ARCTIC
VOL. 61, NO. 1 (MARCH 2008) P. 14–22

Unusual Predation Attempts of Polar Bears on Ringed Seals in the Southern Beaufort Sea: Possible Significance of Changing Spring Ice Conditions

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(*Received 8 January 2007; accepted in revised form 26 July 2007*)

ABSTRACT. In April and May 2003 through 2006, unusually rough and rafted sea ice extended for several tens of kilometres offshore in the southeastern Beaufort Sea from about Atkinson Point to the Alaska border. Hunting success of polar bears (*Ursus maritimus*) seeking seals was low despite extensive searching for prey. It is unknown whether seals were less abundant in comparison to other years or less accessible because they maintained breathing holes below rafted ice rather than snowdrifts, or whether some other factor was involved. However, we found 13 sites where polar bears had clawed holes through rafted ice in attempts to capture ringed seals (*Phoca hispida*) in 2005 through 2006 and another site during an additional research project in 2007. Ice thickness at the 12 sites that we measured averaged 41 cm. These observations, along with cannibalized and starved polar bears found on the sea ice in the same general area in the springs of 2004 through 2006, suggest that during those years, polar bears in the southern Beaufort Sea were nutritionally stressed. Searches made farther north during the same period and using the same methods produced no similar observations near Banks Island or in Amundsen Gulf. A possible underlying ecological explanation is a decadal-scale downturn in seal populations. But a more likely explanation is major changes in the sea-ice and marine environment resulting from record amounts and duration of open water in the Beaufort and Chukchi seas, possibly influenced by climate warming. Because the underlying causes of observed changes in polar bear body condition and foraging behaviour are unknown, further study is warranted.

Key words: polar bear, ringed seal, Beaufort Sea, climate change, predation, nutritional stress, sea ice

RÉSUMÉ. En avril et en mai des années 2003 à 2006, de la glace de mer inhabituellement raboteuse et entassée s'est étendue sur plusieurs dizaines de kilomètres au large du sud-est de la mer de Beaufort, à partir de la pointe Atkinson environ jusqu'à la frontière de l'Alaska. Les ours polaires (*Ursus maritimus*) avaient donc du mal à attraper des phoques malgré la chasse intense. On ne sait pas si les phoques s'y trouvaient en moins grande abondance par rapport aux autres années ou s'ils étaient moins accessibles parce qu'ils maintenaient des trous d'air sous la glace entassée plutôt que dans les congères, ou si un autre facteur entrait en jeu. Cependant, de 2005 à 2006, on a repéré 13 endroits où les ours polaires avaient griffé des trous dans la glace entassée pour essayer d'attraper les phoques annelés (*Phoca hispida*), puis un autre endroit dans le cadre d'un autre projet de recherche en 2007. Aux 12 endroits mesurés, l'épaisseur de la glace atteignait 41 cm en moyenne. Ces observations, en plus des observations d'ours polaires cannibalisés et d'ours polaires affamés trouvés sur la glace de mer dans à peu près la même région du printemps 2004 au printemps 2006, laissent croire que pendant ces années, les ours polaires du sud de la mer de Beaufort éprouvaient du stress alimentaire. Des recherches effectuées plus au nord pendant cette même période, recherches réalisées à l'aide des mêmes méthodes, n'ont pas permis d'aboutir à des observations similaires près de l'île de Banks ou du golfe Amundsen. Du point de vue écologique, une explication sous-jacente consisterait en un fléchissement décadaire des populations de phoques. Cependant, une explication plus plausible consisterait en des changements majeurs caractérisant la glace de mer et le milieu marin découlant de quantités et de durées records d'eau libre dans les mers de Beaufort et de Chukchi, ce qui pourrait être le résultat du réchauffement climatique. Puisqu'on ne connaît pas les causes sous-jacentes des changements observés sur le plan de l'état du corps et des comportements alimentaires des ours polaires, des recherches plus poussées pourraient être justifiées.

Mots clés : ours polaire, phoque annelé, mer de Beaufort, changement climatique, prédation, stress alimentaire, glace de mer

Traduit pour la revue *Arctic* par Nicole Giguère.

