized, no mention has been made of potential for lethal effects of reduced sea ice on individual polar bears. The net effect of global climate change on polar bear populations remains largely unknown (but see Stirling et al. 1999; Derocher et al. 2004), but its potential for negative impacts may pose one of the greatest conservation challenges to the management of polar bears (Norris et al. 2002; Hassol 2004).

The primary purpose of the Minerals Management Service (MMS) Bowhead Whale Aerial Survey Project (BWASP) is to monitor the fall migration of bowhead whales in the Alaskan Beaufort Sea. However, systematic observations have been made of all marine mammals encountered, including polar bears. Herein, we discuss our observations of polar bears swimming offshore in the Alaskan Beaufort Sea and the circumstances surrounding subsequent observations of dead, and presumably drowned, polar bears.

Study area

The BWASP is based on a set of random field transects within established geographic blocks overlapping or near Chukchi and Beaufort Sea lease sale areas offshore of the north Alaskan coast (140–157°W and south of 72°N, Fig. 1). The study area roughly overlaps a ''core area'' of polar bear activity (see Amstrup 2000, Amstrup et al. 2000, 2001 for further details). In the Beaufort Sea, landfast ice forms during the fall and may eventually extend up to 50 km offshore by the end of winter (Norton and Weller 1984). The pack ice, which includes multiyear ice averaging 4 m in thickness with pressure ridges up to 50 m thick (Norton and Weller 1984), becomes contiguous with new and fast ice in late fall. From early-November to mid-May, the Beaufort Sea remains almost totally ice covered. In mid-May, a recurring flaw lead can form just seaward of the stable fast ice followed by decreasing ice concentrations and large areas of open water in summer (LaBelle et al. 1983). A detailed description of local weather patterns off the coast of northern Alaska is provided by Brower et al. (1988).

Methods

The BWASP survey was conducted from 1987 to 2004 from a de Havilland Twin Otter Series 300 aircraft equipped with two medium-sized bubble windows behind the cabin bulkhead and one on the aft starboard side that afforded complete trackline viewing. Data

