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Possible Impacts of Climatic Warming on Polar Bears

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ABSTRACT. If climatic warming occurs, the first impacts on polar bears (*Ursus maritimus*) will be felt at the southern limits of their distribution, such as in James and Hudson bays, where the whole population is already forced to fast for approximately four months when the sea ice melts during the summer. Prolonging the ice-free period will increase nutritional stress on this population until they are no longer able to store enough fat to survive the ice-free period. Early signs of impact will include declining body condition, lowered reproductive rates, reduced survival of cubs, and an increase in polar bear-human interactions. Although most of these changes are currently detectable in the polar bears of western Hudson Bay, it cannot yet be determined if climatic change is involved. In the High Arctic, a decrease in ice cover may stimulate an initial increase in biological productivity. Eventually however, it is likely that seal populations will decline wherever the quality and availability of breeding habitat are reduced. Rain during the late winter may cause polar bear maternity dens to collapse, causing the death of occupants. Human-bear problems will increase as the open water period becomes longer and bears fasting and relying on their fat reserves become food stressed. If populations of polar bears decline, harvest quotas for native people will be reduced and eventually be eliminated. Tourism based on viewing polar bears in western Hudson Bay will likely disappear. Should the Arctic Ocean become seasonally ice free for a long enough period, it is likely polar bears would become extirpated from at least the southern part of their range. If climatic warming occurs, the polar bear is an ideal species through which to monitor the cumulative effects in arctic marine ecosystems because of its position at the top of the arctic marine food chain.

Key words: polar bear, *Ursus maritimus*, climatic change, Hudson Bay

RÉSUMÉ. S'il se produit un réchauffement climatique, les premières retombées sur les ours polaires (*Ursus maritimus*) se feront sentir aux limites méridionales de leur distribution telles que la baie James et la baie d'Hudson, où toute la population se voit déjà soumise à un jeûne forcé durant près de quatre mois lors de la fonte estivale de la glace de mer. Une prolongation de la période libre de glace va accroître, pour cette population, le stress lié à ses besoins nutritionnels jusqu'à ce que les animaux ne puissent plus emmagasiner assez de réserves de graisse pour survivre à la période libre de glace. Des signes précoces de ces retombées incluront une diminution de la santé physique, une baisse du taux de reproduction, une réduction de la survie des oursons, et une augmentation de l'interaction entre l'ours et l'homme. Bien que la plupart de ces changements chez les ours polaires de l'ouest de la baie d'Hudson soient déjà visibles, on ne peut encore dire avec précision s'il s'agit là des retombées d'un changement climatique. Dans l'Extrême-Arctique, une diminution du couvert nival peut stimuler une augmentation initiale de la productivité biologique. Mais il est probable, à la longue, que les populations de phoques diminueront partout là où la qualité et la disponibilité de l'habitat de reproduction sont réduites. Les précipitations sous forme de pluie à la fin de l'hiver peuvent causer l'effondrement des tanières de mise bas des ourses polaires, amenant la mort des occupants. Les problèmes reliés à l'interaction de l'ours et de l'homme augmenteront avec le prolongement de la période d'eau libre, ce qui amènera les ours en état de jeûne à compter sur leurs réserves de graisse et à devenir stressés par le manque de nourriture. Si les populations d'ours polaires diminuent, les quotas de prélèvement pour les autochtones seront réduits et à la longue éliminés. Le tourisme qui dépend de l'observation des ours polaires dans l'ouest de la baie d'Hudson disparaîtra probablement. Si l'océan Arctique devenait libre de glace chaque année pour une assez longue période, il est probable que les ours polaires disparaîtraient d'au moins la partie méridionale de leur territoire. S'il se produit un réchauffement climatique, l'ours polaire est une espèce idéale s'offrant à l'observation des effets cumulatifs dans les écosystèmes marins arctiques en raison de sa position au sommet de la chaîne alimentaire marine de l'Arctique.