INTRODUCTION

Throughout their range in the Canadian Arctic, polar bears (*Ursus maritimus*) prey primarily on ringed seals (*Phoca hispida*) (Stirling and Archibald, 1977; Smith, 1980). In spring, most hunting by bears takes place along narrow, open or refrozen leads, or at birth lairs in snowdrifts above breathing holes through the sea ice that the seals maintain

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by abrading the ice with claws in their foreflippers. Ringed seals construct haulout lairs and birth lairs by excavating windblown snow that drifts and consolidates over breathing holes. Pups are born in late March or early April (Smith, 1987). Although the snow structures conceal ringed seals from predators, polar bears detect lairs by smell and dig into them, attempting to capture a seal within (Smith and Stirling, 1975, 1978; Stirling and Latour, 1978; Stirling et al., 1993).

In this paper, we document 14 unusual, and previously undocumented, occurrences of bears clawing through solid sheets of rafted sea ice in attempts to capture seals. These attempts occurred in the coastal landfast ice of the southeastern Beaufort Sea, in April and early May of 2005–07. We also integrate related observations of unusual bear mortalities and analyze indices of polar bear body condition to evaluate possible nutritional correlates to this unusual feeding behaviour. Finally, we consider the possible cumulative significance of these events and related observations in the context of ongoing ecological changes in the southern Beaufort Sea.

METHODS

The Study Area

The observations reported here were recorded primarily during a polar bear population assessment conducted throughout the southeastern Beaufort Sea and Amundsen Gulf, east of 141˚ W and south of 75˚ N, from early April through early May in 2003–06 to a maximum of about 120 km offshore (Fig. 1). The Northern Beaufort Sea (NB) and Southern Beaufort Sea (SB) polar bear populations occur in this area. The SB population inhabits the mainland coast from about Baillie Islands in Canada to approximately Icy Cape in Alaska, while the NB population inhabits the west coast of Banks Island and Amundsen Gulf (Amstrup et al., 2005). The final observations were made during a brief field season in the southeastern Beaufort Sea in April and May 2007.

Field Methods

Details of the field methods and data collected during polar bear population assessments were given in Stirling (2002). Briefly, however, all habitat types (Stirling et al., 1993) were searched, and an effort was made to distribute search effort as evenly as possible over the entire study area. Many of the bears were captured by following tracks, during which it was possible to record the habitats they hunted and traveled through, as well as aspects of their foraging behaviour.

Field Assessment of Condition

At the time of capture, we determined a subjective index of body condition for each bear (Stirling et al., 2008). When the bear was sternally recumbent, the body was palpated by hand to determine the relative amount of fat deposited over the rump area and the body as a whole, the visibility of the spinal ridge, and the degree to which the outline of the hip bones and pelvic girdle could be detected beneath the skin and fat. The index is expressed as a qualitative rating from 1, the leanest, to 5, the most obese of bears we see. Although this index is subjective, we have been using it for more than 30 years and have found it repeatable between individual biologists when blind comparisons are done in the field over both short and long time periods. Because of low sample sizes in the upper (4 and 5) and lower (1) condition categories, we pooled the data into two categories. The first category represents bears in relatively poor condition (i.e., bears that were rated as either 1 or 2), and the second represents bears that were in average or above-average condition (i.e., bears rated 3–5). We analyzed the subsequent 2×2 table using a chi-square test to compare the frequencies of condition indices for the two rankings for bears aged two years or more captured in both SB and NB in spring 2003–06. Adult females with cubs-of-the-year were excluded from our analysis because they fast for at least 4–5 months in their maternity dens. Although they are very thin when they emerge just prior to our spring capture season, their condition does not reflect possible geographic variation in the distribution and availability of prey in relation to sea ice dynamics. Some individual bears were handled in more than one year, but because polar bear body condition is dynamic (Watts and Hansen, 1987) and the influence of environmental conditions between years can be substantial (Stirling, 2002), body condition measurements taken in different years are statistically independent.

RESULTS

Area Surveyed and Observations of Sea Ice

During 2003–06, we flew approximately 50 000 km throughout the study area in search of polar bears in April and early May: 8581 km in 2003, 13 778 in 2004, 14 448 in 2005, and 12 834 km in 2006 (Fig. 1). In 2007, we flew 7460 km from our base in Tuktoyaktuk to deploy satellite radio collars. Although the searching methods were the same as in previous years, the area searched was more limited. During our study, sea ice conditions in the southeastern Beaufort Sea showed some major differences from past years (Stirling et al., 1993 and unpubl. data). From 2003 through 2006, large areas of the annual landfast ice from northeast of Atkinson Point to the Alaska border (Fig. 1) were compressed into high pressure ridges interspersed with extensive areas of rafted floes and rubble (especially in 2005; Fig. 2). In some places, these areas extended offshore from the mainland coast for tens of kilometres. Such heavy ice reduces the availability of low consolidated ridges and refrozen leads with accompanying snowdrifts typically used by ringed seals for birth and