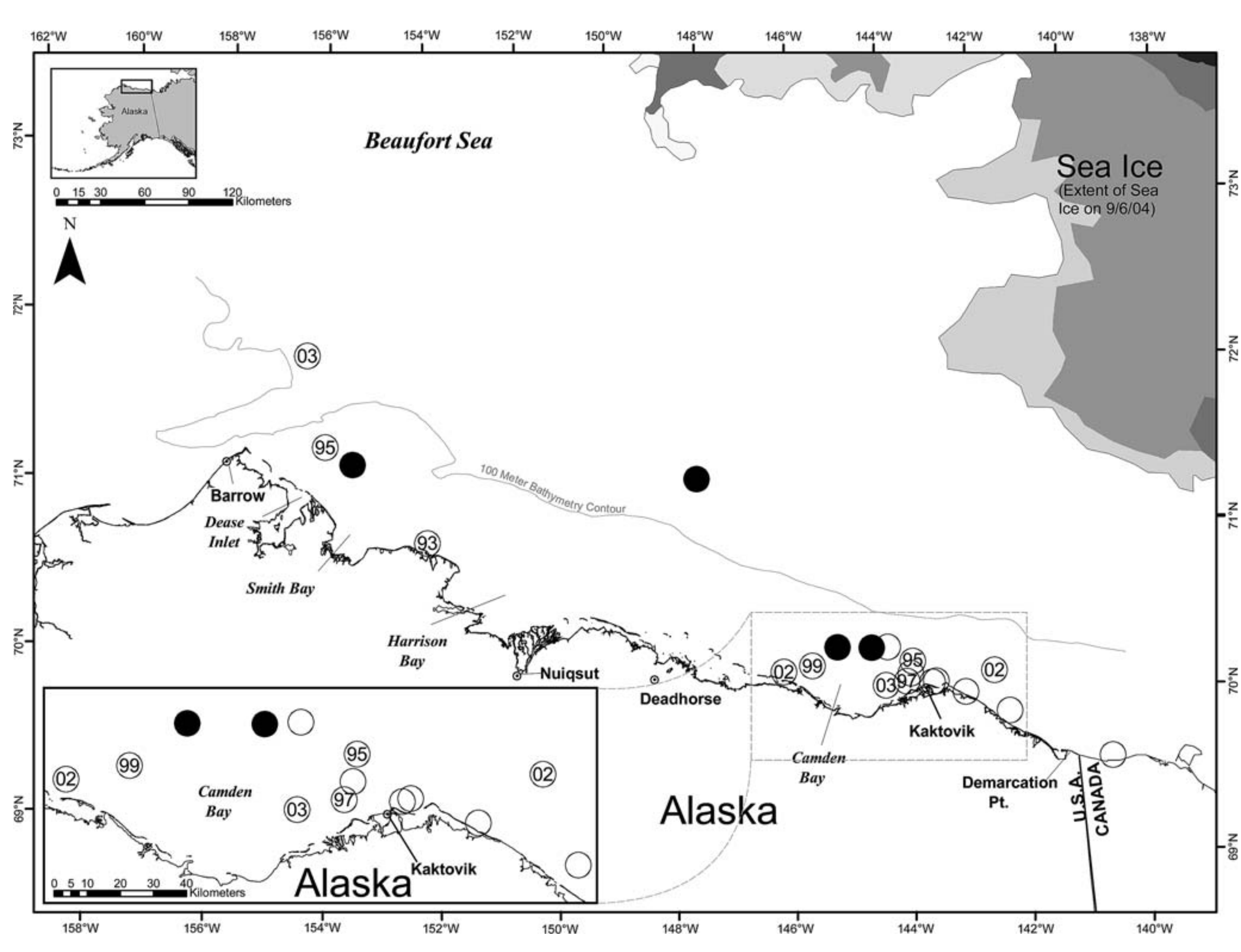

Fig. 1 Distribution of polar bears (*Ursus maritimus*) observed during fall annual bowhead whale (*Balaena mysticetus*) aerial surveys in the Beaufort Sea, 1987–2004. *Open circles* represent live bears that were observed swimming. *Closed circles* represent dead bears observed in 2004. Numbers within *open circles* indicate year in which the observation occurred. *Circles* without numbers represent observations in 2004

on sightings included date, time, latitude, longitude, altitude, aircraft heading, species, total number, observer, behavior (for all whales and some polar bear sightings), size (adult, cow–calf pair, adult female with cub), habitat (for all whales and some polar bear sightings), sea ice type, sea ice coverage, sea state, visibility, weather, glare and response to aircraft. Surveys were generally flown at a target altitude of 457 m and a groundspeed of roughly 200–250 km/h. Surveys were aborted when cloud ceilings were consistently < 305 m or when sea state was consistently greater than Beaufort 4 (Chapman 1977). Survey effort hereafter refers to distance flown in kilometers while on transect, on connect and on search. For a more detailed description of survey methodology (and general findings) refer to Treacy (2002) and Monnett and Treacy (2005).

Data selection and analysis

Analysis was limited to observations during September as nearly all observations of swimming polar bears were made during this month which corresponds to maximum area of open water in the survey region. A caveat of our data is that individual locations represent the latitude–longitude of the aircraft relative to the polar bear at the time of the observation and not the exact location of the animal. However, low sightability dictated that most swimming bears were very near or under the aircraft when their location was registered.

Data on sea ice conditions were obtained from the United States Navy/NOAA Joint Ice Center (NAVY/NOAA 2002) and incorporated into the ArcGIS database. Data on sea ice conditions on or nearest the date bears were observed (range 0–4 days) were used. Distance estimates from land and pack ice edge were generated by selecting on individual points and "connecting" a straight-line from the bear to land and ice, respectively, in ArcGIS.