Mots clés : ours polaire, *Ursus maritimus*, changement climatique, baie d'Hudson

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INTRODUCTION

In recent years there has been a growing scientific consensus that increasing concentrations of greenhouse gases in the atmosphere are causing the climate of the earth to warm (Etkin, 1990). Of particular importance to the Arctic Ocean is how climatic warming may affect ice cover. One dramatic consequence, speculated to be possible in as little as 100 years (Roots, 1989), is that the arctic ice cap might disappear completely. In comparison, Parkinson and Kellogg (1979) modelled the decay of arctic sea ice in response to a CO_2-induced temperature rise and concluded that the Arctic Ocean would still freeze over in winter, even with a mean temperature rise of 6-9°C. Despite differences in absolute projections and uncertainties about when and how feedback mechanisms may take effect, it is clear that more warming means less ice in arctic waters.

The presence of sea ice is critical to polar bears (*Ursus maritimus*) because it provides the platform from which they hunt the seals they feed on. Similarly, the seals, especially ringed seals (*Phoca hispida*) that are the main food of polar bears, depend on the sea ice to provide a platform on which they can give birth to and nurse their pups. Regional yearly variations in the seasonal distribution and abundance of sea ice have been shown to have significant effects on the reproduction and survival of both polar bears and seals (Stirling *et al.*, 1976; Stirling *et al.*, 1982; Smith and Stirling, 1978; Smith *et al.*, 1991). Vibe (1967) demonstrated significant fluctuations in the distribution and abundance of polar bears in Greenland in relation to long-term climatic fluctuations. Consequently, we believe that polar bears will be significantly affected by long-term unidirectional changes in the distribution and abundance of different types of sea ice habitat and in the dates of both freeze-up and break-up.

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We also recognize that the results of some studies are inconsistent with the hypothesis that a long-term trend in climatic warming is occurring (e.g., Kahl *et al.*, 1993). However, if climatic warming is under way, then it will be extremely important to understand and predict as many of the potential consequences as possible. In this paper, we speculate about the possible impacts of climatic change — in particular, climatic warming — on polar bears.

ECOLOGICAL IMPORTANCE OF SEA ICE TO POLAR BEARS

Polar bears evolved to exploit the sea ice niche and they are remarkably adapted to survival on this labile habitat. Polar bears depend on sea ice for several purposes: as a platform from which to hunt and feed upon seals (Stirling and Archibald, 1977; Smith, 1980), as a habitat on which to seek mates and breed (Ramsay and Stirling, 1986; Stirling *et al.*, 1993), as a vehicle from which to access terrestrial maternity denning areas (Harington, 1968), sometimes for maternity denning itself (Lentfer, 1975; Amstrup, 1986), and as a substrate on which to make long-distance movements (Schweinsburg and Lee, 1982; Garner *et al.*, 1990). It is important to recognize that the seasonal distribution of sea ice, percentage of surface cover, and ice type can vary considerably among years and in different parts of the Arctic (e.g., Lindsay, 1975, 1977). These variations affect polar bears in different ways and provide clues about possible responses to unidirectional trends over the long term. In addition, because the effects of global climatic change on sea ice will likely vary with latitude, the responses shown by different populations of polar bears will likely not be the same during the same time period.

There are at least three ways climatic warming may affect hunting success, and hence feeding on seals, by polar bears: reduced access to seals, effects on seals that reduce their abundance or accessibility to bears, and effects on the marine ecosystem that influence productivity. We focus on the effects of climatic warming on polar bears in western Hudson Bay because populations near the southern extent of their range are likely to be affected earlier. We also briefly consider possible effects on High Arctic populations.