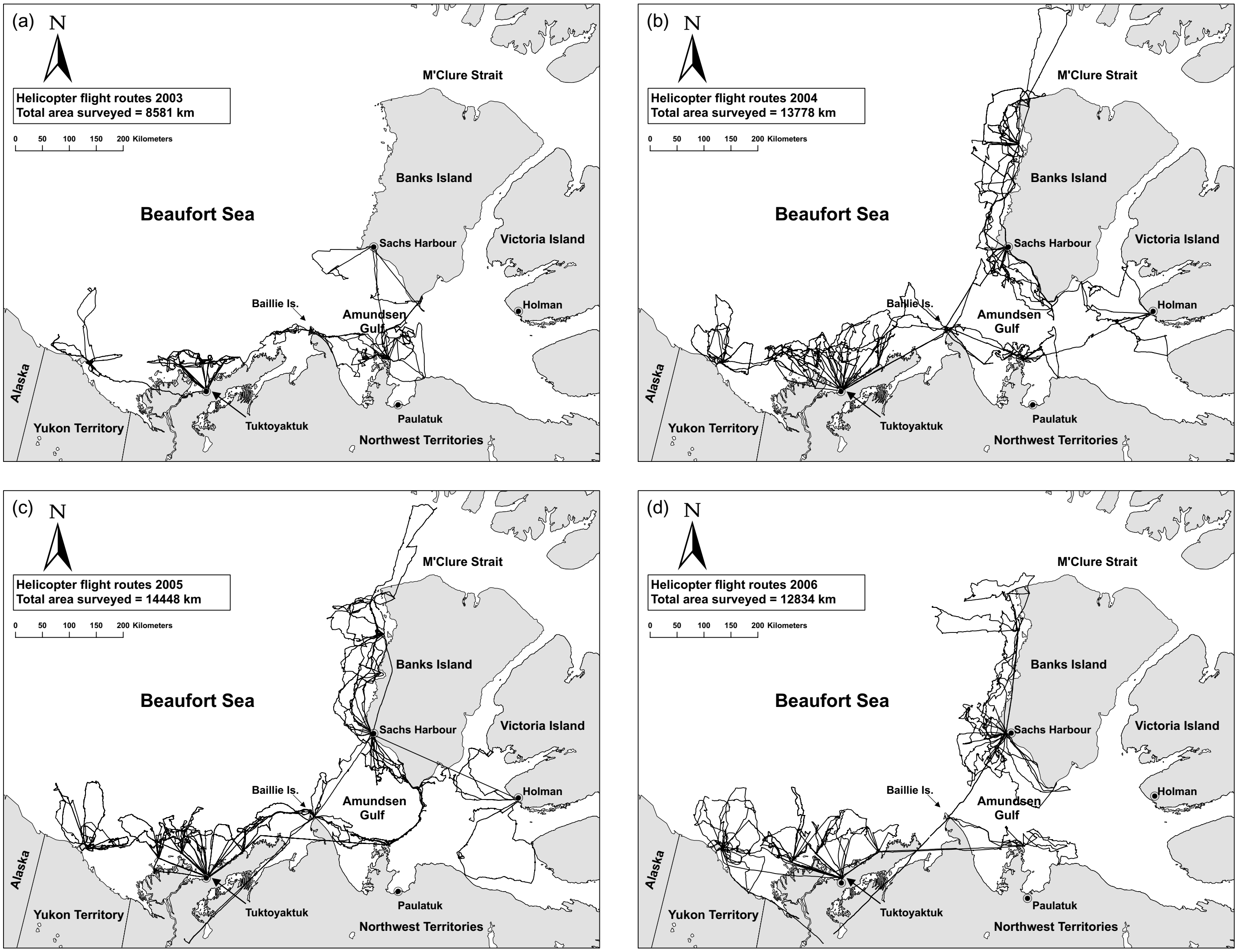

FIG. 1. Map of the study area showing routes flown while searching for polar bears in the southeastern Beaufort Sea and Amundsen Gulf in April–May in (a) 2003, (b) 2004, (c) 2005, and (d) 2006. Additional flights flown in 2007 are not shown.

haul-out lairs (Smith and Stirling, 1975, 1978). Although we were unable to make a quantified comparison, our subjective impression is that in 12 previous spring field seasons surveying the same area for polar bears (1971–79, 1985–87) only once, in 1974, did we observe similarly extensive areas of rubble, pressure ridges, and rafted floes.