Data on wind speeds for September 2004 were taken from the research meteorological station at Endicott (Hoefler Consulting Group 2004) and Barter Island (Kaktovik) weather station (Station Number 700860 99999, National Climatic Data Center, Asheville, NC). The Kaktovik station is located onshore near the village, whereas the Endicott station is more exposed situated approximately 5 km offshore on a causeway.

Distances of observations to land (barrier islands or coastline) were measured in ArcGIS (Environmental Systems Research Institute; ESRI 2001) and only those observations > 2 km north of barrier islands and the coast (definition of open water in the context of this paper) were selected. All descriptive statistics and analyses were performed in SPSS Release 10.1 (SPSS, Inc. 2001). Database manipulations were done in Microsoft™ ACCESS and all spatial analyses employed ArcGIS version 3.2 (ESRI 2001).

Results

Survey effort

Approximately 292,000 km were flown during September (1987–1994). Survey effort (transect + connect + search) varied by year [mean September effort = 16,192 km; range 8,253 (1991)–23,916 (1998)] with effort influenced primarily by local weather conditions. Survey effort and bear sightings are summarized by year in Table 1.

During aerial surveys conducted in 1987–2004, a total of 658 polar bears were observed in all habitats (i.e., land, ice and water). Total number of bears observed during September in all years was 370 and varied annually from 0 to 96 (Table 1).

Development of inclement weather during mid-September, 2004

Surveys were initially flown in the vicinity of Kaktovik on 6–8 September 2004. During that time, light wind conditions (0–10 km/h) were prevailing (Fig. 2). The sea state of nearshore waters where most of the swimming bears were observed was calm. Over the next days, high winds occurred across the study area with light westerly winds switching to strong easterly winds peaking at 54 km/h at Endicott and 46 km/h measured at Kaktovik between 10 and 11 September (Fig. 2). Winds offshore were likely considerably higher because the weather stations are located at relatively sheltered onshore sites. Seas became very rough with wave heights estimated in excess of 2 m. By 14 September, winds had decreased and waves had diminished.

Polar bears in open water

During 1987–2003, a total of 315 live polar bears was observed during September and of those 12 (3.8%) were in open water (Table 2). No dead and floating polar bears were observed. In 2004, a total of 55 polar bears were observed during September. Fifty-one were alive and of those 10 (19.9%) were in open water (Fig. 1). In addition, four polar bear carcasses were seen floating in open water (Table 2), the first such observations over the span of the survey.

Mean distance (± standard error) from land and pack ice edge to the four dead polar bears was 53.6 ± 17.0 and 181.2 ± 25.2 km, respectively (Table 2). Distance from land and pack ice edge for live polar bears swimming in open water in 2004 was 8.3 ± 3.0 and 177.4 ± 5.1 km, respectively. Distance from land and pack ice for all live swimming bears observed from 1987 to 2003 ranged 4.9–75.3 and 22–349 km, respectively.

Table 1 Range of survey dates, number of polar bears (*Ursus maritimus*) observed (total and swimming) and number of flights and kilometers flown as an index to effort during fall bowhead whale (*Balaena mysticus*) surveys, 1987–2004

Year	Survey period[a]	No. of bears observed[b]	No. of bears swimming[c]	No. of flights[a]	Total distance (km) surveyed[d]
2004	1 Sept.–18 Oct.	55 (51)	14 (4)	29	25,865
2003	1 Sept.–19 Oct.	45 (45)	3	28	17,600
2002	22 Aug.–7 Oct.	11 (6)	2	27	23,253
2001	31 Aug.–19 Oct.	6 (0)	0	23	16,996
2000	1 Sept.–19 Oct.	23 (5)	0	28	21,053
1999	31 Aug.–23 Oct.	37 (34	1	36	26,053
1998	31 Aug.–27 Oct.	114[e](96)	0	44	40,813
1997	31 Aug.–19 Oct.	52 (5)	1	36	28,701
1996	1 Sept.–10 Oct.	10 (1)	0	34	26,008
1995	31 Aug.–20 Oct.	5 (5)	5	32	26,276
1994	31 Aug.–18 Oct.	32 (15)	1	33	29,299
1993	1 Sept.–28 Oct.	5 (5)	0	41	36,809
1992	31 Aug.–23 Oct.	209[e](57)	0	45	44,815
1991	31 Aug.–20 Oct.	21 (0)	0	25	18,954
1990	1 Sept.–20 Oct.	1 (0)	0	30	20,424
1989	1 Sept.–20 Oct.	6 (0)	0	31	23,175
1988	1 Sept.–20 Oct.	25 (5)	0	32	28,598
1987	1 Sept.–31 Oct.	0 (0)	0	41	34,836