Reduced Access to Seals

Polar bears hunt seals from the ice using a variety of techniques, depending on the season and the habitat (Stirling, 1974; Stirling and Latour, 1978). There has been one recorded instance of a polar bear apparently capturing a seal in open water (Furnell and Oolooyuk, 1980), but this behaviour appears to be uncommon, probably because the chance of success is low. If warming occurs, one of the first effects is likely to be an earlier break-up and a later freeze-up, which will extend the open water season in summer and fall and reduce the amount of time polar bears can use sea ice for hunting. In Hudson and James bays, all the polar bears in the population already spend about four months of the year ashore fasting on their stored fat reserves. Pregnant females fast for eight months (Stirling *et al.*, 1977; Ramsay and Stirling, 1988). Over the last few years, estimates indicate that the size of the polar bear population in western Hudson Bay is stable, but changes consistent with a population approaching carrying capacity have occurred (Derocher, 1991; Derocher and Stirling, 1992). The average weights of female polar bears were significantly lower in the late 1980s than they were in the early 1980s and were reflected in lower reproductive rates and reduced cub survival (Derocher and Stirling, 1992). We suggest these data indicate that if the condition of females declines further due to climatic warming the population might decline.

An analysis of sea ice extent and anomalies in Hudson Bay from 1953 to 1984 (Mysak and Manak, 1989) indicates sufficient variability that a long-term trend that might be associated with climatic change is obscured. However, a recent analysis of the sensitivity of break-up in Hudson Bay to changes in air temperature suggested that an increase in the mean of only 1°C could advance break-up by about a week in western Hudson Bay and two weeks in eastern Hudson Bay (Etkin, 1991). Etkin did not speculate about how much freeze-up might be retarded under this scenario. He also noted that general circulation models indicate that mean winter temperatures over northern Canada may increase from 4 to 15°C and summer temperatures by 2-6°C (Etkin, 1990). Even changes at the lower range of the projections would have a dramatic effect on ice cover in Hudson Bay and negatively affect polar bears.

The most important feeding period for polar bears is from early April, when ringed seal pups are born, to break-up in July. If polar bears in western Hudson Bay kill seals at a rate similar to their counterparts in the High Arctic in early summer (Stirling and Latour, 1978), then an adult female might kill approximately 1.5 seals per week before coming ashore, assuming the availability of seals remained constant. If the seals killed were one year of age or less, which the great majority are (Stirling and Archibald, 1977), this would represent a dietary intake of about 25 kg of fat; if they were adult seals it would be more (Stirling and McEwan, 1975). From feeding trials on a captive polar bear, Best (1977) calculated an apparent digestibility of fat in excess of 90%. Thus, if break-up occurred a week earlier in western Hudson Bay because of a 1° warming, as projected by Etkin (1991), adult female polar bears might come ashore with up to 10 kg less of stored fat (roughly 22 kg of fat digested from seals caught in a week minus metabolic costs for a week of hunting). Fasting adult polar bears lose an average of 0.85 $kg \cdot day^{-1}$ while being relatively inactive and living on their stored fat reserves (Derocher, 1991). If we assume that a one-week delay in break-up might be accompanied by a similar delay in the timing of freeze-up, this could mean that an adult female would metabolize an additional 12 kg of fat (14 days $\times$ 0.85 $kg \cdot day^{-1}$) before being able to return to the sea ice to hunt seals. She would then return to the sea ice about 22 kg lighter overall (10 kg because of losing a week of hunting and 12 kg from having to fast for an additional two weeks).

From 1982 to 1990, the mean weight of adult female polar bears, scaled to a mean capture date of 21 September, was 283 kg and the minimum weight of a female known to have produced a litter was 189 kg (Derocher *et al.*, 1992), a difference of 94 kg. Thus, it seems likely that if break-up began to occur two or more weeks earlier than it does at present, fewer adult female polar bears would be able to store enough body fat to produce and successfully wean cubs. Eventually, cub production would not balance mortality and the population would decline. Furthermore, it is likely that females that were successful at raising cubs to the fall would be unable to nurse them through the ice-free period because of being unable to store adequate fat reserves.