Unusual Predation Attempts on Ringed Seals

We found 14 sites (10 in 2005, 3 in 2006, and 1 in 2007, Fig. 3) where polar bears had clawed one or more holes through solid ice in buckled or rafted ridges (Fig. 4). Each of these holes was clawed in order to access open lairs below, where seals had apparently been maintaining breathing holes in the refrozen ice on the floor of the chamber. Polar bears clawed through ice with an average thickness of 41 cm (range, 22–75 cm) as they attempted to prey upon seals they could apparently detect (probably by smell) below the solid ice of the buckled or rafted ice floes (Table 1, Figs. 3 and 4). Because of limitations of either daylight or fuel, we were unable to land and take measurements of the holes at three sites in 2005. However, by flying low and slowly over them in the helicopter, we were able to confirm visually that the bears had dug through ice, not snow, and that the holes were similar to those we had inspected and measured. At one inspected site, there was blood on the ice, probably from wearing down or breakage of the claws of the bear that made the hole, since there were no skeletal parts or tissues from a seal that would confirm a successful kill. At three of the 14 sites (2 in 2005 and 1 in 2007), we confirmed that a newborn ringed seal pup had been captured by the abundance of blood and white lanugo remaining on the ice after the pup had been totally consumed. We saw no extended rubble fields and found no holes clawed through ice in the area occupied by the NB polar bear population, either adjacent to the western or southern coasts of Banks Island or east of Baillie Islands through Amundsen Gulf.

The maximum heights of four chambers that could be fully viewed and accurately measured below the rafted ice

FIG. 2. Example of extended rubble field in the sea ice offshore from the coast in the southeastern Beaufort Sea.

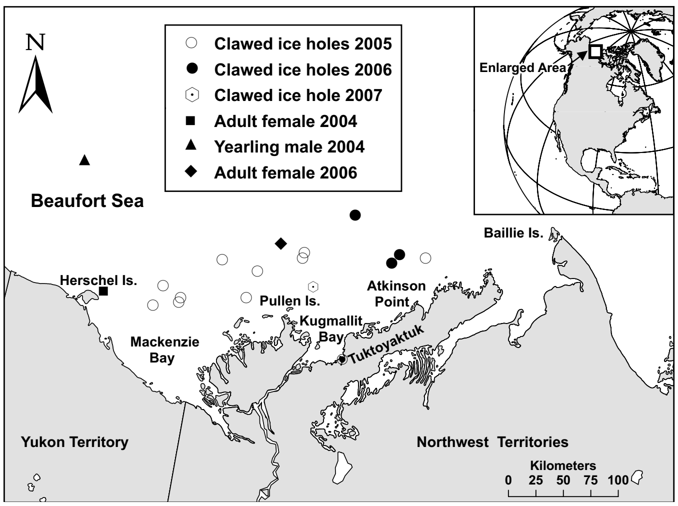

FIG. 3. Locations where polar bears clawed holes in the sea ice or were preyed upon by adult males.

ranged from 23 to 35 cm. At two sites where ringed seal pups were killed, the holes clawed through the ice were large enough (85 × 50 cm and 70 × 45 cm) to permit a small to medium-sized bear (or a person) to enter the sub-ice cavern (Fig. 4, top). At another site, there were four different holes through the ice into the same chamber below (Fig. 4, bottom). At two other sites there were two holes, and at three sites there was one completed hole and two partial holes that did not penetrate all the way through the ice sheet (Table 1).

Usually tracks of more than one bear were found around each site and variable amounts of drifted snow, so it was not possible to confirm the relative size of any of the individual bears that excavated each hole. However, no tracks of large adult male polar bears were recorded at any of the sites.

Predation of an Adult Female Polar Bear

On 2 May 2006, we found a dead, largely consumed, adult female bear 27 km north of Pullen Island. A necropsy

FIG. 4. Examples of sites where polar bears dug through solid ice to try to capture a seal in the air space below.

confirmed she had suffered a substantial blow to one side of her head. Bites to the throat had shattered the larynx and broken a lateral piece off the atlas vertebra. The area was snow-covered, so no tracks were visible, but it is likely that only an adult male polar bear would have been capable of killing an adult female in this way.

Body Condition

Polar bears captured in NB and SB from 2003 through 2006 were classified by body condition category (Table 2).

TABLE 1. Observations of attempts by polar bears to prey on seals by clawing through solid ice in rafted or buckled floes.