[a]Includes all dates for aerial surveys in which the plane left the airport in Deadhorse, AK regardless of whether or not transects were actually flown. In some instances, transects could not be flown due to inclement weather in the study area on a given date
[b]Includes all polar bears observed regardless of location, e.g., on land or ice, and is uncorrected for effort. Numbers in parentheses were bears seen during September
[c]Includes only those polar bears observed swimming ≥2 km from shore. Numbers in parentheses in 2004 were bears confirmed as dead via circling. Swimming in open water was only observed during September
[d]Total distance flown includes all kilometers flown from the time of departure from the airport in Deadhorse, AK until the plane returns back at the airport. Though it provides a rough estimate of effort it overestimates distance actually ‘‘searched’’
[e]Represents some larger groups (≥5 bears) that were resighted in the proximity of villages, usually with concentrations of bears attracted to bowhead whale carcasses, i.e., bone piles

Discussion

To our knowledge, we report here the first observations of polar bears floating dead offshore and presumed drowned while making apparent long-distance movements in open water. Polar bears are considered strong swimmers, but they have rarely been observed swimming far from ice or land. Øritsland (1969) observed a polar bear in open water estimated to be 160 km from land, and Burns et al. (1981) commented that the eventual fate of this bear was unknown. Ferguson et al. (2000) documented only 0.04% (3 of 6,943) of polar bear telemetry observations were classified as occurring in ‘‘open water’’.

Our observations suggest that polar bears swimming in open water near Kaktovik drowned during a period of high winds and correspondingly rough sea conditions between 10 and 13 September 2004. No other deleterious environmental conditions were present that might have led to the deaths of those polar bears. The only human-related activity in the near-shore marine environment in the eastern Alaskan Beaufort Sea during the relevant time period

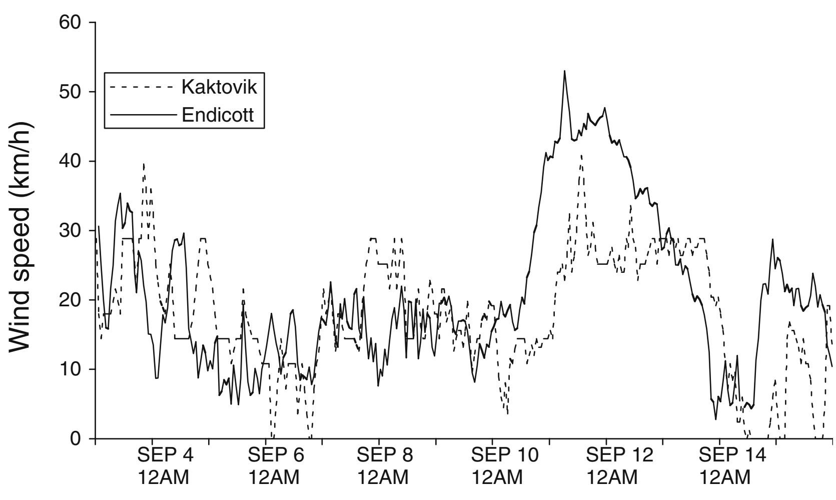

Fig. 2 Time series from data on hourly wind speeds (km/h) from the Endicott (*solid line*; MMS Contract # 31067, Minerals Management Service, Anchorage, AK) and Barter Island (Kaktovik) weather stations (*dashed line*; Station Number 700860 99999, National Climatic Data Center, Asheville, NC) during September 2004