In 1992, break-up of the ice on western Hudson Bay was delayed by about 3-4 weeks (Ice Forecasting Central, Ottawa, unpublished weekly ice maps for Hudson Bay and approaches). This delay in break-up is the opposite of what would be predicted by climatic warming. From data collected between 1751 and 1889, Catchpole and Hanuta (1989) noted a strong association between severe ice conditions in Hudson Bay and major volcanic eruptions. It is possible the cool summer and late break-up in 1992 were caused by the eruption of Mt. Pinatubo in the Philippines.

In 1991 and 1992, we had satellite radio collars on 5 and 9 adult female polar bears respectively, which gave us an opportunity to quantify some observations on the relationship between the timing of break-up and the response of the bears. Figure 1 shows the areas of sea ice occupied by female polar bears while hunting for seals from June through August and the availability of sea ice in mid-July in both 1991 and 1992. Note how much more extensive the ice cover was in 1992, especially for areas of 9/10 ice cover. The area in which polar bears spent most of their time hunting from June through August 1992 was almost free of ice by mid-July 1991. The mean date that female polar bears came ashore in 1991 was 23 July (SE = 11.6 days), compared to 21 days later in the following summer on 13 August in 1992 (SE = 8.19 days). These dates were not significantly different at the .05 level, probably because the sample size was small and the variance was large. Nevertheless, the later mean date of arrival of females on shore in 1992 suggests that polar bears remain on the sea ice hunting seals for as long as possible. From the simplistic energetic information given above, one would predict that adult polar bears, having fed for three weeks longer than in 1991, might be as much as 25-30 kg