Number	Date	Location	No. holes in ice	Incomplete holes (cm)	Thickness of ice (cm)	Diameter hole (cm)	Comments
1	12 April 2005	69˚49.7′ N, 137˚30.0′ W	4	0	22	40	bowed up sea ice, blood from bleeding bear claws, two frozen breathing holes inside, ceiling in cavern approx. 35 cm, no kill
2	12 April 2005	69˚47.3′N, 137˚1.7′W	2	0	–	–	buckled sea ice, bowed up for several metres, no kill
3	12 April 2005	69˚47.6′N, 137˚02.0′W	1	0	–	–	bowed up ice, no kill
4	14 April 2005	69˚42.6′N, 137˚37.9′W	1	1 (27 deep)	30	30	bowed up ice, no kill
5	16 April 2005	70˚04.1′N, 135˚14.9′W	1	0	60	45	buckled ice, 25 cm ceiling in cavern, frozen breathing hole, no kill
6	17 April 2005	70˚16.8′N, 131˚31.9′W	1	1 (16 deep, 24 diameter)	45	50	pup kill, bear entered cavern, all eaten, 35 cm ceiling in cavern, lanugo present, breathing hole frozen
7	20 April 2005	70˚04.7′N, 135˚59.6′W	1	0	43	85 × 50	pup kill, 32 cm ceiling in cavern
8	20 April 2005	69˚49.5′N, 135˚22.2′W	1	1 (15 deep, 27 diameter)	23	27	23 cm high chamber, 2 m diameter, no kill
9	7 May 2005	70˚09.7′N, 134˚22.0′W	2	0	50 40	45 × 55, 25 × 30	large under-ice lair, no kill
10	9 May 2005	70˚10.7′N, 134˚22.0′W	1	0	–	–	no kill
11	16 April 2006	70˚17.5′N, 131˚59.0′W	1	0	51	34 × 40	bowed up ice sheet, no kill, 10 cm diameter hole entering cavern at bottom of hole, no kill
12	16 April 2006	70˚14.4′N, 132˚05.5′W	1	0	16	42	remains of ringed seal placenta inside; no kill
13	16 April 2006	70˚34.3′N, 133˚10.0′W	1	0	38	51 × 59	no kill
14	2 May 2007	69˚59.37′N, 133˚53.2′W	1	0	75	70 × 45	pup kill, bear entered cavern, all eaten

Note that 42.5% of the bears in SB were in conditions 1–2 and 57.0% in conditions 3–5, compared to 33.0% and 67.0%, respectively, for the NB bears, a difference that was statistically significant ($\chi^2 = 5.4507$, df = 1, $p < 0.025$).

DISCUSSION

Body Condition

From 2003 to 2006, the polar bears in SB were in significantly poorer body condition than those near Banks Island or in Amundsen Gulf (NB), which was consistent with the findings of holes clawed through the ice, cannibalism, and starved bears only in the former area. Although the index of body condition is subjective, its use as a variable, in relation to other factors, has been shown to produce statistically valid results in studies of contaminants (Henricksen et al., 2001), as well as in a previous study of cannibalism in polar bears in the Beaufort Sea (Amstrup et al., 2006).

Holes Clawed Through Solid Ice

In late winter and early spring, polar bears throughout the Arctic are in their poorest body condition of the year. In most areas, they depend largely on the availability of ringed seal pups from about the middle of April to breakup in late June to regain the weight lost over the winter. This time of year is particularly important for adult females as they prepare for reproductive costs in the year ahead (Watts and Hansen, 1987). A polar bear's success at catching seals inside birth or haul-out lairs depends largely on its ability to break into a lair quickly enough to seize the occupant before it disappears into the water through the breathing hole (Stirling and Latour, 1978). However, the wind-blown snow in spring is consolidated and hard, which, when the snow is deep, can make it difficult for bears to either break or dig into lairs quickly enough to catch even a relatively naïve pup before it escapes. Hammill and Smith (1991) found a significant negative correlation between mean snow depth and successful predation by polar bears. Even so, most bears gain entry into the lair within a few seconds or, at most, a minute (Stirling and Latour, 1978; Stirling, unpubl. obs.). Having invested the energy to expose a breathing hole, a bear will sometimes remain there in a lying, still-hunting posture in case a seal returns again to breathe (Stirling and Latour, 1978).