Table 2 Dates (number in parentheses indicates multiple bears for a given observation event) of polar bears (*Ursus maritimus*) observed, distance from land, distance to pack ice edge and date in which pack ice edge was estimated during fall annual bowhead whale (*Baelena mysticus*) surveys in the Beaufort Sea, 1987–2004

Year	Date observed	Distance from land (km)	Distance to ice (km)	Date ice estimated
2004	6 Sept.	2.1	185	6 Sept.
	6 Sept.	4.3	188	6 Sept.
	6 Sept. (2)	11.4	195	6 Sept.
	6 Sept.	33.2	188	6 Sept.
	7 Sept.	3.6	187	6 Sept.
	14 Sept. (3)	2.6	160	13 Sept.
	14 Sept.	39.9[a]	158	13 Sept.
	16 Sept.	8.9	156	13 Sept.
	16 Sept.	36[a]	170	13 Sept.
	18 Sept.	33.9[a]	255	20 Sept.
	22 Sept.	104.5[a]	142	20 Sept.
2003	6 Sept.	12.4	22	5 Sept.
	16 Sept.	75.3	305	15 Sept.
2002	10 Sept.	24.2	83	9 Sept.
	13 Sept.	5.7	244	13 Sept.
1999	7 Sept.	16	53	6 Sept.
1997	26 Sept.	6.4	349	22 Sept.
1995	19 Sept. (3)	19.2	246	19 Sept.
1995	19 Sept. (2)	32.5	50	19 Sept.
1993	11 Sept.	4.9	65	12 Sept.

Only years having observations are reported
[a]Indicates dead bears observed floating offshore during aerial surveys

was limited subsistence whaling which was also hampered by weather conditions during the range of dates above.

Only a small total number of bears was seen on > 14,000 km of transect surveyed in 2004, thus limiting our ability to provide accurate estimates of polar bear mortality and associated confidence intervals (see McDonald et al. 1999; Evans et al. 2003). If, however, data are simply spatially extrapolated, bear deaths during a period of high winds in 2004 may have been significant. Our observations obtained from 34 north–south transects provide coverage of approximately 11% of the 630 km wide study area assuming a maximum sighting distance for swimming/floating polar bears of 1 km from the aircraft (coverage = 630 km/ (34 transects×2 km wide transect) = 10.8% of study area). Limiting data to bears on transect and not considering bears seen on connect and search segments, four swimming polar bears were encountered in addition to three dead bears. If these bears accurately reflect 11% of bears present under these conditions, then 36 bears may have been swimming in open water on 6 and 7 September, and 27 bears may have died as a result of the high offshore winds. These extrapolations suggest that survival rate of bears swimming in open water during this period was low (9/36 = 25%).

We believe that the increased risk of swimming in open water is not likely to result simply from long-distance swimming as polar bears are considered strong swimmers (Øritsland 1969; Burns et al. 1981). Long-distance swims may impose higher metabolic costs than standing or walking on ice even under favorable weather conditions. High mortality in 2004 was more likely related to extreme and metabolically demanding conditions, such as high sea states associated with stormy weather. As previously discussed, there is some indication that such conditions may become more common in the future (Serreze et al. 2000; Serreze and Barry 2005). In general, for a given wind speed and direction, wave height (sea state) increases as a function of open water surface area (discussed as sightability of whales in Clarke et al. 1993; see also Moore 2000). Therefore, polar bears swimming in open water will presumably encounter increased wave heights compared to swimming under conditions of ≥50% ice cover for the same wind speed and direction. Open water conditions where ice is virtually absent in August and September are expected to increase if Arctic air temperatures continue to rise (Stroeve et al. 2004), and thus swimming polar bears would be more at risk of encountering unfavorable conditions (i.e., high sea states and increased winds). Presumably, in the future, more time and energy will be allocated to swimming due to increased distances among ice floes, abandoning sea ice for land when ice concentration falls below 50% (Sterling et al. 1999), or during routine travels searching for suitable substrates in which to hunt seals (Derocher et al. 2004).