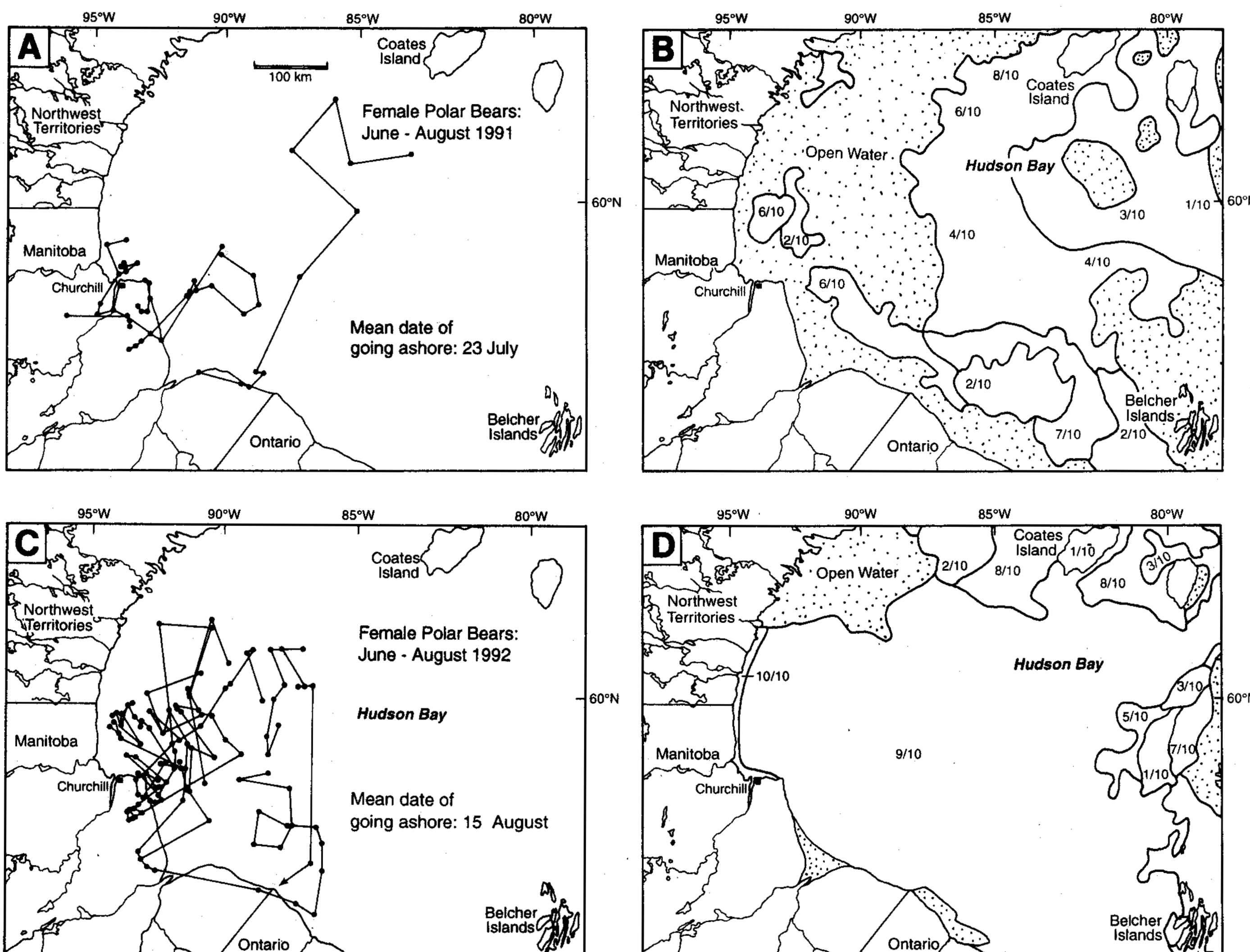

FIG. 1. A) Movement of five adult female polar bears from the sea ice to land from June through August 1991. B) Distribution of sea ice in Hudson Bay, 14 July 1991. Fractions represent the percentage of coverage of ice. C) Movements of nine adult female polar bears from the sea ice to land from June through August 1992. D) Distribution of sea ice in Hudson Bay 12 July 1992.

heavier in 1992. However, adult males and females in 1992 weighed only 15 and 6 kg more respectively than they did in 1991. Although these changes were in the direction predicted, they were not significantly different from the weights of adult males and females the previous year. This result is consistent with the hypothesis that density-dependent responses are being shown by the polar bear population in western Hudson Bay (Derocher and Stirling, 1992) and suggests the polar bear population might already be the maximum size that can be supported by the existing ringed seal population. If an additional three weeks spent hunting does not enable the bears to significantly increase the amount of body fat stored, then it is probable a trend toward earlier break-up and a shortening of the time spent hunting will be reflected fairly quickly in lower rates of reproduction and cub survival.

Effects on Seals That Change Their Abundance or Accessibility to Bears

Climatic warming may also significantly affect polar bears if it has negative effects on their primary prey species, the ringed seal. The increased precipitation expected to accompany climatic warming (Etkin, 1990) may have mixed consequences for ringed seals, which give birth to their young in late March or early April in subnivean birth lairs on the ice (Smith and Stirling, 1975). If increased precipitation came in the form of snow during the winter, it might be beneficial to the survival of seal pups prior to weaning. Hammill and Smith (1991) reported a negative correlation between the depth of snow over birth lairs and success by predators. Alternatively, if there was more rain while seal pups were still in their lairs hidden from predators, the effects could be devastating to the seal population. For example, in mid-April 1979, an unseasonably heavy rain at the end of the Hall Peninsula on southeast Baffin Island caused the roofs of many subnivean birth lairs to collapse, exposed the young seal pups, and resulted in heavy predation by polar bears (I. Stirling and T.G. Smith, unpubl. observations). In such circumstances, predation of neonate ringed seals by arctic foxes (*Alopex lagopus*) can also be significant (Smith and Lyderson, 1991). Thus, it seems likely that if a warming climate significantly increased the frequency or amount of rain when seal pups were in their birth lairs, increased predation by both polar bears and arctic foxes could depress the seal population size enough to cause a significant decline in polar bear numbers.

If sea ice became less consolidated in winter and open water more protracted in summer, conditions might be more favourable for bearded seals (*Erignathus barbatus*), harbour seals (*Phoca vitulina*), harp seals (*Pagophilus groenlandicus*), and walrus (*Odobenus rosmarus*). The degree to which such changes in the distribution and abundance of these occasional prey species might benefit polar bears is less clear. Lavigne and Schmidt (1990) have also speculated that increases in seal numbers as a consequence of global warming might make seal plagues more likely.