Although we have no direct observations, it seems likely that a bear would require many minutes of sustained noisy scratching to penetrate an average ice thickness of 41 cm before reaching a sub-ice cavern that might be occupied by a seal. If the breathing hole below the ice sheet were open, there would be abundant time for a seal to escape to an alternative lair or breathing hole before it was vulnerable to predation. Thus, we suspect that in the two cases where ringed seal pups were captured (Table 1), they may have already been abandoned and the breathing holes frozen over, which precluded independent escape by the pup, or movement by its mother, to an alternative lair.

The total caloric value of ringed seal pups in spring is variable and depends on their age and size. In April (when most of the predation attempts reported here occurred) the energy content of pups is only a fraction of what it would

TABLE 2. Number of polar bears age two years or more classified at each condition level, from 1 to 5, in the southern Beaufort Sea compared to the northern Beaufort Sea (Banks Island and Amundsen Gulf), 2003–06. Numbers in parentheses indicate proportion of the total.

	Fat Index				
	1	2	3	4	5
Northern Beaufort Sea (Banks Island and Amundsen Gulf)	1 (0.005)	69 (0.325)	142 (0.670)	0	0
Southern Beaufort Sea	2 (0.005)	138 (0.425)	178 (0.548)	7 (0.022)	0

normally be at weaning later in May (Stirling and McEwan, 1975; Lydersen and Hammill, 1993). Furthermore, a pup that was abandoned for even a day or two before capture would probably lose a significant amount of its potential caloric value to a polar bear. We do not know how much energy would be required to dig holes through solid ice, but it seems possible that the energy output exceeded the energy intake in the few instances where a pup was captured. We therefore suggest that clawing through solid ice in an attempt to capture a seal is not typical polar bear foraging behaviour and would be undertaken only by an exceptionally hungry bear. The bears with the greatest energy demands are adult females accompanied by dependent cubs and subadults. Subadults not only have a large demand for growth but are handicapped by being less experienced hunters, and often the seals they do catch are taken away from them by larger bears (Stirling, 1974). In contrast, adult males are experienced hunters, are feeding only themselves, and take kills away from smaller bears, which may explain the absence of their tracks at those clawing sites where recent tracks were still visible.

The seal breathing holes at all sites examined were frozen over, but it was unknown how many might have been open and active at the time the bears clawed their way in. We can only speculate as to why more than one hole was clawed through the ice at three sites and additional but incomplete holes were found at three other sites (Table 1). It is possible that after a bear clawed through at one location, the pup within the chamber was able to move or escape through a breathing hole that remained out of reach. It is also possible that while a female accompanied by yearling or two-year-old cubs was clawing at one location, her cubs, which learn to hunt by imitating her hunting behaviour (Stirling and Latour, 1978), were clawing less effectively nearby.

In our previous years of field work with polar bears and seals, both in the Beaufort Sea and elsewhere in the Canadian Arctic and Svalbard, we have observed holes clawed by a bear through rafted sea ice only once before. On 29 April 1975, approximately 30 km northwest of Atkinson Point (Fig. 3), we found a single sheet of rafted sea ice several metres in diameter and 30 cm thick with eight holes clawed through to a large cavern below. There was no evidence of a seal killing, but there was blood on the ice near some of the holes, apparently from the broken and bleeding claws of the polar bear (or bears). This ice-clawing event occurred during a period of abnormally low productivity of ringed seal pups, which lasted from 1974 through 1976 and resulted in lower survival of polar bear cubs born during those years (Stirling and Archibald, 1977; Smith, 1987; Stirling, 2002). Body weights of dependent young and subadult bears (but not adults) were also significantly lower than normal in 1974 and 1975 compared to 1971–73 (Kingsley, 1979), which supported the conclusion that food availability was significantly reduced in the latter period and also that young and subadult bears were the most affected. Thus, our recent observations and the previous observation from 1975 are both consistent with the hypothesis that polar bears over a wide area of the southern Beaufort Sea were in poorer-than-normal physical condition and food-stressed at least through spring in 2003–06, which was most likely the reason they clawed holes through solid ice.