Our count of dead polar bears related to the 2004 windstorm almost certainly represents an underestimate of the actual number of polar bears affected. Swimming and floating polar bears are difficult to see from the survey's standard 457 m altitude even under ideal conditions. Also, some bears that drowned may have sunk or drifted outside the study area.

Other bears may have suffered sublethal effects and later succumbed due to exhaustion or inspiration of sea water as a result of swimming long distances in rough seas. Fatigued polar bears occasionally swim ashore along the coastline of the Alaskan Beaufort Sea (R. Shideler, in litt.) and Hudson Bay (I. Stirling, personal communication) during times when open water is at its maximum extent. After reaching land, these bears may sometimes take up to several days to recover. In one extreme case in 2002 (R. Shideler, in litt.) an adult male bear swam ashore in Prudhoe Bay. Initially, the bear was lethargic, shivering and appeared to be dehydrated because it drank considerable fresh water from nearby pools. After a few hours, managers attempted to haze the bear away from human activities using Karelian bear dogs and noisemakers, but the bear was generally unresponsive. The bear remained near where it came ashore for approximately 2.5 days. Such observations are indicative of the physical stress and high metabolic demands associated with long-distance swimming in cold water. Though estimates of metabolic costs associated with swimming are unavailable, it is likely that energetic costs for this activity far exceed those for walking (Hurst et al. 1982).

Although a number of published papers have discussed implications of climate change on polar bears (e.g., Stirling and Derocher 1993; Stirling et al. 1999; Norris et al. 2002; Stirling 2002; Derocher et al. 2004), to date, mortality due to swimming has not been identified as an associated risk. Evaluations of future population dynamics and the significance of sources of human-related and natural mortality in polar bears may need to consider this previously unidentified source of natural mortality which may be significant in some years (e.g., mild-ice or late-ice) and may become important in the future if Arctic pack ice continues to regress. Such risk might increase if land-based bears are forced to swim in search of ice if the open water period continues to increase in fall. Presumably, changes in sea ice would not affect all sex/age classes of polar bears randomly or uniformly. Lone females and females with cubs may be more prone to deaths during long-distance travel in open water (Derocher et al. 2004, p 166). If this scenario is realistic, there are rather serious population-level implications since additional losses to females above those expected under current "take" agreements (Brower et al. 2002, p 365) could ultimately lead to long-term population declines (Taylor et al. 1987).

Polar bears swimming offshore in the Beaufort Sea risk contact with oil, if spilled and strikes by ships (see Stirling 1988, 1990). Our observations of higher numbers of swimming polar bears in open water than previously supposed should be considered by analysts and managers relative to marine transportation, ice-breaking, oil and gas development and other potential activities in open water. Minimizing and discouraging anthropogenic effects that encourage polar bears to remain or aggregate onshore as annual shorefast ice melts and pack ice recedes could ultimately reduce the risk of drowning.

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References

Amstrup SC (2000) Polar bear. In: Truett JC, Johnson SR (eds) The natural history of an Arctic oil field: development and biota. Academic Press, San Diego, pp 133–157

Amstrup SC, Durner GM, Stirling I, Lunn NJ, Messier F (2000) Movements and distribution of polar bears in the Beaufort Sea. Can J Zool 78:948–966

Amstrup SC, McDonald TL, Stirling I (2001) Polar bears in the Beaufort Sea: a 30-year mark-recapture case history. J Agric Biol Environ Stat 6:221–234

Brower WA, Baldwin RG, Williams CN, Wise JL, Leslie LD (1988) Climatic atlas of the outer continental shelf waters and coastal regions of Alaska, vol III. Final report to U.S. Minerals Management Service, Alaska Outer Continental Shelf Region. OCS Study MMS 87–0013, 524pp