In the High Arctic, it is possible that the initial effects of climatic warming might be beneficial to polar bears. Much of the polar basin and the northern interisland channels of the Canadian Archipelago are currently covered with multiyear ice that is poor habitat for ringed seals (Kingsley *et al.*, 1985) and consequently supports lower densities of polar bears. An initial increase in the proportion of annual ice might be favourable to ringed seal production because it would contain extensive shore lead and polynya systems, which are used by subadult ringed seals through the winter. It is possible that the increase in ringed seal numbers, and subsequently those of polar bears, could initially compensate for losses in the more southerly portions of their range. Eventually however, if climate continued to moderate to the point where ice cover on the Arctic Ocean became seasonal, as suggested by Parkinson and Kellogg (1979), then responses might follow those projected to occur in Hudson Bay. Ultimately, if sea ice disappeared altogether, polar bears would become extinct.

Effects on Productivity in the Ocean

Primary productivity may increase initially as a consequence of a larger amount of open water and thinner ice allowing more sunlight to penetrate and stimulate photosynthesis, especially over the continental shelf areas. However, warming of deeper water layers may eventually result in substantially lower biological production, as has occurred off the coast of southern California because of climatic warming (Lange *et al.*, 1990). Another uncertainty in biological productivity in the Arctic relates to a concomitant reduction in the stratospheric ozone layer. For example, in a recent study in the Antarctic, where the springtime thickness of the ozone layer has declined by about 50%, there was a minimum reduction in primary productivity of 6-12% over a six-week period (Smith *et al.*, 1992). How all these factors will act on each other and what feedback loops will develop can only be speculated upon at this time.

Effects on Breeding Habitat

During April-May, when polar bears breed, oestrus adult females are concentrated in the best feeding habitat and males are drawn to those areas by the females' presence (Stirling *et al.*, 1993). Most mating takes place on open sea ice, although in coastal areas males will sometimes herd females into small bays or onto land, where there are fewer bears and hence reduced competition from other males. The polar ice pack is close to its annual maximum distribution during the breeding season (April-May), so it is unlikely that climatic warming will have as great a negative influence on breeding as on feeding.

Effects on Maternity Denning

In some areas, such as the Beaufort and Chukchi seas, polar bears spend most of the year on the sea ice (Amstrup, 1986; Garner *et al.*, 1990). During the fall, the multiyear pack ice moves south and the open water between the polar pack and the coast begins to freeze, making it easier for pregnant females to reach the land for maternity denning. If because of climatic warming the extent of the polar pack is reduced and freeze-up is delayed, it may not be possible for pregnant females to reach coastal areas for denning. In this circumstance, more females may choose to den on the multiyear ice, as many already do in the southern Beaufort Sea population (Lentfer, 1975; Amstrup, 1986). Alternatively, pregnant females may begin to come ashore at break-up and attempt to fast until going into a maternity den in autumn, similar to pregnant females in Hudson Bay at present (Ramsay and Stirling, 1988).

A serious potential consequence of warmer winters is the increased probability that rain in the late winter will cause maternity dens in the snow to collapse before females and cubs have departed. For example, in early March 1990 we experienced unseasonable rain while conducting surveys in the polar bear denning area south of Churchill, Manitoba, and observed large snow banks along creeks and rivers used for denning that had collapsed because of the weight of wet snow (I. Stirling and A.E. Derocher, unpubl. observations). Had there been maternity dens in any of these banks, it is likely the bears would have been crushed. Clarkson and Irish (1991) reported an adult female polar bear and two cubs that were crushed to death when their den collapsed near the Beaufort Sea coast. Although there was some unusually warm weather in the middle of the previous December, it was unknown if rain was implicated in that den collapse. However, any factors that increase the mortality rate of adult females are particularly serious, since population modelling indicates that if more than about 2% of them are removed each year, the population will decline (Taylor *et al.*, 1987).