Current Knowledge of Seal Populations

At this point, it is unknown if (1) total ringed seal abundance was reduced during the springs of 2003–06; (2) ringed seals were abundant but relatively inaccessible to the bears because of the refugia provided by compressed and rafted sea ice; (3) pups were less abundant because of reduced reproductive rates; or (4) some combination of those or other factors had a negative effect on the condition of the bears. However, in spring 2003–06, we found few seal kills, either in the general areas of the rubble fields where we found holes clawed through the ice or elsewhere, until about early May, when seals begin hauling out near the floe edge. In areas of relatively flat landfast ice where some drifted snow had accumulated beside stable pressure ridges, we tracked several individual bears for tens of kilometres but found only a small number of diggings indicative of attempted seal captures and very few kills. For example, on 18 April 2006, we tracked an eight-year-old male bear for 124 km, over which distance he made only 17 attempts to dig into snowdrifts, none of which was successful. In comparison, from 1971 through 1975 (including 1974 and 1975, the years of low ringed seal productivity), the success rate of polar bears hunting at subnivean breathing holes and birth lairs was 6–9%, and kills were made only a few kilometres apart (Stirling and Archibald, 1977).

Observations on Ice and Open Water

Since the late 1990s, significantly greater retreats of the sea ice in summer have produced a series of record ice-extent minima in the polar basin and freeze-up has been later, resulting in progressively larger areas of open water persisting for longer periods into winter in the southern Beaufort Sea (Rigor et al., 2001; Comiso, 2002, 2003, 2006; Belchansky et al., 2004; Comiso and Parkinson, 2004; Stroeve et al., 2005, 2007). The combination of later freeze-up over wider expanses of open water probably makes large areas of young ice more vulnerable to being broken up and subsequently blown either away from the coast or toward it, depending on the direction of the winter winds, until the pack as a whole consolidates.

The formation of the ice ridges and rubble fields that characterize the landfast ice over the Mackenzie Shelf, and which have been such a dominant feature of the sea ice in the southern Beaufort Sea during the period of our study, has been described by Amundrud et al. (2004) and Harwood et al. (2007). Because the sea ice that forms along the coastline at freeze-up has little strength with which to resist being blown offshore by wind, its stability is dependent on the formation of grounded ice ridges (*stamukhi*) within and near the seaward edge of the fast ice zone. The formation of *stamukhi* is dependent upon a recurring cycle of strong storms that occurs over the Mackenzie ice shelf. Southeasterly (offshore) storms blow the ice away from the flaw lead, alternating with northwesterly (onshore) gales that compress the ice against the land. Each strong northwest gale that follows a southeasterly storm causes young ice along the flaw lead and to the north of it to be fractured and compressed into ridges when it is forced south into the landfast ice again. Initially, these ridges are grounded by *stamukhi* but as the seaward edge of the compressed ice moves farther offshore, the new ridges are not deep enough to ground. As a result, progressively more rubble forms at the fast ice edge as it continues to move seaward. Thus, the storm cycle is critical not only to fast-ice stability, but also to the formation of the extensive rubble fields we observed during this study (Fig. 2).

Harwood et al. (2007: Table 1) summarized the significant storm-driven movements of pack ice over the Mackenzie Shelf from November through March, when the fast ice and thus the overwintering ice conditions for ringed seals were developing, for 2002–05. The winter of 2004–05 had seven significant storm events that resulted in a total of 285 km of accumulated shoreward movement of sea ice. Included was the largest single compression (80 km), which occurred during the intense, once-in-50-years storm in January 2005. This was also the winter in which the rubble fields were most extensive. However, five significant storm events in 2002–03 and two in 2003–04 also produced 190 and 90 km of sea ice compression and considerable rubble fields within the study area. The data on ice compression for the winter of 2005–06 are not yet available.

The frequency of storm events in northern Alaska increased through the 1980s and 1990s and may have been influenced by the greater amount of open water in the Chukchi and Beaufort seas (Lynch et al., 2003; Cassano et al., 2006). The previous authors also concluded that the retreat of sea ice in the Beaufort-Chukchi region will continue to have significant implications for the impact of storms on the Alaskan North Slope coastal zone and that the continuing trend toward even greater sea-ice retreat in the East Siberian Sea may further influence the number and intensity of Beaufort-Chukchi cyclones. At this point, it is unclear to what extent the greater amount of open water in the Chukchi and Beaufort seas may be influencing the frequency of storm events in more recent years and to what degree their occurrence is simply stochastic. Regardless, it seems clear that the unusually strong storms in January 2005 and February 2006 (Meteorological Service of Canada, unpubl. data) contributed significantly to formation of the extensive areas of ridged and rafted sea ice in the landfast areas of the southern Beaufort Sea in those years. Thus, if intense winter storms continue to be frequent over the Mackenzie Shelf, in conjunction with wide expanses of open water between the shore and the polar pack and later freeze-up, it seems likely that the presence of extensive rubble fields near the coast of the southern Beaufort Sea could become a common feature of the winter and spring ecology of polar bears and ringed seals in that area.