Brower CD, Carpenter A, Branigan ML, Calvert W, Evans T, Fischbach AS, Nagy JA, Schliebe S, Stirling I (2002) The polar bear management agreement for the southern Beaufort Sea: an evaluation of the first ten years of a unique conservation agreement. Arctic 55:362–372

Burns JJ, Shapiro LW, Fay FH (1981) Ice as marine mammal habitat in the Bering Sea. In: Hood DW, Calder JA (eds) The eastern Bering Sea shelf: oceanography and resources. Office of Marine Pollution Assessment, NOAA, pp 781–797

Chapman CF (1977) Piloting, seamanship and small boat handling. Hearst Books, New York, p 640

Clarke JT, Moore SE, Johnson MM (1993) Observations on beluga fall migration in the Alaskan Beaufort Sea, 1982–87, and northeastern Chukchi Sea, 1982–91. Rep Int Whaling Comm 43:387–396

Comiso JC (2002a) Correlation and trend studies of the sea-ice cover and surface temperatures in the Arctic. Ann Glaciol 34:420–428

Comiso JC (2002b) A rapidly declining perennial sea-ice cover in the Arctic. Geophys Res Lett 29:1956

Comiso JC (2003) Warming trends in the Arctic from clear-sky satellite observations. J Clim 16:3498–3510

Comiso JC (2005) Impact studies of a 2°C global warming on the Arctic sea ice cover. In: Rosentrater L (eds) Evidence and implications of dangerous climate change in the Arctic. World Wildlife Fund International Arctic Program, Oslo, Norway, pp 43–55

Derocher AE, Stirling I (1992) The population dynamics of polar bears in the western Hudson Bay. In: McCullough DR, Barrett RH (eds) Wildlife 2001: populations. Elsevier Applied Science, London, pp 1150–1159

Derocher AE, Andriashek D, Stirling I (1993) Terrestrial foraging by polar bears during the ice-free period in western Hudson Bay. Arctic 46:251–254

Derocher AE, Lunn NJ, Stirling I (2004) Polar bears in a warming climate. Integr Comp Biol 44:163–176

ESRI (2001) ArcGIS. Environmental Research Systems Research Institute, Inc., Redlands, California

Evans TJ, Fischbach A, Schliebe S, Manly BFJ, Kalxdorff S, York G (2003) Polar bear aerial survey in the eastern Chukchi Sea: a pilot study. Arctic 56:359–366

Ferguson SH, Taylor MK, Messier F (2000) Influence of sea ice dynamics on habitat selection by polar bears. Ecology 81:761–772

Gough WA, Cornwell AR, Tsuji LJS (2004) Trends in seasonal sea ice duration in southwestern Hudson Bay. Arctic 57:299–305

Hassol SJ (2004) ACIA-Impacts of a warming Arctic: Arctic climate impact assessment. Cambridge University Press, Oxford, p 146

Hoefler Consulting Group (2004) Nearshore Beaufort Sea meteorological monitoring and data synthesis project- third quarter 2004 data report. US Department of Interior, Minerals Management Service—unpublished report, 36pp (available from Minerals Management Service, 3801 Centerpoint Drive, Suite 500, Anchorage, Alaska)

Hurst RJ, Øritsland NA, Watts PD (1982) Body mass, temperature, and cost of walking in polar bears. Acta Physiol Scand 115:391–395

Labelle JC, Wise JL, Voelker RP, Schulze RH, Wohl GM (1983) Alaska marine ice atlas. Arctic Environmental Information Data Center, University of Alaska, Anchorage, p 302

McDonald LL, Garner GW, Robertson DG (1999) Comparison of aerial survey procedures for estimating polar bear density: results of pilot studies in northern Alaska. In: Garner GW, Amstrup SC, Laake JL, Manly BFJ, McDonald LL, Robertson DG (eds) Marine mammal survey and assessment methods. A.A. Balkema, Rotterdam, pp 37–51