Effects on Long-Distance Movements

Long-term changes in the timing and extent of break-up and freeze-up of sea ice as a consequence of climatic change will influence the seasonal movements and distribution of polar bears throughout their range. Polar bears are attracted to areas where leads form in the sea ice (Stirling, 1988; Stirling *et al.*, 1993). Similarly, it has been suggested that areas of open water with strong currents can function as barriers to extensive movements of polar bears in southeastern Baffin Island and the eastern Beaufort Sea (Stirling *et al.*, 1980; Stirling, 1990; Stirling and Andriashek, 1992). However, beyond noting the importance of these phenomena, it is not useful to speculate further about effects on long-distance movements at this time.

EFFECTS OF CLIMATIC WARMING ON HUMAN-BEAR INTERACTIONS

In western Hudson Bay in years when bears come ashore thinner for whatever reason or a late freeze-up delays the return of the bears to the ice to feed, more individuals become food stressed and come into the town of Churchill and its dump to scavenge on garbage. This results in an increased number of negative encounters between bears and people. If the open water period lengthens, bears will become progressively more food stressed and eventually have no alternative but to scavenge wherever they can and occasionally prey upon people. This will occur first around the southern limits of their range but will increase farther north if warming of the Arctic continues.

Polar bears are also important economically. At present, approximately 600 polar bears are harvested annually in Canada by native people as part of their culture and economy (Calvert *et al.*, 1991). Because the sustainable harvest level of a polar bear population is small, annual quotas will have to be reduced and eventually eliminated if populations decline as a consequence of climatic warming. The tourist industry developed around viewing polar bears would also be affected. This industry is currently well developed in Churchill, Manitoba, and is beginning in Wager Bay, Northwest Territories, but development is also possible in other areas where populations of polar bears spend protracted periods of time ashore and are accessible for viewing. Depending on how rapidly climatic warming takes place, we could begin to see reduced numbers of polar bears available for viewing in areas such as western Hudson Bay in the foreseeable future.

EFFECTS OF HUMAN ACTIVITIES ON POLAR BEARS AS A CONSEQUENCE OF CLIMATIC WARMING

There is a limit to which it is useful to speculate along this line, but some things appear likely. If a warming climate in the Arctic results in longer periods of open water in summer and lighter ice conditions in winter, it is reasonable to project there will be an increase in activities such as shipping and offshore hydrocarbon development that may have negative effects on polar bears (Stirling and Calvert, 1983; Stirling, 1988, 1990). Associated with an expansion in development will be an increase in the human population in the North, the cumulative effects of which are difficult to predict except that when humans and bears compete for habitat or other resources, bears tend to lose (Servheen, 1990).

POLAR BEARS AS INDICATORS OF CLIMATIC WARMING

Because the polar bear is at the top of the arctic marine food chain and ice is an essential component of its environment, it is an ideal species through which to monitor the cumulative effects of ecological change in arctic marine ecosystems. If climatic warming occurs, we can reasonably expect the first effects to be detectable near the southern limits of the polar bear's range. However, to be able to detect possible effects of any kind of long-term change on polar bears (or any other species or ecosystem), we require long-term historic data bases against which to compare the results of present and future monitoring. Unfortunately, few such data bases exist for any arctic species. An exception is the polar bear population resident on the western coast of Hudson Bay, where data on condition, reproduction, survival, and other population parameters have been collected for over 20 years (Derocher and Stirling, 1992). Thus, we have an extant data base for one of the most relevant species in one of the best possible geographic locations. Continued monitoring of polar bears along the western coast of Hudson Bay in conjunction with studies of the marine system, sea ice conditions, and meteorological data for the Hudson Bay region may provide one of the better opportunities to test hypotheses about the occurrence of long-term climatic change in the arctic marine ecosystem and its possible effects.

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