Compared to the southern Beaufort Sea coast, which was exposed to extensive open water at the time of minimum ice cover prior to the winters of 2002–03 through 2004–05, the west coast of Banks Island and the entrance to Amundsen Gulf, which are occupied by the NB polar bear population, were either still covered with sea ice or at least partially protected from the effects of northwesterly gales by nearshore pack ice (Stroeve et al., 2005). Consequently, the pattern of extensive ridging and formation of rubble fields that developed in the southern Beaufort Sea in response to the storm cycle did not occur in the same way in the northern Beaufort Sea.

Our observations, along with other recent reports from the area (Amstrup et al., 2006; Monnett and Gleason, 2006; Regehr et al., 2006), provide indications that large-scale changes in climate patterns are having significant negative effects on polar bears' foraging activity and body condition, and likely on their overall survival.

CONCLUSIONS

The clawing of holes through solid ice by polar bears attempting to catch seals is a significant departure from normal and documented patterns of hunting behaviour. Thus, it is most unusual to find 14 sites with holes clawed through solid ice in the same general area over a period of three successive springs. Furthermore, during the same general period in SB, Amstrup et al. (2006) reported three instances of cannibalism by adult male polar bears and we found a fourth instance, and Regehr et al. (2006) found three bears starved to death plus a fourth for which the cause of death could not be determined.

Considering the huge scale of the sea-ice area occupied by polar bears in SB, the probability of finding a hole 40–60 cm in diameter clawed through the ice, or the remains of a cannibalized or starved bear, all of which (plus associated tracks) could disappear overnight in drifting snow, is extremely small. Thus, we may have passed over clawed holes in 2003 or 2004 that were already obscured by drifted snow. Had three of the dead bears found by Regehr et al. (2006) not been wearing radio-collars, they would almost certainly not have been discovered. The rarity of any of these events being reported from SB in the previous 30+ years (except for clawed holes at one site in 1975 when ringed seal productivity was known to be exceptionally low) underlines the possible significance of finding so many instances of ice-clawing, cannibalism, or starvation during our study. Taken together, we suggest these observations, and the fact that bears in SB were in poorer physical condition than those in NB, support the hypothesis that hunger was a significant factor.

At this point, it is not certain whether the nutritional stress experienced by polar bears in SB from 2003 to 2006 is a short-term phenomenon or part of a longer-term trend. The 1960s, 1970s, and 1980s each experienced a two- to three-year decline in seal productivity in the eastern Beaufort Sea and Amundsen Gulf, associated with heavy ice conditions, around mid-decade. Each was followed by a decline in polar bear reproduction and condition, after which both seal and bear populations recovered (Smith, 1987; Harwood et al., 2000; Stirling, 2002). The beginning of each of those three periods was associated with heavy ice conditions through the winter before the reproductive decline of the seals, followed by late spring breakup. However, in none of the above time periods were there record summer pack ice minima, extensive areas of open water, early breakup, or late freeze-up similar to the conditions that characterized SB in the 2000s, possibly influenced by climate warming (Comiso, 2003; Belchansky et al., 2004; Stroeve et al., 2005, 2007; Serreze and Francis, 2006).

Thus, we suggest that the dramatic retreat of the pack ice minima in September, the increase in the area of open water adjacent to the coast in SB, and the later freeze-up, via mechanisms not yet understood, have had a negative effect on the survival and reproduction of polar bears in SB since the turn of the century. We further suggest that ascertaining whether this trend continues, and if so what mechanisms may be in play, should be an important area for future research.

ACKNOWLEDGEMENTS

We are particularly grateful to the Canadian Wildlife Service, the Polar Continental Shelf Project, the Inuvialuit Game Council, the Northwest Territories Department of Environment and Natural Resources, the National Fish and Wildlife Federation (Washington, D.C.), the Natural Sciences and Engineering Research Council of Canada, the Killam Trusts, Polar Bears International, the University of Alberta, and the Northern Scientific Training Program (Indian and Northern Affairs Canada) for their support of this project. Dr. Humfrey Melling provided constructive criticism of our discussion of sea ice. Mr. Richard Gordon and the Yukon Territorial Parks kindly allowed us to stay at their facility at Herschel Island. We also thank Dennis Andriashek, Seth Cherry, Tony Green, Benedikt Gudmundsson, David Nasogaluak, Joe Nasogaluak, Bradley Voudrach, Mike Woodcock, and John Thorsteinsson for their assistance in the field.

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