Monnett C, Treacy SD (2005) Aerial surveys of endangered whales in the Beaufort Sea, fall 2002–2004. OCS Study, MMS 2005–037, 153pp

Moore SE (2000). Variability of cetacean distribution and habitat selection in the Alaskan Arctic, autumn 1982–91. Arctic 53:448–460

NAVY/NOAA (2002) United States Navy—National Oceanographic and Atmospheric Administration Joint Ice Center: Seasonal Outlook Western Arctic Ice, 2002. Prepared by Naval Polar Oceanography Center for Naval Oceanography Command. Available on-line at http://www.natice.noaa.gov/

Norris S, Rosentrater L, Eid PM (2002) Polar bears at risk: a status report. World Wildlife Fund International Arctic Programme, Oslo, p 27

Norton D, Weller G (1984) The Beaufort Sea: background, history, and perspective. In: Barnes P, Schell D, Reimnitz E (eds) The Alaskan Beaufort Sea: ecosystems and environments. Academic Press, San Diego, p 465

Øritsland NA (1969) Deep body temperatures of swimming and walking polar bears. J Mammal 50:380–382

Ramsay MA, Stirling I (1988) Reproductive biology of female polar bears (*Ursus maritimus*). J Zool 214:601–634

Rothrock DA, Yu Y, Maykut GA (1999) Thinning of the Arctic sea-ice cover. Geophys Res Lett 26:3469–3472

Serreze MC, Barry RG (2005) The Arctic climate system. Cambridge University Press, New York, p 424

Serreze MC, Walsh JE, Chapin FSI, Osterkamp T, Dyurgerov M, Romanovsky V (2000) Observational evidence of recent change in the northern high-latitude environment. Clim Change 46:159–207

Skinner WR, Jefferies RL, Carleton TJ, Rockwell RF, Abraham KF (1998) Prediction of reproductive success and failure in lesser snow geese based on early season climatic variables. Global Change Biol 4:3–16

SPSS Inc (2001) SPSS for Windows, Release 10.1. Chicago, Illinois, USA

Stirling I (1988) Attraction of polar bears *Ursus maritimus* to offshore drilling sites in the eastern Beaufort Sea. Polar Rec 24:1–8

Stirling I (1990) Polar bears and oil: ecological perspectives. In: Geraci JR St. Aubin DJ (eds) Sea mammals and oil: confronting the risks. Academic Press, San Diego, pp 223–234

Stirling I (2002) Polar bears and seals in the eastern Beaufort Sea and Amundsen Gulf: a synthesis of population trends and ecological relationships over tree decades. Arctic 55:59–76

Stirling I, Andriashek D, Calvert W (1993) Habitat preferences of polar bears in the western Canadian Arctic in late winter and spring. Polar Rec 29:13–24

Stirling I, Derocher AE (1993) Possible impacts of climatic warming on polar bears. Arctic 46:240–245

Stirling I, Lunn N (1997) Environmental fluctuations in Arctic marine ecosystems as reflected by variability in reproduction of polar bears and ringed seals. In: Woodin SJ, Marquiss M (eds) Ecology of Arctic environments, Special Publication No. 13. British Ecological Society, pp 167–180

Stirling I, Lunn NJ, Iacozza J (1999) Long-term trends in the population ecology of polar bears in western Hudson Bay in relation to climatic change. Arctic 52:294–306

Stroeve JC, Serreze MC, Fetterer F, Arbetter T, Meier W, Maslanik J, Knowles, K (2004) Tracking the Arctic's shrinking ice cover: another extreme September minimum in 2004. Geophys Res Lett 32:L04501 (DOI: 10.1029/2004GL021810)

Taylor MK, DeMaster DP, Bunnell FL, Schweinsburg RE (1987) Modelling the sustainable harvest of female polar bears. J Wildl Manage 51:811–820

Treacy SD (2002) Aerial surveys of endangered whales in the Beaufort Sea, fall 2001. OCS Study, MMS 2002–14, 111pp